Water Fluoridation

*The Search and the Victory*
FRANK J. MCCLURE

A respected international authority on fluoride, Dr. Frank J. McClure was one of the first contributors to this field. His research on the metabolic fate of fluorides in the body provided substantial evidence of the safety of fluoridation of water supplies as a public health measure.

Dr. McClure served as chief of the Laboratory of Biochemistry of the National Institute of Dental Research from 1948 to 1966. Following his retirement after 30 years of distinguished service with the Institute, he devoted a major share of his time to the preparation of this book in order to provide a broader perspective of the notable events leading to fluoridation as a vital public health measure. We believe that the volume represents a significant contribution to the literature.

SEYMOUR J. KRESHOVER
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WATER FLUORIDATION

The Search and the Victory

FRANK J. McCLURE

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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1970
In Memory of

H. Trendley Dean

and

Francis A. Arnold, Jr.
"For there was never yet philosopher
That could endure the toothache patiently..."

SHAKESPEARE
"Much Ado About Nothing"
Act V, Scene I
PREFACE

I consider water fluoridation to be the greatest single advance in dental health made in our generation.

DR. THOMAS PARRAN, Surgeon General
U.S. Public Health Service
1936-1948

FLUORIDATION of drinking water provides for the presence of an optimum one part of fluoride in a million parts of water. Use of fluoridated water during the first ten to twelve years of life can significantly reduce tooth decay, most prevalent of all diseases afflicting mankind.

Research in laboratories and population studies which established the basis for this procedure lie within two well-defined periods. The first is notable for research on the cause and prevention of a hitherto unknown affliction of the teeth. Variously named, but generally known as mottled enamel, this dental defect occurs in numerous areas throughout the world. Search for the cause led to water and eventually to its excessive fluoride content. Prevention depends on a reduction of high fluoride concentrations in drinking water used during the first 10 to 12 years of life.

Events making fluoridation history unfolded slowly, however, and the connecting link between mottling and caries (tooth decay) was not immediately discernible. In fact, it came as a great surprise that teeth having mottled enamel should be unusually free of dental decay, and investigators were reluctant to suggest that fluoride could be instrumental in preventing this disease. It seemed improbable that fluoride in drinking water could be both a benefit and a deterrent to dental health, depending on its concentration. But results of extensive research were to prove unequivocally the Jekyll-and-Hyde aspects of fluoride. The second period of fluoridation research celebrated the subdual of Mr. Hyde and the survival of Dr. Jekyll. Fluoridation history—the search and the victory—has thus run a full cycle. Fluoride in drinking water, in an optimum amount determined through extensive study, has indeed become a notable gift to dental health.

Many people throughout the world were involved in the manifold events which culminated in water fluoridation. Mottled enamel was studied in the United States first in Colorado and in Texas. Subsequent research experiments and observations in Arizona demonstrated that fluoride in drinking water was the cause of mottled enamel. Soon there-
after, epidemiological surveys of dental caries were made where natural fluoride-bearing waters were used. They demonstrated the pronounced caries-inhibitory effects of fluoride in drinking water. A preventive effect could occur without causing the undesirable mottled enamel, soon to be known as dental fluorosis. These observations, as well as much additional knowledge related to fluoridation, were possible because of the natural occurrence of fluoride in many public drinking waters in concentrations of one part and more per million.

The moment of truth in fluoridation history came in 1945, when fluoride was added deliberately in a controlled amount to community drinking waters. In that year fluoridation trial studies involving large groups of people were begun in Michigan, New York, and Ontario, Canada. Preceding this initial fluoridation of water, numerous clinical, epidemiological, laboratory, and experimental animal studies had provided acceptable evidence that fluoride at a level of one part in one million parts of water was not a hazard to public health.

The brief period of fluoridation history has produced a voluminous literature embracing a wide spectrum of scientific, medical, and dental disciplines. This narrative does not attempt to review these extensive records of research but rather covers only the major events and the research which provided the basis for water fluoridation. It brings together for the first time in a chronological account the many, varied facets of water fluoridation. Dentists, physicians, students, and informed members of the community may find it of interest. Many people have benefited from this gift of drinking water, and many more may anticipate a future advantage.

It was inevitable that a public health procedure, particularly one affecting drinking water, should give rise to loud and effective dissent. The official approval of responsible professional organizations was imperative to insure success and was forthcoming from the American Dental Association, the American Medical Association, the American Public Health Association, and the Organization of State and Territorial Dental Health Officers, to name but a few supporting groups.

Contradicting its efficacy and safety, the opponents of fluoridation, however, continue in their attempts to have the procedure declared unlawful. A former Surgeon General of the Public Health Service, Dr. Luther Terry, stated, “The four horsemen of public health are the pasteurization of milk, the purification of water, immunization against disease, and controlled fluoridation. None of these gains has been achieved easily—none of the four measures has endured more severe obstruction than fluoridation.”

Acknowledgments

Prior to his untimely death, Dr. Francis A. Arnold, Jr., had read the first chapters and made highly valued comments and suggestions. It was a grievous personal loss to be deprived of his further assistance.
Dr. Donald J. Galagan, Dean of the College of Dentistry, University of Iowa, reviewed the manuscript. As a reflection of his personal interest, experience, and research on fluoridation problems, Dr. Galagan's comments were very helpful and greatly appreciated.

The book was edited by Mr. Horace D. Porter and his wife of Washington, D.C., who brought to this task a diligence matched only by their enthusiasm and personal interest.

The striking color photographs illustrating normal teeth and different degrees of mottled enamel severity are published with grateful thanks to Dr. Ingolf J. Møller of Denmark.

Frank J. McClure
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CHAPTER ONE

VESUVIUS CAST A SHADOW

IN 1901, Dr. J. M. Eager, Passed Assistant Surgeon*, Marine Hospital Service, Public Health Service, while stationed in Naples, Italy, forwarded to Surgeon General Dr. Walter Wyman a brief communication describing a deteriorated condition in the teeth of emigrants embarking at Naples for the United States. His dental-clinical report was destined to become the initial scientific document in the history of mottled enamel (I):

On the examination of certain Italian emigrants embarking at this port, one is struck with the frequency of a dental peculiarity common among the inhabitants of the Italian littoral and known as “denti di Chiaie” or Chiaie teeth. This defect was first described by Prof. Stefano Chiaie, a celebrated Neapolitan, and bears his name.

Dr. Eager went on to state that this “deterioration” is acquired and is “due to local geological conditions.”

The etiology seems to be connected with volcanic fumes or the emanation of subterranean fires, either fouling the atmosphere or forming a solution in drinking water. In Naples it is more often attributed to water than to the air and since the Serino water brought in conduits from a distant mountain height has been in use and local wells condemned, the incidence of the disease among infants has greatly diminished.

Areas marked by unusual severity of the enamel defect were located in a section near Naples known as Santa Lucia along the Riviera, and in Posilipo, a suburb of Naples where the environs are of volcanic origin. The 16,000 inhabitants of Pozzuoli, situated five miles from Naples, had a “distinguishing characteristic of black teeth (denti neri).” Close by Pozzuoli is Solfatara, “a half-extinct crater full of cracks from which gases are constantly issuing.” Some of the inhabitants of Pozzuoli thus “drink the water of springs, a water necessarily charged under pressure with volcanic fumes.”

The description of “Chiaie teeth” included a variation known as “denti scritti” because of a fine black line crossing the incisor teeth horizontally, giving the teeth the appearance of having been written upon.

*Passed Assistant Surgeon is a title formerly used in the U.S. Public Health Service.
Dr. Eager concluded this communication and its prophetic references to drinking water with a statement indicating the newness of the disease:

The different forms of deterioration which are grouped under the name of "denti di Chiaia" are thus seen to be quite unlike any other dental disease and not at all likely to be confounded with Hutchinson's teeth, mercurial teeth, caries, or other maladies of the teeth.

While Eager was the first to report this unusual enamel defect in the scientific literature, an Italian literary journal contains an earlier cursory allusion to denti neri prevalent in a particularly prominent area of Naples known as Chiaia. Volume I of Napoli Nobilissima—A Review of the Neapolitan Topography and Arts was published in 1892; the renowned philosopher and literary and art critic, Benedetto Croce, was one of the editors. In "Napoli Nobilissima" he presented a description of "La Villa Chiaia," and included the observation that "the drinking water caused digestive trouble and was responsible for badly stained teeth." In the context of art, the sagacious Croce thus recorded the real distress created by a severe dental pathology in La Villa Chiaia in 1892—"pulcherriamum mulieres set nigra dente" (beautiful women, but with black teeth).

In October, 1966, (personal letter) Prof. Omero Tempestini, the Director of the Dental Clinic of the University of Catania, Italy, called attention to the fact that Dr. Vincenzo Guerini had reported in 1903 and again in 1912 that dental lesions identical to those described by Eager occurred among the inhabitants of the Neapolitan Coast. Guerini also had "attributed their origin to the action of gases emanating from sources of mineral water existing at that time. . . . From what can be deduced at this later date, there can be no doubt that this phenomenon, which has disappeared today, should be attributed to this water."

Dr. Tempestini had contributed significant information in his studies of fluoride, mottled enamel, and dental caries in Italy (2). In his 1966 letter he called attention to analytical fluoride data obtained by Gautier and Clausmann. These two well-known French chemists were the first to record extensive fluoride analyses of a large variety of materials—water, soil, foodstuffs, and biological specimens. In 1913 and 1914 they demonstrated the occurrences of fluoride, apparently in unusual quantities, in mineral waters and gases prevalent in volcanic areas near Naples. Any possible correlation of fluoride with the new dental lesion was not given a moment's thought at that time.

The environs of Naples provide historic surroundings to bring to attention Dr. Frederick S. McKay, a practicing dentist of the United States. His contributions dominate much of the first 25 or 30 years of mottled enamel history in the United States. In 1927, McKay fulfilled a long-cherished wish to visit Naples and its environs. Since 1901 he had sought to resolve the problem of mottled enamel in the United States. In 1928 he described in detail his observations in Italy (3).
In earlier publications, McKay mentioned his particular interest in the Eager report of 1901. He was not aware of it, however, until its second publication in a dental journal 10 years after the original report, and after he had made his own first observations on mottled enamel, "Colorado Brown Stain," in Colorado.

McKay had corresponded as early as 1912 with Vincenzo Guerini, the gentleman mentioned by Tempestini. McKay sent Guerini specimens of teeth having "Colorado Brown Stain" and Guerini answered McKay with the following disclaimer concerning Eager's 1901 report:

I can assure you, before all, that the name "Chiaia" [Eager had written Chiaie] is not at all the name of an author but that of a quarter of Naples; namely, of the most beautiful quarter where are the public parks and a splendid promenade on the quay. There is also a Chiaia Street and another named Chiaia shore. In the Chiaia region there are in close proximity to the sea numerous sources of mineral water, sulfurous and ferruginous, and the fact that the people living near the sea, just in the localities where such sources are, do have on their teeth the brown spots in question, clearly demonstrates that this alteration of the enamel depends upon the action of the gases emanating from the said "mineral sources."

Inhabitants of other areas similar to the Chiaia littoral showed the same, if not a worse, enamel defect, according to Guerini.

Thus Guerini substantiated the observations recorded by Benedetto Croce in 1892, and it must be recognized that the "denti di Chiaie," attributed to Prof. Stefano di Chiaie by Eager should have been "denti di Chiaia" and thus identified with the Chiaia area of Naples. Eager had mentioned a section "known as Santa Lucia along the Riviera" and indeed Benedetto Croce referred to Villa Chiaia as the "Riviera" of Italy.

Before McKay visited the Neapolitan area he had acquired a great deal of information on mottled enamel. He knew its characteristics and Eager's description of the lesion in the Italian emigrants was regarded by McKay as "remarkably accurate." He believed that the Italian condition was identical with that described in his own publications. McKay confessed "an increased fascination in learning of and particularly in examining new affected districts ... because of the possibility that in one of these he might find some circumstance or condition, which would provide an answer to the cause of this dental defect." He began his surveys in and around Naples with some frustration. He was informed by reliable sources that although this lesion was prevalent in Pozzuoli in former years (as reported by Eager) its further occurrence had ceased. No cases were being produced in 1927. The explanation was provocative but not easily verified—a change had been made in the water supply. He was told also that although the discolored teeth had formerly been produced in Naples, production had ceased and a change in the water supply had also been made there. McKay was excited and enthusiastic when he received this information because he was eagerly awaiting the results of a change in water supplies in Oakley, Idaho, an affected community in the United States.
McKay persisted in further explorations within the Neapolitan area, and good fortune was to come his way. In the ancient city of Resina, built over buried Herculaneum near the foot of Mt. Vesuvius, he "came into direct contact with a district presenting one of the most interesting episodes among the many thus far recorded in this investigation of mottled enamel." His guide was a native of Resina, familiar with the people,

... himself afflicted with a thoroughly typical case of mottled enamel, one of those cases in which there was an extreme manifestation of the associated condition so often described as the "brown stain," except that the teeth were almost black.

As they began their tour of Resina and its environs, this native Resina guide casually imparted to McKay "the astonishing information that within the city proper they would find the defective enamel only in adult individuals, and that the present generation of children would be found to be unaffected." Guided up alleys, into back yards and inner courts, McKay found that his guide was correct in his observation.

He assumed all the prerogatives of a native son in personally opening the mouths and drawing back the lips, literally compelling the proletariat "to show me their teeth," in the meantime keeping up a rapid-fire comment in Italian, prestissima, to intimidate the unwilling. We were usually surrounded during these ceremonies by a motley group of women and children whose mouths were sympathetically half opened, wondering what it was all about. More than this, my guide in more than one instance had to assure the suspicious house-holders that I was not an agent of Mussolini, sent to impose some new form of taxation, possibly upon those who were revelling in the luxury of mottled and stained teeth. But it was a fact that I was shown case after case of adult natives of this city who presented teeth typically marked, while we were not able to find one single native child who had anything but "normal" enamel. I was amazed at the acuteness of the observations of my guide prior to this tour of examination.

Inquiry by McKay concerning the water supply of Resina revealed that a few years before drinking water from the slopes of the hills adjacent to Vesuvius had been piped into the city, but up to that time the adult people had been dependent upon water from wells located in the courtyards. The dental situation which prevailed in Resina was thereby explained. The original wells had been sunk into the ancient lava from Vesuvius and water coming into them had seeped through the extensive lava deposits. The new water supply from hillsides near Vesuvius had had no such contact with lava beds. The adult native population "grew their enamel while the well water was used but the present generation, which is free from the disorder, grew their enamel under the piped-in water."

In an old European city such as Resina, which was built about 900 A.D., generations of families may continue to live in the same houses from birth and, as McKay stated, "Migrations are exceedingly limited and they seldom travel far afield. The habits of life, including diet, also remain practically unchanged from one generation to another." For how many years and in what numbers had generations of Resina na-
tives used water containing fluoride acquired through contact with lava beds laid down by Vesuvius? McKay was informed that some of the outlying wells had been sunk as long as 300 to 500 years earlier, and had been in constant use ever since.

After his survey in Resina, McKay and his guide made their way into outlying rural districts. Examination of adults and children in these areas showed without exception that both the children and their parents were afflicted with the typical mottled enamel defect including the brown stain. "Not one individual who had used water from these old private wells during the enamel-growing period had escaped the enamel defect." Again McKay was impressed by the similarity of this Italian dental defect with that which he had observed previously in the United States. The Resina area surveys had pointed directly to the water used during the years of enamel growth as "the one etiological factor in the occurrence of this lesion within sharply defined geographical limits." Resina may thus be included among those communities in which a change in the water supply marked the end of the development of the enamel defect.

McKay was also impressed by the fact that this was "the first recorded instance in which the water had been derived from or associated with a definite volcanic origin." This observation recalled the fact that deep artesian waters were identified with the enamel defect in the United States. It was thought that these waters, also, might have acquired the same properties from similar formations within the heated interior of the earth, but it was known that endemic areas in McKay's experience were associated with surface waters too. Nonetheless, there was now available some evidence as to a possible source of a waterborne contaminant responsible for the enamel defect.

With McKay's departure from Italy the events and the location of this narrative resume in the United States and return to the year 1901 when McKay arrived in Colorado Springs.

NOTES AND REFERENCES

Dr. J. M. Eager's obituary was published August 26, 1916, in the Journal of the American Medical Association:

John Macauley Eager, M.D., Surgeon, U.S.P.H.S.; College of Physicians and Surgeons in the City of New York, 1888. Entered the Public Health Service as Assistant Surgeon, Feb. 16, 1891; 4 years later became Passed Assistant Surgeon, and was promoted to Surgeon, Dec. 19, 1907; had been on duty in Italy in 1901 and again in 1910 in connection with the cholera epidemic. He was sent back to Naples for duty in 1912 and died in Naples August 18, 1916, age 52.

The first observation of mottled enamel most probably was recorded by C. Kuhns in 1888 (Ditch. Mschr. Zahnheik., 6:446). Kuhns reported an obvious enamel defect in a family formerly resident in Durango, Mexico. He attributed the defect to iron but, as later surveys demonstrated, Durango water supplies had an unusually high content of fluoride.
In 1952, (J. Am. Dental Assoc., 44:154) Drs. Murray Massler and Isaac Shour reported results of a study in Italy on the relation of malnutrition to the development of dental fluorosis. They recalled that, in 1933, Ricci had described characteristic mottling in campagna di Roma. This community, of average economic status, was located some 35 miles northwest of Rome. By comparison, in Quatro, lying in a valley about 15 miles from Naples, "the economic status and the standards of living were low." Mottling of the teeth was prominent. The water of Campagnano di Roma contained 3.5 ppm of fluoride, that in Quatro 1.3 ppm. In general these investigators concluded that endemic dental fluorosis was noticeably higher in both these Italian communities than in comparable areas in the United States.


CHAPTER TWO

COLORADO BROWN STAIN

COLORADO SPRINGS merits an unusual and important place in the annals of water fluoridation. Throughout a half century or more, the population of this city had used drinking water usually containing a quantity of fluoride approaching 2.0 parts per million (ppm). During its early history it appears that more than 2.0 ppm fluoride was present in drinking water of that area. Prolonged use of this naturally fluoridated water provided a population of unique value for epidemiological and clinical studies of physiological effects of waterborne fluoride. From the early years of this century, numerous publications have presented dental and physiological data emanating from investigations on this community.

Colorado City, later to become a part of Colorado Springs, was founded as a typical frontier mining settlement. In 1861 it counted 300 cabins located along a river bank and was advertising its “medicinal waters.” During the Civil War the economy declined, a flood swept away most of the settlement, and Colorado City was almost a ghost town. Colorado Springs proper had its beginnings about 1870. Its founders planned a community “to attract and hold people of means and social standing, [and citizens of] good moral character and strict temperance habits.” The Denver and Rio Grande Western Railroad reached this new town from Denver in October, 1871. Known first as Fountain Colony, it was later renamed Colorado Springs for the mineral springs in the nearby village of Manitou. From its beginning, Colorado Springs and its environs were advertised as a “scenic wonderland and health resort.”

Physicians recommended the dry air and bright sunshine. Its first water supplies were indeed primitive; irrigation ditches bordered every street and ditch water was carried in tubs for domestic purposes, while “clear cold drinking water” was peddled about the streets for 25 cents a barrel. By the turn of the century, Colorado Springs had profited greatly from the Cripple Creek goldfields and other mining developments. Between 1890 and 1900 the population increased from 11,000 to more than 28,000. During the next decade, because of gold and silver mining fortunes, Colorado Springs laid claim to being the most wealthy city per capita in the United States.
An auspicious event in the early history of mottled enamel and water fluoridation occurred with the arrival of Dr. McKay in Colorado Springs in 1901, the year following his graduation from the University of Pennsylvania. His arrival marked the beginning of his fervent interest in the problem of mottled enamel, a dedication which continued throughout the remainder of his life. McKay was later honored as the first to introduce a new element of "personal research" into modern dentistry through his observations on mottled enamel.

McKay was a practicing dentist, and on his arrival in the Rocky Mountain area he was immediately impressed by the fact that many of his patients had an apparently permanent stain on their teeth. His "brown-stained" patients were especially numerous among those who were native to the area. Efforts to resolve this problem through professional contacts proved fruitless. The recently formed El Paso County Odontological Society, with McKay as a charter member, floundered in a feebler effort to study the problem. Letters were sent to dentists throughout the Rocky Mountain area, but McKay reported that the replies "brought very little information of value and the matter of further investigation was allowed to rest for the next six years." In 1905 he went to St. Louis, Mo., to become superintendent of a private school of orthodontics. Ill health was responsible for his return to Colorado Springs in 1908. He opened a dental office and renewed his interest in "Colorado Brown Stain." During his three years in St. Louis he had seen no enamel lesions resembling those so obvious and prevalent in his Colorado patients.

Dr. McKay was to remain in Colorado Springs until 1917, at which time he moved to new dental offices in New York City. During those nine years in Colorado Springs, in addition to practicing dentistry, he followed the trail of mottled enamel. His dynamic, persistent, inquisitive personality, combined with his unusual energy and enthusiasm, accounts for the eminent position he achieved in his pursuit of the cause of mottled enamel. He traveled into remote areas, particularly in Colorado and surrounding states, to observe and record the occurrence and the severity of Colorado Brown Stain. Comparatively few of the numerous towns, small villages, and ranch homes which he visited, and the observations which he recorded can be fully documented within the limitations of this narrative (1).

Shortly after his return to Colorado Springs in 1908, McKay again sought help from the El Paso County Odontological Society. Later, at a meeting of the Colorado State Dental Society, he introduced an individual having an obvious and typical case of severe mottled enamel. Neither of these moves stimulated much interest on the part of the Colorado dental profession. Undaunted, he initiated a more effective scheme. To advance his objective McKay solicited the interest of Dr. Greene Vardiman Black, Dean of the Northwestern University Dental School in Chicago, a leading dental histologist and an authority on the hard structures (enamel and dentin) of the teeth. Largely through
McKay's efforts, the Colorado State Dental Society extended a formal invitation to Black to attend a meeting of the Society. The following July (1909) Black visited Colorado. His personal and professional interests were aroused and his authority and prestige thereafter embraced the cause of mottled enamel.

Observations by H. A. Fynn

McKay appears not to have been the only local dentist in Colorado Springs at that time who was concerned about the problem of Colorado Brown Stain. On July 13, 1909, Dr. H. A. Fynn, a Colorado Springs dentist, read before the Colorado State Dental Society a paper on the defects in the enamel of the children of Colorado Springs (2). This early record of mottled enamel in Colorado Springs has particular interest as clinical evidence that fluoride was present in the drinking water of that area as early as 1900. Fynn stated that "87.5 percent of the children born and raised in this city have defects in the enamel . . . . It is foolish to assume that this enormous percentage of children is suffering from diseases of the skin or otherwise that would produce malnutrition—if malnutrition exerts any influence in this peculiar dental condition." Fynn finally arrived at the conclusion that the cause of this enamel defect was in the food itself, not in its assimilation and metabolism. He believed that the food "lacks a sufficient proportion of inorganic material," mostly calcium.

The condition was regarded as purely local, but Fynn wrote, "I think we shall be compelled to eliminate water." Analysis showed the water to be pure and in no degree different from Denver water. Finally, the dietary calcium deficiency was narrowed down to milk and vegetables, which were both local products. He also believed it reasonable to suppose that lime salts were lacking in the soils of the vicinity. "Furthermore," Fynn wrote, "the demands made by the skeleton exhaust the supply and rob the tooth of those constituents which go to make perfect enamel." To support his speculations on the effect of calcium deficiency he quoted a prominent German authority of that time, Dr. Carl Rose, who had given years to the study of foods and their relation to the tooth. Rose stated, "In proportion to the lime salts in the water and foodstuffs (particularly milk which is one of the best vehicles for carrying lime), the teeth of the people are immune to decay, other things being equal." These erroneous theories of both Rose and Fynn concerning adequate dietary calcium and calcification of the teeth unfortunately have continued into present day thinking about dental caries etiology.

Fynn finally emphasized "that this [calcium deficiency] is a local condition, caused by local influences, and must be cured by local conditions." Thus, at this early date, local foods were extolled for dental health benefits. Some 30 years later, Deaf Smith County, Texas, was to
make a similar claim of producing exceptional food products having remarkable beneficial effects on teeth. Although Deaf Smith County was a name that bewitched and the idea caught on, the mineral content of the local soil and foodstuffs was not the factor. As is now known, these localized dental benefits were due to fluoride in the drinking water. Dr. Fynn died before 1930 and apparently published nothing more on mottled enamel.

McKay and Black Studied "The Essential Injury"

The year 1908 seems to mark the beginning of serious efforts to assemble information from whatever sources possible to resolve the cause of Colorado Brown Stain, later to be recognized, variously named, and identified throughout the world. The disease, as seen by McKay at that time, was not difficult to diagnose. Mottled enamel with brown stain is unsightly because this discoloration is practically always localized in the conspicuous outer surfaces of the upper incisors and cuspids. Black referred to the often intense self-consciousness and bitter attitude generated by the severe form of mottled enamel. Black and McKay first described it in 1916 (3):

The most essential injury occurring in this mottled enamel is in the appearance of the teeth and the general evil effect on the countenance of the individual. The teeth are of normal form but not of normal color. When not stained with brown or yellow, they are a ghastly opaque white that comes prominently into notice whenever the lips are opened, which materially injures the expression of the countenance of the individual. When this opaque white color is mingled with spots of brown, or a very large proportion of brown, the injury is still greater. In very many cases the teeth appear absolutely black as one sees them in ordinary social intercourse. I spent considerable time walking on the streets, noticing the children in their play, attracting their attention and talking with them about their games, etc., for the purpose of studying the general effect of the deformity. I found it prominent in every group of children. One does not have to search for it, for it is continually forcing itself on the attention of the stranger by its persistent prominence. This is much more than a deformity of childhood. If it were only that, it would be of less consequence, but it is a deformity for life. The only escape from the deformity is by the placing of crowns, and possibly of bridges or artificial dentures later in life.

The proportion of the cases so bad as this is really very large. They are not all of the worst type by any means, but the struggle for a better appearance of the teeth, or the stoical endurance of a terrible affliction, is certainly upon from 30 to 100 percent of the persons being reared in the various areas where this deformity is endemic. Many of those counted as having mottled teeth are injured in such slight degree as almost to pass unnoticed. Every degree of injury, from solidly brown front teeth to the white flecking here and there, is represented.

This is the frightening report of the prevalence of mottled enamel in Colorado Springs and many of its surrounding areas early in this century.

Black was provided with specimen teeth from the Colorado Springs
area, and recorded his histological studies. He was the first to describe mottled enamel as Colorado Brown Stain.

All of the crowns I received were of incisors that had been cut away for the purpose of putting on artificial crowns to improve the appearance of the persons. Each of these was of normal tooth form. The lingual surfaces of these teeth were generally an opaque paper-white but mottled with normal spots and clouded areas. The labial surfaces were in part of an abnormal white color resembling white unglazed paper, but a considerable portion of the surface was mottled with dark brown. Some had black bands running across the labial surfaces; some had dark brown bands bordered with yellow which faded away into a paper-white, with normal enamel toward the gingival portion; some of them had enamel of normal color over the immediate incisal edge, but this did not extend to the labial surface. All of the paper-white and discolored portions were opaque, having none of the translucency of normal enamel.

It became clear to Black during this superficial examination that this was a type of dystrophy of the enamel of which nothing had appeared in dental literature and, if the statements were correct, it was endemic in type. But no endemic conditions of the teeth had been known. Further, if the reports were true that 87.5 percent of the children reared in these areas were afflicted with this endemic condition, the cases would be numbered in the thousands and the individual deformities could be very grave. Black felt certain that this diseased condition was, in every sense of the word, a dystrophy of the enamel, resulting from imperfect, defective, or bad formation of growth constituents. He was convinced, in other words, that the primary etiological characteristic of mottled enamel was developmental. The causative factor was present and effective only during the period of growth and development of the teeth. At this early date it was evident, therefore, to him that mottled enamel could not develop after the teeth had formed and had erupted. This fundamental fact was predicted also in the surveys made by McKay. All evidence pointed to the conclusion that this enamel deterioration occurred only in those individuals born and reared in an affected area or who had come into the area in infancy or in early childhood.

As this developmental characteristic of mottled enamel became evident, yet another characteristic of endemic mottling, the so-called "waterborne hypothesis," was soon to be verified with almost equal finality. As Black and McKay wrote in 1916, "From the very beginning of the notice taken of this lesion and before any steps were taken to study it, the sentiment of both the profession and the laity, in the areas of susceptibility, was that the water was in some way responsible. Indeed, it was hardly possible to mention this condition without at once encountering a question and often a dogmatic assertion indicating water as the cause." If water was suspected as being the cause, was it because of the presence or the absence of some waterborne ingredient? Lack of sufficient lime for the needs of calcification seemed plausible. A drinking-water analysis showing only 58 ppm total solids would denote a water of extreme purity and with an extremely low calcium content. These
were analytical data for Colorado Springs drinking water where Colorado Brown Stain prevailed. But Black and McKay hastened to invoke a word of caution. In other parts of Colorado there were highly mineralized waters where lesions had been reported. It was not long before it was concluded that teeth of very poor quality of enamel and having brown stain seemed to occur to a great extent in localities which showed a high lime content. It also occurred in relatively high proportion when the water was very low in lime content. In other words, mottled enamel was equally badly calcified in the endemic districts regardless of the lime content of the waters. This aspect of the problem could only add further confusion to understanding why the lesion distributed itself in such sharply defined areas.

Colorado Brown Stain Seen Elsewhere

McKay continued his surveys in many areas, and encountered further baffling and frustrating situations. Small villages were surveyed, some high in the mountains, some located on the slopes and near the base of Pikes Peak, and others on the nearby plains. McKay mentioned Pueblo, Manitou, La Junta, Ute Pass, Cripple Creek, Woodland Park, Green Mountain, and a small coal-mining camp, Pictou. He traveled the length of Fountain Creek and up its tributary, the Monument. After examining children in four different places along these mountain streams, he established that "removal from afflicted to immune areas for a part of each year during enamel formation exercises in some way an inhibitive action upon the lesion." The account of a survey of the Sigle Ranch located at the headwaters of Fountain Creek is typical of McKay's surveys:

The Sigle Ranch . . . is reached by a railroad that threads its way for fifty miles through one of the most rugged and picturesque gorges in the entire Rocky Mountain region, until the station [not given] is reached. Then a wagon road is followed for two miles back into the hills, and there, in a beautiful meadow, is the homestead, right in the heart of timbered mountains and in utter contrast with the plains region heretofore described.

On this ranch a son and daughter, now adults, were born, and they maintained an absolutely continuous residence there until they were man and woman. I personally examined this son, and found as marked and typical a case of the combined lesion as is possible to describe. The daughter had removed to another state just previously, but she was described as having a condition just as pronounced. The older brother was born elsewhere, and commenced a continuous residence on the ranch at the age of about seven. The enamel on his incisors, cuspids, and first molars was normal, but the bicuspids and second molars were mottled, which set of conditions exactly corresponds with the rule that has been found to operate almost unfailingly in endemic territory.

The neighboring population, of course, was very sparse, but I could get no account of any other family in that locality that was similarly afflicted. The water at the Sigle Ranch was analyzed by the then available methods, and was also analyzed for arsenic. The arsenic report was negative.
McKay and Black had been advised of the occurrence of mottled enamel in other areas outside the Rocky Mountain region and had made examinations where the characteristic enamel lesion was prevalent. These regions included the Atlantic Coast area north and east of Richmond, Virginia; South Dakota; the Texas Panhandle; and Arizona. In 1915, McKay made a number of examinations in Arizona and in the Dakotas. In Arizona he examined native American Indians of the Pima and Maricopa tribes. The mottled enamel situation among Pima Indians was first reported in 1915, however, by Dr. F. E. Rodriguez, a field dentist in the Indian Service (4) who noticed:

As a rule the stain [of mottled teeth] is not productive of premature decay. My belief on this point is due to the fact of having observed innumerable cases in adults, who had had the stain for a lifetime but who otherwise presented a sound, strong, and apparently healthy denture.

To conclude this account of Colorado Brown Stain in Colorado Springs and the Rocky Mountain areas, two quotations from the 1916 papers by Black and McKay are prophetic:

The mottled condition in itself does not seem to increase the susceptibility of the teeth to decay which is perhaps contrary to what might be expected, because the enamel surface is much more corrugated and rougher than normal enamel. It is recognized however, by dental practitioners dealing with this sort of enamel, that caries having occurred, it is difficult at times to find enamel sufficiently dense in which to lay cavity margins.

As to caries, the teeth of these children compare favorably with those of other communities where endemic mottled enamel is unknown. They have a mild climate and almost continuous sunshine during the day. The children are out practically every day the year round, and this in itself certainly has its effect in limiting the amount of dental caries. But when the teeth do decay, the frail condition of the enamel makes it extremely difficult to make good and effective fillings.

For this reason many individuals will lose their teeth because of caries, though the number of carious cavities is fewer than elsewhere. Yet I was of the opinion, at the end of several weeks' examination and study of the conditions, that if the appearance of the teeth could be endured, the injury in their development would, on the whole, not reduce the general usefulness of the teeth.

The Fluoride History of Colorado Springs Drinking Water

A unique feature of the Colorado Springs public water supply is that since its earliest history the water originated from surface sources. The primary source was melted snow from the southwest and east slopes of Pikes Peak. Actual quantitative estimates of the fluoride content of the drinking waters of Colorado Springs and its environs were not recorded until the early 1930's, but the widespread occurrence of mottled enamel in Colorado Springs early in this century is substantial evidence of an excess of fluoride in the drinking water perhaps even prior to 1900.

In 1933, C. H. Boissevain reported the results of an extensive survey
of the fluoride content of many drinking waters of Colorado (5). His primary interest was the relation of these fluoride waters to mottled enamel and this phase of his survey is discussed in a succeeding chapter. He reported the following quantities of fluoride in the Colorado Springs drinking waters (in ppm): Municipal—2.0, Northfield—1.2, Broadmoor—1.4, and Stratton Home—4.0. Fluoride in water supplies of a number of other places in Colorado were: Cripple Creek—2.0, Denver—0.5, Fountain—2.0, Fort Collins—0.0, Grand Junction—0.0, Green Mt. Falls—2.0, Manitou—2.4, Monument—0.5, Pictou—5.0, and Pueblo—0.2. Practically all streams contributing to the water supply of Colorado Springs contained fluorine, although some had ten times more than others.

In 1935 Dean and Elrove (6) recorded that the domestic water of Colorado Springs was provided by melting snow from the south, west, and east slopes of Pikes Peak, and from the east and coast slopes of Mount Baldy. The majority of the population of Colorado Springs had used water from this source for at least the past 20 years, beginning in about 1914. The fluoride content of monthly samples of Colorado Springs water as analyzed by Elrove in 1933 and 1934 was (in ppm): November—2.6, December—2.9, January—2.9, February—3.0, March—3.0, April—3.0, May—2.9, June—2.3, July—2.0, August—1.8, September—1.9, and October—2.0.

In documenting the water history of Colorado Springs, Dean, Arnold, and Elrove (7) pointed out that in its early days Colorado City used water from Southerland and Bear Creek, in addition to water purchased by contract from Colorado Springs. The city health officer of Colorado Springs, Dr. O. R. Gillett, advised these authors that according to the available records, Colorado City was using water from a source similar to that of Colorado Springs as far back as 1878. To quote further from Dean, Arnold, and Elrove, "There would seem some justification, therefore, for assuming that the inhabitants of Colorado Springs, including the annexed portion, Colorado City, have been using a relatively similar type of water for approximately 60 years. There is, moreover, strong epidemiological evidence that the population of Colorado Springs has been ingesting water with appreciable amounts of fluoride for at least as long as 45 years."

J. S. Nichols, Chief of Operations of the Colorado Springs Department of Public Utilities (private communication), made available the following information. Until 1953 the streams flowing from the slopes of Pikes Peak were the first and only source of water. The fluoride content varies seasonally but not annually. Records indicate a practically constant level of fluoride since the earliest records. Typical Pikes Peak streams and the range in ppm fluoride were: West Monument Creek—2.00—2.80, North Slope—2.15—3.00, Ruxton Creek—1.85—2.85, Bear Creek—3.22—3.60, Fountain Creek—2.05—3.00, and Cheyenne Creek—3.72—4.36. Bear Creek, as Dean, Arnold, and Elrove had noted, was a source of drinking water in the early days of Colorado City. According
to Nichols' letter, "For all years prior to 1953, delivered water in Colorado Springs consistently had an average fluoride content in the order of 2.4 to 2.8 ppm." During 1966 "at a representative station," the water varied from 1.6 to 2.5 ppm fluoride. Since 1953 the city's water supply has been increased by two new separate well fields and streams 100 miles distant in western Colorado. "The new sources are lower in fluoride and the fluoride content in Colorado Springs water has been lowered. The Pikes Peak watershed is now contributing about one-half the total city water delivered."

Regarding the source of fluoride in the Colorado Springs drinking water, Nichols commented, "Pikes Peak is composed entirely of a coarse-grained, extensively fractured granite, known geologically as Pikes Peak Granite. It is cut by intrusive dikes of quartz which commonly include fluor spar. Fluorspar has been mined commercially in the Cheyenne Creek area. The common occurrence of fluorspar probably accounts for the fluoride. There are no lava beds in the Pikes Peak region." Fluorspar is essentially all calcium fluoride.

An additional record of Colorado Springs water was presented in 1959 (8) and the fluoride content at different times is listed as: 2.6, 2.4, 2.7, 2.8, 2.0, and 1.6 ppm. The Colorado Springs population was 45,472 at that time. Other communities in Colorado, as recorded in this publication, also used waters containing fluoride (in ppm): Cripple Creek—3.6, Manitou—1.7 and 2.8, Broadmoor—2.4, Pueblo—0.8, La Junta—0.8, and Englewood—0.8—0.9.

A recent personal communication from Dr. Ralph E. Van Alstine, a geologist with the U.S. Geological Survey, provided additional information concerning the occurrence of fluoride minerals in the Pikes Peak area. A specialist on fluor spar, Van Alstine enclosed literature references, a copy of a 1964 Government report on the mineral and water resources of Colorado, and "a map showing the maximum reported fluoride content of Colorado groundwater, whether potable or not. The maximum for El Paso County, which includes the Pikes Peak area and Colorado Springs, is shown as 1.5 ppm fluoride or higher, the highest category on the map." These are fluoride data for groundwaters of the area. But surface waters, as previously noted, have been a major source of Colorado Springs drinking waters and generally have contained even higher concentrations of fluoride. Fluorite deposits may contribute the major amounts of fluoride in groundwaters in Colorado and, as Van Alstine stated,

One of the larger fluorite districts of Colorado is located in the Pikes Peak area, only about eight miles southwest of Colorado Springs. . . . Some fluorine geochemical anomalies are clearly associated with fluorite districts. For example, warm spring waters in Chaffee County, Colo., at fluorite deposits currently being investigated by the Geological Survey, contain 12–15 ppm F. Soil and alluvium adjacent to one of the veins contain as much as 4.84 and 0.80 percent F, respectively.

Fluoride minerals, as Van Alstine stated, were known to be present in the Pikes Peak area as early as 1880.
Thus the mottled enamel observation and subsequent water analyses fix the early 1890's, and certainly the first of this century, as the beginning date of extensive use of fluoride-bearing drinking waters in the environs of Pikes Peak and in Colorado Springs. This exposure to fluoride naturally present in drinking waters continues to this day and it involves ever-increasing numbers of people. Fluoride contents of the water supplies of Colorado have decreased and most of the waters are no longer responsible for a serious mottled enamel problem.

NOTES AND REFERENCES

Frederick S. McKay was born in Lawrence, Mass. in 1874 and received his D.D.S. from the University of Pennsylvania in 1900. He practiced dentistry in Colorado Springs from 1901 to 1905 and the following three years in St. Louis, returning to Colorado Springs where he remained until 1917. Dr. McKay moved then to New York City where he practiced orthodontia until 1940, and then went back to Colorado Springs to continue dental practice. He died in 1959. Dr. McKay was honored by the following awards: Jarvis Medal, 1945; Callahan Medal, 1949; Award from the American Association of Public Health Dentists, 1950; Honorary Member American Dental Association, 1951; Honorary Doctor of Science, University of Pennsylvania, 1952; Spenadel Medal, 1952; Lasker Award jointly with H. Trendley Dean, 1952. A great lover of music, he was President of the Colorado Springs Symphony Orchestra in 1951.

The McKay papers are now in the files of the State Historical Society of Wisconsin. They contain most of his personal correspondence and observations in addition to reprints of his publications on mottled enamel. The first in the professional literature concerning mottled enamel by McKay, with his close collaborator Dr. G. V. Black, appeared in 1915 in the Transactions of the Panama-Pacific Congress. A detailed record, including the histopathology, of the mottled enamel studies of McKay and Black was published in 1916 in a series of five articles in the Dental Cosmos of that year. The G. V. Black papers, in the Northwestern University Dental School Library, in Chicago, are an additional source of detailed accounts of the McKay and Black contributions to the early history of mottled enamel. The minutes of the Colorado State Dental Society are an additional source of information on events occurring during this early period.

CHAPTER THREE

WATER TAKES OVER

Two small communities changed the source of their public water supplies solely for the purpose of preventing the development of mottled enamel: Oakley, Idaho, in 1925, and Bauxite, Ark., in 1928. The results furnished unequivocal proof that the cause of this dental disease was a waterborne factor. Soon to be known also as endemic dental fluorosis, mottled enamel was the first dental disease to be prevented en masse by adjustment of public drinking water. These changes in a communal water supply occurred prior to the knowledge that the causative factor was fluoride in the water.

Oakley, Idaho

In 1908, Oakley was a tiny frontier village 75 miles northwest of Great Salt Lake. To supply water for this settlement a pipeline had been constructed to a warm spring located on a hillside five miles southeast of the town. In August, 1924, the health officer of Oakley contacted Dr. McKay, then visiting in Colorado Springs, and discussed with him the frightful condition of the teeth of children of Oakley. The blemished, unsightly, brown-stained appearance of the children's teeth had become the cause of consternation and resentment on the part of the children's parents. The mothers in the town were reported to be alarmed by this distressing state of affairs. They reported the matter to the Director of Public Health in Boise. Their resentment was aggravated by the knowledge that children in nearby communities did not have "such awful teeth." As in so many similar local situations, the condition was blamed on the water supply. Consultation with McKay readily confirmed this consensus. Action to change the Oakley water supply was demanded by the Womens Civic League. The citizens then passed a $35,000 bond issue to provide a new source of communal drinking water. Donald McNeil reported the details in his absorbing book, The Fight for Fluoridation (1): "Oakley, Idaho, became the first town known to make the amazing decision to change its water supply solely because of the existence of a dental abnormality. Even more astounding
was the fact that the citizens of Oakley made the decision without knowing what was in the water that caused the damage."

Oakley authorities were forced to decide where to obtain a different and safe community drinking water. McKay's position was indeed unenviable when he was asked to give assurance that a new type of water would not produce the disastrous dental defect. As McKay (2) has recorded the situation, "It was a source of regret to be unable to give any definite answer to the most important question, of a proper substitute for the then-existing water supply at Oakley, but I did state that the most valuable and conclusive evidence that could be obtained would be to locate individuals who had spent the years of enamel development in contact with a contemporary source of a new supply. The condition of their enamel would determine the question more definitely than any other means at our disposal."

Located near Oakley was Carpenter Spring, a source of non-thermal water which indicated a different geological source. Four children raised on the Carpenter Spring water had normal teeth free of brown stain. This information, however meager, swayed the officials of Oakley, and a pipeline was laid to Carpenter Spring. On July 1, 1925, a new water supply flowed in the mains of the Oakley settlement.

The climax of the Oakley episode came 7½ years later, in February, 1933, when the teeth of Oakley children were again examined by McKay. He reported that of 24 children born in Oakley following the change in the water supply, all showed normal calcification in those permanent teeth which had erupted. A change to the Carpenter Spring water had solved the problem of mottled enamel in the children of Oakley.

Since a quantitative fluoride analysis of drinking water was by then an accomplished procedure, an analysis of the old Oakley thermal spring water showed that it contained at least 6.0 ppm of fluoride, whereas the Carpenter Spring water contained less than 0.5 ppm fluoride.

Bauxite, Arkansas

Bauxite was organized in 1901 to provide homes for employees of the Republic Mining and Manufacturing Company, a subsidiary of the Aluminum Company of America (ALCOA). The name Bauxite is understandable if not very imaginative. As defined in mineralogy, bauxite is a hydrated aluminum oxide and it is found as a mineral deposit (together with Bauxite the village) about 25 miles southwest of Little Rock.

The first domestic water supply of Bauxite was provided by shallow wells and a few springs. In 1909 a new source of water was obtained from a 297-foot well and in September, 1925, a 245-foot well was added, but these deep wells were soon to be condemned as the cause of severe
mottled enamel in Bauxite children. A practicing dentist, Dr. F. L. Robertson, of nearby Benton apparently was the first to report the presence of mottled enamel in the children of Bauxite. Robertson had informed the Arkansas State Board of Health that it was very severe and easily recognized, and in March, 1926, the State Health Officer requested the U.S. Public Health Service to investigate. A survey was begun in February, 1928, by Dr. Grover A. Kempf of the U.S. Public Health Service and Dr. McKay (3). Before this survey started, however, the deep-well water of Bauxite had already been associated with the development of mottled enamel and steps had already been taken to change the community water. As in Oakley, it was an educated consensus that water was a factor.

In choosing a new source of water, the authorities were aware of the absence of mottled enamel in Benton, where the Saline River was the source of drinking water. There was good justification, therefore, to tap the Saline River water for use in Bauxite. The river was 7 miles distant, a six-inch pipeline was laid, and filtered Saline River water was in use in Bauxite by May, 1928.

The survey by Kempf and McKay indicated that a specific local agent was affecting the children of Bauxite. The agent or condition was limited to the village, because children in the immediate vicinity of the village were not affected. It was thought that the agent was not in the food, because the diet was the same outside as in the village. Mottled enamel attacked children in the well-to-do families as well as those of lower economic status and the children’s physical condition was ruled out. Their only clue was the use of water from the central deep-well supply.

Kempf requested that these waters be analyzed by the Public Health Service in Washington. For some reason Kempf thought that the manganese content of these waters presented some possibility in accounting for the enamel brown stain. Actually none of the analytical data obtained by routine analyses of waters from this and various other endemic areas shed any light on the probable waterborne agent. This was the situation as it existed in 1930. There is little wonder, therefore, that McKay, 30 years after his first observations, would find it extremely unfortunate that the detrimental ingredient of the waters causing mottled enamel had not yet been determined. He was convinced that the one immediate need in these investigations was an accurate and exhaustive chemical examination of the waters in comparison with waters from non-afflicted districts. Dr. G. V. Black also wrote despairingly, “If the hidden cause of this lesion is to be found in the water, it must be by other than the ordinary chemical analysis. Future work must be to search for the presence of some constituent heretofore undetermined.” But one year still remained before fluoride was to be identified as the cause of the lesion.

The Bauxite episode continued 10 years after that May day in 1928 when filtered Saline River water had entered the water mains of Baux-
ite. A resurvey was made in 1938 to determine the occurrence of mottled enamel in the children of Bauxite (4). The mottled enamel condition of the teeth of children who had been examined in 1928 was compared with the condition of the teeth of children living in Bauxite in 1938. The degree of affection observed in the 14- and 15-year-old children whose first group of permanent teeth were calcified largely under the influence of the old deep-well supply was very marked. It was found, however, that mottled enamel was essentially absent in children born after the change in the water supply. The summary statement of the report follows:

1. The production of an unusually severe type of endemic dental fluorosis (mottled enamel) at Bauxite, Ark., was halted with the change in the common water supply.

2. This is the second recorded instance in the United States where a community has abandoned the use of an otherwise satisfactory common water supply solely for the purpose of preventing the development of a permanent dental disfigurement among its children. The efforts in each instance were successful.

Andover and Britton, South Dakota

The small community of Andover has a less complete dental health record of the effects of a change in the drinking water. In 1928 the 800-foot deep-well water supply of Andover failed and a new water supply was provided by a shallow 22-foot dug well. As the presence of mottled enamel in children exposed to the old deep-well water had been recorded by McKay, Andover children were examined again in 1938 by Dean, who reported (5) that "12 children, 6-10 years of age, born since the change in the water supply, presented normal calcification of the permanent teeth."

A change in reverse, so to speak, also was noted in other South Dakota communal water records. In Britton, a few years before 1916, a communal water was supplied for the first time by a deep-drilled well, a change from individual shallow wells. Water from the new deep well was responsible "for the development of mottled enamel in all children," reported McKay. Prior to the change in drinking water, mottled enamel was unknown in Britton.

The history of Britton's fluoride-water supplies and the development of dental fluorosis has been documented recently by Horowitz, Maier, and Law (6). In 1947 Britton's public drinking water was analyzed as 6.7 ppm fluoride and because of this the community was selected as a desirable site for demonstrating a feasible procedure to defluoridate a public water supply. In November, 1948, a defluoridation plant was placed in operation using a synthetic hydroxyapatite as the agent. Bone char was used after January, 1953, providing a much greater reduction in fluoride in the water. From September, 1954, to April, 1965, the de-
fluoridated water averaged 1.6 ppm. The results of dental fluorosis examinations, as expected, reflected this reduced content of fluoride in the water. The findings clearly showed a reduction in fluorosis among the children examined in 1960.

The results of a 1965 survey were particularly striking for children younger than 11 years old, who were born after starting the use of bone char as the defluoridating agent. In 1948 all children in this age group had fluorosis, whereas in 1965 only 29 percent were so classified.

Horowitz, Maier, and Law called attention to the continuing public health problem of dental fluorosis. More than four million persons now live in communities served by water supplies naturally containing sufficient fluoride to cause esthetically undesirable dental fluorosis.

The first period of this fluoridation narrative thus comes to a close. The sporadic occurrence of mottled enamel only added to the uncertainty regarding its cause. But from the very first, drinking water was universally condemned, and before long there was little doubt that an unknown drinking-water factor caused mottled enamel. Drinking waters derived from almost every conceivable source seemed to be responsible. Clear mountain streams; springs; artesian wells; blue lakes, high at a timberline; deep or shallow wells; drilled wells of varying depth—all could provide potentially harmful drinking water.

NOTES AND REFERENCES

In January, 1926, Dr. McKay, who at that time was practicing dentistry in New York City, briefly outlined the status of mottled enamel in a letter to the Surgeon General. He noted that afflicted districts "exist in Colorado, New Mexico, Arizona, Old Mexico, California, Idaho, South Dakota, Texas, Virginia, Bahama Islands, Italy, and Holland." He warned the Surgeon General of the certain damage that would befall unborn generations and that nothing had been accomplished by the investigation, except as a result of the field work which had been reported. McKay noted also that various analyses of drinking waters had been made, but had been inconclusive. He asked for the assistance of the U.S. Public Health Service in order to obtain a more comprehensive chemical analysis of the water. McKay's plea for Public Health Service support was reinforced in 1926 by a similar request from the Chief Sanitary Engineer of Illinois, Harry F. Ferguson.

In July, 1927, an analysis of water known to be associated with mottled enamel was reported by Dr. W. Mansfield Clark of the Hygienic Laboratory, U.S. Public Health Service. The analysis conformed with current standards of water analysis and fluoride was not included.


CHAPTER FOUR

THE CAUSE OF MOTTLED ENAMEL

In a previous chapter, it was noted that Dr. F. E. Rodriguez, a Public Health Service dentist assigned to the Indian Service, had found extensive mottled enamel in the Pima Indian tribe in Arizona as early as 1915. McKay in 1916 also had noted the occurrence of mottled enamel among Indian children and adults of the Pima and Maricopa tribes. According to McKay, mottled teeth were present to some extent in all of 100 adults examined on the Pima reservation and of these adults none was less than about 47 years old. The Pimas had lived in this same locality for many years and had used water from rivers or irrigation ditches or from scooped-out, shallow depressions in the sand along the Arizona rivers. Although the fluoride content of Arizona drinking waters varied greatly, clinical evidence indicated its presence in excessive amounts in water supplies of Arizona early in this century. Mottled enamel was particularly prevalent in communities of the Salt River Valley and in the valley of the Gila River.

In 1916 McKay also recorded the occurrence of mottled enamel in Mexico, just over the Arizona border. In New Trails in Mexico, published in 1912, Carl Lumholtz, a non-dental historian, wrote a description of a Mexican settlement called Sonoita, located on the Sonoita River in northern Mexico only a few miles from the Arizona line: “With many of the Indian children (in an Indian settlement of about a hundred living about a mile down the river below Sonoita), it was noticeable that the four upper front teeth were chocolate-colored, no doubt on account of the water. It appears that the coloring does not take place until the second teeth come in. Some of the Mexican children [evidently at Sonoita] were disfigured in the same way.”

Discovery at Tucson, Arizona

Tuscon is an important city in Arizona, and the site of the University of Arizona, as well as the Arizona Agricultural Experiment Station. The city itself is located in the center of what was formerly an area of severe mottled enamel.
Some 60 miles southeast of Tucson in the San Pedro Valley there was formerly a small community known as St. David. The St. David population was afflicted with a high incidence of severe mottled enamel, typical of rural areas surrounding Tucson. Research scientists at the Agricultural Experiment Station would make good use of St. David’s fluoride drinking water, while the residents of this small community would provide unmistakable evidence of severe mottled enamel.

In 1930, Dr. Alexander E. Bard, previously a member of the faculty of the University of Pittsburgh Dental School, was a practicing dentist in Tucson. As in McKay’s experience in Colorado Springs, Bard was astounded by the disfiguring evidence of mottled enamel which he saw in so many children and adults living in that area, and he resolved to study the problem. At his request Dean H. E. Friesell of the Pittsburgh Dental School made an unsuccessful attempt to obtain funds from the Federal Government to conduct mottled enamel research in Arizona.

A study of the mottled enamel problem was begun in Tucson at the Arizona Agricultural Experiment Station by Dr. Margaret Cammack Smith, head of the Nutrition Department, and her husband, Howard V. Smith, Agricultural Chemist. They too were deeply concerned about this local dental problem. With Edith M. Lantz they made a preliminary report of the experimental work done to discover the cause of mottled enamel. The investigation was begun under a Purnell Project which was approved in June, 1930. Production of mottled enamel on the teeth of experimental animals was accomplished by February 1, 1931. Preparation of a manuscript was begun at that time, but realizing the usual delay of publication, a paper, “The Cause of Mottled Enamel,” was published earlier in Science. The data, upon which both the Science article and a paper read by request before the University of Pittsburgh Section of Dental Research were based, are included in an Experiment Station Bulletin (I).

The experiments were essentially a study of people living in St. David who were drinking water containing fluoride. The occurrence of mottled enamel in the St. David community was determined with major assistance from Bard. All the children in the public schools were examined as well as each member of the family in every home in St. David. Complete data were presented on 39 families (250 residents), including age at beginning of residence in St. David and the mottled condition of their teeth. “From the facts established it appeared that exposure of the child to the environmental factors of St. David during years of growth of the enamel of the permanent teeth is certain to result in mottling.” The authors found untenable any theory of hereditary tendency in mottled enamel or any relation to common diseases of childhood. “Records of the kind and age of occurrence of childhood diseases, such as measles, chickenpox, mumps, whooping cough, etc., showed no significant differences between the members of the family possessing mottled enamel and those who did not.” While the observa-
tion at that time was somewhat cursory, subsequent information on the etiology of mottled enamel attests to its essential validity.

The major experimental studies conducted by Smith, Lantz, and Smith made use of the ubiquitous white rat. In preliminary studies, St. David water was supplied the rats and the results gave "more reason to believe that there was some toxic material in the water, than that the water was lacking in some chemical necessary for the normal development of enamel. . . ." St. David water was then concentrated by evaporation to one-tenth the original volume and was supplied to the experimental rats. In a week's time a difference was noted. The rats' incisor teeth lost translucency, and the normal yellow pigment became white and more opaque. "In a month's time gross defects in the teeth of rats on St. David water were observed, the enamel being strikingly dull, chalky white in appearance, and pitted." These characteristics of the rats' incisors were regarded as "similar if not identical to the mottling seen in human teeth."

In the next series of experiments by the Smiths and Edith Lantz, fluoride was to be studied experimentally for the first time in direct connection with the problem of human mottled enamel and with the primary objective of resolving its cause. The words of these authors are quoted as a notable contribution to fluoride and mottled enamel research:

A review of the literature had revealed a report in 1925 by McCollum and his coworkers (2) of a disturbance in the structure of the teeth of rats, produced by amounts of fluorine only slightly above that occurring in natural foods. The effect of fluorine upon the teeth of another group of our experimental rats was next investigated. McCollum states that the incisors of rats fed sodium fluoride were abnormal in color, the orange tint normally seen on their anterior surfaces being absent. The teeth were also observed to grow into abnormal positions due to change in structure and hardness. In the same year (1925), Schultz and Lamb published a brief report of their results of feeding sodium fluoride to rats, reporting an abnormality of tooth development chiefly characterized by overgrowth of the incisors. (3).

In 1929 Taylor (4) reports the feeding of calcium fluosilicate to dairy cows as producing an effect upon the teeth, the "teeth being narrow and the animal shearmouthed . . . . The grinding surfaces of the molars of these animals were eventually worn down and the nerves exposed."

More recently McClure and Mitchell (5) in connection with a study of fluorine upon the metabolism of calcium have briefly mentioned "overgrowth of the upper incisors," "excessive wearing of the lower incisors," and "the dull white appearance of the teeth" of these animals.

However in no case was the observed defect connected with the mottled enamel of human teeth.

Other similar studies could have been reported by these investigators. In France in 1927 Carlos Bregare had reported that fluoride produced symmetrical "coffee or chocolate colored bands" on both the upper and lower incisors of rats. In 1929 Drs. L. A. Maynard and Chester Tolle, at the Cornell University Agricultural Experiment Station, developed the characteristic tooth changes in rats by feeding phosphate rock (which
contained fluoride) and sodium fluoride, changes which had been de-
scribed by McCollum, Simmonds, Becker, and Bunting (2).

To clarify the record—not without some embarrassment, however—F.
J. McClure and H. H. Mitchell were not aware of the problem of
human mottled enamel until 1932. Their publication referred to above
had appeared in 1931. In 1930, nonetheless, it was their consensus that
the most definitive effect of a small amount of fluoride was an impair-
ment of the quality of teeth of experimental white rats, and possibly of
dairy cattle. It was known that the fluoride content of teeth and bones
increased when fluoride was increased in the ration. McClure and
Mitchell at that time were primarily interested in the phosphate-flu-
oride problem of animal nutrition.

The Arizona workers reported additional results obtained by feeding
sodium fluoride in amounts equaling 0.025, 0.1, and 0.5 percent of the
diet. The characteristic enamel defects which developed in the rats
“were so strikingly similar to those produced by the feeding of the resi-
due from St. David water, that no one could fail to associate the two.”
To support these important experimental results, a fluoride analysis of
St. David’s drinking water was carried out by modifying an analytical
quantitative method in use at that time to determine fluorine in rock
phosphates. St. David drinking waters were found to contain 3.8 to 7.1
ppm fluoride, but the water at the Agricultural Experiment Station in
Tucson contained no fluoride. These authors concluded their historic
report as follows: “Thus definite proof has been advanced to show that
mottled enamel, a defect of the enamel of human teeth, prevalent in
many parts of the world, is caused by the destructive action of fluorine
present in the water supply of the afflicted communities.” A singularly
timely breakthrough in a new endemic problem of dental health had
occurred. The essential results of these studies have been confirmed
many times over since 1931.

Following their experimental animal studies, H. V. Smith and his
wife reported additional data (6). The drinking water of 110 public
and 75 private supplies in Arizona was analyzed, using a modified color-
metric method based on a reaction of fluoride with ferric chloride.
They stated, “While the method is subject to many errors, results may
be duplicated with reasonable accuracy, providing time and tempera-
ture factors are kept constant. This method gives higher results than
the volatilization method upon which the results included in the origi-
nal work were obtained.” The fluoride analyses ranged from 0.0 to 12.6
ppm. Waters in the Salt River Valley of Arizona were analyzed by a
more refined method and the data indicated 0.0 to 5.0 ppm fluoride pre-
cent although a few waters contained 12.5 to 18.8 ppm fluoride—one as
high as 29.5 ppm fluoride (7).

Analytical water-fluoride data obtained in the early 1930’s are signifi-
cant and had a notable impact on the resolution of the cause of mottled
enamel. Much was accomplished by the Arizona investigators through
their water-fluoride analyses and surveys of mottled enamel in Arizona.
Water-fluoride analytical procedures, however, needed to be refined. Notorious as a frustrating analytical procedure, the precise quantitative determination of trace quantities of fluorine in some materials requires further simplification and refinement even to this day. Equally urgent in the early 1980's was the need to refine, standardize, and quantitate the diagnosis of mottled enamel. Fortunately the skilled hand and discerning eye of the dental profession would soon take over in the person of Dr. H. Trendley Dean, a Commissioned Dental Officer of the U.S. Public Health Service. His animation, vigor, and success redounded throughout succeeding major dental events of fluoride history.

Several conclusions disclosed by the Smiths and their associates are timely. Differences in the fluoride concentration in the waters did not relate to the depth nor to the type of well. All artesian and deep-well waters were not characterized by excess fluoride. Arizona's larger cities, such as Tucson, Phoenix, Mesa, and Yuma fortunately did not have excessive fluoride in their drinking water, but this was not generally true of adjacent rural communities having private wells. Finally, to quote from the Smiths, "Elimination of this distressing and disfiguring tooth defect is a matter of prevention which can at this time be accomplished only by a change in the water supply of the community, to one which does not contain toxic concentrations of fluorides."

Findings at Bauxite, Arkansas

H. V. Churchill, Chief Chemist, Analytical Chemistry Division of the Aluminum Company Research Laboratories (later changed to ALCOA Research Laboratories) reported that analysis of the abandoned water supply of Bauxite had revealed the presence of fluoride (8). Churchill recorded that A. W. Petry of the laboratory had spectrographically identified fluoride in the deep-well water from Bauxite. Prior to this publication Churchill had presented these data to the Section on Water, Sewage, and Sanitation Chemistry of the American Chemical Society meeting in Indianapolis, Indiana, April 1, 1931.

The Aluminum Company at that time had more than a passing interest in the occurrence of mottled enamel in Bauxite. Most of the Bauxite men were employed in the ALCOA bauxite mines. A new water supply had recently been provided but it was not certain that a change in the drinking water of Bauxite would correct this particular local dental defect. An exceptional situation might exist in Bauxite and thus complicate the problem. This was a real possibility and gave rise to ALCOA's added concern. The problem could seriously affect business interests of ALCOA. Aluminum cooking utensils at that time had not been on the market for long and "aluminum toxicity" had already signaled trouble. Since Bauxite children were living in an area where aluminum-containing bauxite was being mined, it seemed possible that excessive exposure to bauxite was being made evident by this bizarre den-
toral defect in the children. This prospect was not good for the future of aluminum cooking utensils and the situation pressed for an immediate analysis of Bauxite's old drinking water.

Churchill and Petry had detected the presence of fluoride first by spectrographic analysis and found that Bauxite water showed a definite and specific characteristic band which proved to be identical with the band given by calcium fluoride. Only those salts containing both calcium and fluoride will show this band in the spectrum. The presence of fluoride was confirmed when a residue of Bauxite drinking water after evaporation was tested by a glass etching technique and gave a positive fluoride result.

Concerning the quantitative analysis of fluoride, Churchill stated, "It is fraught with difficulty," and he thought at the time that "the available methods gave low results." However, various waters from areas of endemic mottled enamel in the United States (supplied by Dr. McKay) were analyzed and found to contain the following fluoride quantities:

<table>
<thead>
<tr>
<th>Location of Sample</th>
<th>Fluorine as Fluoride (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep well, Bauxite, Ark.</td>
<td>13.7</td>
</tr>
<tr>
<td>Colorado Springs, Colo.</td>
<td>2.0</td>
</tr>
<tr>
<td>Well, near Kidder, S. D.</td>
<td>12.0</td>
</tr>
<tr>
<td>Well, near Lingerwood, S. D.</td>
<td>11.0</td>
</tr>
<tr>
<td>Oakley, Idaho (old source)</td>
<td>6.0</td>
</tr>
</tbody>
</table>

These results in general are quite acceptable in comparison with subsequent analyses.

In his report, however, Churchill emphasized that "no precise correlation between the fluoride content of these waters and mottled enamel has been established. . . . All that is shown is the presence of a hitherto unsuspected common constituent of the waters from endemic areas." Churchill, still aware of the lack of precise data on the fluoride content of drinking water, analyzed waters from 25 large cities located throughout the United States. He found less than 1.0 ppm fluoride in all of 26 samples analyzed, all of which were waters in use in many of the largest cities of the United States. No fluoride was found, for example, in Philadelphia, Washington, Albany, Fairfield (Conn.), New York, Boston, Newark, Chicago, Dallas, or Atlanta.

The Churchill article closed by stating, "Pending establishment of causal connection between fluorine at certain concentrations in water and the mottled enamel defect, water chemists might well give attention to the problem of the control of fluoride concentration in drinking water. Two questions are raised by this discovery of unsuspected amounts of fluoride in drinking water. First, what physiological effects may be produced by these fluorides; second, what can water chemistry contribute to the concentration control of fluorides?" Churchill no doubt knew of the occurrence of fluoride in natural waters because of reports which had been published before 1931. While these early fluoride analyses may leave something to be desired in accuracy, data on
drinking waters available as early as 1822 were compiled in 1937 by Dr. Kaj Roholm in his classic monograph (9), Fluorine Intoxication.

The fluoride content of sea water was not known with acceptable accuracy until 1933. Sea water ranges from 1.0 to 1.4 ppm fluoride and accounts for the exceptional quantity of fluoride in many sea foods and sea salt.

It is now well established that fluoride occurs in drinking waters widely distributed throughout the world, and few potable waters contain less than 0.05 ppm. This fluoride is accounted for by leaching of certain soil minerals, and deep-driven well waters may contain larger amounts of fluoride due to contact with deep fluoride-bearing rock formations. Fluoride averages 290 ppm in the 10-mile earth crust of igneous and sedimentary rocks and the following minerals contain fluoride as an essential element: fluorite, apatite, cryolite, topaz, phlogopite, lepidolite, zinnwaldite, and others less important. Biotite and muscovite are common soil minerals and may contain as much as 4.0 and 2.0 percent fluoride, respectively. Micas, apatite, and tourmaline seem to be the chief parent materials of fluoride in most soils. Volcanic granites also are an important source of soil fluoride in some areas. The association of fluoride with soil phosphates is particularly significant in both plant and animal nutrition. Fluoride contributes to the insolubility of phosphate deposits, and this combination of fluoride with phosphates has been regarded as an essential factor in the insolubility and preservation of soil phosphates throughout the ages. According to available geological evidence, fluoride, as provided by volcanic activity, serves this purpose and it is regarded as significant that volcanic eruption in the North American continent was especially vigorous at approximately the same time that the deposition of primary phosphates was occurring.

Darmous in North Africa

In many areas of the coastal plains of North Africa there are outcroppings of phosphate-mineral beds. The region is arid, with irrigation necessary for farming and livestock production, and the soil may be unusually high in phosphates. Violent winds blow over the dry land and eroded phosphate-mineral deposits and fill the air with phosphate-laden dust. Dust covers the grazing-land forage, cultivated crops, and garden vegetables; drinking-water supplies are muddied. Furthermore the phosphate beds and the dust contain fluoro-phosphates in a quantity sufficient to cause toxic effects to both the people and their domestic animals.

Afflicted animals and human beings used to suffer from a serious, often painful, deterioration of their teeth. Cold water was intolerable, chewing was painful and difficult, and the animals avoided coarse forage and certain other foodstuffs. Teeth of both animals and man would
turn brown or black, some became fragile and crumbled, and in some cases abraded even to the gum line. This is the picture of *darmous*—the dental fluorosis of North Africa—as it occurred in that area at the beginning of this century. No veterinarian, dentist, physiologist, or health official had attempted to resolve the cause of *darmous*, even though the condition had been in existence possibly for centuries. The word *darmous* (or *dermes*) is of Arabic origin but its meaning is unknown.

According to Dr. H. Velu (10) the first to direct attention to this disease were a Civil Controller, Croix-Marie and a veterinarian, Major Derveaux. Their observations, made in Morocco in 1918, failed to disclose the cause of the disease. Croix-Marie stated that, "Some natives attribute this disease to the water, others to the pastureage, but they had known for a long time that dental lesions in their domestic animals could be prevented by pasturing elsewhere during the period which precedes the eruption of permanent teeth. Subsequent return to old contaminated pasture areas could result in additional toxic effects."

In 1931 Velu began extensive investigations which were to throw new light on *darmous* and incriminate fluoride as the harmful factor. Velu had studied *darmous* first in Morocco in 1923, after which he was commissioned by the Pasteur Institute of Algeria to study the disease in phosphate areas in Tunisia. He came to the conclusion early in his surveys that there was a cause-and-effect relationship between phosphate and *darmous*—a definite association between *darmous* and the use of drinking waters which had passed through a phosphate mineral deposit. The protocols of Velu's studies bear witness to his awareness of phosphate toxicity investigations then being carried on in the United States. The results of these studies had already demonstrated a toxic effect of raw rock phosphate. Teeth of dairy animals were abraded and abnormal and it had been suggested, although not yet verified, that excess fluoride carried by this phosphate mineral was detrimental to dairy cattle.

In his initial animal experiments, Velu subjected five sheep to a natural phosphate regimen and they developed the characteristic lesions of *darmous*. Their grain ration had contained three percent of natural mineral phosphate over a period of two years. Velu then turned his attention to calcium fluoride, "since fluoride in both calcium fluoride and mineral phosphates is very insoluble and has a low physiological availability." He followed an experimental dietary regimen similar to that of Dr. E. V. McCollum and his associates, who, as was previously mentioned, had fed fluoride to white rats. Using adult white experimental rats, Velu observed that all showed the symptoms and lesions characteristic of chronic fluorosis. He was convinced that calcium fluoride and mineral phosphate caused the same toxic reaction. In another series of experiments, young sheep had normal food but their drinking water rested on a bed of natural phosphate in a wooden trough. Characteristic *darmous* lesions developed, and Velu concluded that *darmous* was caused by phosphates and was brought about by the prolonged con-
umption of water coming from a level where it had passed through the phosphate-bearing layer. He also concluded that this phosphate toxicity was caused by fluoride “which is included in all phosphates.” He recorded precise “symptoms of intoxication besides those of dental dystrophy.”

Velu quoted M. Claudon (11) and G. Compain (12) in describing the dental lesions in children living in the phosphate areas. After eruption, particularly of the incisors, the teeth turned yellow and then brown, but were normal if the children did not drink certain waters while their permanent teeth were developing. He referred to a village called Beni Meskine where some children of sheep herders would accompany their parents each winter into an area called Chaouia. These children showed no evidence of damous, but children who remained at home throughout the year, drinking continuously the Beni Meskine water, developed the typical damous lesions. Velu’s report is not only a detailed account of his own extensive studies but includes an extensive review of fluoride literature up to the year 1931.

Following publication of these results, the Department of Public Safety of Morocco was implored to do something about damous problems. “A health impairment, other than that evident in teeth, could be involved,” said Velu. Experiments with sheep that had received fluoride in relatively large quantities had demonstrated to him a pronounced non-dental toxic effect. In the interest of public health he proposed that community public drinking water be obtained by boring wells “to reach levels independent of the phosphate layers.” In the rural areas the problem of water supplies was much more complex. These warnings by Velu gave rise to intensive investigation of individuals afflicted with damous. Private inquiries with the assistance of government physicians were conducted in affected areas and biological studies were initiated at the Algiers Institute of Hygiene by Gaud, Charnot, and Langlais (13). Human dental dystrophies were studied, described, and cataloged by these authors, following closely the descriptions of Eager, McKay, Black, the Smiths of Arizona, and others. The course of the dental lesions was classified into “First”, “Second”, and “Third” degrees. Teeth badly attacked by damous were rapidly covered by tartar. In “Third degree” teeth, there was a pronounced wearing down. Such extreme abrasion was not common even in severe mottling but the authors noted, “In the case of the Morocco natives, the progressive wearing away of the teeth is a phenomenon which is normally much more accentuated than in the case of the Europeans and this is probably related to the manner of eating.” The damous affliction, however, aggravated their normal abrasion and “in an early and rapid manner this state of wear results in the typical black tooth, reduced in all its dimensions, unrecognizable from the morphological point of view, a veritable stump in a mouth which is often half toothless.”

Drs. McKay and Black had not seen a dental disaster such as this in Colorado Springs.
Gaud, Charnot, and Langlais had high regard for Velu's studies, but were surprised to find that no determination of fluorine had been made in the phosphate-bearing water used in feeding his experimental animals. While Velu had obtained a fluoride analysis of water from the phosphate-bearing area of Kourigha, the quantity of fluoride (3.08 ppm) was regarded as insufficient to produce toxic effects. They decided to complete and confirm the experiments of Velu by repeated determinations of fluoride. As usual, it was necessary to improve and develop the method of fluoride analysis. A so-called lanthanum-acetate method was used "introducing a personal modification," and was regarded with satisfaction by these investigators after finding their results agreed with the data Velu had obtained from an analysis made in the United States. Without doubt it was ill-advised for these authors to feel entirely secure in accepting their analytical data. However, the fluoride analysis of tissues of an afflicted animal was their first objective. Their story is recorded in all its details:

A native she-ass, 4 years of age, born in the area, afflicted with *darmous*, in the division of Ouled Bou Ali, tribe of the Beni Smir, register of Oued Zem, which had developed its teeth in Beni Smir, and had lived only in the *darmous* area (Gaada), and presenting a definite attack of all the teeth, and a bilateral osseous tumor in the lower jaw, served for our determinations. During its transportation from the Beni Smir to Rabat, the animal was fed vegetables from Oued Zem, and only drank water from the phosphate-bearing zones. [What a she-ass and what a pedigree! But all was for the best, she rode in state to the guillotine. Reduced to an ignominious specimen (for fluoride analysis at the hands of her masters) she achieved immortality in a historic compilation of fluoride data.] . . . The results of this study of the presence of fluorine and its distribution in the individual attacked by *darmous* [the she-ass, of course] are thus absolutely definite, and fully confirm the conclusions of Velu insofar as they concern the action of fluorine upon the organism. Fluorine indicates the intoxication by its presence in an abnormal amount in certain tissues. Moreover, this amount is greater in proportion as the tissue has been affected to a greater extent.

The determination of fluoride and its distribution in animal tissues was only the beginning of extensive and varied studies by these dedicated French investigators. Diet, drinking water, mud in suspension in the water, vegetation, dust, barley straw (before and after removal of dust), soils (at various depths), phosphates and other soil minerals, and even air passing over crushed phosphates (recalling the natives' theory of gaseous emanations as the cause of the disease) all were analyzed for fluorine. Guinea pigs were given mud, vegetation, water, or dust as a source of fluoride in their diet. The guinea pig was then ashed *in toto* and analyzed for fluoride.

An additional area of interest was investigated when Gaud, Charnot, and Langlais asked, "Are there other manifestations of human *darmous*?" To this end inquiries were extended to all of the phosphate-bearing zones of Morocco. The survey was carried out separately in each sector by local physicians in areas containing 10,000 individuals and "the problem was discussed on the spot with each of them in order
thoroughly to coordinate and unify the methods of examination." The results were always the same. "None of the general difficulties mentioned could be discovered in the case of mankind, in spite of detailed examination." Stillbirth and infant mortality were studied particularly. They stated:

We cannot conclude, at least at present, that *darmous* reduces infant mortality, but we can certainly admit that it does not increase it. Moreover it should be remarked that if human *darmous*, which has always prevailed in the phosphate-bearing zones, produced severe general symptoms among mankind (such as interference with the reproductive functions or abnormal mortality among children) the population of these areas would have been progressively reduced; otherwise the race would have been affected and the defects would have been fixed. However, neither the density of the population in these areas nor the physical state of the individuals confirm this hypothesis. . . . Thus there is removed from our minds this severe worry about a marked effect of *darmous* on the health.

Human *darmous* is very frequent in the phosphate-bearing zones. In different degrees it attacks almost all of the individuals who live there in their childhood or, more exactly, in the period of childhood which precedes the appearance of the permanent teeth, but its pathological symptoms are clinically limited in mankind to dental dystrophies, secondary diseases of the teeth and the gums, and to common gastrointestinal difficulties which may result from the insufficient mastication of the food.

Thus Gaud, Charnot, and Langlais in 1932 evaluated the health status of individuals exposed to a forbidding quantity of fluoride. Several years later a further study of natives of these areas included X-ray examinations of the bones. It is not surprising that osseous lesions in the form of exostoses, as well as a more or less generalized condition of osteoporosis, were reported as prevalent.

How was it possible to prevent, or at least diminish, human *darmous* in the phosphate areas of North Africa? In the final pages of their report the authors discussed the problem in terms of water, mud, vegetation, and soil. It was with less mud in the water

. . . that the war against *darmous* may act effectively. All the procedures for obtaining clear water should be utilized—settling basins, filters, etc. . . . Protect the springs and the wells and prevent man and beast from stirring up drinking water. Said one observer, "Animals are more attacked than man." The repeated operations of drawing water necessary for refilling the drinking troughs disturb the water, resuspending the insoluble matter which had been deposited at the bottom of the well. Man himself prefers to draw his water in the morning while the water is clear. The reports of the natives state that *darmous* is reduced if the supply of drinking water is no longer contained in the *querba* (goatskin vessel), but in pottery vessels the suspended solid material deposits more easily on the walls of the jug and remains there when water is taken from it.

The fluorine content of the water, the mud, and the amount of mud in suspension were the major facets of fluoride ingestion that should be controlled. Removal of dust from vegetables and grain was recommended as perhaps more easily realized than preventing the children from eating dirt which they found especially palatable during the years
of tooth formation. In arid areas animals may eat a considerable amount of dirt when grazing on stubble and stunted vegetation. Finally, "Plant hedges to protect gardens against winds."

In this report on darmous, Gaud, Charnot, and Langlais also discussed the source of fluoride in phosphate minerals of the North Africa area. These phosphate deposits originated, they reported, from "the cadaveric decomposition of marine animals . . . dating from the secondary era and the beginning of the tertiary." The percentage of fluoride in the fossil deposits was so high, "that it does not seem possible that fluorine could have existed at such a high concentration in the living animal." Fossil bones and teeth indeed acquire fluoride through ages of contact with soil waters containing even small quantities of fluoride, and fossil bones which have been in contact with a water containing fluoride may have acquired a very high fluoride content.

NOTES AND REFERENCES

In all probability the first recorded suggestion that fluoride in drinking water might be associated with mottled enamel should be credited to a Canadian chemist, Mr. Frank Hannon. Aware of McKay's reports on mottled enamel and the evidence of its relation to drinking water, Hannon wrote a letter to the editor of Water Works Engineering (July, 1926) in which he suggested that drinking waters from mottled enamel areas should be analyzed for fluoride. It was his idea that this water perhaps did not contain sufficient fluoride. He emphasized that fluoride, to the average water chemist, "was shrouded in obscurity." But for unknown reasons, Hannon's suggestion regarding fluoride in drinking water was disregarded by McKay and others who were concerned about what waterborne factor caused mottled enamel.

In 1933, Sebrell, Dean, and Elvove (Public Health Rept. (U.S.), 48:437) described the effect of a fluoride drinking water on the incisors of white rats. The drinking water of Conway, Horry County, S.C., contained 6.0 ppm fluoride. Children of that area had a high incidence of mottled enamel. Conway water was concentrated to one-tenth of its volume, and caused characteristic changes in rat incisors. A supplemented drinking water containing 150 ppm of sodium fluoride produced changes similar to those of the concentrated Conway water. This effect of natural and supplemented fluoride waters on rats' incisor teeth has been repeated many times by numerous investigators. Thus, the late Dr. Isaac Schour in cooperation with Dr. Margaret Cammack Smith reported results of a very elegant study on the histological changes in the enamel and dentin of the rat incisor in acute and chronic experimental fluorosis (Ariz. Agr. Expt. Sta. Tech. Bull., 52). Fluoride apparently has a direct local action on the enamel-forming cells in the rat incisor. Changes observed in the incisors were not produced primarily by changes in blood calcium and phosphorus or by disturbances in the parathyroids.

Tucson, Arizona


Bauxite, Arkansas


North Africa


CHAPTER FIVE

FLUORIDE TOXICOSIS AND DOMESTIC ANIMALS

AFFLICTED domestic animals in North Africa suffered from too much fluoride ingested in food, soil, and water. Both man and his domestic animals in that environment had developed similar characteristic symptoms of fluoride toxicosis. Extensive reports on the effects of fluoride on domestic animals describe physiological criteria of fluoride toxicity in many instances directly applicable to man. Since the early 1930’s, fluoride toxicosis in domestic animals has been studied extensively, particularly in the United States and Great Britain. In addition to an exposure of domestic animals to fluoride naturally present in excessive quantities in drinking waters, two other more serious exposures have brought about extensive research on fluoride toxicosis. The most serious of these fluoride hazards occurred in areas adjacent to industrial plants where manufacturing processes emitted fluoride-containing gases and dust. Reported from numerous countries, these industrial plants included those producing acid and defluoridated phosphates, engaged in the electrolytic production of aluminum, the manufacture of bricks from fluoride-bearing clays, the calcining of limestone, and special enameling processes. Early in this century such an atmospherically induced fluoride toxicity was reported in animals grazing near a superphosphate factory in Italy, and analytical studies demonstrated “enormous” quantities of fluoride in the bone ash of affected animals.

A serious exposure of domestic animals, particularly cattle and sheep, to excessive quantities of fluoride was brought about by supplementing animal rations with raw rock phosphate and phosphatic limestones which are abundant minerals, economical and suitable to supply essential calcium and phosphorus as a dietary supplement. When first used, these naturally occurring raw rock phosphates and phosphatic limestones contained a toxic quantity of fluoride.

A further interesting fluoride exposure which seriously affected domestic animals recalls our earlier discussion of the shadow of Vesuvius. Gases and dust accompanying volcanic eruptions contaminated grazing-land forage with fluoride in quantities sufficient to cause a severe
toxic reaction in sheep. Fluoride affliction resulting from such periodic volcanic eruptions has an interesting history, dating back many centuries. The situation was recorded by Roholm in 1937 (1):

In the Icelandic literature from round about the year 1000 up to recent times, we find accounts of how domestic animals turned sick and died when there were volcanic eruptions. The earliest attempt to describe the symptoms dates from the year 1694. Later and more comprehensive accounts gave out good descriptions of the disease, especially the disease which broke out in conjunction with Hekla’s last eruption in 1845. The disease which has played a great role in Iceland’s economy has since been observed in 1875 after the eruption of Askja, and probably in 1918 in connection with the eruption of Katla.

The disease attacked animals, especially the sheep, which ate the grass contaminated by the fallen ash. Many animals died acutely, but “chronic changes developed in the course of months.” The bones, especially those of the extremities and the jaws, were thickened by growths which could be cut with a knife. No mention is made of spontaneous fractures. It was characteristic that young animals especially were attacked. The disease was not infectious. The symptoms disappeared when the animals were taken indoors and fed on hay, mown before the eruption. Later symptoms, which could be traced up to 10 or 12 years after an eruption, were a variety of dental afflictions attacking only the permanent teeth of animals which had not shed their milk teeth prior to the eruption. The incisors, which in some cases were smaller and more pointed than normally, were studded with yellow and black spots; they decayed quickly (as tooth). The molars underwent the greater changes, however, being deformed so that the row became irregular, making cud-chewing difficult. Sharp prominences would gnaw holes in the opposite jaw. This dental disease has the ancient Icelandic name of gad-dur or gaddfjaxl (gaddur, spike; fjaxl, jaw tooth).

At the Royal Agricultural and Veterinary College in Copenhagen there is a collection of bones (mandibles, extremities) of adult sheep which grazed on fields in the vicinity of Hekla during the eruption of 1845. The teeth seem to be normal. All the bones are covered with general or more scattered coatings of a characteristic, porous and brittle, osseous tissue. In severe cases the thickness of the bone may be twice the normal. The articular surfaces are normal. Röntgen examination of the bones reveals no definite halisteresis.

Fluorosis in Cattle Caused by Fluoride in Drinking Water

Drs. H. J. Schmidt and W. E. Rand (2) in 1952 recorded that the high-fluoride waters of Arizona caused fluorosis in domestic animals. On the northern outskirts of Phoenix, the Milky Way Hereford Ranch maintained its Hereford breeding operation on the Home Farm on Camelback Road and on the nearby Scottsdale Farm. Fluorosis was never a problem on the Milky Way Ranch, although there was some evidence of mottling and slight wear in the incisor teeth of the cattle. However, the well water on the Home Farm contained 16 ppm of fluoride, and irrigation water analyzed 6.3 ppm. Animals which were spending at least half their time each year on the high-fluoride water at Home Farm, after a 5-year period developed slight mottling and wearing of the incisor teeth. Near these ranches was the Homrighausen
Farm, the home of fine registered Holstein Friesians. One well was used on this farm both for watering cattle and for irrigation. In November and December, 1949, this water analyzed 4.8 and 5.1 ppm fluoride. Some of the animals had been exposed to this water for as long as ten years, but the owner and operator of the farm never suspected fluoride damage to any of her cattle. A different story is reported, however, in the case of the Sunrest Hereford Ranch, near Phoenix, and fluorosis in this choice registered Hereford herd had to be eliminated. The ranch was using water in 1940 which contained as much as 18 ppm of fluoride and during the ensuing four years a severe fluoride toxicity increased steadily. The first evidences were lameness and stiffness followed by a generally unthrifty condition with eventual mild emaciation and anemia. By 1945 the incisor teeth were mottled and severely worn. The condition obviously was fluorosis and the water supply had to be changed to Roosevelt Dam irrigation water and later to Phoenix city water, both of which contained less than 1.0 ppm of fluoride. The trouble with the cattle started receding immediately.

When Dean began extensive surveys in the United States in 1933 to document the distribution of mottled enamel, he reported the occurrence of mottled teeth in dairy cows in Horry County, S.C., where the artesian drinking waters contained 4.5 ppm fluoride (3). Later Dean examined "a dozen skulls of range cattle just slaughtered at an Amarillo, Texas, abattoir." A mottled condition was present on incisor teeth of four specimens. As Dean wrote, the brown-stain mottling was a form "rather common among people in Amarillo and the adjacent territory to the south and west." He concluded, "Based on the widespread distribution of mottled enamel among the people of this section it appears that livestock have few water supplies available that are free from toxic amounts of fluorides."

Animal Fluorosis Induced by Industrial Effluents

Detailed reports have come from England of industrial fluorosis in farm animals attributable to fluoride contamination of pasture forage. Air pollution had occurred particularly in connection with the manufacture of bricks, the calcining of ironstone, and from a color and enamel factory. Generally it was shown that contamination of vegetation was entirely superficial and was not due to fluorine compounds carried down into the soil by rain.

Under auspices of the Medical Research Council of Great Britain, the results of an extensive study of industrial fluorosis in animals and man near Fort William, Scotland, were published in 1949 (4). The Fort William aluminum factory in Inverness-shire is at sea level at the junction of four valleys. The valleys vary in width, and the height of bordering mountains and atmospheric variables affect atmospheric contamination to a large extent. Vegetation growing in the direction of
prevailing winds contained from 1,104 ppm (dry weight) to 85 and 7 
ppm fluoride depending on the distance from the factory. The water in 
the area contained only 0.04 to 0.77 ppm fluoride. Examination of 
sheep and cattle in the Fort William environs revealed abnormal teeth. 
Some animals were debilitated, some were stiff and lame, and bones as 
well as teeth showed decided lesions. Body tissues, especially bones and 
teeth, had an increased fluoride content and urinary fluoride excretion 
was definitely elevated. In this particular survey, clinical, radiological, 
hematological, and biochemical studies were carried out on selected 
groups of individuals living in the Fort William and Kinlochleven 
areas or working in the plants. Examinations revealed little evidence of 
organic disease of a general nature and still less of abnormal physical 
signs which could be attributed to an occupational fluoride hazard. 
The urinary fluoride of individuals most heavily exposed to atmos-
pheric fluoride was 9.03 mg each 24 hours. X-rays showed bone abnor-
malities in 4 percent of the adults, but none in children. Although the 
urinary fluoride data for most individuals indicated an increased inges-
tion of fluoride, there was no sign of typical injury attributable to fluo-
ride exposure. The contaminated forage supplied to the livestock obvi-
ously was the cause of the major fluoride toxicity in animals, but the 
men and women, even those working in the factories, had only a lim-
ited and harmless contact with fluoride in air or dust.

In general the picture of fluorosis in domestic animals in such areas 
was clear, and close correlation was possible between clinical symptoms 
in livestock and average fluorine contamination of grass. Marked cases 
of fluorosis were practically always characterized by lameness and pro-
nounced skeletal changes. Well-defined exostoses were frequently present 
on bones of these animals, and these had occurred when pasture values 
exceeded 25 ppm of fluoride. When the pasture grass contained 14 to 16 
ppm fluoride, mottling of the animals' teeth was observed. Young stock 
from some areas with grass having 7 ppm fluoride did not develop den-
tal fluorosis, although the fluoride content of skeletal tissues was ele-
vated. While severe fluorosis affecting the general health of the animals 
was difficult to diagnose, the rate of growth was often reduced and there 
could be marked cachexia. The gait could become stiff and laborious 
and the animals would remain recumbent for long periods.

In all of these extensive animal studies conducted in Great Britain 
the most sensitive clinical index of fluoride absorption was the mot-
tling, staining, and excessive wearing of permanent teeth formed at the 
time of fluoride absorption. Practically all the investigators, whether 
concerned with field studies or controlled feeding experiments, had re-
ported this effect. This manifestation occurred at a lower level of fluo-
ride ingestion than any other effect. Thus it was concluded that a com-
bined involvement of teeth and bones was a unique characteristic of an-
imal fluorosis, and should be the first subject of any study of a suspected 
toxic fluoride reaction.
Observations at the Tennessee Agricultural Experiment Station

The problem of industrial fluoride effluents was explored extensively at the Tennessee Agricultural Experiment Station (5), and as early as 1920 this station recognized the need to evaluate the incorporation of fluoride in soil, because fluoride-containing insecticides were introduced at about that time to control an invasion of the Mexican bean beetle. This investigation was soon superseded, however, by chemical studies which evaluated the fluoride content of atmosphere, rain and surface waters, phosphate fertilizers, rock phosphates, and slags. Industrial fluoride effluents in the Tennessee area were investigated in collaboration with the Tennessee Valley Authority, the Monsanto Chemical Company, and the Victor Chemical Works. Groups of cattle, yearling heifers, and sheep were subjected to various quantities of fluoride added directly to their ration, or present in hay or in grazed pastures contaminated with fluoride from an aluminum smelting plant. The rations contained fluoride varying from 10 to 1,200 ppm, the excessive quantities affecting appetite, food consumption, and body weight.

A major interest of this investigation was the classification and description of effects of various levels of fluoride on the animals' teeth. Urinary fluoride excretion, as well as fluoride in bones, blood, and bone lesions were reported. Following post-mortem examination, two types of gross bone changes were recognized. One was a typical exostosis found on the external surfaces of the bones of the legs and on the mandible. A second type of bone change was a thickening of shafts of certain bones of the legs and the rami of the mandibles, causing an increase in the bone diameter. As usual, the first evidence of fluoride toxicosis was a structural change in the teeth—striations, bleaching to chalky white, brown stain, and increased wear. Bone storage of fluoride and characteristic bone changes then developed. The percentage of fluoride stored in skeletal tissues was directly related to the amount and the length of time of fluoride ingestion. The severity of bone dyscrasias thus correlated directly with the quantity of fluoride deposited in the bones.

Observations at Utah State University Experiment Station

Late in 1940 Utah State University initiated research on fluoride toxicity, directed by Dr. D. A. Greenwood (6) and motivated by vegetation damage from industrial effluents. Some 200 dairy and beef animals were included in surveys extending over a 12-year period. Animals grazing in industrial endemic fluoride areas and other animals fed diets containing fluoride up to 109 ppm (on a dry basis) were subjected to detailed necropsies. The information obtained, in general, is consistent with other established symptoms and effects of chronic fluorosis. A résumé of some of the observations as reported from these studies follows:
1. Apparently the effects of fluorine on the digestion and absorption of nutrients are secondary, since it required nearly two and a half years for the higher levels to influence these metabolic functions.

2. Cows receiving 12 ppm of F remained normal throughout the long-term experiment. Cows on the diet with 27 ppm of F had slightly mottled incisor teeth and very slight osteosclerosis but no detectable impairment of body functions.

3. Fluorotic dental and bone lesions were correlated with amount of fluorine ingested, amount of fluorine in the bone, age of the animal, duration of exposure, and body processes.

4. Urine analysis, despite its inherent limitations, was useful in indicating current fluorine intake. Taken alone, however, this measurement was an inadequate criterion for a definite diagnosis of fluorosis in cattle.

5. Soft tissues, blood, hoofs, and reproductive efficiency were not affected adversely by any of the treatment levels. Bone alkaline phosphatase activity increased as levels of fluoride ingestion increased. The other enzymes studied, alkaline phosphatase in blood serum, succinic dehydrogenase in heart muscle, lipase and amylase in the pancreas, enolase and pyruvate kinase in skeletal muscle, and papain in the abdominal mucosa showed no treatment effects.

Fluoride in the Mineral Nutrition of Animals

Research in mineral nutrition, particularly of sheep, swine, poultry, and the dairy cow, led to accumulations of major experimental evidence of fluoride toxicosis (7, 8). A dairy cow has an especially critical need for calcium and phosphorus, for growth as well as for milk production. A number of agricultural experiment stations in the United States, therefore, have been interested in the effects of fluoride in such mineral supplements needed by the high-producing dairy cow. These included experiment stations in Ohio, Michigan, California, Tennessee, Wisconsin, New York, and Illinois. In these studies, animal rations were supplemented with raw rock phosphate which contained from 3.25 to 4.00 percent of fluoride, and also with a superphosphate prepared from rock phosphate by driving off from one-fourth to two-thirds of the fluoride. Defluorinated phosphates used as mineral supplement now generally contain less than 0.5 percent fluoride and the fluoride may be reduced to 0.1 percent. For use in animal rations, defluorinated phosphates thus do not now provide a toxic quantity of fluoride.

Studies at the Michigan Agricultural Experiment Station

In 1930, bone flour, limestone rock, raw rock phosphate, and a complex mineral mixture as supplements of calcium in the dairy cow’s ration were studied at the Michigan Station (9). As judged by the degree of clinical symptoms, pathology, and bone and tooth changes, bone flour was superior and raw rock phosphate detrimental to the dairy cow. Present as 1.5 percent of the grain mixture, this raw rock phosphate produced abnormal, badly worn teeth, abnormal changes in
bones (especially the metatarsal bones which were exostotic), and evidence of ankylosis. The authors of these studies concluded that raw rock phosphate should never be fed to dairy cattle because of its detrimental effects possibly due to fluoride. Raw rock phosphate containing 3.5 percent of fluoride added approximately 0.052 percent (520 ppm) fluoride to the grain mixture fed to the dairy cows.

While the above experiments illustrate results to expect from feeding raw rock phosphate containing excessive fluoride particularly to the dairy cow, fluoride toxicity studies on sheep, swine, and poultry had demonstrated the susceptibility of each species as well as characteristic symptoms of fluoride toxicosis. Studies on sheep in Australia showed that in severely affected animals the deformities could lead to infection and alveolar periostitis.

Animal Fluorosis Studied at the University of Wisconsin

Researchers from the University of Wisconsin in 1934 (10) and again in 1957 (11) recorded their conclusions after five or more years of development of fluoride toxicity in dairy cattle:

The earliest observable measures of increased fluorine ingested by young cows were physiologic effects upon the teeth and elevated concentrations of fluoride present in urine and rib bone biopsy samples. After this early evidence of increased fluorine ingestion, no other untoward effects were observed except a steady rise in bone fluoride concentrations until after a considerable period of time had elapsed. Animals receiving 50 ppm of fluoride as sodium fluoride developed the symptoms of extreme fluorosis by the end of the 5½-year period. However 30 ppm was "tolerated with comparative safety," and 30 ppm is near a marginal tolerance level.

Histological examinations of bone tissues of animals uniformly revealed such typical changes concomitant with skeletal fluorosis as atrophy of the spongiosa, defective and irregular calcification of newly formed osseous tissue, and acute periosteal bone formation which is considered to resemble the histological picture of osteomalacia. An important factor evaluated in these animal studies was the relation of toxicity to the form (the chemical compound) in which fluoride was ingested. Above certain minimum levels of intake the water solubility of a fluoride chemical determines to a major extent the relative severity of its toxicity. At high levels of intake sodium fluoride and sodium fluorosilicate are the most toxic, while calcium fluoride, being very insoluble, is the least toxic of the usual fluoride compounds. The fluoride in cryolite (an aluminum-fluoride-silicon compound) and the fluoride in rock phosphate were found to be intermediate in toxicity.

Further Observations in Michigan, Wisconsin, and Utah

Animal studies of toxic fluorosis also go beyond observations on the disastrous effects on teeth and the serious impairment of skeletal functions. Experimental fluorosis developed in cattle, extending over a
four-to-five-year period at both the Michigan and Wisconsin Agricultural Experiment Stations, and 12 years at the University of Utah, was not detrimental to reproductive processes when the quantities of fluoride were as high as 320 ppm of the total feed (dry basis). As much as 320 ppm of fluoride and less did not affect estrus, impregnation, and normal parturition, nor did it affect the birth of normal healthy young. The period of gestation did not change and abortions were not significantly more frequent among fluorine-fed animals than among the controls. Growth and lactation were impaired when food consumption was reduced because of defective teeth, sensitivity to temperature, and painful mastication. Observation on sheep in Australia receiving 20 ppm of fluoride in drinking water over a period of 21 months gave no evidence of an effect on growth, nor did this much fluoride affect the quantity or quality (count) of the wool—an important factor in the economy of a great wool-producing country.

Studies at the Utah Agricultural Experiment Station presented excellent data on the effect of fluoride on the hematopoietic system, liver, and thyroid glands in cattle. The data, gathered by Boogstratten, Leone, Shupe, Greenwood, and Lieberman (12), applied to 32 Holstein-Friesian heifers divided into groups fed 10, 25, 50, and 100 ppm of sodium fluoride (approximately 5, 12.5, 25, and 50 ppm fluoride) for approximately 7½ years.

The composite and individual results of numerous detailed blood studies, identical to those used in evaluating the hematopoietic system in man, established that fluoride, fed daily in concentrations up to 100 ppm for more than seven years: (1) does not show gross, histological, or functional effects on the thyroid gland or liver; (2) does not produce significant changes in the serum calcium, phosphorus, or numerous other blood chemistries studied; (3) had a minimal blood effect in the form of a slightly higher total eosinophil count and a lower level of serum folic acid activity in the 100 ppm group; (4) does not produce anemia or detectable abnormalities of the bone marrow or otherwise affect the hematopoietic system.

Summary

The major clinical sign of severe chronic fluorosis in severely affected livestock is lameness, with characteristic skeletal abnormalities. Bone studies show that the sternum and inferior maxilla are often enlarged, and there is an invariable increase in diameter of the metacarpals, metatarsals, and phalanges. Well-defined exostoses, or bone calluses, show up on the long bones; mastication and appetite are impaired; and the animals are unthrifty and emaciated. Mottling of the teeth is constantly present in cattle. As in the case of livestock on the plains of North Africa, the teeth are often severely abraded and sensitive to temperature changes. Post-mortem findings in all these controlled experimental animal studies reveal the full extent of the fluoride injury. The histopathology is characteristic and discrete. Chemical analysis of bones
and teeth shows that the great majority of fluoride retained in the animal body is found in the bones and teeth. But bones and teeth may increase their stores of fluoride to a remarkable extent without an adverse effect. This accumulative capability of the skeletal tissues is, in a sense, a protective mechanism against fluoride toxicity; but this is not so important nor so effective a protective mechanism as the continuous effective excretion of fluoride by the kidney.

Thus it became evident from animal observations and controlled feeding experiments that fluoride is deposited in skeletal tissues and teeth, and excessive retention causes hypercalcification in skeletal tissues, adverse histological changes, and disabling effects. These also are the characteristics of toxic fluorosis as it occurs in man. In animals and in man the urinary excretion of fluoride is elevated in proportion to fluoride ingestion. Many symptoms suspected as evidence of fluoride toxicity in domestic animals are reported, among which are dryness and stiffness of hide, poor condition of hair, elongated hooves, diarrhea, impaired appetite, decreased weight gain, lowered milk yield, emaciation, cachexia, and anemia. Most of these symptoms, however, are not unique in animals, and are not valid criteria of fluorosis without an accompanying involvement of bones and teeth. Confirmation of toxic fluorosis requires a fluoride analysis of food and drinking water, and a determination of the fluoride content of urine, bones, and teeth.

NOTES AND REFERENCES


(4) Agate, J. N., et al., 1949. A study of the hazard to man and animals near Fort William, Scotland: Industrial fluorosis. Brit. Med. Res. Council Memoir No. 22. There is a wealth of detail in this publication from Great Britain. The information was expertly collected and interpreted by 13 researchers. The data include fluoride analyses of body tissues and fluids, radiographic diagnoses, and blood and urine analyses. Examination of furnace-room workers demonstrated bone changes in some, but none that were examined suffered clinical disability.


(6) Greenwood, D. A., et al., 1964. Fluorosis in cattle. Utah State Univ. Agr. Expt. Sta. Spec. Rept., 17. The results of these studies were supported by the U.S. Steel Corporation and required major portions of the time of ten senior staff members over a period of ten years. Approximately 500 students and others were employed for varying lengths of time to assist in the program. Cooperation was extended to personnel in the Institute of Pathology of the Walter Reed Medical Center, the National Institutes of Health, and Agricultural Experiment Stations in California, Idaho, Montana, Oregon Tennessee, Washington, and Wisconsin. This lengthy and intensive research
is a masterly contribution to knowledge of the criteria of chronic fluorosis in domestic animals. The results convey information clearly applicable to the symptoms of human toxic fluorosis. Only an abbreviated summary of the results of these varied studies is possible within the confines of this book.


CHAPTER SIX

INDUSTRIAL AND ENDEMIC FLUOROSIS IN MAN

Observations in Denmark

During the winter of 1931-1932 two Copenhagen physicians, P. Flemming Møller and Sk. V. Gudjonsson (1), investigated the incidence of silicosis among workers in dust-producing industries in Copenhagen. Included in this survey were 78 employees of a factory where the material responsible for the dust was the mineral cryolite (2). The investigation revealed a number of curious and highly interesting conditions. One in particular was regarded as not previously observed or described. Half of the workers showed symptoms of silicosis but as the investigation proceeded it became evident by roentgenographs that there were pathological changes in the bones and ligaments to which no analogy could be found in any former roentgenological experience. In 30 of the 78 men, X-rays revealed osseous changes in varying degrees and extent, and 42 of these factory workers suffered from more or less acute dyspeptic symptoms. Following extensive physical examination of these and other workers exposed to a dust environment, these investigators concluded that the changes were caused by the cryolite dust being swallowed and fluorine being absorbed through the alimentary tract.

Cryolite processed by the factory workers is a rare fluoride mineral containing the elements sodium aluminum and fluoride (Na₃AlF₆). More than half of cryolite is composed of fluorine. Meaning “ice-stone”, cryolite is generally colorless or white and semitransparent. Extensive deposits are found only at Ivgtut, in southwestern Greenland.

Møller was head of the X-ray department of the Rigshospitalet in Copenhagen. In the light of current interest in possible beneficial effects of fluoride on certain bone diseases, Møller’s observation in 1932 is prophetic:

The curious sclerosis of the bones observed in these cases, which does not cause the affected subject any trouble so long as the ligaments and muscular attachments have not yet become involved, has also suggested the idea whether it would not be possible to use the cryolite or some compound of
fluorine, notably sodium fluoride, therapeutically, especially in such bone diseases as imperfect osteogenesis, brittleness of the bones, osteomalacia, disseminated fibrous ostitis and the like, which result in pronounced osteoporosis. If it were possible by cautious administration of pulverized cryolite or sodium fluoride, given on a full stomach—beginning perhaps with such small doses as from 0.5 to 1.0 grams and eventually increasing to just below the quantity that might cause inconvenience in such forms as nausea and the like—to obtain the deposition, in the diseased bones, of so much calcium fluoride as would produce an incipient sclerosis, it might perhaps be possible to restore to the bones of those unfortunate sufferers, such a degree of firmness, that further troubles arising from their disease would be avoided. Experiments to that effect are being carried out at present, but of the results that may come from them nothing can be said as yet.

Also in tuberculosis of the bones it is possible to imagine that a fluorine therapy might be effective, not only by contributing to a more rapid circumscriptio of the process, but perhaps, also, through the markedly disinfectant property of the fluorine, by causing the processes to heal more rapidly; seeing that, according to the animal experiments, the calcium fluoride becomes deposited in the Haversian canals. Inhalation of fluorine vapors has been tried before, as a therapy in pulmonary tuberculosis, precisely on account of the disinfectant properties of the fluorine, but was soon abandoned; nor can there, of course, after what we have seen, in the foregoing, have been any resorption of the fluorine through the respiratory tract.

Following his 1932 investigations Møller interested Dr. Kaj Roholm in the disease and suggested that he study the problem of fluoride intoxication. Roholm has stated, "Through the medium of an appoint-
ment at private expense, as Assistant Physician under the Inspectorate of Factories and Workshops, I was enabled to complete the principal part of the investigations which form the foundation of the present work (3)." My copy of this classic monograph (Dr. Roholm's personal gift) contains these words written on May 9, 1946:

When I worked out this book I very often felt my insufficiency in meeting all the problems relating to fluorine intoxication. In doing this work I hoped at least to collect and present the sum of knowledge and in this way give some advantage to the man who in some ten years would be able to write a better and more lasting monograph on the subject. . . . It was indeed a great pleasure to meet you in Bethesda last year.

And again in June Roholm wrote these ominous words: "I think it is doubtful whether I shall get an opportunity to go to your inspiring and hospitable country again in my lifetime, but it is also possible that fate will take you to Denmark some day, which I hope will happen."

Roholm had visited us in October, 1945, but fate had ordained he would not return. In July, 1948, I visited Copenhagen hoping to meet again with this charming and dedicated physician who had accomplished so much during the extremely difficult circumstances under which he had to live during World War II. His untimely death had occurred on March 28, 1948. Drs. Harold Hodge and Frank A. Smith dedicated "Chapters on the Biological Effects of Fluoride," in Fluorine Chemistry (1965) to Roholm, ". . . acknowledging our own indebtedness to him and hoping that in this way his many contributions will be recognized by those who labor for the cause of public health. . . . Kaj Roholm left memories of a talented and vigorous scientist, a devoted and dedicated clinician and public health officer and a genuine and gracious human being."

In the limitations of this chapter, it is impossible to give details from the results of Roholm's examination of individuals having chronic fluoride toxicosis. Information of major distinction describing chronic fluorine intoxication in man redounds to Roholm's lasting credit. His thoroughgoing studies on human subjects are the first to set forth in detail the character of adult human fluorosis. He obtained data from 12 cases examined post-mortem, and studied 47 males and 21 females who were working in a cryolite factory. These individuals ranged in age from 20 to 69 years; length of employment averaged 10 years; 21 had worked in the cryolite factory 10 years or more. Dr. Roholm wrote:

The clinical examination was made at the factory during working hours in a room placed at my disposal for the purpose. The Röntgen examination was made at the Rigshospitalet's Röntgen Department. The material from the earlier investigation, made by Flemming, Møller, and Gudjonsson has been at my disposal. For practical reasons it was possible only to make examinations not requiring much time or complicated apparatus. As a rule two or three workers were examined every day in the hours from 9 to 12 a.m.; the blood examinations were made on the afternoon of the same day. Taking them all around, the workers were very willing to be examined. There is no reason for assuming that they suppressed anything, for they were expressly
informed, at a mass meeting before the investigation was commenced and afterwards individually, that the information secured about each person would be withheld from the knowledge of the management.

The investigation comprised the compiling of the medical history and an objective examination. [The physical examination included:]

1. Judgment of the general condition; height and weight noted.
2. General medical examination, with particular reference to teeth and bones.
3. Examination of blood, hemoglobin percentage, number of erythrocytes and leucocytes, differential count, bleeding time and coagulation time, sedimentation rate of erythrocytes and their resistance to hypotonic solutions.
4. Examination of urine for albumin and sugar, microscopy of discharged urine.
5. Röntgen examination of lungs, pelvis, and columna lumbalis; other bones and the teeth were also X-rayed on some workers.
6. Certain supplementary examinations on some workers, serum calcium, fluorine content of teeth and urine, etc.

Roholm recorded a great variety of symptoms brought out by his examinations. He reported physical findings in part as follows:

In 20.8 percent of the workers there was a considerable reduction of columna's motility; in some there was almost complete fixation of the entire columna. Motility of thorax was reduced in 16.2 percent of the workers who had an average excursion of thorax of 0.7 cm. Movement in the other joints of the body was normal on the whole. Röntgen examination revealed signs of diffuse osteosclerosis in 83.8 percent of the workers. The sclerosis, which is characterized by bone formation from both periosteum and endosteum, principally affects the central cancellous bones. The individual bone trabeculae are thickened, give a denser shadow, and sometimes fuse. Compacta becomes wider, marrow cavities decrease in size. The bone contours become irregular on account of periosteal deposits; there is an extensive calcification of ligaments, especially in columna. Röntgenologically the sclerosis is divided into three phases; 10.3 percent of the workers had changes of the most severe grade (3rd phase). On the whole there was conformity between the phase of the osteosclerosis and the reduction of motility.

The physical findings related to the skeletal system (long bones, vertebra, pelvis, and thorax) obviously were the most pronounced, and the essential impairment in the severe cases was evidenced by a considerable reduction in motility in the spinal column as well as in the thoracic region. Movement in other joints in the body in general was not impeded. But following all these careful, exhaustive examinations including post-mortem examination of 10 former cryolite workers, and two necropsies, described in detail, Roholm wrote, "It must be stated as a fact that poisoning with cryolite produced considerable changes of bones and ligaments, but no change—or at most doubtful changes—of the other organs."

Again Roholm stated:

The most important effect of fluorine is on the osseous and dental systems. Fluorine disturbs the normal balance between apposition and absorption in the bone, so that the result is a relative preponderance of the bone-forming
processes. According to the histological picture there is apparently an absolute reduction of the normal lacunary absorption, whilst the bone formation does not give the impression of being especially active (rather narrow osteoid borders coated with mostly flat cells). The qualitative changes in the genesis of the osseous tissue present irregularities in the position of lamellae and the arrangement of osteocytes.

The first thing to emphasize is the fact that the affection is a systemic disease, for it attacks all bones, though it has a predilection for certain places. The pathological process may be characterized as a diffuse osteosclerosis in which the pathological formation of bone starts in periosteum and in endosteme. Compacta densifies and thickens; the spongiosa trabeculae thicken and fuse together. The medullary cavity decreases in diameter. There is a considerable new formation of bone from periosteum, and ligaments that normally do not calcify, or only in advanced age, undergo a considerable degree of calcification. All signs of bone destruction are absent from the picture.

In themselves, changes in the bone tissue seem to be of limited significance to the organism; they do not involve a markedly increased fracture frequency, but in severe cases the elasticity of the bone tissue is reduced. Calcification of the ligaments and the consequent restriction of motility in column and thorax are the principal phenomena in a prognostic sense. The development of these changes requires a regular, perhaps daily, ingestion of fluorine over a long period.

The quantities of fluoride ingested by these cryolite factory workers was difficult to measure. The amounts were unquestionably excessive as verified by the fluoride content of skeletal tissues of the two individuals who came to autopsy. The tissue analyses included sternum, costa, lumbar vertebra, os frontale, pelvis, femur, and radius. To obtain these fluoride data, the dry bone was ashed and fluoride determined. Cryolite workers' bones contained 0.76 to 1.51 percent fluoride, with the exception of an os frontale specimen which contained 0.31 percent fluoride. Such percentages of fluoride in bones are indeed excessive. As Rohholm reported, the costa (rib bone) ash of normal individuals contained only 0.048 to 0.210 percent fluoride whereas the costa ash of the two cryolite workers contained 0.99 and 1.12 percent fluoride (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Percentage of fluoride found in bone specimens after tissue analysis of two workers in a cryolite factory.</th>
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<tbody>
<tr>
<td><strong>Cryolite Worker</strong></td>
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<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Sternum</td>
</tr>
<tr>
<td>Costa</td>
</tr>
<tr>
<td>Lumbar vertebra, corpus</td>
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<tr>
<td>Lumbar vertebra, calcified ligament</td>
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<tr>
<td>Os frontale</td>
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<td>Pelvis</td>
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<td>Femur, corpus</td>
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<td>Radius, capitulum</td>
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<td>Tibia, corpus</td>
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<td>Clavicula</td>
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Rohholm experienced difficulty in making a satisfactory fluoride anal-
ysis of urine specimens, but as was to be expected the fluorine excretion of the cryolite workers was much greater, up to 2.5 mg (per 24 hours), or about 10-20 times the normal.

Experimental animal studies were reported by Roholm. Cryolite, sodium fluoride, and sodium fluosilicate fed in excessive quantities to white rats, swine, calves, and dogs produced extreme toxicity including characteristic effects in bones and teeth. In such large quantities the availability of fluoride became a significant toxicity factor. Cryolite was the least toxic, and sodium fluoride and sodium fluosilicate were about equal in their effect. Sodium fluoride was three times as toxic as cryolite in calf experiments and five to six times as toxic in the dog experiment.

Symptoms in man of excessive exposures to fluoride in an industrial fluoride environment, as observed by Roholm, are prevalent also in endemic fluoride areas of North Africa. India and South Africa are also notable areas of endemic toxic fluorosis.

Endemic Fluorosis in India

In the Madras Presidency and in the Punjab mottled enamel is extensive and the situation is similar to that which prevailed in the phosphate areas of North Africa. The standards of living are low, water supplies are variable and insanitary, food and water may be contaminated with soil, and an unusually high temperature increases water consumption, particularly among laborers. As in North Africa the actual exposure to fluoride in India is difficult to evaluate.

The drinking waters in the Madras Presidency in 1937 were reported to contain from 2.0 to 10.0 ppm of fluoride. Ten individuals exposed to such drinking water for at least 30 years were found to have the characteristics of skeletal fluorosis: immobility in the spine, stiffness in joints, and fixation of ribs which caused abdominal breathing. As usual their disabilities were associated with calcification of ligaments, tendons, and fascia, and formation of osteophytic outgrowths of long bones. This study was summarized by Shortt, et al. (4):

1. Ten cases of chronic fluorine intoxication have been investigated, clinically, radiologically, and, as regards blood and urine, biochemically.
2. The clinical picture is described and relates chiefly to disabilities caused by calcification of ligaments, tendons, and fasciae, the formation of osteophytic outgrowths of bone and the nervous effects of mechanical pressure by encroachment of bone on the spinal canal.
3. The radiological findings show excessive calcification of tendons, ligaments, and fasciae, the production of osteophytic formations from various bones, and the almost complete synostosis of various joints, especially those of the vertebral column. These give the clue to the clinical findings.
4. The biochemical estimation of serum calcium, inorganic phosphate, and serum phosphatase indicates a favourable condition for abnormal deposition of bone.
5. Kidney function in the majority of the cases is impaired.

6. The urine contains amounts of fluorine much above the normal upper limit.

Some years later (1940), fluorosis in the Punjab area of India was said to be limited (3) and the report stated:

No spinal disability or general disturbances of any kind other than pronounced dental lesions were observed in any of the children. Cases of stiffness of the back and other skeletal disturbances resembling rheumatoid or arthritic conditions, have been observed among older people in villages of endemic areas, but a wider survey must be made and comparative figures obtained from endemic and nonendemic areas, with radiological and microscopic confirmation, before these lesions can be safely attributed to chronic fluorosis.

In recent years endemic fluorosis in India has been studied in greater detail by Singh, Jolly, Bansal, and Mathur (6). Their investigations leave unanswered much-needed and all-important information regarding the actual quantities of fluoride being ingested by the affected natives of the endemic areas. There is a close relation between the fluoride content of drinking water and urinary fluoride—the latter is generally only slightly less than the concentration of fluoride in the drinking water. The water supplies in India as reported by Singh, et al., contained on the average 1.0 to 2.0 ppm of fluoride. (One unusual water contained 16.2 ppm fluoride.) The urinary fluoride, however, ranged from 2.3 to 13.5 ppm. Since as much as 13.5 ppm of urinary fluoride is indicative of an unusual ingestion of fluoride, the authors were correct in noting:

Owing to the extremely high temperature in summer and the strenuous type of work done by the farmers, the water intake of the population is considerable. Considering an average of 5 liters daily, it will provide as much as 6.5 to 8.1 mg of fluoride to the individual from the water alone and when it is realized that a good quantity of water is used in cooking and processing of food it is obvious that the total fluoride intake is enormous.

Radiological studies of skeletal tissues (spine and long bone) showed typical changes due to excess fluoride. Nonetheless,

Despite the alarming radiological appearances, the changes in the spine do not produce many symptoms. Usually the only complaint is of vague pains in the back and extremities. The symptoms of the spinal cord lesion tended to develop slowly and progress insidiously. In two cases, the onset was sudden and was related to trauma, which in normal circumstances would have resulted in no sequelae.

There have been reports of neurological manifestations among the affected cases in India. Ten such cases were reported in 1937 in Madras and a few sporadic cases from other areas in India. But the authors found that the symptoms were not well defined. "Such neurological complications occur only in very advanced cases where the ingestion of large quantities of fluoride has continued for at least 20 years. Thus only 42 of our 409 cases of skeletal fluorosis had neurological complications."
Endemic Fluorosis in South Africa

From 1939 to 1942, Dr. T. Ockerse of the Department of Public Health of the Union of South Africa systematically surveyed the status of endemic fluorosis in South Africa (7, 8). From his investigations, which included dental examinations of 46,547 school children, he reported 805 endemic fluoride areas, and 3,067 children with mottled enamel. Rocks, soils, and innumerable samples of water were analyzed for fluoride. Many of the drinking waters contained excessive quantities of fluoride (in ppm): hot spring waters, 4.47 to 12.2; cold spring waters, 6.41 to 40.66; well waters, 2.4 to 7.6; water from bore holes, 1.95 to 58.0; ghorra (a shallow well dug in a dry river bed), 1.8 to 6.29; river waters, 2.32 to 3.04; and dams, 2.19 to 8.89. No mottling was found in Natal where a trace of 0.22 ppm of fluoride was present in the water supplies. All cases of mottled enamel were diagnosed and recorded according to Dean's classification (to be noted later). Ockerse found many severe cases of mottling, some not falling into Dean's classification.

Ockerse determined fluoride by a reliable, although somewhat tedious and time-consuming, procedure and his analytical fluoride data are regarded as quite acceptable. Thus, in light of the excessive quantities of fluoride present in many of the water samples, it is not surprising that endemic skeletal fluorosis should occur in some places, one of which was the Kalkheuvel farm located in a flat, hot area some 42 miles north of Pretoria and three miles east of Pienaars River. Its mean maximum temperature is 78°F, and the minimum average is 51°F. Water for domestic and drinking purposes came from a 350 ft. bore hole but only natives employed in limestone quarries and their families drank this water which contained 11.78 ppm of fluoride. Some children had severe fluorosis and Ockerse reported typical dental fluorosis in four cows drinking the water; in a survey of 300 natives, nine complained of stiff backs and painful joints. Although the majority of natives in the area were reported to "come and go," seven of these nine cases had used this water continuously since 1922, a period of approximately 20 years. Considering the hot climate and perhaps the hard labor in the quarries, consumption of drinking water and fluoride ingestion were no doubt unusually large. The general clinical picture as described by Ockerse follows:

It is a record of typical skeletal fluorosis, brought about by excessive fluoride ingestion via drinking water. (1) Stiffness of the lumbar, thoracic and cervical regions of the spine. The most advanced case showed complete rigidity of the entire spine, with complete restriction of head movements. (2) Pain and stiffness around the joints of the upper and lower limbs and lumbar regions. These symptoms correspond to those described by Shortt et al. and Roholm.

The radiological picture was as follows: (1) Curved spine, with ossification of practically all the vertebrae, giving the appearance of the typical "bamboo" spine. (2) Osteophytic growths along the borders of the ribs at the site
of the muscle attachments. (3) Osteophytic growths between the radius and ulna at the muscle attachments and around the elbow joint. (4) Increased density of bone.

Ockerse also noted that the incidence of dental caries among children with mottled enamel was considerably lower than among those with no mottling. Other investigators had reported similar findings.

Fluoride in 850 waters in Kenya (East Africa) was reported by Williamson (9) to be 0.1 to 0.9 ppm in 339 waters, 1.0 to 1.9 ppm in 146, and 2.0 to 3.9 ppm in 148 waters. The other waters contained more than 4.0 ppm fluoride of which 32 contained 29.9 ppm or more. The excessive quantities of fluoride were present in waters from rivers and bore holes.

NOTES AND REFERENCES

Dr. Kaj Roholm was born in Copenhagen, Denmark, on October 7, 1902. He was a medical graduate, with honors, from Copenhagen University in 1928, was granted a Master of Public Health degree in 1933, and received his Doctor of Medicine from the same university in 1935. His thesis was titled "Fluorine Intoxication." An acknowledged specialist in both internal medicine and metabolic diseases, Dr. Roholm became Deputy City Health Officer of Copenhagen in 1940 and held this position until the time of his death on March 28, 1948.

Apropos the fluoride problem in India, P. Sita and P. Venkateswarlu (J. Dental Res., 46:307) recently raised the question relative to ingestion of an excess of fluoride via rock salt:

This consideration leads us to investigate the fluoride content of different samples of common salt (table salt, kitchen salt, cooking salt) consumed in India. The fluoride content of 10 samples of salt ranged from 10 to 20 ppm. The only sample of rock salt (75 percent NaCl) contained as much as 170 ppm fluoride (228 ppm corrected for NaCl content). On recrystallization, the same sample contained 40 ppm fluoride. Of the four samples of rock salt obtained from other sources, one sample contained as much as 200 ppm fluoride and the other around 40 to 50 ppm.

As these authors stated further, the dietary consumption of rock salt was once very prevalent but is now on the decline; it is peculiar to regions like Punjab in North India, where endemic fluorosis has occurred, whereas sea salt is commonly used in South India. Sea salt may vary considerably, but it averages 5 to 15 ppm fluoride, while a daily consumption of 20 gm of rock salt, containing as much as 200 ppm of fluoride, could provide 4.0 mg of fluoride daily in addition to that ingested in drinking water and other dietary sources, including tea, which is one of the important sources. But the collection of information of the consumption of different types of rock salt in different regions in India over the past years will require considerable time.

The fluoride content of salt will recur again in this narrative as a subject discussion, but in this case fluoridated table salt, i.e., salt to which fluoride is added directly, will be evaluated as a particularly important and practical source of fluoride for prevention of dental caries where fluoridated drinking water cannot be made available.


CHAPTER SEVEN

MOTTLED ENAMEL AND FLUORIDE WATER

Now there is at Jerusalem by the sheep market a pool, which is called in the Hebrew tongue Bethesda, having five porches. In these lay a great multitude of impotent folk, of blind, halt, withered, waiting for the moving of the water. For an angel went down at a certain season into the pool and troubled the water: whosoever then first after the troubling of the water stepped in, was made whole of whatsoever disease he had. JOHN 5:2-4

The National Institutes of Health (NIH) including the National Institute of Dental Research (NIDR) are located in Bethesda, Maryland. The largest building of the NIH group is the Clinical Center, containing laboratory and research facilities as well as hospital accommodations for 500 patients. Two small reflecting pools are placed on each side of the main entrance of this huge building. Appropriately named "Pools of Bethesda," they beautifully symbolize the missions of the world-renowned National Institutes of Health.

The National Institute of Dental Research became the third institute of the National Institutes of Health in June, 1948. The substantial achievements which demonstrated the dental health benefits of fluoride had justified—indeed became a foundation stone for—the organization of this dental research unit of the U.S. Public Health Service. The first Director of the new institute was Dr. H. Trendley Dean.

A dental health mission at the NIH became a reality in 1931 with the organization of a Dental Hygienic Unit. Dean was responsible for this dental research unit and was the first dental officer of the Public Health Service to be given a non-clinical dental assignment. Before 1980, with few exceptions, dentists in the Public Health Service were engaged in strictly dental-care activities. The specific mission assigned to Dean was to resolve the relation of waterborne fluoride to endemic mottled enamel. This initial Government-sponsored dental research was destined to move rapidly and establish the fluoridation of drinking water and other applications of fluoride for the control of dental caries.

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Fluoride conference. (Left to right) F. J. McClure, F. A. Arnold, Jr., H. T. Dean, and Elias Elrove.
In 1938 Dean (1) published the first of his systematic surveys of the distribution of mottled enamel in the United States—a paper which had been read at the 74th Annual Meeting of the American Dental Association in 1932. The survey was accomplished by letters and questionnaires sent to secretaries of state dental societies requesting information on the occurrence and extent of mottled enamel in each state. Prior to this survey 70 mottled enamel areas had been reported. Seventy-three additional areas were located, five of which were confirmed by Dean's personal diagnosis, although some reports were eliminated because of questionable information. Special items of interest include Dean's own personal observations. He cited in particular one report from Oklahoma, which indicated a slightly lower incidence of dental caries among those with mottled enamel than those having no mottled enamel. In areas of Tennessee Dean observed mottled enamel in children of a few families using spring water which traversed rock phosphate beds. (This is reminiscent of the source of fluoride causing dark yellow in North Africa.) In 1916 Dr. Frederick S. McKay had reported mottled enamel in Franklin and Courtland, Va.; in 1931 Dean examined 222 children in this area. Among 29 children living in Courtland, he diagnosed mottled enamel in 28. Mottling was also prevalent in children living in Smithfield, Va., and in native-born children on Jamestown Island, Va. Dean also cataloged information from Illinois, including the village of Minonk which had already acquired an interesting identity with endemic mottled enamel, and an association of this mottled enamel with reduction in dental caries.

In 1928, Bunting, Crowley, Hard, and Keller (2) had reported observations on mottled enamel in Minonk, Ill. For many years Dr. Russell W. Bunting was the esteemed Dean of the School of Dentistry of the University of Michigan, and was a co-author with Dr. E. V. McCollum and others of the studies published in 1925 showing the effect of fluoride on the teeth of white rats. Bunting examined these rats' incisor teeth and concluded that they were underdeveloped and hypoplastic. Some years later he expressed chagrin that he had failed at that time to recognize these abnormalities as mottled enamel. The observations in Minonk in 1927 and again in 1932 were reported by Bunting (3) as follows:

The community was in a mining district in which the local water supply was from deep artesian wells. The children in the public schools who had been born and raised in this community had varying degrees of dental hypoplasia and discoloration. Those who lived on farms outside the town, where only shallow-well water was available, for the most part, had normal tooth development.

In the first examination of these children the Michigan group was impressed by the fact that although the teeth of those affected were poorly formed, the caries rate seemed much less than had been observed in children of other communities. There were fewer cavities, and those that did occur were small slow-growing lesions, quite similar to caries in older persons who chew tobacco. This striking difference was reported and the impression was gained.
that it was associated with the water supply. What the controlling influence was we did not know, for this was some time before the factor of fluorine had been discovered. In 1929 McKay reported similar findings in other mottled-tooth areas.

Mottled Enamel Classification and Community Index

For purposes of recording quantitatively the various degrees of severity of mottled enamel, Dean developed standards of classification (4).*

Each tooth present in the mouth was classified under one of six groups:

**Normal.** The enamel presents the usual translucent semi-vitriform type of structure. The surface is smooth, glossy, and usually of a pale creamy white color.

**Questionable.** The enamel discloses slight aberrations from the translucency of normal enamel, ranging from a few white flecks to occasional white spots. This classification is utilized in those instances where a definite diagnosis of the mildest form of fluorosis is not warranted and a classification of "normal" not justified.

**Very mild.** Small, opaque, paper-white areas scattered irregularly over the tooth but not involving as much as approximately 25 percent of the tooth surface. Frequently included in this classification are teeth showing no more than about 1-2 mm of white opacity at the tip of the summit of the cusps or second molars.

**Mild.** The white opaque in the enamel of the teeth is more extensive but does not involve as much as 50 percent of the tooth.

**Moderate.** All enamel surfaces of the teeth are affected, and surfaces subject to attrition show marked wear. Brown stain is frequently a disfiguring feature.

**Severe.** Includes teeth formerly classified as "moderately severe" and "severe." All enamel surfaces are affected and hypoplasia is so marked that the general form of the tooth may be affected. The major diagnostic sign of this classification is the discrete or confluent pitting. Brown stains are widespread and teeth often present a corroded-like appearance.

To quote further from Dr. Dean:

The various degrees of mottled enamel severity having been defined, the application of this classification to the determination of a mottled enamel index of a community is necessary for epidemiological purposes and subsequent correlation with chemical and other studies.

Accordingly the following indexes have been arbitrarily defined in terms of the degree of severity of mottled enamel observed clinically:

* In a previous publication (Journal of the American Dental Association, 21, 1934) Dean described seven unit-classifications of mottled enamel, but later eliminated the moderately severe classification and included many such cases as severe.
Negative. When less than 10 percent of the children show "very mild" or more severe types of mottled enamel.

Border line. When 10 percent or more, but less than 35 percent, show "very mild" mottled enamel or worse.

Slight. 35 percent or more show "very mild" or worse, but less than 50 percent are "mild" or worse, and less than 35 percent "moderate" or worse.

Medium. 50 percent or more are "mild" or worse, but less than 35 percent are "moderate" or worse.

Rather marked. 35 percent or more, but less than 50 percent are "moderate" or worse, but less than 35 percent are "moderately severe" or worse.

Marked. 50 percent or more are "moderate" or worse, but less than 35 percent are "moderately severe" or worse.

Very marked. 35 percent or more are classified as "moderately severe" or worse.

While the percentage of individuals examined showing dental fluorosis documents the prevalence of dental fluorosis in a community, i.e., "negative," "border line," "slight," etc., Dean stated, "This does not adequately make clear the marked differences in the degrees of severity among the groups studied... To take into account these differences, a numerical weighted index of clinical severity (index of dental fluorosis) was calculated for each group examined." The index was computed by giving a definite weight to each of the six classifications used in measuring effects. These weights, arbitrarily selected, were: normal, 0; questionable, 0.5; very mild, 1; mild, 2; moderate, 3; and severe, 4 (Table 1). The data used are from observations in Amarillo, Texas.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Weight (w)</th>
<th>Frequency (f)</th>
<th>Frequency x weight (fw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Questionable</td>
<td>0.5</td>
<td>19</td>
<td>9.5</td>
</tr>
<tr>
<td>Very mild</td>
<td>1</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Mild</td>
<td>2</td>
<td>81</td>
<td>162</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>98</td>
<td>294</td>
</tr>
<tr>
<td>Severe</td>
<td>4</td>
<td>38</td>
<td>152</td>
</tr>
</tbody>
</table>

\[ \Sigma (f) = N = 289 \quad \Sigma (fw) = 661.5 \]

Index of dental fluorosis:

\[ \frac{\Sigma (fw)}{N} = \frac{661.5}{289} = 2.3 \]

\[ \Sigma = \text{sum of} \]

\[ N = \text{number} \]
Variations of the index of dental fluorosis with the fluoride concentration of the community water supply are shown in Figure 1.

![Figure 1](image_url)

**Fig. 1.—Index of dental fluorosis associated with the continued use of a communal water supply having fluoride content (in ppm).**

Hodge (5) analyzed Dean's community fluorosis data and noted, "The severity of mottling increased in a linear fashion when the community index of fluorosis was plotted against the logarithm of the parts per million (ppm) fluoride in the drinking water, from about 1.0 ppm to nearly 10 ppm. ... Below 1.0 ppm a second straight line appears nearly horizontally placed, i.e., there is practically no difference in the community index whether the drinking water contains about 0.1 or 1.0 ppm. ... The linearity of the response above 1.0 ppm gives these data considerable reliability in the eyes of pharmacologists because responses to many drugs increase with the logarithm of the dose. The severity of mottling is seen to conform to this criterion of a typical pharmacological or toxicological response." (Fig. 2)

![Figure 2](image_url)

**Fig. 2.—Degree of mottled enamel and fluoride concentration in water.**
Mottled Enamel in Texas

The status of mottled enamel in Texas was studied by Dean and Elvove (6) and it was evident that mottled enamel was so widespread in the state that no detailed cataloging of the communities was possible. Reports indicated, however, that the Panhandle area constituted by far the most extensive afflicted area in the country and involved more people. The condition centered around Amarillo and Canyon but included most of the area.

In 1935 Dean, Dixon, and Cohen (7) published an extensive report on mottled enamel in Texas. In cooperation with the Texas State Department of Health during November and December, 1934, a total of 66 towns, cities, and rural communities in 44 counties was visited and 3,723 children examined, generally of the fourth, fifth, and sixth grades in school. Dean's standard of classification of the degree of severity of mottled enamel was used.

This Texas survey produced the following summary:

The Panhandle and West Texas

1. The Panhandle-West Texas region constitutes the largest mottled-enamel area in the United States. As a result of the unusual population influx between 1920 and 1930, the number of children affected correspondingly increased.

2. Of 53 communities surveyed in 37 counties, only 6 could be classified "negative" or "border line."

3. The fact that the municipal water supplies of such large cities as Amarillo, Lubbock, and Plainview contain the causative factor of mottled enamel in sufficient concentration to produce this hypoplasia in a high percentage of their children has developed an acute and urgent public health problem.

East Central Texas

1. An endemic area of unknown size is reported in east central Texas between Austin and Dallas.

2. Of 13 communities surveyed, only 2 were classified as "border line" and none was classified as "negative."

According to Dean, in 1935 the region of greatest severity centered around Lubbock, extending east toward Spur and Post, north to Plainview and Amarillo, and south to Lamesa. In the endemic area located in east central Texas, between Austin and Dallas, a small village called Bartlett had the severest mottled enamel and as much as 8.00 ppm fluoride present in the drinking water.

At the time of these first Texas studies by Dean, a more accurate procedure to determine fluoride in drinking water was being perfected by Dr. Elias Elvove of the Public Health Service. While the standard method for a fluoride analysis of water has been improved and extensively modified since that time, Elvove's procedure was convenient and
was accurate to at least 0.1 ppm fluoride. The water-fluoride analysis reported for a number of places in Texas at that time was (in ppm): Amarillo, 3.9 to 5.6; Lubbock, 3.8 to 4.2; Spur, 3.8; Post, 6.0; Lamesa, 5.2; Plainview, 2.9; Midland, 2.5 to 3.6; Hereford, 3.2; Slaton, 5.2; and Loveland, 3.5.

An Early Survey in Maldon, England

While the epidemiology studies of Dean and his associates moved with unabated enthusiasm in the United States in the early and middle 1930's, in other areas of the world mottled teeth had also become a primary concern of dental public health. Writing in 1933, Dr. N. J. Ainsworth (8) gave an interesting account of the mottled enamel situation in the town of Maldon in Essex. He referred to an early edition of Colyer's *Dental Surgery and Pathology* in which he had read a rather detailed description of mottled enamel as first reported by McKay and Black. Ainsworth wrote:

Having read this as a dental student, I regret to say I forgot it together with a great many other paragraphs in that volume, immediately after qualifying. When I was a student in Middlesex Hospital in 1921, I chanced to be given charge of a girl patient, aged 15, in one of the surgical wards and noticed that her teeth showed a very unusual appearance. They were curiously opaque and freckled with brownish black spots. It appeared that many other people in her home town, Maldon, Essex, were afflicted in the same way, and it was generally supposed that the drinking water was responsible. I fear that I had already forgotten Rocky Mountain mottled teeth but the condition was so unusual that I made a mental note that I would look for a chance to verify the girl's statements. A year later I undertook a tour of Council Schools in various parts of England and Wales for the Dental Diseases Committee of the Medical Research Council, and remembering the incident I arranged that Maldon should be included.

Ainsworth examined 157 children between 5 and 15 years old in Maldon and 55 in the nearby Heybridge Council School. Both deciduous and permanent teeth were diagnosed for mottled enamel and dental caries. In the 5- to 8-year age group, the deciduous teeth showed no departure from normal. He noticed, however, that the permanent teeth of the group were later than usual in erupting. Actually, Ainsworth found a tendency to late eruption of permanent teeth in all age groups. To substantiate this early observation of delayed eruption as an effect of fluoride, Short (9) in 1944 concluded from his observations that drinking water containing 2.6 ppm of fluoride was associated with delayed eruption in children 12 years of age. This effect was not observed where less than 2.0 ppm fluoride was present in the water.

Ainsworth also observed that in the 6- to 7-year age group, the permanent teeth in 12 of the 22 children examined were mottled. In the upper age groups, 8 to 15 years, there was a higher percentage of mottling in the permanent teeth and in that group he saw for the first time "a faint brown stain on the mesial corners of the labial surface of the
upper central incisors.” Of the 18 children in the next group (age 9 and 10), 16 showed white mottled teeth and half of them showed brown stain. In this group a third phenomenon became apparent, a speckled appearance of small pits in the enamel, varying from pinpoint size to half a millimeter and more in diameter, and stained to dark brown or greenish black (the denti neri of Naples). Ainsworth then turned his attention to discover the nature and cause of the condition. His conclusions from the data were also published in 1928, five years prior to the identity of fluoride in drinking water as the causal factor.

In 1928, Ainsworth (10) stated:

The distribution of the stain, first on the most prominent part of the exposed teeth, spreading gradually to less prominent parts, and then to the most prominent part of the teeth second in order of exposure, points to an outside origin for the stain, either atmospheric or in the water, since these are precisely the surfaces most exposed to air and fluid in the acts of speaking and drinking respectively. My own view, and it is little more than a guess, is that the cause of both mottling and stain will be found in some quality or impurity of the drinking water not ascertainable by ordinary analytical methods, the first condition being an interference with, or modification of, enamel growth, the other a mechanical infiltration from without inwards. The impurity, if such it is, may conceivably be bacterial or minute quantities of a substance not found because not tested for in routine analyses.

In 1928 Ainsworth saw no reason to question the similarity between his observations and the descriptions which had been published by McKay and Black in America. There was no reasonable doubt that the conditions were identical. By 1933 Ainsworth was aware of the role of waterborne fluoride in this dental problem and recognized the need to obtain a fluoride analysis of the Maldon drinking water. As he described the events:

Public authorities are slow-moving bodies, and in the end I paid a surprise visit to Maldon with a car and a crate of Winchester quart bottles. These were filled at the various pumping stations in the district, and as a control, one from the drinking water of Witham, a town a few miles distant, which I had already found to be immune, though the water supply was declared exactly similar by the county analyst. The National Physical Laboratory, at my request, had already worked out a method of estimating minute quantities of fluorine in water, and they found that they could be reasonably sure by using de Boer’s colorimetric method of attaining an accuracy of 0.1 part per million. Using this method, they tested the five samples and reported that, whereas Witham water contained 0.5 parts of fluorine per million, the water from the four endemic areas contained from 4.5 to 5.5 parts per million.

The appearance of Maldon teeth was also studied microscopically in some detail by Ainsworth, and the pathology of the mottled teeth was similar to what had been recorded by Black and later by Dr. Leon Williams. Other areas in Essex having natural fluoride in drinking water sufficient to cause mottled enamel were West Mersea, Burnham on Crouch, and Harwich. West Mersea had 5.8 ppm fluoride in the drinking water, the highest in Great Britain according to a 1954 report. In general the concentration of fluoride in the water supplies of Great Britain varies from a trace to this high.
A not unusual observation concerning dental caries in Maldon children was recorded by Ainsworth:

The condition of their teeth generally was good, well above the average for Council Schools. There was relatively little caries: 7.9 percent of the permanent teeth were carious, as compared with an average in all districts examined of 18.1 percent; and 12.9 percent of deciduous teeth were carious against 43.3 percent in all districts.

Mottled Enamel in Colorado—1933

A comprehensive survey of mottled enamel in Colorado was published by Boissevain in 1933 (11). Steiger's titanium sulphate method was used to determine the fluoride in the drinking water of 169 communities in Colorado. Boissevain reported that of the water supplies analyzed 80 contained varying amounts of fluoride among which 25 contained more than 1.0 ppm. Fluoride in amounts larger than 1.0 ppm occurred in the water supply of all the towns that receive water from the Pikes Peak watershed: Colorado Springs, Manitou, Cascade, Green Mountain Falls, Woodland Park, Cripple Creek, Victor, Goldfield, Penrose, Portland, Pinon, and Fountain. Mottled enamel was common in all these towns. In coal fields north of Denver, Boissevain located another group of communities where the water contained more than 1.0 ppm fluoride. In Burlington near the Kansas border, in Pictou (a small coal mining town previously mentioned by McKay), and in Moffat in the San Luis Valley fluoride was sufficient to cause mottled enamel—it was especially bad in Pictou, as McKay had reported. Boissevain covered many of the areas previously studied and in general confirmed many of McKay's observations, with additional information about the fluoride content of the drinking water. In general, to quote Boissevain, "The correspondence between the amount of fluorine in the water and the occurrence of mottled enamel among the population is remarkable, and the exceptions (Firestone and Portland) are such as rather to strengthen our conviction that a fluorine content of more than 1.0 ppm will cause mottled enamel in at least 90 percent of the native children." The principal endemic areas, as previously noted by McKay, were found by Boissevain in the Pikes Peak region.

Mottled Enamel in South Dakota

A special study of mottled enamel in South Dakota, described by Dean, Elvove, and Poston in 1939 (12), is especially appropriate in light of significance epidemiological results obtained in this area in 1965 concerning fluoride in water and its beneficial effect on osteoporosis. As early as 1916 McKay had observed mottled enamel in seven small villages in South Dakota. In 1932, Dean, while studying selenium poisoning in South Dakota, found mottled enamel present in other areas of
this state. In 1939 Dean surveyed 53 cities, towns, and rural communities in 21 counties and examined 3,350 school children. This survey provided general information on the extent of the affected areas and the severity of the mottled enamel. Chronic endemic mottled enamel, some objectionable, obviously was widespread in South Dakota and extended into North Dakota.

A First Study Including Galesburg, Illinois

The 1935 report by Dean and Elvoie included a survey of the status of mottled enamel in Galesburg and Monmouth, Ill. A number of other surveys were to include Galesburg. Mottled enamel and dental caries, as well as physiological effects of fluoride in drinking water, were documented by surveys conducted in the Galesburg community.

Galesburg, on the fertile Illinois prairie land widely known as the “Land of Lincoln,” has an interesting history. Knox College is there and its “Old Main,” built in 1857, is the only extant building associated with the famous Lincoln-Douglas debates of 1858. Not far from the Knox College campus is a little three-room cottage, the birthplace of the late Carl Sandburg. Now restored, it is a shrine and memorial to this famous poet and biographer of Lincoln.

The Galesburg community was established in 1835 by a group of people from the Mohawk Valley in New York. They were led by the Rev. George Washington Gale and 2 years later founded Knox College “for the training of Christian ministers.” In his biography of Lincoln, Carl Sandburg stated that he wanted to portray “this country lawyer and prairie politician who was intimate with the settlers of Knox County neighborhood” where Sandburg had heard “the talk of men and women who had eaten with Lincoln, given him a bed overnight, heard his jokes and lingo, remembered his silences and his mobile face.” The Mayor of Galesburg in 1858, to quote Sandburg, “is the only individual of casual record who carried warm cistern water to a bathtub for Lincoln and saw Lincoln taking a bath.” Water supplies in Galesburg in 1924, some 75 years after the famous Lincoln “cistern water bath,” were not limited to cisterns in the back yard. It was in 1933-1934 that 9-year-old children of Galesburg were studied, to determine the dental effects of a lifetime use of a communal Galesburg drinking water containing upwards of 2.0 ppm of fluoride.

The first report by Dean and Elvoie in 1935 on Galesburg and Monmouth included data obtained in Colorado Springs and Pueblo, Colo., as well as some other communities (Table 2). The water history of all these places was carefully evaluated by Dean prior to these studies. The public water supply of Galesburg from 1920 to 1930 was obtained from deep wells (2,414 ft) and the first well installed in 1920 had been in continuous use since that date. In 1928 a second well of the same depth was completed. As Dean and Elvoie stated, Galesburg water history be-
fore 1924 was omitted as the time would be prior to the year of birth of the group of children examined and therefore would not be relevant. The fluoride in the drinking water of Galesburg at that time was 1.9 ppm; in Monmouth it was 1.8 ppm.

Table 2. Comparison of fluoride and the presence of mottled enamel in 13 U.S. communities. (From Public Health Reports, 1937)

<table>
<thead>
<tr>
<th></th>
<th>Fluoride (ppm)</th>
<th>Mottled enamel diagnosis</th>
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<td>Pueblo, Colo.</td>
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The first four localities studied—Pueblo, Colorado Springs, Galesburg, and Monmouth—were supplied with drinking waters which averaged respectively 0.6, 2.5, 1.9, and 1.8 ppm fluoride, according to a 1933-1934 analysis. Nine-year-old children were examined, continuous residence in the community since birth having been certified by a house-to-house check. From all available evidence the water supplies in use at the time of the mottled enamel examinations had not changed during the nine years since the birth of these children. Dean found the mottled enamel index of Colorado Springs "slight." A milder type of mottled enamel was endemic in Monmouth and Galesburg, although the index of both these communities was also "slight." In Pueblo the index was negative. At the conclusion of this report Dean made reference to the monthly variations in fluoride content of Colorado Springs water. He pointed out that if the study in Colorado Springs had been correlated with the August analysis, the water-fluoride figure would have been 1.8 ppm, whereas the average water fluoride during February, March, and April was 3.0 ppm.

In an endeavor to determine more precisely "what constitutes a permissible amount of fluoride in a water supply," Dean and Elvoe obtained the mean annual content of fluoride in these communities' drinking waters based on 12 consecutive monthly samples. In this report (13) the authors discussed problems of sampling, the effect of the age of the children examined on the mottled enamel index of a community, and the need for quantitative purposes of specified classifications of the mottled enamel diagnosis.
The extensive observations by Dean and his associates provided convincing evidence that wherever fluoride up to 1.0 ppm was present in drinking water, the community index of mottled enamel was not prohibitive. A careful inspection of the data shows that up to 1.3 ppm fluoride could be present in drinking water and the fluorosis index would remain below 0.6, as in the case of Joliet, Ill., where its 1.3 ppm fluoride in drinking water showed a fluorosis index of 0.46. Dean (14) regarded an index of dental fluorosis of 0.4 or less as of no concern from the standpoint of mottled enamel per se. However, when the index exceeds 0.6, it constitutes a public health problem warranting increasing consideration.

Worldwide Occurrence of Mottled Enamel

The geographical distribution of mottled enamel throughout the world was reported in 1942 by Dean (15). In the United States at that time there were 345 areas surveyed or reliably reported in 25 different states. "In 252 of these areas," wrote Dean, "the endemicity has been demonstrated by survey or so reported in the literature. Of the 345 areas, 298 (or 86 percent) are located west of the Mississippi River and 94 (or 27 percent) are in Texas." This extensive occurrence presented a pressing public health problem in Texas, Colorado, South Dakota, and Arizona, according to Dean.

In discussing endemic areas outside the United States, Dean took particular note of Tunisia, Algiers, and Morocco. The Argentine Republic was among other foreign countries with more seriously affected areas. Known as dientes veteados, as Dean stated, "There were well over 200 endemic areas in the Argentine Republic." In Japan endemic mottled enamel at that time was largely limited to the southwestern section of the archipelago. Mottled enamel was first reported in China in 1930. Mottled enamel and more severe forms of chronic fluorosis were known in India. Endemic areas in Essex, England, as studied by Ainsworth, have been mentioned. In addition to the situation in the Neapolitan area of Italy discussed in the first chapter, denti sereziati (as mottled enamel was often known in Italy) was prevalent in Campagna, an area near Rome. Dean noted its presence in Australia, Ecuador, Greenland, Malaya, Mexico, the Netherlands Indies, South Africa, Tristan da Cunha, and in the Middle East in Iraq, Trans-Jordan, Syria, Arabia, and Palestine. Thus, because of fluoride naturally present in drinking waters, mottled enamel occurred in all the continents of the world including Australia. At the present time areas of endemic dental fluorosis are documented more precisely in terms of the specific quantity of fluoride present in the local drinking water.

The following foreward in the A.A.A.S. monograph in which most of the above geographical data were published was written by Moulton
MOTTLED ENAMEL AND FLUORIDE WATER

(16) who presented a résumé of dental fluorosis as it had been established by dental epidemiology and research up to the year 1941:

From the purely scientific point of view dental fluorosis is an exceptionally interesting phenomenon. It is a new and quite different illustration of the fact that very minute quantities of certain elements and of certain organic compounds (vitamins and hormones) sometimes have extraordinary effects upon living organisms. A peculiarity of fluorine is that, so far as is known at present, its ingestion from natural sources by people living under sanitary conditions produces sensible biological effects only upon the teeth—apparently beneficial ones if in quantities that are somewhat below well-determined limits, and certainly tragically harmful ones if well-known limits are exceeded.

As a public health problem, dental fluorosis is rapidly assuming large proportions. Perhaps this is fortunate, for it concentrates governmental and public attention on the importance of dentistry for the health of children and wins general support for preventive measures. Like other nutritional questions, the effects of fluorine on teeth can be investigated by animal experimentation with significant results. Since the amounts of fluorides in water vary widely in otherwise similar geographic, climatic, nutritional, racial and cultural areas, the methods of epidemiology are exceptionally useful in investigating dental fluorosis and lead to trustworthy conclusions. The results of investigations by all these methods are presented in this volume.

An even more important problem of health is forecast by the material presented in this symposium on the possible relation between fluorine and the decay of teeth (dental caries). If the apparent caries-inhibiting effect of fluorine in moderate amounts is proven beyond question, then ways and means can be found to reduce materially the incidence of this almost universal human ailment through public health measures.

Recent Epidemiological Studies in Finland and Denmark

The occurrence of mottled enamel and dental caries in relation to the concentration of fluoride in drinking water was studied recently in Finland and Denmark.

The Finland survey (17) included nine communities situated in the southeastern part of the country. The entire population of these communities used well waters for drinking and cooking, occasionally up to five families using the same water supply.

The final results of this study were based on 983 school children, age 11, having a history of residence of six years or more in their home community. Two hundred and eleven children used drinking water with 1.60 ppm or more of fluoride, 195 used 1.00 to 1.59 ppm; 199 used 0.40 to 0.99 ppm; and 378 used water containing less than 0.40 ppm fluoride. The highest fluoride concentration recorded was 5.0 ppm. The survey report stated: "Assuming a low degree of dental fluorosis to be expected as related to a low water consumption in a cool climate, the following sensitive index of fluorosis was computed on a tooth-unit basis: (1) normal enamel in all teeth erupted, (2) questionable opacities in one or more teeth, (3) small irregular white spots in one or
more teeth, (4) white opacities involving at least one-quarter of the facial surface in one or more teeth, (5) beginning discoloration of tooth surface in one or more teeth." Duplicate examinations were made on 169 boys and 170 girls in order to evaluate variability between the examiners and the error of the method.

These authors reported "a highly significant difference between the fluoride concentration groups in relation to the degree of mottling." They noted, however, that their particular index yielded much higher values than Dean's index. Nonetheless they found that the degree of mottling remained at a very low level and yielded results between "very mild" and "normal" in all the concentration groups. The low degree of mottling, as the authors anticipated, probably reflected a low consumption of water because of the cool climate. The dental caries results obtained in this survey as well as in a study conducted in Denmark are reported in a following chapter.

In addition to the Finland study, a splendid survey was made in Denmark by Dr. Ingolf J. Møller (18). Møller has kindly permitted reproduction of his color photographs of mottled enamel (see color plate). They illustrate exceptionally well the unobjectionable appearance of "questionable," "very mild," "mild," or some "moderate" mottled enamel. Møller's investigations established the relationship current in Denmark between fluoride in drinking water and the prevalence of dental fluorosis and dental caries. One purpose of his study was a comparison of conditions in Denmark with other countries, particularly the United States. The Danish Public Health Service, between 1948 and 1951, had analyzed more than 2,000 water supplies, the results indicating that 53,000 inhabitants used drinking waters containing 1.0 to 1.5 ppm fluoride, 40,000 drank waters containing 1.5 to 2.5 ppm, and approximately 1,500 used water with more than 2.5 ppm fluoride. Møller's water-fluoride analyses of 1959 compare very favorably with the data of the National Health Services for 1948-1951. In eleven communities in which drinking waters contained 0.05 to 3.4 ppm fluoride, 2,027 children aged 12 to 13 were examined. Mottled enamel was diagnosed and classified with some modifications from Dean's system. "Problems arose as would be expected," he stated, "concerning differential diagnosis of dental fluorosis vs. initial carious lesions, internal hypoplasia, and amelogenesis imperfecta."

Møller discussed in detail the distribution of endemic dental fluorosis, and summarized the results of his findings:

In areas where the drinking waters contained 0.5, 0.2, 0.25, and 0.34 ppm fluoride, no dental fluorosis was observed.

Drinking water containing 1.2 ppm fluoride is associated with dental fluorosis of negligible prevalence and severity. Adverse symptoms of cosmetic significance do not occur. On the contrary the teeth of these areas are pretty and, clinically speaking, often perfectly mineralized.

At concentrations up to 2.0 ppm fluoride in the drinking water, dental fluorosis is more evident, although still of limited severity and creating no cos-
### Clinical Standards Used for Diagnosing Dental Fluorosis

Dental Fluorosis and Caries

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Andebogtrykkeri i Odense

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*Arbitrary scores used by Dr. Møller to designate the degree of dental fluorosis. These figures are similar to Dean's numerical "weights": i.e., normal 0.0; questionable 0.5; very mild 1.0; mild 2.0; moderate 3.0; and severe 4.0. Brown stain is a secondary effect in moderate and severe fluorosis and is related to local oral factors.
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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
metic problems as no cases of disfiguring changes in visible teeth have been observed in such areas in Denmark. The average community index of dental fluorosis does not exceed 0.63.

Dean, it will be recalled, regarded a community index above 0.6 as warranting consideration as a public health problem and the data on Denmark agree fairly well with Dean's 0.6 index which was associated with approximately 2.0 ppm fluoride in drinking water. Møller believed that the prevalence and the degree of severity of dental fluorosis were lower in Denmark than in the United States when both had identical contents of fluoride in the drinking water. Quantitative differences in the consumption of drinking water might have caused this, due in part to differences in diet. Calculations of the optimal fluorine ion concentration in drinking water showed him that in Denmark this concentration must be assumed to be between 1.2 and 1.5 ppm fluoride. The "image of dental fluorosis" varied among individuals using the same drinking water as did the degree of severity of fluorosis from tooth group to tooth group. Finally, Møller concluded that the type of enamel classified as "optimal" in the investigation was most frequent with 1.2 ppm fluoride in water in one area and 1.6 ppm fluoride in another.

NOTES AND REFERENCES

Dr. H. Trendley Dean was born in Winstanley Park, Ill., in 1893. He received the D.D.S. degree from St. Louis University in 1916. He served in the Army Dental Corps in World War I, and in 1921 joined the U.S. Public Health Service. In 1931 Dr. Dean became the first dental officer assigned to the National Institute of Health. In 1948 he was selected to be the first Director of the newly organized Naional Institute of Dental Research. He filled the post until retirement in 1953. From 1953 to 1959 Dr. Dean served as Secretary of the Council on Dental Research of the American Dental Association. He achieved international renown by documenting the relation of fluoride in drinking water to endemic mottled enamel, and demonstrated, with his associates, the remarkable cariostatic benefits of fluoride drinking water. In recognition of his achievements he was awarded the Gorgas Medal, the Goodell prize of the American Water Works Association, the Jarvis Medal, the Distinguished Service Medal of the American Association of Public Health Dentists, the Lasker Award (jointly with Dr. Frederick S. McKay), and the Award of Merit from Georgetown University. Dr. Dean died at the age of 68 in Evanston, Ill., April, 1962. In 1962 the Fédération Dentaire Internationale awarded Dr. Dean posthumously the Miller Prize for his outstanding achievements in the field of international dentistry.


(2) BUNTING, R. W., CROWLEY, M., HARD, D. G., and KELLER, M., 1928. Further studies of the relation of Lactobacillus acidophilus to dental caries, III. Dental Cosmos, 70:1002.


CHAPTER EIGHT

CARIES REDUCTION AND FLUORIDE WATER

By 1930 the time had arrived when epidemiological research was on the verge of demonstrating with unequivocal certainty the alliance between dental caries prevention and an optimum quantity of fluoride in public drinking waters.

In the middle 1930's the prevalence of dental caries in the United States and the dental care requirements of school children received much-needed attention from the Division of Public Health Methods, U.S. Public Health Service. At that time the principal investigators of the problem were Drs. Henry Klein, Carroll E. Palmer, and John W. Knutson. Realizing the dire need for information on the epidemiology as well as the developmental and etiological characteristics of dental caries, these men were responsible for extensive dental caries surveys.

Hagerstown and American Indian Studies

One of their more notable surveys pertained to grade-school children. It was conducted in Hagerstown, Maryland, where in 1937 a total of 4,416 white children were examined by officers of the Public Health Service (1). This Hagerstown study has become a historic quantitative record of developmental pattern, incidence, and prevalence rates of dental caries in children of grade-school age. To quote Knutson, Klein, and Palmer (2) from a 1940 report of the Hagerstown survey:

Current nation-wide interest in the subject of adequate dental care has created a pressing demand for quantitative facts concerning the problem of dental needs. Since a knowledge of such facts would appear to be a prerequisite to an intelligent discussion of this problem, we are placed somewhat in the position of being asked to examine, critically, Duchamp's modernistic painting "Nude Descending a Staircase." Those interested in architecture would undoubtedly be baffled by an inability to count or visualize the form, size and style of the stairs, but most of us would be frustrated by our inability to discern the delineating characteristics of the nude.

Similarly, we are now confronted with the task of analyzing the problem of dental needs with little more than the equivalent of an artist's concept to guide us. Obviously, such statements as "more than 90 percent of all chil-
dren aged 15 and older have dental defects" contribute little toward a knowledge of the prevalence and incidence rates of defects in the teeth of a community. It is apparent, therefore, that recent interest in the subject of dental needs and adequate dental care has awakened us to a glaring deficiency in our present dental knowledge, namely, the paucity of quantitative, epidemiologic data on dental disease, or, more precisely, the gross neglect of the field of vital statistics of tooth populations.

Prior to the Hagerstown study an improved system for a quantitative evaluation of dental caries had been proposed by Klein and Palmer (3) who wrote: "A reconstitution of the caries experience in the permanent teeth of children may be accomplished with a fair degree of precision by totaling the mutually exclusive numbers of carious teeth (irrespective of the number of defects per tooth), the number of filled teeth, and the number of extracted teeth, plus those indicated for extraction. A summation of these values gives a count of the number of permanent teeth showing evidence of having been attacked by caries." The term "decayed, missing, or filled" (DMF), means that the mouth contains one or more actively decayed, or one or more filled, or one or more missing permanent teeth. It follows that a count of the number of teeth decayed, plus the number filled, plus the number missing gives a count of the total number of teeth affected by caries, the DMF count. (The number of teeth lost by small boys on playing fields does not constitute a statistically important factor.) Caries rate per 100 children or average DMF teeth per child has become a standard quantitative statement of the dental caries experience. Such data are acceptable for comparisons among the many varied groups of children which have to be examined in epidemiological and clinical studies.

Klein and Palmer also conducted surveys among American Indian children. They studied the caries experience, dental needs, tooth mortality, and sex differences in caries experience in elementary school children. Their examinations followed the newly developed system of recording caries in terms of percentage DMF. Caries data on American Indian children were collected during 1929 through 1932, and were based on 8,257 examinations, all having been made by Dr. E. B. Sterling, Medical Officer in charge of the Office of Field Investigations in Child Hygiene, U.S. Public Health Service. This survey included some 18 States, mostly west of the Mississippi River, and, as the authors stated: "The wide geographic distribution of these Indians, the differences between tribal groups in physical constitution, in habits, and in customs, and the availability of the separate groups at Government reservations, make the American Indian tribes particularly appropriate for studies on the epidemiological characteristics of dental caries." One objective was the improvement of diagnostic procedures and interpretation of caries pattern and experience data. These 1937 data indicated that the severity of caries in the permanent teeth of American Indian children varied widely. The disease was most severe in the Northwest and least in the Southwestern United States. The Southwest had
the lowest caries attack rates of all the areas studied. The investigators were aware of epidemiological surveys by Dean and others which designated the Southwestern United States (Arizona and Texas) as an area of extensive dental fluorosis, and had reason to anticipate a concomitant reduction in dental caries. Thus Klein and Palmer in 1937 suggested "that perhaps a measure of the responsibility for low caries attack rates in the southwestern area may be the result of the drinking of fluoridated waters." They mentioned that support for this concept was discernible in the literature and cited three references. They also recognized disadvantages and fallacies in their caries data but felt that:

In spite of the shortcomings of the present data, it appears justifiable to conclude that the epidemiological fact is satisfactorily established that striking differences in dental caries rates do exist among the different Indian tribes and in the aggregate of tribes living in different localities in the United States.

This was evidence that a significant difference in dental caries experience extended to all children, not only those of Indian tribes.

To return to the Hagerstown study, the examiners made note of variations in caries susceptibility of different tooth surfaces and different teeth as well as tooth mortality. Their data uncovered astounding facts. The prevalence of defects in permanent teeth per 100 boys was 25 carious teeth with 35 defective surfaces at age 6. By age 15, when permanent dentition had occurred, this had increased to 668 carious teeth with 1,435 defective surfaces. A similar trend was apparent in girls and all the data afforded quantitative evidence of the seriousness of dental caries in school children.

The authors concluded their report of 1940, in part:

Although we are all more or less qualitatively familiar with the gravity of the problem of dental needs, it is obvious that its solution is difficult, if not impossible, without access to an examination of its objective aspects through records and accurate data. Furthermore, quantitative facts instead of impressions must be employed that we may evaluate the progress and relative merits of our various attempts at solving this problem: a problem which largely resolves itself into one of so redistributing the dental services in the chronologic age scale of the human population that, through proper and adequate dental care at the most effective age, youth, less may be required for the dentally healthier adult of the future.

Although the Hagerstown study emphasized the deplorable state of dental health and the dental needs of grade-school children, the dental health problem in the United States was most dramatically documented and publicized by the examinations of recruits for the armed services in World War I and particularly in World War II.

Dental health problems in England had been the subject of extensive study and were reported in 1925 (4). One report stated that the gravity of dental caries and particularly the failure to meet children's dental needs was apparent but little was known about this disease and prevention was practically impossible to implement.

The epidemiological surveys documented in this chapter are distin-
guished by sound basic disciplines required of classic epidemiology and many benefited from the new methods and refinements in quantitative recording and diagnosis. Dental caries experience and prevalence rates were tabulated according to the DMF system of Klein, Palmer, and Knutson. The Hagerstown study and other caries surveys had shown emphatically that populations of school children aged 12 to 15 years were particularly desirable as a group to study because of the unusually high incidence and severity of caries in that age range. It was also an inestimable advantage to have this age group available at local public and parochial schools.

Furthermore, Dean noted that endemic dental fluorosis had provided a rare opportunity for studying physiological effects by the epidemiological method. “Whole cities were exposed to a measurable constant, i.e., a public water supply of known fluoride concentration. . . .” This unique situation would prevail in forthcoming epidemiological studies of dental caries in relation to fluoride drinking waters. Surveys could be related to a constant fluoride concentration in a public drinking water and caries could be studied in large local “captive” groups of children. In other words a fundamental epidemiological characteristic of dental caries had been clearly defined and was subject to control. The precision of epidemiological fluoride-caries studies was commensurate with this unique and nearly ideal epidemiological situation.

The Dental Caries Benefit of Fluoride in Drinking Water

H. Trendley Dean had recognized the need to know positively what constituted a permissible amount of fluoride. This permissible quantity had been determined by extensive epidemiological surveys, but it was necessary to know how that quantity of fluoride in water (approximately 1.0 ppm) affected the prevalence of dental caries. Extensive epidemiological surveys had to be planned and organized precisely, therefore, to evaluate the relationship of caries to approximately 1.0 ppm of fluoride in drinking water.

Previous reports showed a practically universal consensus that mottled teeth were not unusually susceptible to dental caries and compared favorably with teeth of children living where endemic mottled enamel was unknown. Admittedly it had been observed that there was difficulty in filling carious teeth that were severely mottled, because a hypoplastic condition interfered with retention of a filling. Such teeth eventually might be lost through extraction. But this circumstance did not indicate an increase in dental caries because of mottled enamel. Not only was there suspicion on the part of investigators that a caries-protective factor might be concomitant with mottled enamel, but it was surmised that caries protection might be associated with the same waterborne factor that caused mottled enamel. Even at that time it was thought that a benefit in reducing dental caries might be expected from fluoride
in drinking water. But unequivocal evidence was needed. It was to be forthcoming in results documented as the major development of this period of fluoridation history.

The events of this period encompass eight to ten years, beginning in the mid-1930's. To a large extent the initial epidemiological studies were organized and directed at the National Institutes of Health by Dean. In 1937 F. A. Arnold, Jr. was assigned to work with Dean and from that time on Arnold was active both as organizer and participant in many major fluoride-dental caries studies. Dr. Philip Jay, a member of the faculty of the University of Michigan Dental School, participated in many of these surveys, particularly in connection with observations pertaining to oral bacteriology. Population surveys by Dr. Henry Klein added significant information on the fluoride-dental caries relationship.

In 1938 Dean wrote (5):

Probably the first attempt to study specifically the relationship of mottled enamel to dental caries was made by McKay, who in 1929 attacked the hypothesis that dental decay might be superinduced by "defective" enamel structure, by citing as evidence the observation that mottled enamel teeth, which probably constitute "the most poorly constructed enamel of which there is any record in the literature of dentistry," do not appear to show any greater liability to dental caries than do normally calcified teeth.

McKay's study had used data obtained in Bauxite, Ark.; Minonk, Ill.; Towner, Colo.; and in the Pima Indian School at Sacaton, Ariz. The data as tabulated for the three latter areas indicated in every instance that mottled teeth had a lower percentage of caries than normal teeth.

In 1928 Bunting, Crowley, Hard, and Keller reported the occurrence of mottled enamel in Minonk, Ill. This was one of the first attempts to record quantitatively the occurrence of dental caries in an endemic mottled enamel area. There had been no definitive surveys to determine the incidence of caries in mottled teeth, nor was it known then that fluoride was the cause of mottled enamel.

Bunting and his group were especially impressed by the fact that caries was remarkably limited in most of the children examined in Minonk. They stated that there might be some principle in the drinking water which either inhibited the activity of dental caries or protected the teeth from this injury. No conclusions could be drawn from this survey, however, other than that there was a direct relationship between the water of that community and the dental dystrophies there, and that the behavior of dental caries and the presence of *L. acidophilus* in the mouth was somewhat different from that in other localities.

Dean referred to observations which he had begun in 1933-1934 to determine the minimal threshold of fluoride toxicity resulting in chronic endemic dental fluorosis, which included in certain cities not only mottled enamel, but other defects such as percentage of caries, past caries (fillings or extractions), pits and fissures, and hypoplasias. Dean
reported than an analysis of the data indicated that a higher percentage of caries-free children was found in cities whose water supplies contained relatively high amounts of fluorides, than in those communities with water supplies not so affected. Thus, caries data tabulated for Pueblo, Colo.; Junction City, Kan.; East Moline, Mommouth, and Galesburg, Ill.; and Colorado Springs indicated a greater freedom from dental caries in 122 children exposed to domestic waters of high fluoride concentration, with respect to both permanent and deciduous teeth. Of the 122 children reported, 60 were found to be caries-free in their permanent teeth and in 33, or 55 percent, of these 60 children the incidence of mottled enamel was 53 percent. Dean concluded that "these rather limited observations suggest that the limited-immunity-producing factor present in the water is operative whether or not the tooth is affected by mottled enamel. Whether this mechanism functions locally, systemically, or both ways is not known."

Caries and Natural Waterborne Fluoride in South Dakota, Colorado, and Wisconsin

After Dean surveyed mottled enamel in South Dakota, he saw fit to make use of these data to help resolve the dental caries-mottled enamel relationship. To do so he referred to data obtained in 1933-1934 from an extensive dental caries survey conducted in 26 states (6). This later survey included 34,283 dental examinations of children in South Dakota. Dean had diagnosed mottled enamel in approximately 3,300 school children in 51 South Dakota communities and saw the advantage of coordinating his mottled enamel data with the dental caries data previously available. In brief he stated that his study indicated:

In the intermediate group of counties where mottled enamel is generally prevalent, an examination of 1,902 white children 12-14 years of age disclosed 201 carious permanent teeth per 100 children. In the intermediate group of seven counties where the mottled enamel distribution was uneven, and at times sporadic, the examination of 2,765 children showed 314 permanent teeth affected per 100 children; and in the third group of counties and the cities of Huron and Sioux Falls, where no endemic mottled enamel areas are known to exist, an examination of 3,481 children showed a dental caries attack rate of 415 permanent teeth per 100 children. These data indicate that the dental caries attack rate in this particular population is inversely proportional to the prevalence of mottled enamel.

Similar comparisons of mottled enamel and dental caries data available from four Colorado cities indicated that:

In the non-endemic communities Pueblo, Fort Collins, and Denver, the dental caries attack rate is 194, 296, and 343 respectively; on the other hand, in the endemic area, Colorado Springs, only 163 permanent teeth per 100 children were affected. Applying the same methods of study to eight Wisconsin cities, it was found that in the seven cities where no endemic mottled enamel is known to exist and where the fluoride content of the communal water supplies ranges from 0.1 to 0.5 ppm, the severity of dental caries showed
rates from 646 to 917 carious permanent teeth per 100 children. But in the city of Green Bay, where the city water contains 2.3 ppm of fluoride, only 275 carious permanent teeth per 100 children were recorded.

An analysis of data from South Dakota, Colorado, and Wisconsin cities gave substance to the conclusion that "the severity of dental caries was lower in mottled enamel areas as compared with normal areas in the same state." But with characteristic conservatism and restraint, Dean wrote:

While on the basis of our present knowledge it appears justifiable to associate the observed results with the presence of fluorides in the domestic water, the possibility should not be overlooked that other elements of comparatively rare occurrence in water or ordinary constituents of drinking water present in unusually large concentration may directly or through a synergistic action with the fluoride produce the observed effects. For this reason, it appears essential to obtain as complete chemical analyses as possible of the domestic water of communities which are under investigation for dental caries.

Dean specified indebtedness to the Wisconsin State Board of Health for supplying information on the fluoride content of the water supplies of seven Wisconsin cities with high dental caries attack rates. These cities' drinking waters contained from 0.12 to 0.50 ppm fluoride, which was in striking contrast to the water of Green Bay, Wis., which, according to an analysis by Elvove, contained 2.3 ppm fluoride, and was associated with a strikingly low dental caries experience in the Green Bay children.

Singular interest is attached to these preliminary Wisconsin fluoride-dental caries data. Very soon after it became evident that fluoride in drinking waters had a significant beneficial effect on caries—in Wisconsin children, as well as in children in many other states—a small but extremely enthusiastic group of dentists and health officials in Wisconsin made an intense effort to have all public water supplies in their state immediately fluoridated. They were confronted at that time with opposition, particularly on the part of the American Dental Association, the U.S. Public Health Service, and influential local authorities.

A Second Study Which Included Galesburg, Illinois

Galesburg, Monmouth, Quincy, and Macomb, Ill., were chosen by Dean to evaluate further the relationship between mottled enamel, dental caries, and the fluoride content of drinking water. Thus a second fluoride survey was centered on the broad prairie lands of west central Illinois. Jay, Arnold, McClure, and Elvove collaborated with Dean in this study (7). The results supported the hypothesis that domestic drinking water could be responsible for a reduction in dental caries without the production of objectionable mottled enamel. This momentous development and events which would follow from the observations of this survey were beyond comprehension at that time.
The water supplies of Galesburg and Monmouth at that time contained respectively 1.9 and 1.6 ppm fluoride, while the drinking waters of Macomb and Quincy were relatively free of fluoride; they contained approximately 0.2 ppm or less fluoride. The Galesburg and Monmouth drinking waters were supplied by deep wells (approximately 2,400 ft) and the Macomb drinking water was obtained from the Lamoine River and an impounded Spring Lake Reservoir. Quincy's common water was supplied by the Mississippi River.

The selection of these four Illinois cities took into account several factors other than the drinking water which might influence the occurrence of dental caries. The proximity of the cities themselves would eliminate extreme climatological variations, particularly sunlight. The investigators limited all clinical examinations to 12-, 13-, and 14-year-old white children, with a known continuity of use of the local drinking water. A stipulation regarding use of the local water supply was a permissible absence from the community for 30 days in each calendar year. Dean's description of the sampling and selection of the children examined in Galesburg is typical:

In Galesburg there are three junior high schools covering the seventh, eighth, and ninth grades. The study was conducted at two of these schools (Hitchcock and Lombard). On the day of sampling there was present in the three junior high schools 1,059 12-, 13-, and 14-year-old children. About 70 percent, or 743, were pupils of the two schools where the study was made. Of these 743, cards were made out for 589 pupils, 319 of whom were examined. Of the 50 not examined, 39 were children who, on subsequent questioning during the clinical examination, were found to have had breaks in continuity of exposure, while the remainder were children absent on the day of the examination, a few not examined because of lack of time, and colored children who, because of very small numbers, did not warrant a separate classification. Of the 319 children examined, 243 gave a history of continuous use of the Galesburg city water; the remaining 76 showed breaks in continuity prior to 6 years of age, but had continuously used the city water since. The 319 children examined represented about 42 percent of the total number of 12-, 13-, and 14-year-old children present in these two schools on the day of sampling.

This same careful selection of children was made in Monmouth, Macomb, and Quincy. Furthermore Dean documented in great detail a history of the communal water supplies of these four cities.

The major findings of this study were recorded as follows:

In Galesburg 319 children were examined, in Monmouth 148 children, and the number of carious permanent teeth per 100 children in the two cities was 201 and 205 respectively. At Macomb and Quincy examinations of 112 and 306 children respectively disclosed rates of 401 and 638 carious permanent teeth per 100 children. In other words, there was approximately twice as much dental caries in Macomb and more than three times as much in Quincy as was observed in Galesburg or Monmouth.

In Galesburg and Monmouth about 35 percent of those examined were caries free, whereas in Macomb and Quincy only 14 and 4 percent respectively were free from dental caries. (These overall data are illustrated in Figure 1.) Dean made a further detailed analysis of the caries
Fig. 1.—Distribution of the four signs of dental caries experience in permanent teeth, classified according to amount per 100 children examined (885 selected 12- to 14-year-old white children of four Illinois cities).

data obtained in "fluoride" Galesburg and Monmouth as opposed to "non-fluoride" Quincy and Macomb. Limiting the comparison to interproximal or smooth-surface caries, it was shown that in Galesburg and Monmouth there were only 0.59 surface carious lesions per 100 tooth surfaces, while in Macomb and Quincy there were 8.9 lesions per 100 children. He found that 16 times as much of this particular type of dental caries was present in Macomb and Quincy as in Galesburg and Monmouth. Very conservatively the summary of his paper states in part:

While it seems reasonable to associate the low dental caries rates with the higher fluoride content of the communal water supplies, the possibility that the composition of the domestic waters other than fluoride content may be a factor should not be overlooked, and in addition from an epidemiological standpoint it is difficult to ascribe these differences to any cause other than the common water supply.

While a definitive answer even at the end of this study still remained a matter of some speculation, a source of additional data was already in the making.

Caries in Children—Eight Suburban Chicago Communities

The demonstration of marked differences in the dental caries experience in Galesburg and Quincy had made further similar studies imperative. It was urgent to know exactly what level of dental caries experience was concomitant with the maximum permissible concentration (1.0 ppm fluoride) in drinking water. Furthermore it was necessary to know whether even lower fluoride concentrations in a public water supply would be associated with reduced dental caries.

Dean, Jay, Arnold, and Elvove (8) conducted the study in a subur-
ban Chicago area. The communities selected had to possess two requisites: (1) a population sufficient in size to permit the selection of an adequate sample of children continuously exposed to the variable under investigation, and (2) a public water supply of the desired low-fluoride concentration with no serious, interfering, or relevant variables in either its content or its source during the life of the group examined. A number of suburban Chicago communities with small amounts of fluoride in their domestic water supplies presented these desired requisites and thus provided the unusual epidemiological opportunity of comparing their dental caries experience rates with those of neighboring cities using fluoride-free Lake Michigan water. Elmhurst, Maywood, Aurora, Joliet, Elgin, Evanston, Oak Park, and Waukegan were selected for this study (Figs. 2 and 3). Meticulous attention to details in the sampling and selection of children were followed, as in the previous study on the “Lincoln Prairie Land.” David C. Johnson and Edwin M. Short were responsible for the clinical examinations. All the children were examined by one or the other of these two dentists—each examining approximately an equal number in each city.

The clinical findings of this study revealed a remarkable difference in the amount of caries in the selected groups of 12-, 13-, and 14-year-old children, both with respect to the percentage of incidence of affection and the dental caries experience. For instance, “the combined dental caries experience rate for the 1,421 children of those communities (Elmhurst, Maywood, Aurora, and Joliet) whose public water supplies contain fluorides in excess of 1.0 ppm is 288 per 100 children, in contrast to a rate of 746 per 100 children in the 1,008 children of communities (Evanston, Oak Park, and Waukegan) using water with a fluoride content of 0.0 ppm. In other words there is 2.6 times as much dental caries in the latter communities as in the former.” It is difficult to appreciate the inestimable value and significance of this study. The following passages from the report may convey some comprehension of its importance to dental science.

The location of these communities and the fluoride concentrations of their public water supplies make them peculiarly fitted for epidemiological study of the relationship of fluoride concentration in the domestic water supply to the amount of dental caries experience. The most pertinent finding of the study was the disclosure that water supplies, the fluoride concentrations of which were not far from the minimal threshold of endemic dental fluorosis, 1.0 ppm of F (e.g., Aurora, 1.2 ppm), were associated with unusually low dental caries experience rates. Thus, the dental caries inhibitory factor, presumably present in the water and probably fluoride, was operative at levels where mottled enamel per se was of minimal public health and no esthetic significance. On the other hand, the three communities using the fluoride-free waters were all characterized by high dental caries experience. This suggests that fluoride levels even under 1.0 ppm of F influence dental caries experience.

Considering the relative homogeneity of these urban populations and the sampling method followed, it is difficult from an epidemiological standpoint
Fig. 2.—Eight communities studied in vicinity of Chicago.

to ascribe these observed differences to any cause other than the common water supply.

The dental caries inhibitory factor, presumably fluoride, was operative at such low concentrations (e.g., 1.2 ppm of F in Aurora) that mottled enamel as an esthetic problem was not encountered.
The demonstration of the variation in dental caries experience among selected urban population groups opens up important avenues pertinent to the possibility of partial control of this highly prevalent disease.

Additional Studies of Fluoride Waters and Dental Caries

Studies immediately following those in the eight suburban Chicago communities were reported in 1942 by Dean, Arnold, and Elvove (9) and the clinical examinations were again made by Johnson and Short. With respect to age, sex, race, continuity of exposure, and other epidemiological controls, this survey was similar to that in the Chicago suburban cities as well as in the four other Illinois communities. Their paper "describes studies made in Illinois, Indiana, Ohio, and Colorado, and reports the amount of dental caries experience found associated with the continuous use of common water supplies obtained from Lake Michigan, the Mississippi, Ohio, and Arkansas Rivers, from deep wells of different fluoride concentration and mineral composition, and in one instance from melted snow high on Pikes Peak (Colorado Springs)."

The results of this additional study and the findings in the eight Chicago suburban communities were then combined in order that all the results might be presented as a whole. Thus all the data were represented in an impressive summary table of basic observations on the effect of low concentrations of fluoride in drinking water on the occur-
rence of dental caries in 12- to 14-year-old children. The authors' summary of this accumulation of data follows:

1. A study of the intensity of dental caries attack, as evidenced by the observed dental caries experience, disclosed striking differences among children of different cities. This study embraced 7,257 white urban schoolchildren, aged 12 to 14 years, of 21 cities; in the main the children were apparently of largely comparable circumstances and the groups examined were relatively equitable respecting sex ratio. These totals, 7,257 children of 21 cities, represent the 4,425 children of 13 cities reported in detail in this paper and the 2,832 children of 8 suburban Chicago communities previously reported. The groups studied were limited to those children continuously exposed throughout life to the variable under investigation (the common water supply). Clinical examinations in all 21 cities were made by the same two dental officers and in each city an equal number of children were examined by each examiner. It seems unlikely that such marked differences in the prevalence of dental caries can be explained on the basis of the hardness on the domestic water, the hours of sunshine, or gross dissimilarities in diet (water excluded).

2. A general inverse correlation between the fluoride concentrations of the public water supplies in the 21 cities studied and the amount of dental caries was observed. Differences in dental caries experience rates of as much as two and three times the observed minimal were not unusual; the highest rate, 1,037, at Michigan City (Ind.) was 4.4 times that observed in the city with the lowest rate, 236, at Galesburg (Ill.). Strikingly low dental caries prevalence was found associated with the continuous use of domestic waters whose fluoride content was as low as about 1 part per million, a concentration which under the conditions prevailing in the localities studied produced only sporadic instances of the mildest forms of dental fluorosis of no practical esthetic significance.

3. As in previous studies, marked differences were observed with respect to (a) the amount of dental caries experience in the proximal surfaces of the four superior permanent incisors, and (b) the first permanent molar mortality rates. Of the 4,425 children of the 13 cities whose caries experience is reported in detail in this report, the 2,859 children living in communities whose public water supply contained less than 0.5 ppm of fluoride showed about 19 times as much proximal surface caries experience in the four superior permanent incisors as was observed in the 1,566 children living in cities where the common water supplies contained from 0.6 to 2.6 ppm of fluoride. In these same two groups of children, the first permanent molar mortality rate for those living where the water supply contained less than 0.5 ppm of fluoride was about 4 times as high as that observed in the children using a domestic water containing more than 0.5 ppm of fluoride (66.0 and 15.6 per 100 children examined, respectively). Inasmuch as the group with the higher first permanent molar mortality rate showed 58 percent of its total first permanent molar caries experience with fillings as opposed to only 26 percent in the group characterized by the lower mortality rate, there would seem justification in assuming that such differences in first permanent molar mortality rates are influenced to a considerable degree by a variation in the intensity of dental caries attack, and/or the resistance of the teeth to caries attack.

Endemic dental fluorosis in this study was recorded by Dean and associates. In Elmhurst, Colorado Springs, and Galesburg, where drinking waters contained respectively 1.8, 2.6, and 1.9 ppm fluoride, the community index of fluorosis was respectively 0.67, 1.31, and 0.69. In all of
the other 18 cities, this index was less than 0.6, and mottled enamel thus did not present a prohibitive problem of dental public health (Fig. 4).

<table>
<thead>
<tr>
<th>NUMBER OF CITIES STUDIED</th>
<th>NUMBER OF CHILDREN EXAMINED</th>
<th>NUMBER OF PERMANENT TEETH SHOWING DENTAL CARIES EXPERIENCE* PER 100 CHILDREN EXAMINED</th>
<th>FLUORIDE (F) CONCENTRATION OF PUBLIC WATER SUPPLY IN P.P.M.</th>
</tr>
</thead>
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<tr>
<td>11</td>
<td>3867</td>
<td></td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>3</td>
<td>1140</td>
<td></td>
<td>0.5 TO 0.9</td>
</tr>
<tr>
<td>4</td>
<td>1403</td>
<td></td>
<td>1.0 TO 1.4</td>
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<tr>
<td>3</td>
<td>847</td>
<td></td>
<td>&gt; 1.4</td>
</tr>
</tbody>
</table>

X. DENTAL CARIES EXPERIENCE IS COMPUTED BY TOTALING THE NUMBER OF FILLED TEETH (PAST DENTAL CARIES), THE NUMBER OF TEETH WITH UNTREATED DENTAL CARIES, THE NUMBER OF TEETH INDICATED FOR EXTRACTION, AND THE NUMBER OF TEETH MISSING (PRESUMABLY BECAUSE OF DENTAL CARIES).

Fig. 4.—Amount of dental caries (permanent teeth) observed in 7,257 selected 12- to 14-year-old white school children of 21 cities of four states, classified according to fluoride concentration of public water supplies.

Dean (10) mentioned several variable factors which might have affected the dental caries experience data in addition to fluoride in the drinking water. He dismissed diet variability and hours of sunshine as having no significant relation to the striking effects of fluoride on a reduction in caries. But he paid special attention to the possible effect of hardness of water. Earlier, as Dean stated, a few papers had indicated that an increased hardness in the drinking water is associated with a lower amount of dental caries. These studies had found that users of "hard" water had less dental caries than users of "soft" water. Thus Dean proceeded to examine the data of these 21 cities in order to be assured that the observed differences in dental caries experience could not be explained on the basis of water hardness and that the effect of fluoride had not been influenced by total hardness. This analysis and inspection of the data provided no evidence of a relation of hardness of water to the anticaries effect of waterborne fluoride. Dental caries data plotted against the total hardness of the water supply suggested "a very poor or non-existent relationship."
An Early Survey in Wisconsin

In 1936, Dr. F. A. Bull, Dental Director of the Wisconsin State Board of Health, surveyed the mottled enamel situation of Green Bay, Wis., a city of 45,000 having 2.1 ppm fluoride in its water supply. His observations showed that the mottled enamel index for Green Bay was about what would be expected from that quantity of waterborne fluoride. Aware of the increasing interest regarding the amount of dental decay concomitant with mottled enamel, Bull decided to undertake a caries study in Green Bay and to include a control city of like population, Sheboygan, which had an almost fluoride-free water supply from Lake Michigan. Bull was confronted with the same major problem which Dean had made such a special effort to control: the continuity of exposure of his study groups to the particular drinking water of the area. Bull's data are compromised to some extent by uncertain control of the continuity of exposure to the local drinking water. His dental examinations provided dental caries experience data in terms of DMF as follows: Green Bay children, 2.62; children living outside Green Bay, 4.59; total for Green Bay school children, 3.06. For Sheboygan children the DMF was 8.54. These data are in good agreement with the Green Bay data on the effect of fluoride in the water of Green Bay and other Wisconsin cities in the development of caries in deciduous teeth (11).

Fluoride Waters, Mottled Enamel, and Dental Caries Studies on World War II Selectees in Illinois

Dr. Charles F. Deatherage, through the Division of Dental Health Education, State Department of Public Health, Springfield, Ill., published three timely reports on the dental health status of Illinois children and young adults (12, 13, 14). The studies were pursued during World War II, at which time dental examinations obtained by the Selective Service System provided information quite acceptable to evaluate dental caries experience in older age groups in relation to exposure to fluoride waters. From the latter part of September, 1941, until December 12, 1941, approximately 6,000 dental examination work sheets were received from local boards throughout Illinois. Using information selected from these dental health records, as well as his own data on 9- to 12-year-old children, Deatherage collated information concerning the cariostatic effect of Illinois fluoride waters. It is noteworthy that the data obtained at that time on older age groups are probably among the first epidemiological observations to contribute information on the continuity into adult life of the caries-preventive effect of fluoride drinking waters.

Deatherage reported in great detail regarding public water supplies of Illinois, particularly fluoride-bearing waters. He stated:
In northern Illinois there are four great water-bearing formations: the Silurian limestone, the St. Peter, the Dresbach, and the Mt. Simon sandstones. The sandstones dip to the south and are tapped for water at depths as great as 2,700 feet. Many wells obtain water from more than one of these formations.

In the east-central part of the State there is an interesting group of soft fluoride-bearing waters from another source. A shale formation extending in a narrow ridge from north to south was eroded by the glaciers, and the debris was distributed over the underlying limestone for a distance to the westward. This shale contained glauconite, a natural greensand, which softens the water percolating through it and also furnishes fluorides. It is these soft waters which cause the most severe mottled enamel.

Illinois communities have provided stable populations using on the one hand fluoride-free waters from the Mississippi River and Lake Michigan, and on the other hand drinking waters (obtained from deep wells) which contained variable but appreciable quantities of fluoride. There is little wonder that Illinois thus became the area for many meritorious epidemiological studies on the effects of fluoride as against non-fluoride waters.

The first observations by Deatherage concern three groups of individuals: (a) 551 children aged 9 to 12 years who had lived in Illinois areas of endemic mottled enamel their entire lives, (b) 164 selected 21- to 28-year-old Selective Service inductees from 27 Illinois cities living their entire lives in areas where the water supplies had been constant for 28 years and contained 1.0 to 4.0 ppm fluoride, and (c) 164 selectees aged 21-28 (general population) living in non-endemic areas their entire lives. From the dental records sent to the Illinois State Health Department it was possible to select an additional small group of 77 selectees from 17 cities where water supplies contained 1.00 ppm or more fluoride. The records indicated that these men had lived in these areas for only the first eight years of life during which time the enamel of the permanent teeth (excepting the third molars) had been completely calcified. The dental caries experience of these 77 men was compared with that of 82 selectees who had lived in a non-fluoride Illinois area the first eight years of life.

In this first study Deatherage also examined 1,100 9- to 12-year-old children in 25 endemic communities. These dental caries data were compared with data of a second group of 4,825 children of the same age living in non-endemic areas. "The 551 children living in endemic areas their entire lives showed that 208, or 37.7 percent, were free from present dental caries," as compared with the general population of 4,825 children of the same age group living in non-endemic areas. Only 19.7 percent of the latter group were free from caries, a difference of 18 percent in favor of the fluoride-bearing waters. Another group of particular interest was composed of 21- to 28-year-old men. Deatherage regarded these data as preliminary to his conclusions:

The one factor that is different in these groups is the water supply, the one containing fluorine 1 ppm or above and the other 0.5 ppm and below. In
view of this relatively small number of observations we must interpret these findings with caution. However, from an epidemiological standpoint it is reasonable to assume that the marked differences in dental caries experience may be ascribed to the use of the common water supply. Attention also is called to the lesser number of selectees rejected whose teeth were calcified on waters containing appropriate amounts of fluorides.

Deatherage based two succeeding articles on data obtained from examinations of Illinois Selective Service men. The first pertained to 2,026 white selectees divided into three groups living in 91 Illinois communities. The fluoride in their drinking waters was: Group A, 0.0-0.1 ppm in water supplied by Lake Michigan or the Mississippi River; Group B, 0.5-0.9 ppm fluoride in water, which Deatherage regarded as slightly suboptimal for maximum caries inhibition; and Group C, 1.0 ppm and over, under average conditions in Illinois—a concentration considered optimal for dental caries inhibition. These latter fluoride areas included the familiar Illinois communities of Aurora (1.0 ppm), Elgin (0.9 ppm), Elmhurst (2.0 ppm), Galesburg (1.9 ppm), Joliet (1.4 ppm), Maywood (1.6 ppm), M Ionk (2.2 ppm), and Monmouth (1.7 ppm). Among the non-fluoride (0.0 ppm) communities were Evanston, Waukegan, Quincy, and Oak Park.

All selectees were examined by local Selective Service Board dental examiners. Questionnaires provided residence history, age, and continuity of exposure to local water supplies so that the individuals could be classified according to whether they had used the domestic water either during their entire life or during the first eight years of life only, the period of tooth calcification. On the basis of “present and past rates of dental caries,” selectees who had lived the first 8 years, but not their entire lives, in areas where water contained 0.5-0.9 ppm fluoride or 1.0 ppm or more fluoride had significantly lower caries than those who had lived in non-fluoride areas. Deatherage found a lower percentage of selectees rejected for military service because of dental conditions and a lower percentage using various forms of dental prostheses, particularly dentures, in selectees from fluoride water areas.

In his final article Deatherage presented data gathered by studying (a) men living in fluoride-free areas their entire lives, which in this particular study was limited to domestic waters obtained from either Lake Michigan or the Mississippi River; and (b) men living in fluoride areas from 1 to 24 years, following the period of calcification of the permanent teeth, but not in a fluoride area the first 8 years of their lives, thus calcifying their teeth on fluoride-free waters. The waters of the fluoride areas contained 1.0 ppm fluoride or more. The data (per 100 selectees) are reported as follows:

Group A. Michigan or Mississippi River water used their entire lives, 286 men, caries experience—1,079.

Group B. Water containing 1.0 ppm fluoride used their entire lives, 454 men, caries experience—621.

Group C. Water containing fluoride but used following the period of tooth calcification, 263 men, caries experience—838.
Caries Reduction and Fluoride Water

Of particular interest is the record per 100 selectees of 838 caries experience who used fluoride water (post-calcification) as compared with 1,079 per 100 for those who had used no fluoride water during their entire lives. The data were statistically significant, and the conclusion stated by Deatherage was:

Other factors being essentially the same it is reasonable to assume that the marked difference in dental caries experience by the two groups is attributable to the differences in the fluoride content of the domestic waters used, and indicates that fluoride has an inhibitory effect on dental caries after the calcification of the permanent teeth.

Thus, Deatherage in 1943 had approached the difficult problem of dental effects resulting from exposure of the mature tooth to fluoride. This problem was to be studied later from the viewpoint of both systemic and oral sources of fluoride enamel. At that time the general consensus was that a fully calcified erupted tooth was not subject to chemical modification.

When Deatherage began his studies on adults who had used fluoride following tooth eruption, he was aware of data published in 1942 by Armstrong (15) and in 1943 by McClure (16), indicating that fluoride was retained by dental tissues of the experimental rat following tooth eruption, and that this secondary fluoride deposit was caries-inhibitory in the experimental rat. In 1942 it was also demonstrated that the fully calcified tooth of an older dog could acquire fluoride post-eruptively, particularly in the dentin. Deatherage felt justified in attempting to demonstrate that this benefit from a secondary fluoride deposit also might apply to the adult human tooth and that this might be demonstrated in young adult selectees. His data indicate that there was a slight anticaries effect resulting from post-eruptive exposure to fluoride waters. The fact that the residence histories of these inductees were not verified possibly compromises these data.

Fluoride and Caries Studies by Klein

The possibility that dental decay might be reduced in children even if exposure to a fluoride water began at an age beyond date of birth but before tooth eruption was explored extensively by Dr. Henry Klein (17, 18). He considered especially whether a fluoride water inhibits decay in erupted permanent teeth; to what extent caries is reduced in permanent teeth which erupt during the period of exposure to a fluoride water; and the effect of a fluoride water on the incidence of new caries in those individual teeth which have the highest caries susceptibility, namely first and second molars and second bicuspid.

Klein's data on fully erupted or erupting teeth during the time of exposure to a fluoride water were based on some 316 children of Japanese ancestry who were transferred late in 1942 from their homes in the Los Angeles area to War Relocation Centers in California and Arizona.
The children in California consumed fluoride-free drinking water (less than 0.1 ppm) whereas the Arizona drinking water averaged 3.0 ppm fluoride. After two years of residence in these areas there were differences in the number of teeth newly attacked by caries (Fig. 5).

![Graph showing caries incidence by age and fluoride exposure.](image)

**Fig. 5.—** Relation between age and number of caries-free permanent first molars per 100 children of both sexes in fluoride and control areas.

Klein reported:

These findings lead to the conclusion that, among young children (ages 8 to 10 years) transferred to an area where the drinking water contained 3 ppm of fluoride, the incidence of new caries experience in previously noncarious erupted teeth was reduced approximately 60 percent below that which would be expected on the basis of the incidence observed in the control group. The data are sufficient to indicate that exposure of the erupted permanent teeth of younger children to fluoride waters provides a larger measure of protection against caries than does the same exposure of the erupted teeth of older children. It follows, therefore, that, among teeth present in the
mouth at the beginning of exposure to fluorine, those most recently erupted were those most protected against caries attack. Since the present report was prepared, a communication by R. Weaver, British Dental Journal, 47:185 (1944), has become available. This worker has arrived at similar conclusions from prevalence observations on 800 English children who had immigrated into an area where the drinking water contained 1.4 ppm of fluorine.

The data obtained by Klein also provided the finding that "addition of small amounts of fluorine to community water supplies deficient in this element effects a reduction in caries incidence in the erupted permanent teeth of residents of school age; and that such caries inhibition is most noticeable in the erupted teeth of the younger children."

Although this was regarded as a pilot study, further analysis of the data indicated that "first and second molars and second bicuspids already erupted in the mouth are protected significantly against caries attack, provided they become exposed to the fluorine-bearing waters within a short time after eruption." Data on erupting second molars and second bicuspids suggested that teeth which go through the process of erupting during exposure to fluoride waters receive the greatest protection against caries attack. Klein had thus embarked on two basic problems concerning the mechanism of the fluoride action and the local effect of fluoride on oral tooth surfaces. Both are very complex and are intimately involved in topical fluoride treatment. They are still the subject of intensive study.

Fluoride Waters and Dental Caries in New Jersey

A fluoride-dental caries study published in 1948 by Klein (19, 20) included three New Jersey communities: Glassboro (now a world-famous community because of the Russia-United States summit meeting of 1966), Pitman, and Woodstown, all of which in 1927 had changed to a communal water supply providing drinking waters containing 1.2 to 2.2 ppm of fluoride. Conducted in 1946, this survey documented the effects of 19 years of continuous use of fluoride water. Two nearby communities, Clayton and Williamston, with water supplies essentially fluoride-free (0.1 ppm fluoride) were used as controls. School children were examined; of them 1,922 were lifetime residents of the fluoride area, 350 were born and reared in the non-fluoride area; 599 living in both areas used waters from shallow wells; 882 were migrants into the fluoride area; and 425 were migrants into the non-fluoride areas. Klein found that examinations of both deciduous and permanent teeth of the children born and reared in the fluoride area indicated that residence in such an area in New Jersey is associated with low caries attack rates in both deciduous and permanent teeth. He also called attention to the fact that children need not be born in the fluoride area to experience the protection associated with residence in the area. But he stated that the earlier in the area and the longer they are exposed, the
greater is the protection. Age at eruption and the developmental status of individual teeth influenced the ultimate benefits of fluoridated water.

The subject was due for further study in connection with the effects of directly fluoridated water. Klein used the results of his surveys in New Jersey and evaluated the caries-depressant effect of fluoride on different types of teeth whose characteristics would be expected to influence caries susceptibility. For comparison he made use of dental caries data obtained from examinations of 6,000 children living in Hagerstown, Md. The data on children living in the control non-fluoride area in New Jersey appeared to be excessively high, whereas the Hagerstown data were more acceptable as representative of non-fluoride areas.

Klein reported:

The depressant effect of fluorides on caries may be approximately of equal potential for all the different types of teeth. However, because of the different gradients in the characteristic or expected caries susceptibilities of the different teeth, the resultant effect may be a variation in the percent reduction of caries among the different teeth, such as described above for the New Jersey children. Consideration of the differences in caries reduction among the different teeth leads to the view that the differential effects are perhaps related to basic differences in the characteristic susceptibilities of the different teeth.

From a practical point of view, the findings direct attention to the pertinent observation that even after prenatal exposure and a postnatal residence of 15-19 years in a fluoride environment, caries attack is reduced only by about a third of normal expectation in the lower molar teeth of lifetime residents, although this is a significant reduction, particularly from the last examination.

Klein noted that "approximately two-thirds of the treatment problem for caries in the fluoride area still arises among molars, a phenomenon which probably explains why practicing dentists in that area did not, previous to the present study, independently consider that the teeth of their patients were uniquely different from those of other children in the United States." Some of Klein's extensive data are illustrated in Figure 6. His graphs illustrate the effect of fluoride on the DMF in specified kinds of teeth in left and right side of the upper jaw (maxilla) and in the lower jaw (mandible).

Observations in South Dakota

In 1949, Russell (21) conducted studies which are particularly pertinent to the effects of fluoride during and after eruption of permanent teeth. He recorded the dental caries experience of migrant children living in South Dakota who through a definite age span of at least one year's duration had used drinking waters containing 1.0 ppm or more fluoride. In all, 297 migrant children ranging in age from 5 to 18 years were examined. Of these, 133 children used fluoride both before and
after eruption of permanent teeth; 12 used fluoride water only after these teeth had erupted. Russell stated, "It is unfortunate that so few cases of purely post-eruptive fluoride exposure occurred." His data are consistent, however, with those reported by Klein for larger groups of children with post-eruptive fluoride exposure.

Russell regarded these preliminary studies with reservation and cau-
Fluorides may be incorporated into tooth enamel either during the process of calcification or after eruption and when so incorporated are effective in the inhibition of dental caries.

2. This inhibitory effect tends to persist so long as fluoride exposure is continued but tends slowly to be lost after fluoride exposure is discontinued, particularly in teeth highly susceptible to caries; hence

3. Periodic or continuous renewal of the fluoride content of tooth enamel is required for maintenance of the maximum caries-inhibitory effect.
Fluoride and Dental Caries as Studied in Missouri

Still another study was made of dental caries and the use of drinking waters containing an average natural fluoride content of 0.2, 0.5, and 1.1 ppm. This stimulating and extensive survey conducted in 1953 by Nevitt, Diefenbach, and Presnell (22) was characterized by meticulous attention to significant details. The data show the cariostatic value of 1.0 to 1.1 ppm of fluoride, an amount which did not esthetically detract from the appearance of the teeth of the children. This was a cooperative study made by the Missouri Division of Health and the U.S. Public Health Service. The subjects were continuously resident white children, ages 6 through 14, living in nine selected Missouri cities with public water supplies bearing different fluoride concentrations.

This survey and other studies were made after the actual advent of fluoridation of drinking water. Their results not only add evidence to the cariostatic value of fluoride present naturally in drinking water but the data bring credible evidence to the fact that fluoridated water and a natural fluoride water provide the same beneficial caries effects.

All the children who qualified in each study area were included in the survey.

The sample was composed of: (1) white children between the ages of 6 and 14 years inclusive; (2) children who had a verified continuity of residence from birth in their city; and (3) children who had used the public water supply as their regular source of water. Children who had received topical fluoride treatments were not included in the study. The school nurse was present to add her personal knowledge of the history of each child.

The results of this survey left no doubt that there were marked differences in the prevalence and the amount of dental caries in the children. Nevitt, Diefenbach, and Presnell stated:

It seems unlikely that the differences found in dental caries among the 3,206 children would be due to differences in heredity or diet in these communities. Considering the relatively close geographic locations of these nine cities, the similarity of their climates, the homogeneity of their populations and the comparability of the diagnoses made, it seems very probable that the fluoride present in the water supplies is the dental caries inhibiting factor.

An average of 57 percent of the children living in the high fluoride cities were caries-free (Fulton, Mexico, Columbia) compared to 18 percent of the children in the low fluoride cities (Rolla, Sedalia, Chillicothe).

Fluorides were present in the water supplies in amounts that did not esthetically affect the teeth of the children examined.

Natural Fluoridation in Jacksonville, Florida, and in Three Nearby Georgia Cities

Two other significant studies on dental caries as affected by natural fluoride waters have been reported—one in Florida (1957) and the other in Georgia (1959). Because of the geographic proximity and cli-
matological similarity of the areas, the data of both surveys contribute
information to the problem of climate and its effect on water consump-
tion, and on the determination of the optimum amount of fluoride that
should be present in drinking waters. The data apply to an area where
the mean annual temperature averages 69.4° F in Jacksonville and
76.6° to 80° F in the Georgia cities.

According to Kroschel, Hasty, DeCamp, and Sowder (23), fluoride
was first detected in Jacksonville water in 1934 and ranged from 0.55 to
0.75 ppm; in 1946 this water contained 0.60 ppm; in 1949 and 1951,
0.70 ppm. The water history indicates that Jacksonville's water source
has been constant and uniform for more than 20 years. Their study de-
termined "(1) the extent of protection against dental caries afforded by
continuous use of Jacksonville's naturally fluoridated water, and (2) if
this fluoride ion concentration causes any harmful or esthetically objec-
tionable dental fluorosis (mottled enamel)." Their study group con-
sisted of 1,590 white children, ages 6 through 17 years, having lived
since birth in Jacksonville. Data on the Jacksonville children were com-
pared with those for Aurora, Ill. (1.2 ppm F in drinking water), pre-
sented by Dean, Jay, Arnold, and Elvoe in 1941. A comparison of den-
tal caries health of the two cities was made on the basis of (1) children
with caries experience, (2) tooth mortality, and (3) DMF teeth. The
authors suggested the following conclusions:

1. The naturally occurring fluoride content, 0.60 to 0.70 parts per million, of
Jacksonville's communal water supply is providing a protection against den-
tal caries for persons with continuous use of this water during the calcifica-
tion of their permanent dentitions.

2. The degree of caries reduction effected appears to be as adequate as any
yet found in other communities whose public water supplies contain higher
concentrations of fluorine.

3. Since no objectional or harmful fluorosis has resulted, no need to de-
crease the natural fluoride content of Jacksonville's communal water is indi-
cated.

4. On the basis of present knowledge of the effectiveness of water fluorida-
tion, there is no reason to believe that any increase in the present fluoride
content of Jacksonville's communal water would effect any greater protection
against dental caries.

The effect of natural waterborne fluoride on the caries incidence in
three Georgia cities was reported in 1959 by Lewis and Leatherwood
(24).

Dental health services of the Georgia Department of Public Health and of
the Public Health Service in Region IV were requested by the Dental Soci-
ety, Chamber of Commerce, and Health Department of Savannah, Georgia,
to make a detailed study of the prevalence of dental caries in the children of
Savannah in relation to the fluoride content of its water supply. The natural
fluoride content of Savannah's water supply was approximately one-half the
concentration recommended by the State health department. The question
was: How much additional reduction in the caries attack rate would be de-
erived from the adjustment of this concentration to the approved range?
The drinking water of Savannah contained from 0.3 to 0.5 ppm of fluoride; Macon and Moultrie, chosen as control cities, used water supplies containing 0.0—0.5 and 0.3—1.4 ppm fluoride, respectively. There was some uncertainty regarding the consistency of the fluoride in these water supplies but the approximate average figures were 0.11 ppm for Macon, 0.38 ppm for Savannah, and 0.75 ppm for Moultrie. Participation in this dental survey was limited to white school children 6 to 15 years old who were continuous residents and had used only the one public water supply since birth. A total of 9,801 school children was examined, 3,890 in Macon, 4,871 in Savannah, and 540 in Moultrie. Inspection of the data led these authors to state:

An inverse relationship exists between the caries attack rates and the concentration of fluorides in the water systems of these three communities. Approximately one-fourth of the permanent teeth of the children examined in Macon were decayed, missing, or filled, one-fifth in Savannah, and one-ninth in Moultrie.

The DMF percentage difference between Savannah and Moultrie demonstrates decisively the additional protection against dental decay that could be achieved in Savannah by increasing the fluoride concentration of the water system from 0.38 ppm to at least 0.75 ppm (but no more than 1.0 ppm).

A Dental Caries-Fluoride Study in Nebraska

A survey was conducted in 1954 by Gillooly, Heinz, and Eastman (25), as a cooperative multidisciplinary endeavor engaged in by the Nebraska State Department of Health, Dental Committeemen of the Nebraska State Dental Association, school and health authorities, and the Public Health Service Regional Office staff. The study was developed on the basis of a threefold purpose:

1. To determine the prevailing need—the amount of dental caries existing in the mouths of a selected group of Nebraska children at the time of the examination.

2. To determine if there is an inverse relationship between fluoride content of drinking water and dental caries.

3. To determine the optimum fluoride concentration for use in cities of this state if a positive relationship between fluoride and dental caries is established.

The study group consisted of 1,163 continuously resident white children aged 7, 10, and 13. They had a verified continuity of residence from birth and continuous use of the public water supply as drinking water. Twenty-three cities were selected for the survey and the fluoride concentrations of their water supplies between 1939 and 1954 varied from 0.1 to 1.5 ppm. Nine low-fluoride cities averaged 0.2 ppm; Omaha, a medium-fluoride city, averaged 0.5 ppm; and 13 high-fluoride cities averaged 1.1 ppm fluoride. In the low-fluoride cities 523 children averaged 3.65 DMF; in Omaha, 385 children had a 2.80 DMF average;
while 304 children in the high-fluoride cities had a DMF average of 1.41. The authors concluded:

In view of the low DMF experience and the absence of fluorosis in the children living in the study cities having 1.0 to 1.3 ppm fluoride-bearing water supplies, it was determined that a range of 1.0 to 1.3 ppm should be maintained for all cities in Nebraska. . . . No evidence of dental fluorosis was observed in the low or medium fluoride groups of cities. Children of the sample group living in high fluoride cities with an average fluoride content of 1.4 ppm and above exhibited very mild dental fluorosis. Only in the city of Benkelman, Neb., whose water supply contained an average of 1.6 ppm fluoride, was mottling of the enamel of three children noticeable to others than the dental profession. These three children, however, did not consider their teeth as being anything but pretty even though there was a slight spotty white discoloration to the enamel. Except in these three cases there was no aesthetic significance of this degree of fluorosis.

Dental Caries and Natural Fluoride Waters—Surveys in Many Areas Throughout the World

Numerous surveys of the prevalence of dental caries in many areas outside the United States have produced consistent evidence of the cariostatic effect of fluoride when ingested in elevated quantities in drinking waters. As might be expected, the magnitude of this cariostatic effect has varied among these surveys. Although assurance that fluoride was the one and only caries-preventive factor involved, or that the drinking water was the only source of fluoride, may have been uncertain in some surveys, there was nonetheless a universal consensus that fluoride is remarkably cariostatic. There were understandable variations in the uniformity of methods of diagnosing and measuring caries which may account for variations in the magnitude of the caries-preventive effect of fluoride. The limited résumé herewith will mention relatively few of these worldwide surveys which concern specifically fluoride's relation to dental caries.

In Great Britain in 1944, Dr. Robert Weaver (26) reported a 45 percent smaller incidence in dental caries in children aged 12 living in South Shields than in children living in North Shields. The drinking water of South Shields contained approximately 1.4 ppm fluoride; that of North Shields, 0.25 ppm. At the time of this survey, Weaver was aware of the previous evidence obtained by Dean and others in the United States, as well as earlier studies in England by Dagmar Wilson, Margaret M. Murray, and others, which had related dental fluorosis or fluoride in drinking water to a reduction in dental caries. Nonetheless, Weaver, with utmost caution, wrote: “For the present it would perhaps be well to refer to the inhibiting factor operating in South Shields as F without committing oneself to a definite statement that F is to be regarded in this case as the chemical symbol for fluorine. It can be taken to represent the inhibiting 'factor' which is probably fluorine.” Later he was to express concern and report some observations as to what age
in life the caries-preventive effect of the “fluoride factor” would continue to prevent the development of caries.

In 1949 Omero Tempestini (27) published results of studies in Italy: “Research on the frequency and activity of dental caries was carried out on a total of 2,261 children 6 to 10 and 11 to 15 years of age in zones of fluorosis (Latina Nuova and Castel di Indica), where water contained 1.0 ppm fluoride, and in zones poor in fluoride, for example, Catania with water containing 0.15 ppm. The investigations have confirmed in the endemic zones of fluorosis a reduction equal to 50-60 percent in the frequency of caries in comparison with zones with waters low in fluoride. . . .”

F. D. Barnard (28) the author of an extensive survey of 6,787 children in New South Wales, Australia, reported

... caries experience of children who had lived in Warren continuously since birth and had used only water containing 0.9 ppm fluoride. These children showed considerably less dental caries than the other groups. Only one child was observed to have what appeared to be mild dental fluorosis. The prevalence of hypoplastic and hypocalcified teeth was found to be slightly higher than the average for the state but was not as high as the prevalence in some fluoride-free areas. Some of the opacities were possibly a very mild form of dental fluorosis but the concentration of fluoride was below the generally accepted threshold value for dental fluorosis.

A recent survey of the prevalence of dental caries and its relationship to natural fluoride in drinking water was conducted in Denmark. Mentioned previously in the discussion on mottled enamel (Fig. 7), caries and mottled enamel data were obtained by Ingolf J. Møller (29); the same children were included in the dental caries and the

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<th>DISTRICT</th>
<th>FLUORINE CONTENT IN WATER (PPM)</th>
<th>NUMBER OF CHILDREN EXAMINED</th>
<th>PERCENTAGE DISTRIBUTION OF SAMPLE ACCORDING TO SEVERITY OF AFFECTION</th>
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Fig. 7.—Distribution of severity of dental fluorosis in continuously resident children.
mottled enamel diagnoses. The fluoride content of the drinking waters varied from 0.05 to 3.4 ppm. The groups of children were aged 12 to 13 years, divided into continuously resident boys, continuously resident girls, non-continuously resident boys, and non-continuously resident girls.

The discussion and conclusions were stated in part by Møller:

The lower caries prevalence in fluoride areas, reported in numerous other countries, was found to exist in Denmark too. Thus the caries prevalence in children born and raised in areas with 1.2 ppm F⁻ (Naestved H.) or more (1.6 ppm F⁻ in Praestø, 1.8 ppm F⁻ in Naestved N., 1.9 ppm F⁻ in Strøby and Egede, and 3.4 ppm F⁻ in Tapperøje and Strøby By), in the drinking water is two to three times less than that in children living in areas with a low fluoride content in the drinking water (0.05 ppm F⁻ in Vejen, 0.2 ppm F⁻ in Aalestrup, 0.25 ppm F⁻ in St. Heddinge, and 0.34 ppm F⁻ in Slagelse).

In the fluoride areas the caries prevalence is not substantially lowered if the fluoride ion concentration in the drinking water rises from 1.2 ppm F⁻ (Naestved H.) to 3.4 ppm F⁻ (Tapperøje and Strøby By).

Seven to twelve times as many decayed, missing, or filled upper incisors are found in the low-fluoride areas as in the fluoride areas. The difference is even greater for the lower jaw: almost no lower incisors are decayed, missing, or filled in the fluoride areas, while in low-fluoride areas as many as 13 percent of these teeth are decayed, missing, or filled. The difference becomes even more striking when the proximal surfaces of the incisors are compared. As few as 5 percent of mesial or distal surfaces are decayed, missing, or filled in the fluoride areas, and up to 49 percent in the low-fluoride areas.

A comparison between the results of caries surveys in the U.S.A., Sweden, and Denmark shows that only half as high caries prevalence is observed in areas with 1 ppm F⁻ or more in the drinking water as in low-fluoride areas. This (>50) percent reduction is obtained regardless of differences in the caries levels of the three countries. The slight difference between the caries levels in Sweden and Denmark may be attributed wholly or partially to differences in caries diagnosing, while the big difference between the caries levels in Denmark/Sweden and the U.S.A. probably is a real one. (See Fig. 8)

Witkop, Barros, and Hamilton (30) studied the status of dental caries in Chile in 1960. The surveys included 1,906 Chileans (1,000 civilians and 906 military personnel, geographically distributed throughout Chile). Individuals residing in northern Chile had the least caries and some mild fluorosis. The mean number of DMF teeth of children of 12 to 14 years in the northern regions was 1.81, whereas in the central and southern regions the mean DMF was 4.43. There was no dental fluorosis evident in this latter group but the authors reported a fluorosis index of 0.58 for children examined in the northern region. They found that drinking waters of northern Chile contained only 0.4 to 0.6 ppm fluoride; this much fluoride had produced dental effects similar to the effects of 1.0 to 1.2 ppm fluoride in communities of the northern United States. The authors postulated that "this amount of fluoride is sufficient under conditions prevailing in northern Chile to account for the biological effects seen because of higher ingestion of water per day per child, as compared with the northern United States." It was sug-
Fig. 8.—Caries experience of children in Denmark and Sweden, aged 12 and 13, and in the United States, aged 12 to 14, in relation to fluoride content of public water supplies. (From Møller. 1965)

Suggested by the authors that a higher average temperature and low milk consumption would increase water intake (and thus total fluoride) of Chilean children above that of children living in the northern United States.
NOTES AND REFERENCES

With few exceptions, detailed accounts of the early history of the relationship of fluoride to dental caries mention first an 1874 publication by Erhardt (Kali Fluoratum fur Erhaltung der Zahne Memorabiliew [Mouatschette fur Rationelle Aerzte] Heilbronn, 19:959). As cited by Dean, Erhardt assumed that fluorine gave hardness and lasting quality to enamel and could therefore protect against caries. On this assumption he recommended potassium fluoride pastilles for children during dentition and for women during gestation. Sir James Crichton-Browne is usually mentioned because of his speculation in 1892 that a marked increase in caries in England might be due in part to a dietary fluoride deficiency. Similarly in 1897 in Germany, Michel proposed that fluorine in the teeth could be bactericidal and anti-enzymatic and thus increase resistance to caries. In following years other speculative assertions appeared in the literature, but it seems evident that such speculation lacked substantial clinical and scientific evidence. In 1805, Gay Lussac and Bethollet had found fluorine present in enamel of normal teeth and thus there arose at that early date many questions which remain unanswered to this day regarding a physiological role, the chemistry, and the essentiality of fluorine present in enamel and dentin.

A major objective of studies conducted in Galesburg, Monmouth, Quincy, and Macomb, and in the eight suburban Chicago cities by Dean, Arnold, and their associates, was a quantitative evaluation of *L. acidophilus* in saliva specimens obtained from representative numbers of children. Major interest in the oral lactobacilli originated from research at the University of Michigan and this bacteriology problem was influenced largely by studies of Dr. Philip Jay and his associates. Their research had indicated that the lactobacillus organism was associated with the presence of dental caries. Jay and Arnold were particularly interested in quantitation of the oral lactobacillus count of saliva with the dental caries experience. Thus in the Galesburg-Quincy study an estimation was made of *L. acidophilus* in saliva of 188 children in Galesburg and 209 children in Quincy. "The group population difference in the oral lactobacilli closely reflected the differences in the amount of dental caries, i.e., the percentage of bacteriological counts of 30,000 or over was 3.4 times higher in Quincy than in Galesburg. The results of similar bacteriological studies in the Chicago suburban cities also indicated differences in the percentage incidence and dental caries experience rates, proximal caries rates, and the counts of *L. acidophilus* present in the saliva, similar to what had been observed in the Quincy vs. Galesburg, Ill., data."


(8) Dean, H. T., Jay, P., Arnold, F. A., Jr., and Elvove, E., 1941. Domestic water and dental caries. II. A study of 2,832 white children aged 12-14 years, of eight
suburban Chicago communities, including *L. acidophilus* studies of 1,761 children. Public Health Rept. (U.S.), 56:761.


(18) **Klein, H.,** 1946. Dental caries (DMF) experience in relocated children exposed to water containing fluorine. II. J. Am. Dental Assoc., 33:1136.


CHAPTER NINE

FLUORIDATION TRIALS—UNITED STATES

The significant cariostatic effect of an optimum quantity of fluoride naturally present in drinking water led to the proposal by Dr. Arnold in 1953 that fluoride be added to public water supplies for the purpose of partially controlling dental caries (1). Arnold called attention to the fact that 1.00 ppm fluoride in water is a trace quantity, so small that the mildest types of dental fluorosis which might occur would be sporadic and inconsequential and there was no likelihood of other toxic effects. As Dr. Dean would have expressed it, this was the considered judgment of one who had “beat the bushes and followed the rails and trails” of epidemiology in pursuit of mottled enamel, dental caries, and fluoride in drinking water.

As noted in the previous chapters, practically all the reports of epidemiological studies demonstrating the dental health benefits of fluoride naturally present in drinking water had mentioned that dental caries might be partially controlled by the direct addition of fluoride to drinking water. In 1939 Dr. Gerald J. Cox and his associates at the Mellon Institute evaluated the epidemiological evidence and viewed with amazement the teeth of their experimental rats whose diet contained supplemental fluoride. Cox suggested that adjustment of fluoride in drinking water might become an attractive means of mass reduction in dental caries (2). In June, 1943, Dr. David Ast (3) published a plan to test the value of directly fluoridated water—a plan consummated by the Newburgh-Kingston fluoridation study.

These proposals were not surprising. It was logical to anticipate controlled fluoridation of public drinking water and it was agreed that information on the status of fluoride as a direct additive to public drinking water was needed. Population studies to obtain this information were to begin soon. In an address to the people of Grand Rapids whose officials ten years before had approved a fluoridation study project proposed by the University of Michigan, the Michigan State Health Department, and the U.S. Public Health Service, Dr. John W. Knutson had stated, “Let no one think that any one of us would seriously consider exposing the population of a city of 165,000 (Grand Rapids’ popu-
lation in 1944) to a possible hazard of unknown risk” (4). This position was voiced at the Grand Rapids Meeting of the Michigan State Medical Society in September, 1953, at which time Knutson was the Chief Dental Officer of the U.S. Public Health Service.

It was the consensus of health authorities that information on dental and other physiological effects of natural fluoride-bearing drinking waters would not deter the initiation of full-scale population studies of 1.0 ppm of controlled waterborne fluoride. The initial fluoridation studies were approved on the basis of substantial knowledge and sound judgment of public health officials, as well as by authorities of medical and dental professions. Fluoride was recognized to be only one of many trace elements unavoidable in human nutrition, an element occurring normally in trace quantities in plants and foods and present in tissues and organs of man and animals. As a trace component of many variable diets, fluoride was compatible with normal health and well-being. For many years hundreds of thousands of individuals in many areas throughout the world had consumed drinking waters which contained up to 1.0 ppm of fluoride. Indeed, for generations many populations scattered throughout the world have used drinking waters containing fluoride in quantities greater than 1.0 ppm. These people have experienced no health problems other than dental fluorosis. The occurrence of endemic dental fluorosis is not prohibitive when 1.0 ppm or less fluoride is present in drinking water. Much significant biological information on fluoride had accumulated before water fluoridation.

There is no precedent in the annals of human nutrition and public health for providing a permissible quantity of a beneficial dietary nutrient in communal drinking water. The initial fluoridation studies signaled a “new order” in the public control of a widespread disease. As Knutson said, “The whole world owes a debt of gratitude to a large community such as Grand Rapids which was willing to be the first to take on the ‘new order’ that some of the old might be laid aside.”

Between 1944 and 1947 fluoridation studies were begun in Grand Rapids, Mich.; Newburgh, N.Y.; Brantford, Ontario; Sheboygan, Wis.; Evanston, Ill.; Midland, Mich.; Lewiston, Idaho; and Marshall, Texas. The studies in Grand Rapids, Newburgh, Brantford, and Evanston will be discussed in detail, because these communities were the first to have their drinking water adjusted to the permissible optimum level of 1.00 ppm fluoride. The basic objectives of the studies were: (1) to secure evidence of a significant reduction in caries by artificially controlled fluoridation of drinking water, (2) to demonstrate the technical as well as the financial feasibility of the procedure, and (3) to continue observations on the development of dental fluorosis as well as non-dental physiological effects possibly concomitant with the addition of this trace quantity of fluoride to various types of drinking waters.

In all the fluoridation trials the results were consistent and showed beyond doubt that fluoride added directly to drinking water inhibits dental caries. Its continuous use during formative tooth life reduces
dental caries to a remarkable extent. This is, therefore, a beneficial physiological effect of fluoride which merits unquestionable authority and acceptance.
GRAND RAPIDS

"GRAND RAPIDS CITY COMMISSION VOTED TO APPROVE FLUORINE STUDY." This telegram sent to H. Trendley Dean of the National Institute of Health from Dr. William Dekleine, Commissioner of the Michigan Department of Health, on August 2, 1944, was the result of a series of letters and discussions on the subject. The first was a letter addressed to Dr. Francis A. Arnold, Jr., using his nickname:

Lansing, Michigan
January 21, 1943

Dear Pokey,

What are the chances at the present time for adding commercial sodium fluoride to the municipal water supplies? We have met with the city managers, water works people, dentists and health departments, and they are all lathered up to start . . . . Is there any information we can get from you, or would it be possible for our Department and the University of Michigan to proceed on such a project?

(signed) Ray
C. R. Taylor, D.D.S.
Bureau of Public Health Dentistry

Arnold replied:

I received your letters of the 21st and 22nd, together with Mr. Faust's report on Bay City, Muskegon, and Grand Rapids. Thanks a lot for all this information because, as you know, we are vitally interested in the problem.

According to Mr. Faust's report it would appear that Muskegon may be the best place to attempt such a study. The size of the city and the type of equipment seem nearly ideal.

Another point to consider is the political setup at Muskegon. Do you think there is much of a chance that a study of this type would become a political football? Should this occur it may easily happen that the study would be terminated long before any results could be observed.

How would the officials and all others concerned at Grand Rapids react to being the "control community" in such a study? Also, how do these cities compare relative to their experience, so far, in dental health programs?

On July 17, 1944, Dean wrote to Dr. William R. Davis, of the Bureau of Public Health Dentistry of the Michigan Department of Health. The letter was forwarded through W. H. Sebrell, Chief of the Division of Physiology, and R. E. Dyer, Director of the National Institute of Health.

We recently completed preliminary discussions respecting the question of low fluorination and the study of the effects thereof, both dental and non-dental. Should it still be the desire of the Michigan Department of Health to test this hypothesis in a study of a Michigan city and a control, I feel that we are in a position to furnish much of the necessary professional personnel incidental to the study. For some of the later house-to-house checking it may be necessary to call upon the Department for some assistance. We will not be able to pay for the sodium fluoride and the feed equipment. You would probably have little difficulty in obtaining this from a foundation, for inst-
ance the Kellogg Foundation. As a matter of fact, funds from a foundation would assure continuity of treatment through the period of test, something that an official agency cannot be sure of with appropriations being made on an annual basis.

I still think Grand Rapids would probably be the most desirable place for the fluorination, Muskegon being kept for a control. Before reaching a final decision, I do think we should assure ourselves that Grand Rapids actually has a high prevalence rate and check over such other details as would seem essential before reaching a final decision respecting its selection as a study city. We have roughly figured that it will take four dentists and four dental hygienists to make the annual examinations. Other personnel will be gone into later. Let me know what you think of actually getting started on this proposition.

Dr. Philip Jay of the University of Michigan Dental School provided first hand information regarding the meeting of July 31, 1944, that brought forth Dekleine's telegram. The following is from a letter of May 3, 1967:

Mayor Welch and the City Commissioners listened to statements by Trendley Dean, William R. Davis, who was then Director of the Dental Division of the Michigan Department of Health, Dr. C. Ray Taylor, Dr. Russell W. Bunting, Dean of the Dental School, Dr. Philip Jay, Professor of Dentistry of the Dental School, and perhaps a few others. The Mayor wanted to know whether there was any concern on the part of the dental profession that fluoridation would affect their incomes adversely. Dr. Russell Klimes-teker, President of the local Dental Society, responded with the best example of professional ethics which I have ever heard. I wish that it had been a written statement. He assured the Mayor that the dental profession's concern was the treatment and prevention of dental disease and it was very anxious to reduce the impact of dental caries in any way that was possible. At this meeting I suggested that we make every effort to enlist the interest of the Public Health Service, particularly Dr. Dean.

Dean wrote shortly after the start of fluoridation in Grand Rapids that the first efforts “in respect to applying epidemiological findings to control measures were in October, 1942, when Dr. Pelton and myself conferred with Mr. H. W. Streeter, Engineering Officer in Charge, USPHS, Cincinnati, Ohio.” They were assured that no engineering difficulties would be encountered in the process of controlled fluoridation. Dean went on:

Because of our extensive experience with the study of the water of the Lake Michigan area (Waukegan, Evanston, Oak Park, Escanaba, Michigan City), it was decided, if possible, to select two cities obtaining their public water supply from this source. Lake Michigan is about 250 miles long and 100 miles wide, and the chemical composition of this lake is relatively constant.

Methods, Procedures, and Material for the Study

In 1944 the water requirement of Grand Rapids was a little more than 200,000 gallons daily. The water came from Lake Michigan and was treated first in a filtration plant at the lake shore. It analyzed 0.05 ppm fluoride. At that time sodium fluoride was the preferable source of
fluoride for fluoridation and a little over 400 lbs. of sodium fluoride of 90 percent purity would be needed daily or an estimated 155,000 to 157,000 lbs. for one year. The June 2, 1944, cost of sodium fluoride of 90 percent purity, in barrels and carload lots with the freight allowed, was $0.07 per pound. The annual cost for chemicals would approximate $11,000. Two gravimetric feeders would be needed, with accuracy within 1 percent, a feeding range of 1 to 100 lbs. per hour, and a hopper capacity of 11 cu. ft. Cost of this original equipment in 1944 was $3,100 (at today's prices $8,000). A first 5-year total cost of fluoridating thus was estimated at $57,760. Since October, 1958, sodium silicofluoride, which is about a third the cost of sodium fluoride, has been used and the current yearly cost of fluoridation in Grand Rapids per capita is approximately $0.07.

The Public Health Service assumed responsibility for all professional personnel and provided funds to cover costs of the equipment and sodium fluoride during the test. Incidental expenses incurred at the water filtration plant were borne by the city. Addition of sodium fluoride at the plant was supervised by W. L. Harris, Chief Chemist of the city. Harris was responsible for fluoride analysis of the water and maintenance of the desired fluoride content. On January 30, 1945, he wrote Arnold and Jay, "Sodium fluoride application to the local water supply started 4:00 p.m., Thursday, January 25. A total of 107 barrels, each holding 375 lbs. of fluoride was received in car PRR 35981 [only a meticulous analytical chemist would mention this detail] on the morning of the above date."

In May, 1946, F. J. Maier of the Public Health Service visited Grand Rapids and described the fluoridation procedure in a memorandum to John W. Knutson:

After reaching the plant, the water is chlorinated, dosed with alum, mixed in two basins (1.273 mg), settled in four basins (5.052 mg), dechlorinated (sodium bisulphite), fluorinated and filtered. Activated carbon is occasionally added for taste and odor control. The alum dosage is determined from the chlorine demand of the water. This has been previously computed and has been found to vary only seasonally or with sudden temperature changes.

Serious overdosages are prevented in that the solution tank on this feeder can dissolve a maximum of 120 lbs. an hour. Since the hopper holds 500 lbs. it would require about 4½ hours to empty the machine. At the present pumping rate, this would represent a dosage of 7.0 ppm. The accuracy of this machine is such that in one day, a maximum variation of two lbs. of sodium fluoride feed has been experienced.

Any deleterious effects of inhaling sodium fluoride dust by the plant personnel are minimized by a complete exhaust and dust collecting system, by the use of masks when dumping barrels of sodium fluoride into the hoppers, and by a submerged shield in the solution box.

The Dental Caries Results

Dental data of the Grand Rapids study were published first in 1950
by Dean, Arnold, Jay, and Knutson (5). The Grand Rapids and Muskegon children provided base-line caries data and caries rates were obtained in Aurora, Ill., where the drinking water first analyzed in 1939 contained natural fluoride at a level of 1.2 ppm. Aurora, it may be recalled, was one of eight suburban Chicago cities subjected to a dental caries study previously discussed. Although the first direct fluoride analysis of Aurora drinking water was made in 1939, at a much earlier date the Aurora public water supply contained more than normal quantities of fluoride.

The base-line caries data for this study were obtained in 1944–1945 by detailed dental examinations of virtually the entire school population of Grand Rapids, Muskegon, and Aurora: 28,614 examinations in Grand Rapids, 7,786 in Muskegon, and 8,312 in Aurora, Ill. The age of the subjects ranged from 4 to 16 years. Examinations of sample age groups of children in Grand Rapids continued yearly for the duration of the study. Muskegon remained a non-fluoridated control city until July, 1951, at which time city officials decided to fluoridate the water because of the significant decrease in caries in Grand Rapids. However, dental examinations were continued in Muskegon for three more years. At the end of this three-year period there was a substantial decrease of caries in Muskegon children aged 8 years or younger.
The 1949 data in the first Grand Rapids report pertain principally to individuals aged 5, 6, 9, 13, and 16 years. Comparisons were related to dental caries in deciduous and permanent teeth of subjects aged 5 through 16, all continuous residents during the first five years of water fluoridation. The results indicated a definite reduction in caries in permanent teeth had occurred during this five-year period, most pronounced in the younger age groups whose dentition was largely calcified following addition of fluoride to the water. This decrease applied both to permanent and deciduous teeth, but more time would be required to evaluate the effect of fluoridation in older age groups.

A seventh-year report was published in 1953 by Arnold, Dean, and Knutson (6). The 1951 data of this report presented the Grand Rapids caries picture after 6½ years of fluoridated water. The summary follows:

1. There has been a reduction in dental caries rates in permanent teeth of Grand Rapids children ranging from 66.6 percent in 6-year-old children to 18.1 percent in the 16-year age group. Similar results have been obtained regarding the deciduous teeth.

2. Similar reductions have not been observed in Muskegon where the water supply remained "fluoride-free" (0.2 ppm F) until the last 3 months of this study period.

3. This change in dental caries rates at Grand Rapids was also reflected in observations based on objective assessment, that is, a reduction in the number of missing teeth.

4. A comparison of the 1951 caries rates in Grand Rapids with those of Aurora, Ill., shows that insofar as can be determined to date the use of a fluoridated water gives the same beneficial effects as does the use of a natural fluoride water of similar concentration.

The authors also observed:

From an epidemiological standpoint the results of this study, together with those of other comparable studies, permit the conclusion that adjusting the fluoride content of public water supplies will result in a reduction of the incidence of dental caries in school children.

The next publication of Grand Rapids results appeared in the 1956 Public Health Reports. Presented by Arnold, Dean, Jay, and Knutson (7), the report documented results after 10 years of water fluoridation. Data for def (deciduous teeth) and DMF (permanent teeth) for each year 1945 through 1954, and basic examination data for def teeth are shown graphically in Figure 1. After ten years, 1.0 ppm fluoride added to drinking water had produced the following effects:

1. A striking reduction in the prevalence of dental caries in the deciduous teeth. At the peak of prevalence, namely 6 years of age, the caries rate for the deciduous teeth was reduced by about 54 percent.

2. A marked reduction in the prevalence of dental caries in the permanent teeth. In children born since fluoridation was put into effect, the caries rate for the permanent teeth was reduced on the average by about 60 percent.
3. Some benefit among persons whose teeth have already formed or erupted when fluoridation is begun.

4. No undesirable cosmetic effect from dental fluorosis.

![Graph](image)

**Fig. 1.—Grand Rapids, Mich.: Def teeth before and after ten years of fluoridation.**

Arnold published in 1957 (8) results pertaining to the 11th year of Grand Rapids fluoridation. These observations, together with the results of other similar studies, confirmed the dental health value and the practical feasibility of water fluoridation. Arnold wrote, “In all the studies the findings show a reduction of 60-65 percent in the prevalence of caries in the permanent teeth of children born subsequent to the change in water supply.” In addition the evidence strongly suggested that there were beneficial effects on teeth which were formed or erupted prior to the initiation of water fluoridation, a finding which agreed with results reported by Deatherage and by Klein relative to post-eruptive benefits of fluoride naturally present in drinking water.

The final report of the Grand Rapids study was published in 1962 by Arnold, Likins, Russell, and Scott (9). It delineates the results of examinations made during the 11th through the 15th year of fluoridation and the data pertain to children of junior high school age. Dental caries prevalence in permanent teeth of continuously resident Grand Rapids children aged 12 through 16 in 1959, following 15 years of fluoridation, are reported. Similar data for individuals of the same age living in Aurora, Ill., in 1945-1946 are recorded. These results are presented graphically in Figure 2. After 15 years of water fluoridation in Grand
Rapids, dental caries had been reduced by 50 to 63 percent in children aged 12-14 years and by 48 to 50 percent in children aged 15 or 16 years. Arnold, et al. observed:

No such dramatic and persistent inhibition of caries in large population groups had ever been demonstrated by any other means than fluoridation of a domestic water supply. While there were marked decreases in caries attack rates of European children during World War II, these were associated with restriction of sugar.
Roentgenographic Evaluation

The dental caries experience in practically all the epidemiological and clinical studies previously described was determined by direct clinical examination. While direct observation is more convenient, bite-wing radiography is more exact for early detection of incipient carious lesions, particularly in the approximal surfaces. X-ray diagnosis together with direct observations consistently give a higher value of caries prevalence. Some observers, including Blayney and Ast who directed the Evanston and Newburgh fluoridation trails respectively, regard an X-ray examination as a very important, if not an essential, criterion for evaluating the efficacy of any caries control measure. In consideration of this consensus Grand Rapids investigators determined whether or not supplementing direct observations with roentgenographic examinations would affect the conclusions based on direct observations alone. "In 1946, 1947, and 1953 (approximately 21, 33, and 105 months after fluoridation was begun) the annual dental examinations of children in the first, fourth, and eighth grades of four selected schools were supplemented by bite-wing X-rays." This study was reported by Hayes, McCauley, and Arnold (10) and additional data were obtained on 736 continuously resident children of Grand Rapids.

Both methods of estimating the effect of fluoridated water and the combination of the two had all demonstrated a significant decrease in total caries experience between 1946-1947 and 1953. The decrease appeared to be greater for deeper lesions than for shallow lesions. "The decrease in the deeper lesions without a balancing increase in the shallow lesions suggests that fluoride retards the development of caries and that it also prevents the inception of caries. Subsequent observation may provide more evidence that some benefit of fluoride waters may be realized even if exposure begins later in life and a lifetime benefit may be realized by continued use of fluoridated water."

Validity of the Dental Examinations

The 15-year report of the Grand Rapids study states:

The statistical validity of the reported difference and the possible effects of examiner variation on the conclusions that have been reached have been given special attention. Three dental officers participated in the 1959 examinations. The same qualitative and very nearly the same quantitative conclusions are supported by the findings for the whole team. Each set of figures for each examiner is statistically different from the 1944-45 means for each age group and by astronomical odds. In the smallest individual sample of only 32 12-year-olds, the odds are about 2,500,000 to one that the difference is not due to chance. In this large sample study, with the difference so great, it has been deemed redundant to list statistical probabilities. Standard errors for means in the data previously published, however, can be readily computed by Grainger's Q with negligible departures from the actual values.
During the entire course of the study all criteria of the caries diagnosis were designed to assure the highest practicable degree of comparison among examiners. All examinations were carried out by dental officers of the National Institute of Dental Research, but among them David Scott was the only one to participate in each of the 15 examinations. There was understandable reliance and attention directed, therefore, on the examination procedures as conducted by Scott, who reported, "What we normally did was observe each other in the beginning, working together, and then after a period we worked each at a separate chair with a separate recorder, both examining the same group of about 100 children. A subject passed from one examiner to another and the second recorder wrote the information on the same form with a different color pencil." Minor discrepancies between the examiners were disregarded but where major differences were apparent the two examiners conferred at an additional diagnosis and examination of the subject. Thus there was a continuing endeavor each year to assure consistency in the caries diagnoses.

Dental Fluorosis

An evaluation of dental fluorosis in Grand Rapids became an essential part of the protocols. Thus in the report of results at the end of the 11th year of the study Arnold pointed out that the dental fluorosis index of a community as defined by Dean is based on an examination of erupted permanent teeth exposed to fluoridated water during growth and development. A standard fluorosis index in Grand Rapids could be obtained only after permanent teeth had erupted. However, after 11 years it was apparent that the degree of fluorosis in Grand Rapids could in no respect be a deterrent to the use of fluoridated water.

In the fifteenth-year final report of the Grand Rapids study the status of dental fluorosis in Grand Rapids was again reported. The data are similar to those after 11 years.

Dental fluorosis was recorded and classified according to Dean's criteria. The findings were very similar to those reported for younger children after 11 years of fluoridation. Four of 1,031 continuous-resident children exhibited mild fluorosis; none of these cases was obvious enough to impair appearance. About 10 percent of the total group showed the nearly imperceptible signs associated with questionable or very mild fluorosis. About the same total percentage of enamel opacities of all types was observed in the 1,112 children not included in the study group because they had been born in another city or had lived in some other place than Grand Rapids for an extended period. About half of these opacities were classified as questionable or very mild fluorosis with three children (0.3 percent) classified in the mild category.

Mottled enamel after 17 years of fluoridation was recorded by Russell (11):

In 1961, the seventeenth year of fluoridation in Grand Rapids, Mich., 822 students in the seventh, eighth and ninth grades in Central High School were
surveyed for fluorosis and for idiopathic enamel opacities. The findings indicate that, with 1.0 ppm fluoride in the community water, there is a twofold margin of safety against mottling. Enamel opacities of all types were no more prevalent in these children than in Maryland children who always imbibed water low in fluoride (0.0 to 0.2 ppm).
THE NEWBURGH-KINGSTON FLUORIDATION STUDY

On the eleventh of April, 1946, David B. Ast, Chief of the Dental Bureau, State of New York Department of Health, addressed a letter to H. Trendley Dean:

For your information and in order to keep the record clear, the Newburgh-Kingston caries-fluorine demonstration was initiated on March 20, 1944, when the City of Newburgh went on record approving the treatment of its communal water supply with sodium fluoride. Dental examinations in connection with this demonstration began on May 8, 1944, following the recommendation of the Advisory Committee on the Fluorination of Water Supplies that this department proceed with its plans. The medical examinations were started in November, 1944. Sodium fluoride was added to Newburgh's communal water supply on May 2, 1945, following the completion of basic examinations. Thus far, the date when fluorine was actually introduced into Newburgh's water supply has not been recorded in the literature.

I do not have definite information concerning communities other than Grand Rapids and Brantford, where actual fluorination is under way. However, I am advised that Madison, Wisconsin, is considering this procedure, and Evanston, Illinois, has completed its preparations for basic examinations prior to fluorination. Marshall, Texas, has either begun fluorination or will do so shortly.

In 1944, the year marking the start of the Newburgh-Kingston study, the New York Institute of Clinical Oral Pathology presented a symposium on the subject of fluoride and dental caries. The participants in-
cluded Dean, Ast, McKay, Armstrong, and Bibby, with Arthur H. Merritt as chairman. A brochure of this symposium (12) was published, some 100,000 copies distributed, and the Institute is proud of the fact that it early advocated advances in fluorine research. In the preface Merritt wrote:

For years there has been increasing interest in the relationship of fluorine to dental caries. The possibility of immunizing an entire community against dental caries, by the addition of sodium fluoride to the public water supply, has a dramatic appeal. Professional and lay publications, alike, have given the matter wide publicity. More recently, public attention has been focused on the experiments now in progress at Newburgh, N.Y., at Grand Rapids, Mich., and at Brantford, Ontario. These experiments have greatly increased the interest in the subject.

Because of this widespread interest, and as a public service, the New York Institute of Clinical Oral Pathology is sending copies of this booklet to every dentist in the United States. At the same time, the Institute is making the booklet available to others who may wish to obtain copies. By thus focusing attention on the possible use of sodium fluoride to immunize against dental caries, the Institute hopes that this booklet will prove helpful, not only to those who receive it, but to the public as well. If the booklet achieves this purpose, the Institute will feel amply rewarded for the effort expended.

On December 12, 1955, a second symposium reported the results of water fluoridation in Newburgh (13). Subjects discussed were: history of the project, pediatric implications, fluorine metabolism, and dental aspects of the study.

Before the year of the first symposium, Ast had published a thesis in which he suggested a plan to test the caries hypothesis and outlined details for a practical community study to determine the effect of fluoridating a public water supply (14). Plans for this study moved forward with official approval of the New York State Department of Health.

The Department explored the selection of communities suitable for such a study. Newburgh and Kingston, located about 35 miles apart on the Hudson River, each with a population of about 30,000, and each using a fluoride-deficient water supply, were suggested for the study. The proposal was discussed with the local health officers, physicians, dentists and key lay persons. It then was presented to the City Council of Newburgh, which agreed to participate as the study area and to have its water supply treated with sodium fluoride to bring its fluoride content up to 1.0 ppm. Kingston also agreed to serve as the control area and continue to use its fluoride-deficient supply without change.

Since May, 1945, the Newburgh water supply has continously contained 1.0-1.2 ppm of fluoride.

A special interest in this study was the effects on the growth and development of children and other systemic effects of fluoridated Newburgh drinking water. Comparison with Kingston was made of the prevalence of various specific conditions as disclosed by medical histories, physical examinations, and laboratory and roentgenographic studies.

Initial dental examinations were made on all elementary grade
school children aged 6 to 12 in both public and parochial schools in Newburgh and Kingston, and recorded according to an established classification which provided for caries-free teeth, untreated caries, filled, missing, and unerupted teeth. The age-adjusted DMF rate in the baseline examinations was approximately 20 DMF teeth per hundred in both Newburgh and Kingston. The DMF in first permanent molars was approximately 58 per hundred erupted teeth in each city.

Annual clinical dental examinations were made in Newburgh in each of the years 1944-1945 through 1954-1955 and in Kingston from 1945-1946 through 1954-1955. In addition to the clinical examinations, roentgenograms were included in the examinations for the years 1949-1950, 1953-1954, and 1954-1955. All of the dental examinations in Newburgh and the first series in Kingston were made by the same examiner, Dr. Sidney B. Finn. The subsequent examinations in Kingston, using the same technique, were made by two dental hygienists trained by Finn.

Results of the Newburgh-Kingston study were made available early in the study. In October, 1949, at the 77th Annual Meeting of the American Public Health Association, Ast, Finn, and McCaffery presented results of dental findings after three years of water fluoridation later published in the Journal of the Association (15). They reported that the DMF rate for permanent teeth showed a consistent downward trend in Newburgh from 21.0 to 14.8 per 100 permanent teeth. This indicated a saving of 6.5 permanent teeth per 100 in Kingston at the last examination. "Among first molars, which account for the major part of the caries problem in children, after three years of fluoride experience Newburgh's rate was 48.0 DMF per 100 first molars, while Kingston's was 58.7, or a difference of 10.7 DMF per 100 first molars. This represents a saving of 18 percent in DMF first molars. The greatest benefits are noted in the younger age groups." Ast and associates noted that with Newburgh as the base, Kingston children averaged 8.3 times as many DMF teeth and 2.4 times as many def teeth.

Greatest benefits in younger age groups were again noted in a report published after four years of water fluoridation by Ast, Finn, and Chase (16). An analysis was made of data on dental caries experience of both deciduous and permanent teeth of approximately 3,200 school children 5 to 12 years old in Newburgh and 3,100 children of the same age in Kingston.

Summarizing their data of the end of 4 years of fluoridation in Newburgh, these investigators reported a consistent downward trend in the DMF rates of 6- to 12-year-old Newburgh children, whereas in Kingston no change in the caries experience was observed. The caries reduction in Newburgh was from 20.6 DMF per 100 permanent teeth to 13.9, or a reduction of 32.5 percent.

The caries results after six years of fluoridation are shown in Figure 3 (17).

Among the 10- to 12-year-old children the differences were 52 to 53
percent. The 13- and 14-year-old children showed a 48 percent difference and in the 16-year-old children the difference was 41 percent. As the authors pointed out, children at these older ages had not been exposed to fluoridated water all their lives but had lived in Newburgh continuously following fluoridation. These investigators paid special attention to the first permanent molar, because it is well known that in these age groups this tooth accounts for the major incidence of caries. As these investigators mentioned, because the first permanent molar tooth erupts at about six or seven years of age and because of its morphology, it frequently succumbs to the hazard of caries early in life. Comparing Newburgh and Kingston data they found that the DMF rate in this tooth was reduced by 58 percent in 6- to 9-year-old Newburgh children who had lived their entire lives on fluoridated water. The DMF rate for this tooth in Newburgh children who did not have lifetime exposure to fluoridated water, compared to the non-fluoridated Kingston children, was lower by 30 percent in the 10- to 12-years-olds and lower by 14 percent in the 13- and 14-year-olds. With regard to missing first molars the Kingston children had more than four and a half times the Newburgh missing first-molar rate at ages 10 to 12, about a 70 percent higher rates at ages 13 and 14, and 48 percent higher at age 16.

Tables 1 and 2 show DMF data after ten years of water fluoridation. The investigators made additional comparisons between the two cities. Generally, except at age 16, the rate for filled first molars was the same for both cities. Comparison of the caries status of first and second permanent molars showed that the 13-year-old children in Newburgh had a 15 percent lower DMF rate in second molars than did the Kingston
### Table 1. DMF teeth per 100 erupted permanent teeth in children ages 6-16, based on clinical and roentgenographic examinations, 1954-1955.

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<thead>
<tr>
<th>Age</th>
<th>Newburgh</th>
<th>Kingston</th>
<th>Newburgh</th>
<th>Kingston</th>
<th>Newburgh</th>
<th>Kingston</th>
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<th>Kingston</th>
<th>Newburgh</th>
<th>Kingston</th>
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<td>640</td>
<td>11,139</td>
<td>13,888</td>
<td>15.4</td>
<td>32.2</td>
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<tr>
<td>13-14</td>
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<td>441</td>
<td>7,123</td>
<td>11,989</td>
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<td>43.0</td>
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*Adjusted to permanent tooth population in Kingston 1954-1955 examinations.

### Table 2. DMF teeth per 100 children ages 6-16, based on clinical and roentgenographic examinations, 1954-1955.

<table>
<thead>
<tr>
<th>Age</th>
<th>Newburgh</th>
<th>Kingston</th>
<th>Newburgh</th>
<th>Kingston</th>
<th>Newburgh</th>
<th>Kingston</th>
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*Adjusted to age distribution of children examined in Kingston who had permanent teeth in the 1954-1955 examination.
children. The difference for the 14-year-olds was 14 percent for the first molars and 44 percent for the second molars. The data of this two-year report indicated that "in all age groups there was a significantly lower proportion of differentiable carious proximal surfaces in Newburgh than in Kingston." The researchers noted that the detection and correction of proximal surface caries is much more difficult than is occlusal surface caries. "The data indicate, therefore, that in addition to the quantitative benefit which occurs from ingested water-fluoride, that is, the reduction of DMF rates by about 60 percent, there is also a qualitative benefit in that fluoridation is especially effective in preventing those lesions which are most difficult to detect and to correct." Fluoridation, in other words, affords selective protection for the proximal surfaces of posterior teeth in comparison with occlusal surfaces. The caries data also showed that there were about six times as many children in Newburgh ages 6 to 9 who had all their deciduous cuspids and molars present and free of caries than was noted in Kingston.

The investigators emphasized the consistent decrease in untreated dental caries in Newburgh whereas the untreated caries remained stationary in Kingston. This could not be attributed to any differences in the amount of corrective service in both cities, since they were substantially the same. They raised the hope that this may ultimately lead to a decrease in caries "to a point where the present personnel and facilities may be able to meet the professional requirements."

Dental Fluorosis

A special study of dental fluorosis in Newburgh and Kingston was made by Dr. A. L. Russell, at that time an officer in the Public Health Service with long experience in the detection of the mildest forms of enamel lesions. Russell examined 621 children aged 7 to 14 in Newburgh, of whom 438 had had continuous residence there since the start of fluoridation, and 612 children of the same ages in Kingston. There was no evidence of any disfiguring mottled enamel among the Newburgh children. Forty-six Newburgh children had questionable fluorosis, 26 very mild fluorosis, and six had mild fluorosis. In Kingston 115 children showed non-fluoride enamel opacities, although only 36 did in Newburgh.

Through the courtesy of Dr. Ast, Dr. G. N. Davies of the University of Queensland, Australia, examined the teeth of 70 Kingston and 70 Newburgh children eleven years after water fluoridation. Although the number of children was small, Davies' results agreed with the previous observations of Ast and his associates. The significant difference in dental caries was confirmed as was the mottled enamel experience. Davies made the following comments regarding enamel defects in these two communities:
Enamel defects were much more prevalent at Newburgh than at Kingston, but it is interesting to notice that the defects seen at Newburgh were of no greater significance than the idiopathic enamel defects seen at Kingston. In neither case were the defects unsightly. In fact, enamel defects due to fluorosis and classified as "Questionable" and "Very Mild" were far less obvious than the idiopathic white spots. Obvious fluoride defects were found in only one child living at Newburgh. Only two teeth were involved and the defects were classified as "Mild." Neither defect was any more obvious than an idiopathic white spot. The prevalence of enamel defects was much higher at Newburgh than at Kingston, but the defects caused by fluorosis were of less aesthetic significance than the idiopathic enamel defects which were found more frequently at Kingston.
As a multivarded detailed investigation, the Evanston study is unsurpassed among fluoridation trials.

Drs. J. Roy Blayney, Iden N. Hill, and S. O. Zimmerman of the University of Chicago Zoller Memorial Dental Clinic conducted the study and their findings were published in a special issue of the *Journal of the American Dental Association*, "Fluorine and Dental Caries" (18).

Evanston, the fluoridated study city, and Oak Park, the non-fluoridated control city, were included among the eight suburban Chicago cities surveyed in 1941 by Dean, Arnold, Jay, and Elvove. Both of these communities used fluoride-free water from Lake Michigan. The DMF in permanent teeth per 100 children in 1941 was quite similar in both communities—in Oak Park 722, in Evanston 673.

In 1944 the Health Commissioner of Evanston, Winston H. Tucker, requested the North Suburban Branch of the Chicago Dental Society and the similar branch of the Chicago Medical Society to appoint a committee to study the possibility of fluoridating the Evanston drinking water. Tucker had been aroused by the 1941 report indicating that
there was 2.6 times as much caries in Evanston and Oak Park children as in children in Aurora, Joliet, and Maywood. The committee recom-
mended that such a project be carried out under carefully controlled conditions and agreed to support the study and interpret it to the public. After being approached by Tucker, the Zoller Clinic accepted the responsibility of designing and conducting such a fluoridation pro-
ject. Blayney and Hill stated:

The Illinois State Health Department indicated an interest in the study and offered to cooperate through the Divisions of Public Health Dentistry, San-
tary Engineering, and Bureau of Vital Statistics. The City of Evanston agreed to supply the sodium fluoride, the feeding machine, and personnel to do the necessary work. The study was to be financed by the Zoller Clinic, assisted by the State Health Department and the City of Evanston. In addi-
tion, from June 15, 1948, through December 31, 1964, the National Institute of Dental Research provided substantial yearly research grants to the Zoller Clinic for the support of the project.

The Evanston City Council approved the plan in November, 1945, and the Department of Health and Water was authorized to proceed according-ly. There was no referendum prior to this study because the council members believed the decision involved a public health prob-
lem for which they were responsible, rather than a political question.

The Evanston study began in January, 1946, and fluoride was added to the water in February, 1947. Priority was given to findings concern-
ing caries and the health of all tissues and structures in the oral cavities of children raised under the influence of water fluoridation and records of the children from the control area, Oak Park, are included. The data, 38,713 dental examinations supported by full-mouth radiographs of various conditions observed in the oral cavity of growing children, will continue to be analyzed. School children aged 6 to 8 and 12 to 14 made up the study groups because they were most suited for the assessment of caries in deciduous teeth and initial caries attack rates in the permanent teeth. A voluminous quantity of data accumulated and the investigators realized that manual tabulation or listing of each item evaluated in the survey would be impossible and that computer tabulation would be necessary. It was from these tabulations that Zimmerman determined the degree of significance for the respective items.

Results of the study relate to the effects of 14 years (1946-1960) of use of fluoridated water in Evanston. Two dental examinations for base-
line data were made in Oak Park, in 1947 and again in 1956. No signif-
icant change in the Oak Park data not readily accounted for occurred over this nine-year period. At the start of the Evanston-Oak Park study local environmental and economic factors compared quite favorably in these two communities situated in close proximity to one another. In later years, however, economic advancement in Evanston tended to im-
prove the extent and quality of dental care practiced in Evanston as compared with Oak Park. This does not appear to have been a serious factor in the overall difference in the caries experience resulting from Evanston's fluoridated water as opposed to the non-fluoridated Oak
Park water. Evanston children aged 6, 7, 8, 12, 13, and 14 were examined each year.

The essential findings of this extensive study demonstrated a pronounced reduction in dental caries in Evanston children. The data are classified in three categories: (a) results in 6-, 7-, and 8-year-old group, deciduous teeth, (b) results in permanent teeth in this group, and (c) results in 12-, 13-, and 14-year-old group, permanent teeth (Figs. 4 and 5).

![Bar chart showing DMF rate per 100 permanent teeth exposed to risk of caries: 6-, 7-, and 8-year-old Evanston children, 1946 base line; Oak Park, 1947 and 1956, fluoride-free; and Evanston, 1960, entire life on fluoridated water.](image)

A barely significant reduction in the caries rate of Evanston children was indicated for the group that was 6 years old in 1953, born during the first year of fluoridation. The 6-year-old children examined in 1955, 1958, and 1960, whose mothers used water containing fluoride during the entire period of gestation, experienced a greater reduction in the prevalence of caries. A reduction for the 7- and 8-year-old groups was not evident until 1955 and 1958 respectively. A greater reduction in caries prevalence rates was observed in those children whose mothers drank fluoridated water during pregnancy than was found in children of like age but born during the first year of fluoridation. The annual caries increment rate for Evanston children's deciduous teeth was 47.15 in 1946 and 40.68 in 1960, a reduction of 13.72 percent. Corresponding data for Oak Park children were 52.58 (1947) vs. 50.50 (1956), a drop of 3.95 percent.

The data for caries in permanent teeth in the 6-, 7-, and 8-year-old groups indicated that all three groups experienced a definite reduction in caries prevalence after one year of water fluoridation. It was six to eight years before significant reductions were found in deciduous teeth.
The annual caries increment for permanent teeth per 100 children in this age group was reduced from 101.54 to 43.55 after 14 years of fluoridation in Evanston; this rate had increased from 97.77 to 108.53 in Oak Park between 1947 and 1956.

To evaluate the data for 12-, 13-, and 14-year-old Evanston children's permanent teeth, Blayney and Hill based conclusions on comparisons related to several special facets of the overall caries experience. They compared data on the number of teeth exposed to risk rather than the number of children studied. Like age groups were compared and in every group there was a high percentage of increase in the number of teeth that were completely free from caries attack after lifetime exposure to fluoridated water; a distinct percentage of decrease in the number of teeth either decayed or filled or both; and a corresponding percentage decrease in the number of teeth extracted because of decay. Blayney and Hill compared caries prevalence rates in maxillary and mandibular dentition, and found that the maxillary teeth received the greatest benefit. Mandibular permanent first molars were more susceptible to caries attack than the maxillary molars. In younger children the maxillary molars received the greater protection from fluoridation. In older age groups the difference was slight. Mesial surface caries was studied as a particularly important problem, and for each age group there was an increase in the percentage of mesial surfaces free from caries attack. The data, which included radiographic findings, indicated to
these investigators the importance of radiography for the recognition of incipient carious lesions on the proximal surfaces. As in Grand Rapids, significant decreases in caries were evident by direct observation alone. Blayney and Hill, however, felt the need of a radiographic diagnosis to provide minute details of the proximal surfaces. They stated, "Workers in the field of caries research are not in complete accord regarding the value or need for a radiographic examination. . . . The findings in the Evanston study support the view that in any program designed to test the value or the efficacy of a procedure to reduce the prevalence of a disease, the most exacting steps to recognize the diseased condition in the incipient state must be used."

The Evanston examination data were used to evaluate dental caries experience rates of white and Negro children. Evanston at that time had a stable Negro population of about 10 percent and provided an opportunity to compare the caries prevalence rates of white and Negro children. While dental caries was significantly reduced in both Negro and white boys and girls, the investigators stated that "these data support the conclusion that the Negro children of Evanston are not as susceptible to dental caries attack as the white children of comparable age and that girls tend to experience more caries than boys of a like race."

In addition to caries data Blayney and Hill studied mottled enamel. They found no evidence that the fluoridated water had an undesirable esthetic effect on the appearance of the teeth. They reported findings that supported previous observations of other investigators that "the use of water containing 1.00 ppm of F materially reduces the frequency of idiopathic lesions and tends to promote a more uniform and orderly formation and calcification of the teeth." Blayney and Hill concluded:

Public health may be defined as the science and art that deals with the prevention or control of disease by methods that cannot be employed effectively by the individual. In other words, public health is an organized community health program.

Fluoridation of a community water supply fulfills this definition in all respects. It is the first community-wide effort to reduce the prevalence of tooth decay. It is to the credit of the Evanston City Council that they did not consider water fluoridation as a political issue requiring a popular vote but as a public health measure and therefore their responsibility. The Illinois legislature, a former governor, and the State Supreme Court have held the same opinion.

The extensive reduction in the prevalence of tooth decay resulting directly from water fluoridation is a significant factor in changing the practice of dentistry from purely a reparative procedure to a preventive practice. With each passing year the emphasis on prevention of dental disease is becoming more popular among the profession and the public. The complete elimination of dental caries requires both a community effort and self-discipline for each individual.

The economic value of water fluoridation is considerable. Evanston families with children in the 6- to 8-year-old group have experienced a reduction in dental fees of 35 to 40 percent. Those families with children 12 to 14 years of age have had a reduction of at least 50 percent in dental fees as a result
of fluoridation. Great as the savings in dollars, time loss, and discomfort may be, far greater is the saving in the most precious possession—health.

NOTES AND REFERENCES

Francis A. Arnold, Jr., was born in Orrville, Ohio, in 1910. He studied at the University of Arkansas and Western Reserve University where he received his D.D.S. in 1934. After serving an internship at the U.S. Marine Hospital in Cleveland, Ohio, he was commissioned in 1936 in the Dental Corps of the Public Health Service. The following year he was assigned to the National Institutes of Health and was with the National Institute of Dental Research from its inception in 1948. He was the Institute Director from 1953 to 1966 and then was appointed Chief Dental Officer of the Public Health Service. Dr. Arnold retired in September, 1967, and accepted the position of coordinator of research at the School of Dentistry of the University of the Pacific. Dr. Arnold pioneered in the study of fluoride and its effect on teeth in both experimental animals and human population groups. Together with Dr. Dean he conducted many epidemiological surveys which were a major contribution to the fluoridation of drinking water. Dr. Arnold received many honors in recognition of his accomplishments and promotion of dental research. Among these were the Callahan Award, the Gies Award, and the Columbia University Alumni Research Award. He was the first recipient of the H. Trendley Dean Award and the World Prize in Dental Research of the Massachusetts Dental Society. He was an honorary member of many American and foreign scientific and dental societies. In 1962 he was awarded an honorary Doctor of Science by Western Reserve University. Dr. Arnold's untimely death occurred in San Francisco on December 1, 1967.

Grand Rapids

The account of the Grand Rapids trial, limited as it is, may be enhanced by describing the multivariated administrative details and public relations problems which occurred. Some of these are more than likely inevitable in any study extending over a long period and involving large numbers of people living in one community. The fluoridation studies in Grand Rapids at the time of their initiation had no precedent in the annals of dental or medical research. In many respects the problems were unique because of the nature of the study. Many of the problems are not mentioned in formal scientific reports. Some no doubt arose during the course of fluoridation trails in Newburgh, N.Y.; Brantford, Ontario; Evanston, Ill.; and other places.

Public and parochial school teachers, superintendents, and city officials in Grand Rapids, as well as Michigan State health authorities, became indispensable participants in this study. All the dental examinations were made in school buildings. Residence histories, vital statistics of the children, and parental permission to conduct the examinations had to be obtained with the assistance of school teachers and local health authorities. A suitable place in school buildings had to be provided to carry on the examinations. Schedules had to give way to essential school and classroom activities, vacation periods, teachers' meetings, and other events. Interruptions in the school program had to be reduced to a minimum, wherever and whenever possible. In the first year the entire school population of Grand Rapids was examined. Dental caries data became available after each year of the study.

One facet of the Grand Rapids study required collection of saliva specimens at intermittent periods for bacteriological examination. As the dental caries results accumulated the public as well as some professional individuals became anxious that progress and conclusions be announced. The situation was made more urgent by the fact that the Grand Rapids study was being financed by Federal funds. It was conducted largely by employees of the Federal Government, most of whom were dental
officers of the Public Health Service. The touchy, unyielding problem of suppression of data and withholding of information was bound to arise and the implications could reach high levels in the Federal Government.

This circumstance became an important rallying point later on in the hands of the opponents of fluoridation, particularly in regard to the possibility of a public health hazard in fluoridated water.

Public Health authorities were pressured for statements concerning the study. After four years of fluoridation, Arnold stated that the overall caries rate in Grand Rapids did not differ materially from other cities. In December, 1949, it was announced that the observations made in 1947 and 1948 suggested a trend for a beneficial result in the younger age group (5- to 5-year-olds). This trend had not been observed in the older groups. In 1951 Arnold again stated that it was too early to be conclusive as to what effect the Grand Rapids study would have on the improvement of the dental health of children in the United States. In 1950 G. S. Slemons, the Health Officer of Grand Rapids, had written, "No beneficial effects have been observed so far as caries control is concerned . . . and no adverse physical findings have been reported in any way."

Earlier, in August, 1946, Grand Rapids was visited by a very enthusiastic proponent of water fluoridation who, after looking around the city and visiting the water works plant, was told of the various kinds of information being accumulated. He then stated that much of the information was unnecessary and expressed a disclaimer to the effect that if acceptance of fluoridation was being slowed down by too many details and if the Public Health Service would not give out information, the study would probably end. However, Drs. McCarthy and Edwards, of Wisconsin, and Mr. Walter Pierce, Manager of the Racine Wisconsin Water Department, in a letter dated October 26, 1948, to Dr. Arnold, expressed appreciation for the detailed information which he gave.

Caries prevention by use of a fluoride solution topically applied to tooth surfaces is discussed in a following chapter. Although evidence of an anticaries effect was available before the initiation of fluoridation trials the value of this procedure concomitant with the use of fluoridated water was not known. Even to this day concrete evidence of a significant additive value of topical fluoride treatment in association with fluoridated water remains lacking. Nevertheless this problem arose early in the Grand Rapids-Muskegon study.

On February 4, 1948, Arnold wrote that he did not believe enough topical applications would be made in either Grand Rapids or Muskegon to influence the study. The records would show just how many dentists in each place had obtained topical fluoride solutions, and up to that date the number was negligible. It thus became the consensus of Arnold, Jay, and Wertheimer that it would not be right to withhold topical applications from children in either Grand Rapids or Muskegon. The problem was resolved on the premise that too few children would be affected to alter the results. There is no evidence that topical fluoride treatments influenced the events that occurred in Grand Rapids concerning the benefit of fluoridated water.

A number of dentists of the U.S. Public Health Service participated in the Grand Rapids study. Dr. Edwin Short was among the first to be stationed in Grand Rapids in charge of the study at the start. Other participants were David B. Scott, Robert C. Likins, Robert M. Stephan, Harold Stanley, A. L. Russell, D. E. Singleton, F. S. Loe, H. Berton McCauley, Stanley J. Ruzicka, Norman W. Littleton, Richard L. Hayes, Charles Donnelly, and Carl White. Dr. Fred Wertheimer, Director of the Bureau of Public Health Dentistry, Michigan State Health Department, and Dr. W. B. Prothro of the City-County Health Department of Grand Rapids, were also active participants.

On the occasion of the 20th anniversary of fluoridation in Grand Rapids, the Surgeon General of the U.S. Public Health Service, Dr. Luther L. Terry, sent the following telegram to the Mayor of Grand Rapids:
I extend my congratulations to the fine citizens of Grand Rapids. You have a right to be proud today—your 20th anniversary of fluoridation. As the first city to offer the benefits of community water fluoridation to its children, you have played a major role in contributing to the dental health of our nation. The 65 percent reduction in tooth decay among the people of Grand Rapids has inspired over 2,700 other American communities to follow your lead. You have helped to convince 71 million people in the United States and in the world that fluoridation is a safe, practical, and effective means of preventing dental caries. Grand Rapids' efforts to afford its citizens better dental health represents a major step toward our national goal of improved total health.

The population of Grand Rapids is now (1969) a little over 200,000. A new $6,000,000 water filtration plant which has been built on Lake Michigan assures a daily capacity of 100,000,000 gallons of fluoridated water.

Newburgh-Kingston

An advisory committee composed of authorities in many areas played a very effective role throughout the conduct of the Newburgh-Kingston study. Dr. Ast and his immediate associates expressed their gratitude to this committee:

Their understanding of the numerous problems faced, their expert guidance and technical assistance, and their enthusiasm played a major role in making this new public health practice a reality. Members of the committee were Harold C. Hodge, Ph. D, professor of pharmacology, University of Rochester, Rochester, N.Y., Chairman; Katherine Bain, M.D., assistant to the chief for program development, Department of Health, Education, and Welfare, Washington, D.C.; Henry L. Barnett, M.D., attending pediatrician, The New York Hospital, New York; Basil G. Bibby, Director, Eastman Dental Dispensary, Rochester, N.Y.; John Caffey, M.D., attending roentgenologist, The Babies Hospital, New York; John W. Fertig, Ph. D., professor of biostatistics, Columbia University, New York; William J. Gies, Ph. D., professor of biological chemistry, Columbia University, New York; and Samuel Z. Levine, M.D., pediatrician-in-chief, The New York Hospital, New York.

On the basis of five years of observations in Newburgh and Kingston, a statement of policy for New York State was issued January 2, 1951, by the State Health Department with regard to fluoridation of public water supplies. In view of the significant results it was recommended that all communities in the State which could fluoridate their water under adequate control measures should do so. Specific criteria were prepared which dealt with installation of the dispensing equipment, laboratory tests required to assure a constant accurate application, and responsibilities of the operator of a treatment plant which fluoridate the water.

Evanston

In the foreword in the Special Evanston Issue of the Journal of the American Dental Association, Arnold wrote:

As may be readily recognized, this group of studies produced many preliminary and briefly summarized reports. All of these played an important role in the advancement of fluoridation of water in this country and abroad. None, however, presented detailed data which could be analyzed in the depth that the original study protocol made possible. The report by Blayney and Hill does present such detailed data in regard to the Evanston study. As
stated by the authors: "This being a fact-finding report it is not the wish of
the authors to restate or summarize their findings. The reader can readily
review the data listed in each section of the report."

Here, in a single report, are data on the effect of water fluoridation on den-
tal caries so completely documented that the article is virtually a textbook
for use in further research. It is an important scientific contribution toward
betterment of the dental health of our nation. It is a classic in this field.

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Evanston

(18) BLAYNEY, J. R., and HILL, I. N., 1967. Fluorine and dental caries. J. Am. Dental Assoc., 74:233. The contents of this issue are as follows. There are 35 figures and 66 tables. (Foreword by F. A. Arnold, Jr.):
1. INTRODUCTION: Early history of fluorides; origin, organization, and resolutions; methods.
2. FINDINGS—BY AGE GROUP: Results in 6-, 7-, and 8-year-old group: deciduous teeth; results in 6-, 7-, and 8-year-old group: permanent teeth; results in 12-, 15-, and 14-year-old group: permanent teeth.
3. FINDINGS—BY CLINICAL AND RADIOGRAPHIC EXAMINATIONS: Clinical versus radiographic findings; comparison of benefits of fluoridation for the occlusal surfaces with the proximal surfaces of maxillary and mandibular permanent first molars; caries experience rates in the permanent dentition: maxillary versus mandibular; maxillary versus mandibular permanent first molars; caries experience of mesial surfaces of permanent first molars.
4. FINDINGS—AS RELATED TO PERSONAL FACTORS: Value of fluoride: prenatal and postnatal; caries experience rates of public school children compared with parochial school children; comparison of caries experience rates of white and Negro children; type of infant feeding and caries susceptibility.
5. FINDINGS—AS RELATED TO CONSEQUENCES OF FLUORIDATION: Extent of dental fluorosis associated with the use of water containing 1.0 ppm of the fluoride ion; enamel hypoplastic and hypoplasia—idiopathic and fluorosis—associated with fluoride-free water and water containing 1.0 ppm of F; rate of shedding of deciduous teeth and eruption of permanent teeth in a fluoridated and a non-fluoridated community; frequency of extraction of permanent first molars of Evanston children before and after 14 years of fluoridation; prevalence of malocclusion in an urban population; actual count of carious lesions versus estimate of caries prevalence in a community by use of Knutson's formula; comparison of caries experience of maxillary with mandibular anterior teeth; fluoridation and fractured or chipped incisal edges; ratios of untreated and treated permanent tooth surfaces before and after lifetime exposure to fluoridated water.
6. FINDINGS—AS RELATED TO OTHER STUDY ASPECTS: Caries experience observed in 182 pairs of twins; oral salivary lactobacillus study; congenitally missing teeth; deciduous teeth and future caries experience; chemical laboratory report.
7. CONCLUSION
CHAPTER TEN

FLUORIDATION TRIALS—FOREIGN

BRANTFORD, ONTARIO

BRANTFORD, 75 miles due west of Niagara Falls, was a city of some 35,000 in 1945. The Grand River which flows through the city is the source of its water supply. The late Dr. William L. Hutton was the Medical Health Officer of Brantford and Director of the Brant County Health Unit at that time. An active promoter and participant in the fluoridation study in Brantford, he has been called the father of fluoridation in Canada. He was the first health authority in the world to accept full responsibility for application of this public health procedure.

The Brantford study got under way in August, 1942, when a special meeting of the Board of Health discussed the appalling dental caries among Brantford children and a proposal was made to embark on a fluoride experiment. Cooperation of the Provincial Department of Health was advised in order that a control city might be set up, and all the conditions of valid scientific research observed. Brantford water, it was noted, contained the merest trace of fluoride and could not be listed among those fortunate communities with a natural fluoride content in the public water. An educational campaign brought on a strong public demand for fluoridation and eventually the approval of local dental and medical societies, the two Boards of Education, the Board of Trade, Rotary, Kiwanis, and other service clubs, labor unions, and the City Council. After various negotiations the Public Utilities Commission agreed to apply the fluoride and pay the costs. On June 20, 1945, sodium fluoride was added to Brantford city water, and the fluoride content was thereafter maintained at 1.0 to 1.1 ppm.

The Department of National Health and Welfare soon became interested in the study and was instrumental in setting up two communities to serve as controls: one was Stratford, a short distance northwest of Brantford with a water supply containing 1.0-1.5 ppm fluoride naturally; the other was a non-fluoride community, Sarnia, farther to the west of Brantford and about 75 miles northeast of Detroit. In 1947 the Department of National Health and Welfare appointed H. K. Brown to
direct this part of the study independently of the studies in Brantford.

Twelve annual dental surveys were made in Brantford totaling 56,347 examinations, all made by the same dentist, B. W. Linscott. Two reports of the study were made by Hutton, Linscott, and Williams, one in 1954 (1) and one in 1956 (2). A final report was published in 1965 by Brown and Poplove (3). Results for 1952, which Hutton had forwarded to Dean in 1953 in a personal communication, are shown in Figure 1.

![Graph showing DMF rates in continuously resident children of Brantford, Ontario, before and seven years after fluoridation of community water supply.]

**Fig. 1.**—DMF rates in continuously resident children of Brantford, Ontario, before and seven years after fluoridation of community water supply.

In 1954 Hutton, Linscott, and Williams had presented results showing the average caries reduction to be 39.2 percent (def) and 53.7 percent (DMF), the result of eight years of use of fluoridated water by children aged 5-16 years. Following 15 years of fluoridation, def was reduced an average of 42.1 percent and DMF 53.9 percent.

The first series of dental examinations for the three-city study began in Brantford in January, in Sarnia in March, and in Stratford in October, 1948. During January, February, and March of 1951, examinations were made in Brantford and Sarnia, in October in Stratford.

The 1965 report of this study presents results for native continuously resident 16- and 17-year-old children examined in the three cities. This age group represented children who had used mechanically fluoridated water in Brantford and naturally fluoridated water in Stratford continuously since birth. The Sarnia group had used a non-fluoride water since birth. All the examinations for this final report were done by Dr. Brown, who used a portable light, plane mouth mirrors, and No. 5 Clev-dent explorers. The lowest limit in size for a carious lesion was defined as one in which the point of the explorer would stick and resist direct withdrawal, or in which softness could be felt. Hard, discolored
enamel surfaces and enamel imperfections were not recorded as caries. Although this report presents only DMF for permanent teeth, tooth decay was recorded in the detail necessary for analysis in terms of the number of tooth surfaces affected. Every tooth space was accounted for. The indexes of caries were therefore: (1) percentage of caries-free children, (2) tooth mortality, (3) DMF permanent teeth per child, and (4) caries-free permanent upper incisors. The mean DMF permanent upper incisors per child was 1.23 ± 0.061 in Sarnia, 0.25 ± 0.029 in Brantford, and 0.19 ± 0.034 in Stratford. The data were obtained by examinations of continuously resident children who were at least 14 and not yet 15 years old.

A highly significant difference between Sarnia and Brantford children was apparent, although there was no significant difference between Brantford and Stratford children. Considering permanent upper incisors separately, they found that the DMF rate per child was 1.38 in Sarnia, 0.22 in Brantford, and 0.30 in Stratford (Fig. 2). The author's summary observed:

Fig. 2.—Mean DMF teeth per child in 16- to 17-year-old Sarnia, Brantford, and Stratford children in 1968.
The 1968 findings of the Brantford Fluoridation Study are consistent with those of previous surveys of the native child populations of Sarnia, Brantford, and Stratford. There has been continuing reduction in caries experience in 16- and 17-year-old Brantford children during the 17½ years following the introduction of water fluoridation in Brantford. The Brantford data for these children are compared to similar data from Sarnia (not fluoridated) and from Stratford (naturally fluoridated).

The data indicate that there is no observable difference in caries-reducing effect between a mechanically fluoridated water supply and a naturally fluoridated water supply. This beneficial effect of water fluoridation extends at least until the eighteenth year of life.

No cases of unsightly mottling were observed among the children examined in Brantford and Stratford. The health authorities and the practicing physicians of Brantford and Stratford reported no ill effects attributable to the drinking water.
UNITED KINGDOM

The Medical Research Council of the United Kingdom recommended to the Minister of Health that a small mission should visit the United States to study fluoridation. In mid-February, 1952, personnel of the mission arrived in New York to begin an investigation of every facet of the procedure. Fluoridation trials were then in the seventh year in the United States and Canada. Francis Bacon stated that there are three parts in truth: first, the inquiry which is the wooing of it; second, the knowledge of it which is the presence of it; and third, the belief which is the enjoyment of it. These words embrace the objectives of the talented members of the British mission. Authorities in their separate fields of interest, all were eminently qualified to fulfil their assignments.

In order to accomplish their manifold objectives to the fullest extent,

It was considered necessary to attempt an evaluation of the dental results obtained from the fluoridation of domestic water supplies in the United States and Canada; to consider possible effects of fluoridation upon the general health of the community; to give attention to possible repercussions on industry; to make a detailed study of the technical processes involved in the fluoridation of water supplies; and to study the researches in progress at the National Institute for Dental Research at Bethesda and at certain University centres (4).

The official itinerary of the four individuals was a seemingly unending Cook's tour, including many communities in the United States and Canada using fluoridated water, major dental schools, communities using drinking waters which contained 1.00 ppm or more fluoride naturally (Colorado Springs, Colo.; Bartlett, Texas; Aurora, Ill.), health departments, filtration plants, Government agencies, and the National Institute of Dental Research. Their efforts produced a reliable, unbiased consensus of the status of water fluoridation as it had developed to 1952.

The material of this 100-page report contains much information already presented in our preceding discussion, particularly that relating to the fluoridation studies in Grand Rapids, Newburgh, Evanston, and Brantford. At the time of this visit Select Committees of the Congress of the United States were conducting public hearings concerning the safety of water fluoridation. This subject is discussed in the report which includes comments on various toxic hazards emphasized by fluoridation opponents.

They concluded:

Epidemiological studies in America have demonstrated beyond doubt that among children and adults who have been born and brought up in areas where the drinking water contains fluoride at a level of 1 ppm or more, there is much less dental caries than in areas where the water is free from fluoride. Compared with areas where the drinking water contains little or no fluoride there is about 60 percent less dental caries among children aged 12 to 14 years and about six times as many children have permanent teeth.
which are free from caries (18 to 29 percent compared to about 4 percent). A few studies among adults, both in England and in the United States, show that the effect of fluoride persists at least up to about 40 years of age.

In our opinion the evidence is conclusive that among children in fluoridation areas there is a reduction in the incidence of dental caries to a level comparable with that experienced where fluoride occurs naturally in the water.

There is nothing to suggest that a water containing fluoride, naturally derived, has properties different from those of a water to which fluoride has been added. At the concentration of fluoride used, about 1.0 ppm, it is the fluoride ion that is operative and the nature of the salt used is of secondary importance.

We consider that an artificially fluoridated water is similar in its action to one containing naturally derived fluoride. There is therefore sufficient evidence to indicate that the benefits derived by young children will accompany them into adult life. It is realised that time alone can demonstrate the truth of this contention.

Doubt has been expressed about the risk of mottled enamel . . . . This, in our opinion, is not a hazard. We observed that when mottling occurs it amounts only to an occasional white fleck in the enamel and is so slight that it cannot be recognized without expert examination. The appearance of the teeth is excellent.

We have found no scientific evidence that there is any danger to health from the continued consumption of water containing fluoride in low concentration. In the areas where naturally occurring fluorides are present at a level of 1.0 ppm mortality statistics do not indicate any hazard due to fluorides and medical experience in such areas has not produced any evidence of increased morbidity. Many suggestions have been made that certain ill effects may nevertheless occur. We can only comment that the proving of a negative is extremely difficult. Meanwhile, we are impressed by the fact that millions of people are living in ordinary good health on waters containing fluorides at levels of 1 ppm or more.

We could not find any evidence that fluoridated water had an adverse effect on industrial processes.

The mechanical addition of fluoride to a water supply at any desired level presents few difficulties. With a correctly designed plant and proper controls there is no danger of adding a toxic overdose of fluoride.

The final recommendations of this Committee included:

It follows from our conclusions that we consider fluoridation to be a useful means of reducing the incidence of dental caries in North America. It is reasonable to assume that it would also be useful in this country. We therefore recommend that its adoption in this country should be considered. However, certain investigations are desirable before the general adoption of fluoridation.

In our opinion it would be advisable in the first instance to add fluoride to the water supplies of some selected communities. These preliminary fluoridation projects should be regarded as study centres and include full medical and dental examinations at all ages.

Fluoridation Studies in Great Britain

On advice of the Standing Advisory Committee of the British Gov-
ernment, the recommendations of the American mission were accepted. A steering committee was named which included dental, medical, chemical, water supply, and statistical authorities drawn from British government agencies. The Medical Research Council was also represented and after the study areas had been selected the committee was joined by health officers and water engineers of the local authorities concerned, and the British Dental Association.

The occurrence of fluoride in certain water supplies of Great Britain was noted in the account of the extensive surveys of endemic mottled enamel by Ainsworth, and in the dental caries studies by Weaver. Prior to initiating fluoridation trials it was thought advisable to have some basis for adopting 1.0 ppm of fluoride as the appropriate level. One factor suggested for consideration was eating and drinking habits, particularly in the quantities of tea known to differ from American custom. A medium-strength infusion of average quality tea brewed with fluoride-free water may contain up to 1.0 ppm of fluoride. Ten to twelve cups of such tea per day, which might be rather much even for an adult Englishman, would provide nearly 1.0 mg of fluoride daily. Preliminary studies of urinary excretion in both children and adults in Great Britain were conducted, but the data provided no evidence that fluoride in water for Great Britain should differ from a level of 1.0 ppm. Consideration was given to the possibility that adults who were unusually heavy tea drinkers might consume too much fluoride. But in the light of reports regarding adults of Bartlett, Texas, where the water naturally contained 8.0 ppm fluoride (who were compared with adults of Cameron, where the level of fluoride is 0.4 ppm), and other evidence, this hypothesis was judged to be unfounded.

The Great Britain fluoridation trials, as finally organized, consisted of three study and three control areas. The Gwalchmai zone in Anglesey, North Wales, started fluoridation in November, 1955, at a level of 0.9 ppm fluoride. In Kilmarnock, Scotland, 0.9 to 1.0 ppm fluoride was provided in April, 1956, and in Watford, England, fluoride in the drinking water was stabilized at the required concentration in mid-June, 1956. The usual precautions were followed for protection of the waterworks staff against inhalation of any fluoride dust. A routine fluoride analysis was carried out on water samples taken at the waterworks plant and in the distribution system. The majority of the waters were in the range of 0.9 to 1.1 ppm fluoride. The results of these first fluoridation studies after five years were published in 1962 (5). A report after eight years was presented by Forrest and James (6).

The dental examinations were limited to first permanent molars and permanent incisors. Since the latter group of teeth was of recent eruption, only five incisor teeth were found to be carious, all among control children. This eight-year report is limited, therefore, to first permanent molars. Data from the North Wales trial are shown in Table 1.

A summary of combined results from the three studies and three control areas was published by Forrest (7). The caries reduction based on
WATER FLUORIDATION

Table 1. The mean numbers of decayed, missing, or filled first permanent molars in 8-year-old children from test and control areas of Anglesey (Gwalchmai zone), North Wales.

<table>
<thead>
<tr>
<th>Year</th>
<th>Gwalchmai zone (fluoridation area)</th>
<th>Bodafon zone (control area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>1961</td>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>1963</td>
<td>1.35</td>
<td>2.1</td>
</tr>
</tbody>
</table>

The average number of carious teeth per child after 5 to 5½ years is shown in Table 2.

Table 2. Combined results after approximately five years of fluoridation of water in Kilmarnock, Scotland; Watford, England; and Anglesey (Gwalchmai zone), North Wales.

<table>
<thead>
<tr>
<th>Children's age (years)</th>
<th>Study area (percentage reduction)</th>
<th>Control area (percentage reduction)</th>
<th>Adjusted percentage reduction in study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>66</td>
<td>6</td>
<td>64</td>
</tr>
<tr>
<td>4</td>
<td>57</td>
<td>7</td>
<td>54</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>5</td>
<td>47</td>
</tr>
<tr>
<td>6</td>
<td>26</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>3</td>
<td>11</td>
</tr>
</tbody>
</table>

Among children three and four years old whose teeth had all been calcified after fluoridation started, caries was significantly reduced by 64 and 54 percent respectively. Most of the teeth of children aged five, six, and seven were calcified at the time fluoridation was started and the caries reductions were less.

Forrest compared these findings in Great Britain with data from the Grand Rapids study, based on children aged four and five years. Grand Rapids data showed a caries reduction in deciduous teeth (def) of 47 percent at age four and 58 percent at age five based on full dentition for this age group. Forrest reported a "caries adjusted percentage reduction" to be 42 percent at age four and 45 percent at age five in Grand Rapids, compared with 54 percent at age four and 47 percent at age five in the Great Britain combined study areas, based on dmf teeth. Although there is a difference in criteria (dmf in Great Britain and def in Grand Rapids), "the British results are very much in line with those in the United States."

The results of these trials in Great Britain were carefully considered by the Minister of Health and by his advisory committee, who advised him to take action to promote fluoridation. Accordingly he urged all local health authorities to make arrangements for fluoridation of public water supplies. Forrest reported that despite the success of the study in Kilmarnock, under pressure from opposition groups, the Burgh Council "made the regrettable decision to discontinue fluoridation." On the
contrary, both study and control areas in Anglesey are now being fluoridated.

During these studies Forrest paid special attention to the development of enamel opacities. She found no obvious or objectionable mottling of the teeth of children in the fluoridation areas.
NEW ZEALAND

No public water supply in New Zealand contains naturally a sufficient quantity of fluoride to produce beneficial dental effects. In 1951 the population was reputed to be very susceptible to caries, presumably more so than residents of those communities in America where the value of fluoridation had been under investigation since 1945. Since the actual benefit of fluoridation had not yet been definitely assured by these studies, it seemed desirable that a dental benefit of fluoridated water be demonstrated in New Zealand.

Hastings, in the eastern area of Hawkes Bay, had a population of about 20,000 in 1951. The city water was provided by artesian sources and contained 0.15 ppm of fluoride. In March, 1951, the suggestion was made to the Hastings Borough Council that their city might be considered as the first of its kind in New Zealand to study the effect of fluoridating a public water supply. However, it was not until September, 1954, following an unsuccessful experience with fluoridating equipment designed for sodium fluosilicate, that the Hastings water was fluoridated at a level of 1.0 ppm, using sodium fluoride. This project was directed thereafter by a subcommittee of the New Zealand Department of Health.

The effect of fluoridation on the prevalence of caries in Hastings children was assessed "by means of the autistic type of study in which caries experience of Hastings children before fluoridation is compared to that of Hastings children of an equivalent age subsequent to its introduction." Thus during September, October, and November in 1954, T. G. Ludwig obtained base-line caries data by a dental examination of 1,869 children of European extraction aged 5 to 16 years who were lifelong residents of Hastings and had consumed only the city water (8). In March and April, 1957, 1,868 subjects were again examined by Dr. Ludwig. Because of failures in the fluoridating equipment between March, 1953, and September, 1954, all the children examined had received an intermittent supply of fluoride during this initial 18-month period. But the sodium fluoride solution feeder had operated continuously since September, 1954.

Three years of fluoridation in Hastings resulted in an approximate 14 percent reduction of caries in deciduous teeth in children aged 5 years. In 6-year-old Hastings children the number of permanent teeth with evidence of caries experience had fallen from 1.41 per child in 1954 to 0.82 per child in 1957, a reduction of about 42 percent. In 7-year-old children the reduction in permanent tooth caries was about 39 percent; in 8-year-olds about 18 percent. In view of the shortness of this period of fluoridation in Hastings it was too early for maximal effects of fluoridation to have become apparent.

In March and April of 1961, after 75 to 78 months of fluoridation, Ludwig again examined 5- to 16-year-old children who had lived
throughout life in Hastings. Ludwig’s data indicate that caries experience (DMF) in children aged 6, 7, and 8 years had been reduced approximately 74, 59, and 46 percent respectively, and in children aged 9 to 16 from 33 to 17 percent. Caries in deciduous teeth (def) in children aged 5, 6, and 7 years was reduced by about 43, 42, and 30 percent respectively. The results were similar to those obtained elsewhere after a comparable period of fluoridation (9).

In September, 1954, the regular dental examinations and radiographs were repeated. The subjects, as in previous examinations, were aged 5 to 16 years and “information about the residential history of the children, the nature of the water supply available to them, and their date of birth was obtained by forwarding questionnaires to parents for completion and by questioning the children themselves.” The data for 1954 and 1964 are shown in Tables 3 and 4 (10). The expected reduction in

**Table 3. Distribution by age and sex of Hastings children examined in 1954 and in 1964.**

<table>
<thead>
<tr>
<th>Age in years</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hastings, 1954</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>94</td>
<td>136</td>
<td>120</td>
<td>93</td>
<td>72</td>
<td>77</td>
<td>72</td>
<td>74</td>
<td>73</td>
<td>62</td>
<td>44</td>
<td>22</td>
</tr>
<tr>
<td>Females</td>
<td>99</td>
<td>123</td>
<td>128</td>
<td>109</td>
<td>73</td>
<td>80</td>
<td>50</td>
<td>65</td>
<td>74</td>
<td>66</td>
<td>44</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>193</td>
<td>259</td>
<td>248</td>
<td>202</td>
<td>145</td>
<td>157</td>
<td>122</td>
<td>139</td>
<td>147</td>
<td>128</td>
<td>88</td>
<td>41</td>
</tr>
<tr>
<td>Hastings, 1964</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>88</td>
<td>100</td>
<td>80</td>
<td>102</td>
<td>67</td>
<td>99</td>
<td>84</td>
<td>85</td>
<td>66</td>
<td>85</td>
<td>65</td>
<td>39</td>
</tr>
<tr>
<td>Females</td>
<td>75</td>
<td>105</td>
<td>91</td>
<td>84</td>
<td>76</td>
<td>114</td>
<td>84</td>
<td>81</td>
<td>82</td>
<td>80</td>
<td>53</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>163</td>
<td>205</td>
<td>171</td>
<td>186</td>
<td>143</td>
<td>213</td>
<td>168</td>
<td>166</td>
<td>148</td>
<td>165</td>
<td>118</td>
<td>65</td>
</tr>
</tbody>
</table>

**Table 4. Comparison of caries prevalence rates in permanent teeth of Hastings children in 1954 and in 1964.**

<table>
<thead>
<tr>
<th>Age in years</th>
<th>No. of children *</th>
<th>No. perm. teeth present</th>
<th>No. perm. teeth DMF</th>
<th>Mean no. perm. teeth/child</th>
<th>No. of children *</th>
<th>No. perm. teeth present</th>
<th>No. perm. teeth DMF</th>
<th>Mean no. perm. teeth/child</th>
<th>Percent reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>216</td>
<td>1254</td>
<td>304</td>
<td>1.41</td>
<td>171</td>
<td>976</td>
<td>40</td>
<td>0.23</td>
<td>84</td>
</tr>
<tr>
<td>7</td>
<td>246</td>
<td>2170</td>
<td>677</td>
<td>2.75</td>
<td>168</td>
<td>1537</td>
<td>125</td>
<td>0.74</td>
<td>84</td>
</tr>
<tr>
<td>8</td>
<td>202</td>
<td>2247</td>
<td>754</td>
<td>3.73</td>
<td>186</td>
<td>2075</td>
<td>231</td>
<td>1.24</td>
<td>67</td>
</tr>
<tr>
<td>9</td>
<td>145</td>
<td>1921</td>
<td>645</td>
<td>4.45</td>
<td>143</td>
<td>1924</td>
<td>298</td>
<td>2.68</td>
<td>58</td>
</tr>
<tr>
<td>10</td>
<td>157</td>
<td>2665</td>
<td>861</td>
<td>5.48</td>
<td>215</td>
<td>3942</td>
<td>523</td>
<td>2.46</td>
<td>55</td>
</tr>
<tr>
<td>11</td>
<td>122</td>
<td>2285</td>
<td>869</td>
<td>7.12</td>
<td>168</td>
<td>3412</td>
<td>571</td>
<td>3.40</td>
<td>52</td>
</tr>
<tr>
<td>12</td>
<td>139</td>
<td>3047</td>
<td>1316</td>
<td>9.47</td>
<td>166</td>
<td>4172</td>
<td>856</td>
<td>5.16</td>
<td>46</td>
</tr>
<tr>
<td>13</td>
<td>147</td>
<td>3819</td>
<td>1758</td>
<td>11.82</td>
<td>148</td>
<td>3943</td>
<td>1067</td>
<td>7.21</td>
<td>39</td>
</tr>
<tr>
<td>14</td>
<td>128</td>
<td>3455</td>
<td>1837</td>
<td>14.35</td>
<td>165</td>
<td>4481</td>
<td>1458</td>
<td>8.84</td>
<td>38</td>
</tr>
<tr>
<td>15</td>
<td>88</td>
<td>2404</td>
<td>1478</td>
<td>16.80</td>
<td>118</td>
<td>3217</td>
<td>1152</td>
<td>9.76</td>
<td>42</td>
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<tr>
<td>16</td>
<td>41</td>
<td>1100</td>
<td>681</td>
<td>16.61</td>
<td>65</td>
<td>1783</td>
<td>753</td>
<td>11.58</td>
<td>30</td>
</tr>
</tbody>
</table>

*Includes only children with permanent teeth erupted.
caries prevalence rates "of 50-60 percent had been obtained." The reduction in both deciduous and permanent teeth of Hastings children very closely resembled that obtained in Grand Rapids after 10 years of fluoridation.

In 93 children approximately 5 percent of all examined in 1964, minute areas of enamel opacity were seen, corresponding to the "very mild" grading of dental fluorosis described by Dean. Ludwig stated, "In all cases these opacities were of minor nature and in most instances could be detected only with difficulty. In an additional 157 children representing about 8 percent of the children examined in 1964, enamel opacities and defects which could be classified as idiopathic in origin and which were unrelated to fluoridation were seen."

NOTES AND REFERENCES

Brantford

During the first ten years of the Brantford study Dr. Hutton was in touch with Dean, Arnold, and Russell at the NIDR, advising them of developments. In NIDR files a letter of July 11, 1955, from Hutton to Arnold expressed thanks "for letting me see the striking charts of the Grand Rapids study." He noted that he had been honored by a visit from McKay, "He has found the secret of growing old graciously, and I admire him tremendously."

In 1955 the Brantford plant pumped 6,000,000 imperial gallons for a water population of 50,000. The cost of fluoridation was from $0.09 to $0.14 per capita daily. After ten years the source of fluoride was changed from sodium fluoride to sodium fluosilicate.

In a letter of June 6, 1967, Dr. Brown, now on the Faculty of Dentistry of the University of British Columbia, stated that Sarnia River water, as indicated by analysis of a long series of samples, contains from 0.0 to 0.12 ppm fluoride. The concentration in the Stratford water has remained constant at 1.6 ppm. Brantford water has been kept constant at 1.0 to 1.1 ppm since the inception of fluoridation in June, 1945.

United Kingdom

The members of the United Kingdom mission to study fluoridation in the United States were:

J. Longwell, D. Sc., F.R.I.C., Principal Scientific Officer in the Department of the Government Chemist, in charge of the division dealing with the examination and treatment of water.
H. H. Stones, M.D., M.D.S., F.D.S.R.C.S., Professor of Dental Surgery and Director of Dental Education, University of Liverpool; Director and General Consultant, Liverpool Dental Hospital; Member of the Dental Research Committee, Medical Research Council; Member of the Liverpool Regional Hospital Board; and of the Board of Governors of the Liverpool United Hospitals.
A. M. Thomson, B. Sc., M.B., Ch. B., Research Lecturer, Department of Midwifery, University of Aberdeen.

The official report of this mission, published in detail in 1958, was directed to the Rt. Hon. Iain Macleod, M.P., Minister of Health Rt. Hon. James Stuart, M.V.O.,
M.C., M.P., Secretary of State for Scotland; and Rt. Hon. Harold Macmillan, M.P.,
Minister of Housing and Local Government, Medical Research Council.

The report stated:

Every possible assistance was received from the Surgeon General of the
United States Public Health Service, Dr. Leonard A. Scheele, who with mem-
ers of his Dental Division went out of his way to ensure that every possible
facility was put at our disposal. In particular Assistant Surgeon General
Bruce D. Forsyth, D.D.S., Chief, Division of Dental Public Health; and Dr.
H. Trendley Dean, D.D.S., Director, and Dr. F. A. Arnold, Jr., D.D.S., Asso-
ciate Director, National Institute of Dental Research, were most helpful in
our official enquiries and moreover did much to make our visit personally
more happy.

We were anxious to assess the reactions of the profession and the public to
this latest United States public health measure and we were materially as-
sisted in both these directions and in arranging certain of our visits to fluori-
dation projects and to research departments by Dr. Harold Hillenbrand,
D.D.S., Secretary of the American Dental Association, who placed himself
and members of his staff at our disposal.

We met a large number of civic authorities, public health officials, medical
and dental research workers, public dental practitioners, all of whom readily
gave us every possible help in our enquiry. In particular we wish to ac-
knowledge that we were given a considerable amount of unpublished infor-
mation which has been used in preparing our report.

In addition, we received much kindness and hospitality for which we have
personally expressed our gratitude; but we should like to place on record
our appreciation of the welcome and the very real assistance we received
wherever we went in the United States and Canada.

New Zealand

Having in mind the objectives of the United Kingdom Mission to the United States
the New Zealand Government passed a "Commission of Inquiry Act," which required
the Governor General to appoint an official commission to inquire into and report
upon the following:

1. Whether benefits to dental health may reasonably be expected in New
Zealand from the addition of fluoride to public water supplies, having re-
gard to results of fluoridation of water supplies in other countries;

2. Whether any disadvantages may result from addition of fluoride to waters
naturally containing less than one part of fluoride per million;

3. Whether it is desirable or expedient that local authorities be permitted to
decide on such addition for the benefit of residents, particularly children, of
their districts;

4. Whether there are any practical methods of adjusting the daily intake of
fluoride other than by addition to the water consumed;

5. Whether, and to what extent, the Government should take steps in relation
to the powers or actions of local authorities in respect of any of the
foregoing matters.

The three members of this commission were W. F. Stilwell, Judge of the Arbitration
Court, N. L. Edson, Professor of Biochemistry, and P. V. E. Stainton, merchant. The
report, Fluoridation of Public Water Supplies, was presented to the Governor Gen-
eral of New Zealand on July 10, 1957. Its 240 pages cover essentially every phase of
problems of dental health and fluoridation as a public health procedure. Five public
hearings were held and 121 witnesses presented evidence. Statements by representatives of antifluoridation organizations are included in the report. An exhaustive review of the literature on fluoride, its dental and physiological effects, and safety at a level of 1.00 ppm in drinking water were presented. The accumulated evidence of dental benefits of fluoride in drinking water (including the studies then in progress in Hastings), engineering, chemical, and mechanical aspects of fluoridation were thoroughly investigated.

The committee was convinced that benefits to dental health might reasonably be expected in New Zealand, and that no disadvantages would result from the addition of fluoride to waters naturally containing less than 1.0 ppm. In keeping with administrative principles outlined in the report, the committee concluded that widespread use should be made of fluoridation to achieve an urgently needed improvement of dental health in New Zealand.

As was the case in observations relating to the United Kingdom, ingestion of fluoride by drinking tea was considered by New Zealand investigators. The average adult's daily urinary excretion of fluoride without tea was 0.27 mg (0.18 ppm) fluoride, with tea 0.52 mg (0.33 ppm) fluoride was excreted. It was concluded, however, that tea is not considered desirable for children in the United Kingdom and or New Zealand and is not given at an early age. They reported no evidence that an increased quantity of fluoride ingested by drinking tea is responsible for reduction of caries.

CHAPTER ELEVEN

OTHER ISSUES

The Caries-Preventive Effect of Fluoridated Water in Adult Life

STUDIES on the subject of the continuance of caries prevention in adult life have been conducted in the United States—one by A. L. Russell and Elias Elvove (1) and another by Harold Englander and Donald A. Wallace (2). Deatherage had already obtained dental caries data in Illinois selectees for the Armed Forces of World War II which indicated a continuation of benefits resulting from use of a fluoride drinking water. Robert Weaver made a report on the effect of fluoride on caries in English children in 1944 and obtained additional data from a second study in which one objective was to see whether the comparative freedom from caries experienced by South Shields children (1.4 ppm fluoride in water) would extend to older members of the population (3). In this report Weaver reflected on the use of the word "prevention" with respect to dental caries. "Prevention," wrote Dr. Weaver, "is a word which is sometimes used rather loosely as for example when we speak of preventable deaths. That particular phrase, however, is not misleading since everyone on reflection realizes that deaths are not preventable—they can only be postponed. On the other hand it may be misleading to speak of prevention of caries." More bluntly we would ask, are carious teeth preventable or inevitable? Dr. Weaver pursued this idea further by stating, "This is the kind of a test which ought to be applied to any measure which is advocated for reducing the incidence of caries, whether it be the ingestion of fluoride, the employment of dental hygienists, or a modification of the physical or chemical composition of the diet."

Weaver's reflections are well taken and he would no doubt hold vigorously to the necessity of prolonged periods of observation before evaluating many recent measures being proposed and clinically tested for their cariostatic value.

Weaver tested his hypothesis by examining 100 mothers attending maternity and child welfare centers in North Shields and South Shields. Weaver wrote:

This was done, but the interpretation of the results is not so easy as in the case of school children. In the first place, the loss of teeth in adult life may in some cases be the result of periodontal disease, rather than of caries, though there appears to be no good evidence that the incidence of periodon-
tal disease is affected one way or the other by ingestion of fluorine. A greater difficulty arises from the fact that patients who have lost, or are about to lose, a considerable number of teeth sometimes have sound teeth extracted merely in order that they may obtain a full artificial denture or dentures. This, however, was not considered to be a matter of much importance as far as this inquiry was concerned, since the investigation was directed to finding out the extent to which, from a dental standpoint, the mothers seen in South Shields were better off than those seen in North Shields. Whether the loss of teeth was directly, or only indirectly, due to caries was not material.

Weaver's data indicated that at age 40 and over North Shields and South Shields mothers were practically equal in caries experience. However, as Russell and Elvove pointed out, Weaver's data essentially represented tooth mortality rates. "His sample was highly selected, . . . mothers attending maternity and child welfare centers of whom the great majority had not well-cared-for mouths."

In conclusion, Weaver stated:

It would be unwise to make generalizations based on these figures and to argue that the caries-inhibiting factor can do no more than postpone caries for about three years in childhood and for about five years in adult life. Average figures give no information as to the extent to which individuals may have benefited. I suggested in my earlier article that F may not be a very powerful inhibiting factor and, if that view is correct, it is quite possible that in well-cared-for months F can provide just that extra protection which may mean so much. The great majority of the mothers seen in that investigation had no well-cared-for mouths, and in those circumstances it is possible that the destructive forces may be too strong for F to be capable of producing much lasting effect. If F should prove to be fluorine, the ultimate verdict may perhaps be that as far as inhibition of dental caries is concerned, fluorine helps those who help themselves.

Weaver at that time was still not convinced that F (the protective factor) was fluoride in the water. His data on the continuing effect of waterborne fluoride are quite limited.

Russell and Elvove selected Colorado Springs as the site of a study on dental caries in adults because of its long and reliable water fluoride history. Nearby Boulder was used for a control population; Boulder and Colorado Springs both lie in the semiarid plain at the eastern border of the Rocky Mountains. Census statistics in both 1930 and 1940 showed that there were 98 percent native-born white residents in Boulder and 96 percent in Colorado Springs. These cities were quite similar in economic status and occupations; both populations were "highly literate." The Boulder drinking water from March, 1950, through March, 1951, varied from 0.0 to 0.1 ppm fluoride. The Colorado Springs water has contained approximately 2.0-2.5 ppm fluoride since the turn of the century.

Age limits of 20 through 44 years were established because younger persons were not listed in the directories and because Boulder tap water may have contained fluorides from adjacent watersheds before establishment of the pipeline system in 1906. The meticulous care used in selecting subjects for this study is described in detail by these investigators.
When assembled, the samples proved to be random cross sections of all the people of the two communities. Both groups had received adequate dental care of high quality, and personal dental hygiene was generally good. All the dental examinations of this substantial study were made by Russell. His diagnosis of mottled enamel revealed its total absence in Boulder. Severity of mottled enamel in Colorado Springs was "very mild" or "mild." There were striking differences between total DMF rates in Colorado Springs and Boulder in individuals aged 20 through 44 years, differences statistically valid at each age point and for the pattern as a whole. The caries experience data of this survey were also evaluated in terms of (a) filled tooth surfaces, (b) caries-free individuals, and (c) tooth mortality. As stated by these authors, "The most reliable measure of the difference in the dental caries experience of these two groups is the difference between their total DMF rates." These rates were approximately 60 percent lower in Colorado Springs than in Boulder for each age group. The phenomenon of caries inhibition continued undiminished through the age of 44. Boulder natives had lost three or four times as many teeth from dental caries as had natives of Colorado Springs (Fig. 1).

In an additional analysis of these data Russell specifically evaluated the dental caries prevention in the approximal tooth surfaces. The suggestion had been made that anterior tooth surfaces would be more

![Graph showing tooth mortality in natives of Boulder and Colorado Springs, adjusted for number of school years completed.](image-url)
available for topical contact with fluoride in drinking water than would posterior tooth surfaces. While Russell’s data apply only to smooth surface approximal caries, “there was a systematic diminution of caries inhibition from the anterior toward the posterior part of the mouth.”

A footnote in his report reads,

Since this report was prepared for publication a personal communication describing a comparable study has been received from Peter Adler. Adler found that female natives of Kunzermarton, Hungary, where the water contains from 0.8 to 1.6 ppm of fluorides, showed lower dental caries rates through the age range of 21 to 45 years than did newcomers of Kunzermarton or comparable natives of Nagybaracska, Debrecen, and vicinity who had used waters which were low in fluoride.

Another Study in Illinois

Aurora and Rockford, Ill., were the site of the study by Englander and Wallace. Fluoride in Aurora water has averaged 1.2 ppm since about 1890; Rockford drinking water is practically fluoride free. Since this study was part of a survey of periodontal disease, only persons with at least 10 natural teeth were examined. White natives numbering 896, aged 18–58, were examined in Aurora, 935 in Rockford. In the Aurora group 32.5 percent and in Rockford 26.7 percent were over 40. All of the Aurora subjects had used the local fluoride water practically continuously the first 18 years of life and had not been absent from the city thereafter for a total of more than five years. None of the Rockford group had had any significant exposure to a fluoride water, and averaged 32.0 years’ use of fluoride-deficient waters. The dental caries experience was significantly less in Aurora than in Rockford. The low caries experience rates previously reported for 12- to 14-year-old Aurora children thus apparently remained low up to an approximate age of 50 years. Viewed in light of dental care requirements, it is of interest that “although approximately 70 percent of all DMF surfaces were filled for persons in each city, the Rockford subjects had an average of approximately 2.3 times as many unfilled carious lesions.”

Any drinking water averaging approximately 1.2 ppm fluoride (as in Aurora) is very near the permissible level of 1.0 ppm fluoride as provided by artificially fluoridated water. The results of this study thus strongly suggest that the use of controlled fluoridated water provides caries prevention which continues into adult life. More evidence of the continuing effect of fluoridated water in older age groups should be obtained by future studies. However, the outcome of such studies will presumably be in agreement with the studies pertaining to Colorado Springs and Aurora where naturally fluoridated waters are in use. The evidence in these studies strongly supports the view that a dental benefit of fluoridated water may continue throughout life.
Periodontal Health and Fluoridated Water

Periodontal health is an accessory consideration of water fluoridation because of the possibility of two effects, one a hazard to the sensitive gingival tissues, the other, a benign influence on periodontal disease. A beneficial effect may derive from a possible stabilization of the alveolar bone due to an increase in its content of fluoride. Both these possibilities were evaluated in a study of the oral effects of the 8 ppm fluoride drinking water of Bartlett, Texas (4).

In the first health survey of Bartlett (1943), 116 residents in Bartlett and 121 in Cameron were examined for dental caries, mottled enamel, and periodontal disease. In 1953, 76 individuals in Bartlett and 80 in Cameron were examined again. In 1953, gingivitis was assessed by the P.M.A. index of Massler and Savara and in addition periapical roentgenograms were taken of all the examined subjects except two persons in each group. These films were evaluated for alveolar bone loss independently by four dentists, and bone resorption was classified as "mild," "moderate," and "severe." Calcification was further differentiated as "horizontal" or "vertical," according to the predominant type. The degree of alveolar bone resorption and the amount of gingivitis did not differ significantly between the two groups, nor was there evidence of any effect of excessive waterborne fluoride on calculus or prevalence of leukoplakia, lichenplanus, soft tissue color abnormality, pulp stones, horizontal and vertical alveolar bone resorption, periapical rarefaction, condensing osteitis, or dentigerous cysts.

Russell carried out three definitive studies of the periodontal status of residents of fluoride and non-fluoride communities. A widely renowned epidemiologist, he devised a system of classification and scoring for prevalence of periodontal disease known as the Russell Periodontal Index.

Discussed in the order of the age of the persons examined and the concentration of fluoride in the drinking water, the studies compared Newburgh and Kingston, Colorado Springs and Boulder, and Bartlett and Cameron. The water supplied to the fluoride-drinking populations contained approximately 1.0, 2.5, and 8.0 ppm fluoride which had been used from 7 to 44 years (5).

As a result of this survey, Russell stated:

A more favorable condition of the periodontal tissues was observed in the fluoride community. If use of a fluoride domestic water has any adverse effect upon the health of periodontal tissues, it is quite likely that this effect would have been revealed early in one or all of these studies. The fact that no adverse effect is evident is wholly incompatible with any hypothesis that use of fluoride-bearing domestic waters is harmful to the periodontal tissues of children or of adults. On the other hand, the slight differences in favor of the fluoride communities are too weak for acceptance as evidence that use of a fluoride water is beneficial to periodontal tissues.

Russell also studied the differences between native and migrant
school children living in Montgomery and Prince Georges Counties, Md., and Muskegon and Grand Rapids, Mich. All of these communities use fluoridated drinking water. A careful evaluation of a periodontal examination of 17,890 children led Russell to conclude, "There was a weak tendency for the periodontal health of native children to improve relative to that of migrants as their advantage in waterborne fluoride consumption increased." Most of the differences were slight and again Russell pointed out that "there is no evidence that fluoridated water either improved health of periodontal tissue, or that periodontal tissues are harmed by use of fluoridated water."

Another study on the effect of natural fluoride water on the periodontal health of adults was reported by Englander, Kesel, and Gupta (6). The data pertain to 906 white lifetime residents aged 18 to 70, of Aurora, Ill., and 948 continuous residents of Rockford, Ill., who served as the non-fluoride controls. "Subjects in both cities were distributed similarly according to age, sex, socioeconomic status, education level, health, and quality of dental care." The Russell Periodontal Index was used to determine prevalence and severity of periodontal disease and the status of oral hygiene evaluated by a method proposed by Greene and Vermillion. Englander, Kesel, and Gupta summarized their results:

1. Although the prevalence and severity of periodontal disease was high in both cities, lower periodontal indexes (PI), indicating somewhat less severity of disease, were found at each age level in continuous residents of the naturally fluoridated city. For all ages combined, the difference between periodontal indexes for the cities was statistically significant (P < 0.01).

2. The percentage of persons with one or more frank periodontal pockets was significantly higher in Rockford.

3. There was no difference in the proportion of persons free from overt periodontal involvement between the cities.

4. Oral hygiene scores were about the same in Aurorans and natives of Rockford. Calculus was equally present, indicating that the continuous consumption of optimally fluoridated water neither promotes nor inhibits calculus deposition.

5. Differences in severity of periodontal disease may be due indirectly to disparity in caries rates between the two cities. Fluoridated water may also have a deterrent influence on the progress of destructive disease that has become established.

Because of the consistency of findings in all these surveys it must be concluded that the effect of a fluoride water on gingival tissues and on the development of periodontal disease is negligible.

Prenatal Fluoride and Caries Prevention

The clinical data on the efficacy of prenatal fluoride recently were substantially increased by a superior study conducted by Horowitz and Heifetz (7). Prior consensus regarding the efficacy of prenatal fluoride
was dependent on interpretation of data obtained in fluoridation trials and on some limited observations on the effects of natural fluoride waters. In the Grand Rapids study, for example, the def experience of 6-year-old children having used fluoridated water from birth was 42.0 percent less than that of 6-year-old Grand Rapids children who had never been exposed to fluoridated water. On the other hand 6-year-old children exposed both prenatally and postnatally to Grand Rapids fluoridated water had 53.7 percent fewer def teeth than the control non-fluoride 6-year-olds.

The Evanston trial of Blayney and Hill produced data relative to prenatal fluoride. Six-year-old children whose mothers drank fluoride water during pregnancy had a 36 percent reduction in caries, as compared with control Evanston 6-year-olds. Evanston children, about half of whom had had no prenatal exposure to fluoride, had only a 10 percent reduction in caries in the deciduous teeth. Comparisons of caries experience in older age groups indicated similar benefits of prenatal fluoride. Blayney and Hill wrote (8):

The data presented led to the conclusion that the ingestion of fluoride, through the use of water containing 1.6 ppm of fluorine, during the prenatal period and followed by its postnatal use contributes added protection to the deciduous teeth over that provided by only the postnatal use.

Data on this subject from the Newburgh-Kingston fluoridation trial have been published by Carlos (9). An effect of prenatal fluoride was not evident in the data which Carlos presented. There was a 19.2 percent reduction in deciduous teeth of seven-year-old children born in 1943–1944, prior to fluoridation of Newburgh water and without prenatal exposure to a fluoride water. There was a 21.1 percent reduction of caries in seven-year-old children born in 1945–1946 who did have prenatal fluoride exposure. Children aged six years had a 22.8 percent and 21.3 percent reduction respectively without and with prenatal fluoride. Carlos was disturbed by the fact that his results did not agree with the data of the Evanston study and pointed to some possible errors in the interpretation of the Evanston data. He believed that a conclusion of a positive effect of prenatal fluoride was not justified by the data. Carlos wrote that he thought the Evanston data offered "no convincing evidence of a beneficial effect from fluoride ingested during pregnancy."

Horowitz and Heifetz in their 1967 report stated the status of the prenatal-fluoride problem prior to their study (7):

Because of these discrepant findings, it is difficult to formulate a sound scientific opinion on when fluoride ingestion should be started to produce the greatest decay preventive benefits. For deciduous teeth, which calcify both prenatally and postnatally, formulating an opinion becomes even more difficult because the question concerning placental transfer of fluoride is superimposed on the conflicting data. It has not been shown unequivocally that fluoride at optimum levels passes the placental barrier in sufficient amount to impart resistance to caries in the developing deciduous teeth.

Most calcification of deciduous teeth occurs after birth. Therefore, if expo-
sure to fluoride during the last stage of tooth mineralization is sufficient to produce maximum inhibition of caries, whether or not fluoride crosses the placental barrier has only theoretical implication. On the other hand, if the mechanism for greatest protection necessitates exposure to fluoride before birth, the question of maternal transfer of fluoride is of more than academic interest. The answer would provide some basis for either recommending or discouraging the use of dietary supplements of fluoride by pregnant women to protect the deciduous teeth of their offspring.

There are many observations which substantiate the conclusion that there is some maternal transfer of fluoride. This fact of fluoride metabolism still may have only theoretical implications. According to Gedalia, Zukerman, and Mayersdorf (10), fluoride at 1.03 ppm in water caused a slight age-related increase of fluoride in human fetal bones and teeth, but the difference between 0.5–0.6 ppm fluoride and 1.0 ppm was not reflected in fetal uptake. A prenatal anticaries role of fluoridated water can be confirmed only by clinical observations, including especially those obtained recently by Horowitz and Heifetz. Their project was conducted in Minneapolis where fluoridation began in August, 1957; the fluoride level was maintained at 1.0 to 1.2 ppm, an optimum quantity for that Minnesota area. A large and stable school population was available for the study and 2,509 carefully screened children were examined. Only deciduous cuspids and molars were diagnosed for caries, and if missing these teeth were considered as extracted. Spaces for 12 deciduous teeth were examined, and a count was made of "decayed," "missing due to extraction," and "filled teeth and surfaces," identical to the DMF index used for permanent teeth (Table 1).

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of children</th>
<th>Prenatal fluoride exposure (months)</th>
<th>dmf teeth per child</th>
<th>dmf surfaces per child</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>509</td>
<td>None</td>
<td>3.43</td>
<td>6.35</td>
</tr>
<tr>
<td>B</td>
<td>426</td>
<td>Less than 3</td>
<td>3.47</td>
<td>6.70</td>
</tr>
<tr>
<td>C</td>
<td>473</td>
<td>3-6</td>
<td>3.32</td>
<td>6.20</td>
</tr>
<tr>
<td>D</td>
<td>568</td>
<td>6-9</td>
<td>3.09</td>
<td>5.72</td>
</tr>
<tr>
<td>E</td>
<td>533</td>
<td>Full term</td>
<td>3.23</td>
<td>6.02</td>
</tr>
</tbody>
</table>

1 Spaces for 12 deciduous teeth were examined in each child.

In spite of some fluctuation in the mean rates, the data indicate that the children in the five groups experienced only slight differences in caries experience. Inspection of these data as well as the investigators' statistical evaluation leave little doubt that the relation, if any, between prenatal exposure to fluorides and resistance of deciduous teeth to decay is minimal. The findings from the Minneapolis study agree very closely with data obtained by Carlos in the Newburgh survey.
Fluoride tablets are an alternative of fluoridated water. The data of this Minneapolis study thus contraindicate any conclusion that fluoride tablets are beneficial during pregnancy. For this reason, the U.S. Food and Drug Administration has banned the sale of fluoride tablets as an additional prenatal preventive of dental caries. The official consensus is that no increased benefits are derived from a fluoride supplement used during pregnancy, although there is no health hazard involved in the daily ingestion of a 1.0 mg fluoride tablet during pregnancy.

Katz and Muhler recently reported results of a study of the effects of prenatal and postnatal fluoride on the dental caries experience in deciduous teeth (11):

Comparisons of dental caries experience in deciduous teeth of children exposed prenatally and postnatally and exclusively postnatally to fluoride in the same city show no difference between groups, indicating that the effect of fluoride on deciduous teeth is mainly, if not entirely, postnatal. Further evidence indicates a difference in the response of deciduous teeth and permanent teeth to fluoride.

Fluoride in Metabolic Bone Disease

In connection with studies of skeletal fluorosis in cryolite workers of Copenhagen, Dr. P. Flemming Møller in 1932 suggested "whether it would not be possible to use cryolite or some compound of fluorine, notably sodium fluoride, therapeutically, especially in such bone diseases as imperfecta osteogenesis, brittleness of the bones, osteomalacia, disseminated fibrous osteitis, and the like, which result in pronounced osteoporosis." Support for a role and possible therapeutic use of fluoride in preventing certain bone diseases, especially osteoporosis, has been accumulating from recent clinical studies. Prior to this and following the comprehensive studies of skeletal tissues of residents of Bartlett, Texas (8.0 fluoride in the drinking water), in 1953 Leone and his associates had found some indication that the ingestion of excessive fluoride in water might have a beneficial effect in counteracting the osteoporotic changes of the aged. Major contributions to the clinical use of fluoride in bone disease have been made by Clayton Rich of the Veterans Administration Hospital in Seattle, and John Ensinck and P. Ivanovich, of the University of Washington School of Medicine, Seattle (12); M. J. Purves (13); G. A. Rose (14); and Anderson and others (15) in England; and by investigators at the Forsyth Dental Center and Harvard University (16). A 1966 epidemiological survey by Bernstein, Sadowsky, Hegsted, Guri, and Stare (17) from Harvard University and Peter Bent Brigham Hospital is a major contribution relative to a skeletal health benefit from fluoride in drinking water in North Dakota.

In the selection of areas in North Dakota these investigators had resorted to a water-fluoride environment which as early as 1916 had come to the attention of Frederick S. McKay. In 1932 and again in 1939, Dean had reported the widespread occurrence of mottled enamel in this
Dakota area. Some ten years later (1949) Russell had studied dental caries in South Dakota, particularly the effect of the span of exposure to fluoride in drinking water and reduction of dental caries. Bernstein and his associates confirmed that high-fluoride drinking waters had remained in continuous use in this Dakota area for a half century or more.

Their study was made

... in the rural parts of North Dakota where the people are mainly of German and Scandinavian origin or descent. The "high-fluoride area" was in the southwestern part of the state (the towns of Mott and Hettinger) where the drinking water ranged from 5.5 to 5.8 ppm in Mott and 4.0 to 4.8 ppm in Hettinger and came mainly from artesian wells. The "low-fluoride area" (range, 0.15 to 0.3 ppm) was in the northeastern area of the state (the towns of Grafton, Carrington, and New Rockford). The residents of these two areas are engaged in similar occupations (mostly farming and some small business).

In each town there was a clinic staffed by one or more general medical practitioners. The subjects studied were outpatients who were willing to participate in the study. A questionnaire was completed for each subject; the first page was filled out by the subject (patient’s form), the second page by the physician (physician’s form). A roentgenogram of the lateral lumbar area of the spine was taken for each subject. Standard technique for preparing roentgenograms of the lumbar area of the spine was used. The technique necessarily varied slightly in the different clinics because of differences in X-ray equipment, but the cassettes, screens, and film were constant throughout.

The interpretation of bone density was made by a radiologist (N.S.) who had no previous knowledge of the subject’s residence or of the results of the questionnaire. Other interpretations made were in relation to osteophyte formation, number of collapsed vertebrae, and presence or absence of detectable calcification of the aorta. Bone density was rated as follows: normal (0); mild demineralization (−1); moderate demineralization (−2); severe demineralization (−3); slight increase in mineralization (+1); and mild increase in mineralization (+2). Sample X-ray films (60 from each area) were interpreted by another radiologist for comparison.

The roentgenogram and questionnaire results were coded for computer evaluation. The statistical significance of differences observed according to age, sex, and area of residence (high and low fluoride content) against selected variables was determined by the calculation of Chi-square. A Chi-square indicating a P-value of 0.05 or less is considered significant.

There were 1,015 subjects in this study, 300 from the high-fluoride area and 715 from the low-fluoride area.

The study determined "whether prolonged ingestion (essentially a lifetime in more than 50 percent of the sample) of small amounts of fluoride has an effect on bone density and the rate of progression of osteoporosis." Comparisons between the two groups were based on bone density, collapsed vertebrae, osteophytic changes, bone disease, and other variables.

The results, carefully and statistically evaluated, "indicate that fluoride in a concentration between 4.0 and 5.8 ppm in the water supply (high-fluoride area) probably has significantly decreased the prevalence of osteoporosis." The authors noted further:
The areas are believed to be similar as regards climate and geography, and the populations sampled are believed to be of similar racial origin, occupation, climate, geography, and various socioeconomic categories such as income and social stratification. Both populations had been living in their respective areas for most of their lives and this was especially true of the residents of the high-fluoride area.

The investigators were concerned as to the effect of milk and cheese consumption on the observations, but after careful evaluation of this variable factor they concluded that it was very unlikely that these sources of calcium intake had a significant effect on the result. The report concludes:

Evidence of osteoporosis, reduced bone density, and collapsed vertebrae was substantially higher in the low-fluoride area, especially in women. Visible calcification of the aorta was significantly higher in the low-fluoride area, particularly in men. Limited information on milk and cheese consumption does not indicate that differences in calcium consumption are a significant factor. Fluoride consumption is important in the prevention of osteoporosis and may also play a significant role in preventing calcification of the aorta.

In agreement with this conclusion there is earlier clinical evidence that patients with osteoporosis who have been treated with substantial quantities of fluoride develop a mild positive calcium balance and a reduction in urinary calcium excretion, indicative of recalcification of skeletal tissue. There has been some improvement also in general clinical symptoms of these patients.

If fluoride proves influential in prevention of bone disease it is essential that the most effective and desirable quantities be defined, and that associated variables be understood. There is a general consensus that although bone density rates are difficult to evaluate and compare, the diagnosis of collapsed vertebrae as reported in the North Dakota study is a satisfactory objective diagnosis. The significant reduction of collapsed vertebrae in women may enhance the conclusion that the relatively high levels of waterborne fluoride reduce the prevalence of osteoporosis. A sizable reduction found in the prevalence of calcified aortas remains an observation of considerable interest in view of the prevalence of arterial disease.

The benefits observed from the relatively large quantities of fluoride used therapeutically as well as the ingestion of the relatively high-fluoride waters of North Dakota do not justify the consensus that drinking water fluoridated to 1.0 ppm is a beneficial factor in the control of either osteoporosis or other bone diseases. The benefits observed thus far are provocative but much additional evidence and experience are required to provide substantial and unequivocal data in regard to a beneficial skeletal effect of fluoridated water.

Fluoridated Water and the Appearance of the Teeth

The protocols of fluoridation trials did not overlook the necessity of
evaluating the occurrence of dental fluorosis. Blayney and Hill stated in their Evanston fluoridation report:

When a community is debating the subject of water fluoridation, one of the questions often asked is, "Will my child's teeth be discolored?" To provide a definitive answer to this question we recorded our findings for each child at each examination. Every effort was made to differentiate between the round idiopathic type of opacities and the linear or rectangular forms associated with fluoride. Not a single opacity was observed in the deciduous dentition. None of the subjects who had dental fluorosis had the type that could be recognized during a social conversation. The most common areas of involvement were on the cuspal ridges of the bicuspid teeth. No community that has already fluoridated or is considering fluoridating its water supply need fear an undesirable esthetic effect on the teeth of the children reared in the area.

This opinion is adequately supported by observations made in Grand Rapids, Newburgh, and Brantford and is in agreement with the minimum of undesirable fluorosis which Dean found in his surveys of waters containing 1.00 ppm fluoride. These observations eliminated concern regarding unsightly dental fluorosis as an effect of fluoridated water.

Current use of the terms mottled enamel and dental fluorosis is misleading and unfortunate. Thus, "mottled enamel" may designate a "questionable," "very mild," "mild," and "moderate" effect of fluoride as well as "severe" and "very severe" objectionable effects of fluoride. Furthermore, the word "mottled" is used to describe malformed enamel having white spots, and other defects which are not the result of fluoride. "Questionable," "very mild," "mild," and even some "moderate" mottled enamel classifications are not disfiguring because they do not cause the cosmetic impairments characteristic of "severe" and "very severe". Møller's excellent color photographs illustrate this fact most strikingly (See plate facing page 72).

Møller stated that mottled enamel classified as optimal had a creamy color, looking somewhat like mother-of-pearl and clinically deemed to be ideally mineralized, without signs of dental fluorosis, enamel hypoplasia, or other defects in enamel structure (18).

There is a consensus that an optimum quantity of fluoride may actually enhance the appearance of the teeth. Many investigators in their reports of studies on the anticaries effects of natural fluoride waters have mentioned the frequent occurrence of whiter teeth, especially pleasing in appearance, with 1.00 ppm or slightly more fluoride in the water.

Dr. Gerald J. Cox expressed his ideas of the situation in 1954 (19):

"Mottled enamel," or any of the other terms used to describe the malformed enamels which develop during the ingestion of excess fluoride, is not a proper term to apply simultaneously to the beautiful white teeth that result from ingestion of the most favorable amounts of fluorine. The term "fluorosed enamel" could be used for the latter situation because of its good semantic values until we have reached the stage of maturity of recognizing this type of enamel as merely normal. Such bad names as "mottled enamel"
wrongly applied are obstacles to the achievement of the best that can be had in reduction of dental caries incidence as promoted by fluorine in the formation of enamel.

Recently Drs. Viron L. Diefenbach, George A. Nevitt, and John M. Frankel (20) made a special study of fluoridation and the appearance of teeth. They described a method to classify subjectively the appearance of teeth into four broad categories primarily according to color. These categories (1, 2, 3, and 4) are illustrated in the accompanying color plate. This classification was cataloged in communities having different fluoride concentrations in the water supplies, Neosho, Mo. (0.1 ppm), Grand Prairie, Texas (1.6–2.8 ppm), and Bartlett, Texas (8.0 ppm). Altogether 2,332 children were examined in groups of younger than 11 years, 11 and 12, 13 and 14, 15 and 16, and 17 and over. They were classified “resident” or “non-resident” in the community according to a questionnaire completed for each individual.

The authors concluded from this study, “Even using rigorous criteria, we found teeth of enhanced appearance more frequently in children who were native-born and continuous residents of the communities having an optimal or slightly higher fluoride level in the water supplies than in children who were reared where water supplies had either a deficiency or an excess of fluoride.”

Dr. Diefenbach is an authority on tooth appearance vis-a-vis fluoridation. He has published a popular story titled “Putting the Smile on Young Faces,” published in Today’s Health in February, 1967, in which he wrote, “Most of us would agree, I believe, that teeth that are white or bluish-white, that are sparkly and lustrous, even and regular, that have a shiny, translucent quality, would be considered prettier than teeth of an ordinary or yellowish-white appearance, or teeth which are lackluster, striated, or chipped.” These “handsome teeth” are without doubt an asset to good-looking faces, undeniably an important advantage to both girls and boys who are fortunate enough to grow up in a fluoridated area. They will have healthier teeth and “they will flash more beautiful teeth” wrote Diefenbach, and he has the support of numerous other investigators who would agree that beauty is a part of the fluoridation story.

Forrest has studied mottled enamel extensively in England (21). She emphasized that in the lowest grades, “questionable” or “very mild,” there is no unsightly disfigurement of the teeth. “Careful examination is required to detect the few white flecks or spots which occur on some of the teeth and it is difficult to distinguish them from very similar dystrophies which have no connection with fluoride.” In England she found that enamel defects occurred more frequently and were often more unsightly in the non-fluoride areas than where 1.0 ppm fluoride was present in the water. At this level the teeth were “well formed and excellent in appearance.” She suggests “that this level of fluoride is necessary for good tooth formation.”
Climate and Controlled Fluoridation

Environmental factors affecting consumption of fluoridated water have been evaluated extensively by Donald J. Galagan, formerly Chief, Division of Dental Public Health and Resources, U.S. Public Health Service, and his associates (22, 23, 24, 25). The basic concern of this research was to maintain a maximum cariostatic effect while eliminating all likelihood of any occurrence of objectionable dental fluorosis, by adjusting the fluoride in the water according to local climatic conditions. Their first research protocol was based on the premise that if objectionable fluorosis was not associated with fluoride levels around 1.0 ppm in areas with extremely high temperatures, then at least that concentration would be desirable in the supplementation of fluoride-deficient water in practically all parts of the United States.

Communities chosen for this study were Yuma, Tempe, Tucson, Chandler, Casa Grande, and Florence, Ariz. Mean fluoride in Yuma water was 0.4 ppm. In the other communities, in the order listed above, fluoride in drinking water was 0.5, 0.7, 0.8, 1.0, and 1.2 ppm.

These six communities met the necessary requirements for investigation. They had water supplies with adequate continuity and with fluoride concentrations ranging around 1.0 ppm. They were of sufficient size to yield a sample of native-born children large enough to be significant. They had mean annual temperatures ranging from 67 to 72°F, with an average mean annual temperature of approximately 70°F. This area is consistently reported as one of the hottest inhabited areas in the United States, exceeded in temperatures only by certain communities adjacent to Death Valley, Calif.

The mean maximum temperature of the six communities varied from 82.5 to 87.8°F. Mean relative humidity was 37 percent, with 80 to 85 percent of possible sunshine and very high daytime temperatures.

Mottled enamel was recorded for 726 children aged 9 to 16 having a history of continuous residence in their respective communities. The fluorosis data converted to a community fluorosis index were compared with similar data for ten midwestern communities where the mean temperature varied from 49.4 to 32.1°F. Although the two groupings of data may be subject to some error because of examiner differences, they indicate that the children residing in the Arizona communities developed approximately twice as much dental fluorosis as midwestern children exposed to water containing the same concentrations of fluoride. Mottled enamel data are shown in Figure 2. The conclusion from this study is obvious. Arizona children drink more water than children living in more temperate climates and the quantity of fluoride ingested is correspondingly increased.

In light of the significant differences in mottled enamel indexes of these two groups of communities, Galagan also documented dental caries experience as a criterion of the fluoride exposure. He wrote:

The similarity between the upper limits of the midwestern rates and the lower limits of the Arizona rates is evident. Even though determined on a limited number of observations in Arizona, these data also suggest that the
Teeth that are representative of four categories.

Category 1: — Pearl white to bluish white color

Category 2: — White flecks or thin white bands

Category 3: — Cream white color

Category 4: — Opaque chalk white color
children in the Southwest area are ingesting about twice as much fluoride as children in midwestern communities where the water supplies contain comparable fluoride concentrations.

The mean annual temperature is the most practical measurement of climatic conditions affecting drinking water consumption, and fluoride concentration should be adjusted to this climatic variable. One to 1.2 ppm of fluoride was considered optimum in zones comparable to the Great Lakes area, whereas 0.6 ppm was considered equally effective in areas similar to southern Arizona.

Exact data on the fluid intake of children was recognized as the most desirable basis for determining the optimum fluoride concentration of drinking water. In cooperation with J. R. Vermillion, Galagan measured the fluid intake of children in Antioch and Brentwood, Calif., and obtained data indicating that for every degree increase in maximum daily temperature between 50 and 100° F, water intake increased on the average by 0.062 ounces per pound of body weight. Based on the mean maximum temperature for at least a five-year period for the community in question, and similar data for an area where the optimum fluoride concentration is known, a formula was devised to calculate the recommended optimum fluoride concentration for the area in question. The basic structure of the formula developed for estimating optimum fluoride concentration is: parts per million of fluoride equals optimum
water consumption divided by estimated water consumption. Thus, the optimum fluoride concentration for a given community is equal to a constant (the average amount of water containing 1 ppm fluoride that affords optimum protection against dental caries), divided by the estimated water consumption of children in a given community. Both measures are in ounces of water consumed daily per pound of body weight. This formula is now the basis of an official directive on the permissible fluoride content of water, presented in Public Health Service Drinking Water Standards as revised in 1962.

This official report states the fluoride standard as follows: "Where fluoridation (supplementation of fluoride in drinking water) is practiced, the average fluoride concentration shall be kept within the upper and lower control limits" as shown in Table 2. "Presence of fluoride in average concentrations greater than two times the optimum values (shown in the table) shall constitute grounds for rejection of the supply."

**Table 2. Official control limits for fluoridation. Temperature data is based on data obtained for a minimum of 5 years.**

<table>
<thead>
<tr>
<th>Maximum daily air temperatures (annual average)</th>
<th>Recommended control limits (fluoride concentrations in mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0-53.7</td>
<td>Lower Optimum Upper</td>
</tr>
<tr>
<td>53.8-58.3</td>
<td>0.9  1.2  1.7</td>
</tr>
<tr>
<td>58.4-63.8</td>
<td>0.8  1.1  1.5</td>
</tr>
<tr>
<td>63.9-70.6</td>
<td>0.8  1.0  1.3</td>
</tr>
<tr>
<td>70.7-79.2</td>
<td>0.7  0.9  1.2</td>
</tr>
<tr>
<td>79.3-90.5</td>
<td>0.7  0.8  1.0</td>
</tr>
</tbody>
</table>

Recently a comprehensive five-year study was conducted by the Division of Dental Health, California State Department of Public Health (26). More than 9,000 children aged 12 to 14 years living in 18 specific fluoride-temperature zones were examined for caries and dental fluorosis. More than 100 communities in six states were studied. The significant effect of an increase in temperature on the dental effects of use of a fluoride water are brought out dramatically by this excellent study. The data show, for example, that an environmental temperature of 65° F or lower, and 80° F or higher (where 1.1–1.3 ppm fluoride was present in the drinking water) resulted in 22.2 ± 2.8 percent of caries-free children in the lower temperature range and 48.1 ± 2.8 percent caries-free children in the higher. The effect of environmental temperature on water consumption is convincingly evident in these dental examination data. Regarding the occurrence of dental fluorosis the investigators' data show, as was to be expected, that "when the fluoride level or ambient temperature is increased, with the other held constant, a greater percentage exhibit clinical evidence of fluorosis in the teeth." These findings
generally agree with the data reported by Galagan and others. Optimum fluoride concentrations for the three mean maximum temperature ranges are: 65° F or lower, 1.2 ± 0.1 ppm; 66 to 79° F, 0.9 ± 0.1 ppm; 80° F or higher, 0.6 ± 0.1 ppm. Findings from the study thus provide data of importance to all parts of the United States and other countries interested in establishing optimum fluoride levels in community water supplies for health improvement.

Engineering and Economic Aspects of Water Fluoridation

The addition of fluoride to a municipal water supply is basically similar to the addition of various other water treatment chemicals, the principal difference being the requirement of absolute accuracy of feed rate. As with other water treatment chemicals a choice of compounds to perform the necessary function is available. Important factors in selecting a fluoridation process include size of plant, number of application points, equipment costs, pressure at application point, storage space, and maintenance and handling convenience. A small water plant may choose more expensive sodium fluoride since it can be used with a small proportioning pump and a saturator, instead of a costly dry feeder required for less expensive sodium silicofluoride.

Five compounds are now being used for water fluoridation. In decreasing order of cost they are: fluosilicic acid, sodium fluoride, ammonium silicofluoride, sodium silicofluoride, and fluorspar. Each of these compounds possesses physical characteristics which govern the choice of equipment. Fluosilicic acid, a liquid, must be fed with a proportioning pump or by a rotary feeder. Sodium fluoride may be administered with a dry feeder, either volumetric or gravimetric depending on size of installation, or in a solution prepared and fed the same as fluosilicic acid. The solubility of sodium fluoride also permits use of a saturator, a device which automatically prepares solutions of fixed concentration. Ammonium silicofluoride may be used with either dry or solution feed, while sodium silicofluoride, having limited solubility, must be fed with one of the types of dry feeders. Fluorspar, which is practically insoluble in water, must be dissolved in an alum solution and fed with a solution feeder. Dust-control devices for personnel are required when finely powdered materials are being used, and where dissolving chambers with dry feeders are used, as well as scales to check the weight of material being fed. The devices are required also where bag-loading hoppers for bagged chemicals are needed, water softeners are needed for water in solution preparation, and where hopper agitators are required for dry materials which do not flow smoothly. Because of the corrosive nature of concentrated solutions of fluoride salts and acids, the construction materials become a factor in choosing the fluoridation mechanism (27, 28).

The overall cost of providing fluoridated water depends not only on
the cost of the fluoride chemical but on the size and degree of sophisti-
cation of the water plant installation. Striffier, et al. (29) demonstrated
the feasibility and economy of installation and centralized monthly
maintenance of fluoridated water systems for small rural communities.
Serving populations ranging from 70 to 760 persons, 25 rural water sys-
tems were fluoridated successfully with a minimum of technical diffi-
culty. A typical installation cost about $100.00, and the annual per cap-
ita cost was $1.22 in the mid-sixties. A relatively inexperienced san-
tarian was trained to install and maintain the systems with only mini-
mal supervision.

As the size and complexity of a fluoridating installation increases, so
does its initial cost and the costs for labor, materials, and maintenance.
Although an extremely large fluoridation installation may cost in the
hundreds of thousands of dollars and require additional personnel, cost
to the consumer is actually less than for a smaller installation. At cur-
rent prices large cities can fluoridate their water supplies at a cost of
approximately $.10 per person per year.

Ingram and Moore (28) showed the cost of fluoridation in the late
fifties in Figures 3 and 4.

Reduced Costs of Dental Care

The saving in cost of dental care which results from use of fluori-
dated water in Newburgh as against Kingston, New York, was reported
by Ast, et al. (30). Kingston children averaged 8.3 times as many DMF
teeth and 2.4 times as many def teeth as Kingston children. After care-
ful evaluation of variable factors involved in this study, the authors re-
ported that cost of initial care per child each year in Kingston was
about 2.3 times that in Newburgh, and 1.9 times more in cost of incre-
mental care, based on three years of initial care and two years of annual
incremental care. The mean annual cost per child for initial care was
$11.92 in Newburgh, $27.61 in Kingston. Incremental care per year cost
$6.17 per child in Newburgh and $11.81 in Kingston. The consensus
that fluoridated water will reduce costs of dental care is supported by
these Newburgh and Kingston observations.

Dr. Hillis S. Ingraham, New York State Health Commissioner, dis-
cussed fluoridation's potential savings for parents and government pro-
grams in an editorial in the September, 1968, issue of Health News of
the New York State Department of Health. Dr. Ingraham related his fig-
te to a hypothetical community of 100,000 people. In such a popula-
tion, roughly 35,000 are under 21 years of age of which approximately
one-fourth are eligible for dental care under Medicaid. If this commu-
nity did not have a fluoridated water supply, the cost of treating these
children under Medicaid would come to $137,000. In a fluoridated
community of the same size, the cost would be less than half, $63,000.
Adding the $6,000 annual cost of fluoridation in a community of this size, the dollar savings to the community with fluoridated water comes to something over $16,000 a year in local Medicaid costs. Another $48,000 would be saved in state and Federal funds.
Fig. 4.—Annual fluoridation costs per capita.

The $65,000 a year savings is money saved from local, state, and Federal treasuries. It does not include the savings of parents who pay their own dental bills, an average of $8 a year for each child.
NOTES AND REFERENCES


CHAPTER TWELVE

ALTERNATIVE USES OF FLUORIDE

At the 54th Annual Meeting of the Fédération Dentaire Internationale (FDI), held in Tel Aviv, Israel, in July, 1966, a special joint subcommittee, consisting of Drs. Finn Brudevold, U.S.A.; Yngve Ericsson, Sweden; G. N. Davies, Australia; Jamil Kostlan, Czechoslovakia; Thomas Marthaler, Switzerland; with Drs. John Knutson and Seymour J. Kreshover, U.S.A., as co-chairmen, presented a report concerning the status of alternatives to water fluoridation. The report took note of the fact that the FDI approved water fluoridation in 1953 and continued to regard fluoridation as the first choice where communal water supply systems were available. Although aware of the fact that alternative vehicles for using fluorides for dental caries prevention were less supported by research and experience than fluoridated water, the FDI approved their selective use. It was recommended that promising alternatives be actively promoted where communal drinking water was not available or not being fluoridated.

The effectiveness, the cost, problems of administration, and the scope of testing of alternatives vary widely. Many variable local factors greatly influence the selection of a suitable alternative. The committee reported that staple foods such as salt, flour, bread, and rice may possibly become suitable vehicles for the dietary administration of fluorides. Fluoridated salt has been tested extensively and is the first choice for fluoride supplementation. Fish protein concentrate, recently approved as a desirable protein supplement, may become a source of supplemental fluoride in the diet of infants and children. Fluoridated milk cannot be considered seriously as suitable. Flour may have some advantages in certain European countries.

As the committee report indicated, substantial caries prevention can be affected by a topical application of fluorides. Improvements in the topical fluoride solution and modifications of the treatment procedure have developed rapidly and have enhanced the potential value of this alternative. Nevertheless any individual method is time-consuming and may be expensive and difficult to administer on a public health scale. Group methods of spraying, rinsing, or brushing for application of fluoride to the teeth seem preferable, and may be more economical and practical particularly if performed at a natural congregating center.
such as a nursery or in the school classroom. The limited accessibility of toothbrushes and toothpastes to people in primitive or developing countries sharply restricts the applicability of this preventive measure. Dentifrices obviously are widely advocated and in use in most advanced countries.

Fluoride Tablets

The cariostatic value of a daily fluoride supplement has been studied according to an individual, parent-supervised regimen, as well as under conditions of a school-supervised program (1, 2, 3). A review of the use of fluoride tablets was published by Gedalia (4). Studies showed that daily ingestion of fluoride in a prescribed amount in the form of a tablet brought about a reduction in caries. In a 4-year program started in Hessen, Germany, in 1952, 8,381 children 6 to 9 years old (grades 1-3) received 2.21 mg sodium fluoride (1.0 mg fluoride) tablets, administered largely by school authorities (5). After three years the dental status of these children was compared with that of 5,335 control children. A similar four-year program in Germany also compared 13,585 children receiving fluoride tablets with 4,975 controls. The two fluoride groups in these studies showed a reduction of 20 to 22 percent in dental caries. It was concluded that fluoride tablets, although started at 6 years or older, were effective under conditions provided by school supervision. A similar three-year study involving more than 1,000 Marburg, Germany, school children, and continuing up to the third grade, indicated a 33 percent lowering of the dental caries experience. An earlier study had indicated a 35 percent reduction in caries incidence among 650 school children who were six years old when they started taking fluoride tablets.

The value of fluoride tablets was studied in a home setting by Arnold, McClure, and White (6). Included in this study were children who started taking the tablets soon after birth; nearly two-thirds began the tablets before their third birthday. There were 121 children from 4 to 15 who ingested 1.0 mg fluoride as sodium fluoride daily (under parental supervision) for an average of two-thirds of their lives. Dental examinations showed a reduction of caries in both deciduous and permanent teeth which compared favorably with the use of drinking water containing 1.0 to 1.2 ppm of fluoride (Fig. 1).

As in the use of fluoridated drinking water an ideal fluoride tablet therapy is aimed at providing an optimum daily quantity of fluoride throughout the developmental life of the enamel and dentin. There are unresolved questions regarding the age of initiation and the initial preferred quantity of fluoride in using fluoride in tablets. There has been no consensus that prenatal fluoride has a significant effect in reducing dental caries in either deciduous or permanent teeth. It is generally recommended now that tablets containing 0.5 mg of fluoride may be started shortly after 6 months and continue to 3 years, at which time a 1 mg tablet should be ingested daily until the child is 8 or 10 years old.
Fig. 1a, b.—Comparison of cariostatic effects of sodium fluoride tablets, fluoridated water, and non-fluoridated water.
No advantage except convenience of administration can be claimed for the simultaneous administration of fluoride with a vitamin supplement. A fluoride tablet supplement is contraindicated where the drinking water contains 0.7 ppm or more fluoride.

The evidence of value of fluoride tablets administered in a school setting has had its counterpart in a study of the effect of fluoride added to milk supplied as a part of a school lunch program (7). During approximately three and a half years dental caries data were obtained on young children to whom half a pint of milk containing 1.0 mg of fluoride was given at an initial age of 6 years as a part of their daily school lunch. According to this study the most significant caries reduction, approximately 70 percent less caries incidence, occurred in teeth which erupted following use of the fluoridated milk. A year and a half after termination of the fluoride program about 50 percent less caries was present in the fluoride group of children. Teeth newly erupted at age 6 showed some benefit of this additional dietary fluoride. While milk was the fluoride carrier in this study, there is no consensus that this result can justify using fluoridated milk for caries control. As a public health procedure there is an obvious lack of control and regularity of consumption of fluoride.

In light of the benefits obtained by administration of tablet fluoride in a school program and in milk with the school lunch, it is evident that in school age children and even lacking the desired regularity of daily use, fluoride supplementation may have cariostatic significance. In other words, continuous regular daily exposure to supplementary fluoride from birth throughout formative tooth life to age 8-10 years is not a sine qua non for some caries prevention. This recalls the evidence where cariostatic effects result from using fluoridated water after tooth eruption.

Difficulties surrounding community use of fluoride tablets are reflected in reports of attempts to implement such a program. Distribution of tablets was not successful due to lack of interest and initiative by parents even though the tablets were free. They soon voiced preference for water fluoridation instead of having to provide a tablet every day for their children. These experiences discredit the proposals of local officials who oppose water fluoridation on the grounds that free fluoride tablets can be provided and the parents can come and get them. No doubt practical problems of administration can prevent the achievement of even minimum benefits from using tablet fluoride both as a community health program and in a home setting.

Salt Fluoridation

As a universal component of human diets, salt is second only to drinking water. It is possible, therefore, for fluoridated salt to be utilized practically and effectively as a source of fluoride. Fluoridated salt would suffice in rural homes and in the many areas of the world which
do not have, nor will have for years to come, a fluoridated communal water supply. In addition to worldwide consumption, salt is comparable to drinking water because it is a component of the average diet throughout life. Its advantage as an automatic source of supplemental fluoride is obvious.

The first and one of the foremost advocates of salt fluoridation was Dr. H. J. Wespi, Department of Obstetrics and Gynecology, Cantonal Hospital, Aarau, Switzerland (8, 9), who evaluated the fluoridation of cooking salt in Switzerland on an individual basis. In Sweden Dr. Gunnar Santesson measured salt ingestion and the practicability of fluoridated salt as an alternative to water fluoridation (10).

Fluoridated salt was made available as a food with a prophylactic purpose in Zurich in 1955. Wespi compared the efficacy and practicability of fluoridated salt with iodized salt which was introduced in Switzerland in 1922. By 1961 fluoridated and iodized salt containing 200 mg of sodium fluoride and 10 mg of potassium iodide per kg was available in 16 of the 25 Swiss cantons. Wespi noted in 1961, "The fact that fluoridated salt has spread out over more than half of Switzerland in less than six years seems to be proof that salt fluoridation is considered by our authorities as a practicable means of replacing water fluoridation, because it is simple, cheap, and does not include any compulsion." This alternative to water fluoridation has special significance in Switzerland because many areas have no communal water supplies.

Dr. Thomas Marthaler (11) and Marthaler and Sahenardi (12) published data showing the reduction of caries in children after five and a half years of use of fluoridated table salt. According to a previous study including 600 children in three age groups, fluoridated table salt had produced only a limited cariostatic effect. In a second study, as in the first, the salt contained 90 ppm of fluoride as sodium fluoride. The 1,241 children lived in Wadenswil, a community of 12,000 on the Lake of Zurich. The decision to use fluoridated table salt was left to the parents and the limited effect that resulted may have been due to lack of continuity and insufficient fluoride. Caries reduction was evident only in 5- to 7-year-old children who had used the fluoridated salt regularly, but this inhibition was statistically significant and was most pronounced in the proximal and buccolingual surfaces.

A question which Muhlemann discussed at length in 1967 (13) was whether fluoride in the salt should be increased to afford a fluoride intake comparable to the use of water containing 1 ppm fluoride. Concerning the average daily consumption of salt and drinking water, Marthaler and Sahenardi had written:

In demonstrating the analogy between naturally fluoride-containing and artificially fluoridated water, this concentration (1.0 ppm) was adopted while little attention was paid to individual variations in water intake. On the other hand, the attention paid to individual variations in salt consumption since its introduction, and the lack of occurrence of naturally fluoridated salt resulted in a low fluoride concentration, chosen with respect to individual
observations on people consuming large amounts of salt. Extensive studies by Kruger, however, revealed extremely large variations of water and other fluid intake, comparable to the variability of salt intake. In order to arrive at the recommended daily fluoride intake, Dr. Wespi suggests introducing table salt with 200 milligrams of fluoride per kilogram, salt which would be safe according to his and Aeppli’s observations.

Marthaler and Sahenardi suggested that the first two or three years of life might be relatively unimportant for the cariostatic effect of fluoride. They cited data from the Newburgh-Kingston and Grand Rapids fluoridation studies in support of this conclusion and were not disturbed by the possibility of a low consumption of salt during the first years of life. They wrote, “A study of salt consumption in infants, children, and adults points to a rather striking parallelism of salt and water intake.” Numerous data concerning daily consumption of salt, most of which apply to young and middle-aged adults, indicate variations comparable to the variations in daily consumption of drinking water.

Additional information on fluoridated salt is now being accumulated from a comprehensive study in progress in Colombia (14). Don Matias, San Pedro, Montebello, and Armenia, isolated villages which lie within 30 miles of Medellin, are the sites of this study. Dr. Herman Velez, of the medical faculty of the University of Antioquia, is directing the project supported by a grant from the National Institute of Dental Research. The isolated, practically immobile populations of these villages are particularly desirable for this study. Dental caries rates are very high (the staple of the diet is sugar cane) and few dentists are available. Extensive rural areas lack public water supplies. Salt is a govern-

Children being examined in Colombia
ment monopoly in Colombia and for this study salt distribution, both fluoridated and non-fluoridated, is adequately controlled by Velez in cooperation with government authorities.

This study provides for annual dental examinations, accumulation of data on salt consumption, and study of native dietary habits. The urinary excretion of fluoride followed closely will serve as a criterion of the level of fluoride ingestion by the use of fluoridated salt, and thereby indicate the optimum quantity of fluoride to add to the salt. One of these villages has a community water supply which is fluoridated, another uses salt fluoridated with calcium fluoride, another adds sodium fluoride to the salt, and a fourth serves as a control. Calcium fluoride (fluorspar) is abundant in Colombia and is much less expensive than sodium fluoride which must be imported. At the start of the study 100 ppm of fluoride were added to the salt. This quantity has now been increased because the urinary fluoride excretion associated with the use of the fluoridated salts did not equal urinary fluoride accompanying the use of fluoridated drinking water. Initial urinary fluoride data were: control village specimens averaged 0.23 ppm; sodium fluoride in salt, 0.55 ppm; calcium fluoride in salt, 0.59 ppm; and fluoridated water, 0.89 ppm. The fluoride additive will be increased in the salt to a level which results in a fluoride excretion comparable to use of fluoridated water. Wespi estimated that salt as used in Switzerland may have to contain as much as 200 to 250 ppm of fluoride in order to produce maximum cariostatic effects.

The similarity in urinary fluoride excretion resulting from calcium fluoride and sodium fluoride is indicative of their equivalence in systemic metabolism at this low level of ingestion. It is likely that they will have similar equivalence in cariostatic effect.

Fish Protein Concentrate

Whole fish protein concentrate (FPC) has been formally approved by the U.S. Food and Drug Administration as a safe and wholesome diet supplement. The major value of FPC lies in the fact that it may correct the protein malnutrition prevalent in many undernourished infants and children throughout the world. The quantity and high quality of protein in FPC equals if not actually exceeds the protein in milk and meat.

At this time FPC may be used as a food additive under prescribed conditions and specifications established by the U.S. Food and Drug Administration. Food and Drug Directive, No. 6, specifies that "the additive (FPC) shall contain not in excess of 100 ppm of fluorides (expressed as F)" and that "the additive is used or intended for use in the household only as a protein supplement in food. When consumed regularly by children up to 8 years of age, the amount of the additive in their total diet shall not exceed 20 grams per day."

The presence of fluoride in FPC obviously merits major interest from the public dental health community. The NIDR, as well as a Committee
of the Food and Nutrition Board of the National Research Council and other authorities, approve the provisions of the current directive of the Food and Drug Administration.

The use of FPC stands to be evaluated on the one hand in relation to the possibility of undesirable dental fluorosis, and to be looked at realistically as a practical source of fluoride for the prevention of dental caries. Obviously basic factors which require consideration are (a) the quantity and the physiological availability of the fluoride present in FPC and (b) the quantity of FPC ingested daily during formative tooth life from infancy to 8 to 10 years old. It seems undeniable, however, that the dental caries prevention which could occur from an optimum quantity of fluoride in FPC would far outweigh consideration of any likelihood of objectionable dental fluorosis. As was noted above, the FPC supplement is to be added to common foodstuffs such as flours, cereals, pasta, other special local foods, and perhaps bread. The quantities added may equal as much as 10 percent of the basic foodstuff. It is estimated that a daily intake of fluoride from FPC, added in such a quantity to a common food, would approximate 3.5 to 4.0 mg of fluoride. The physiological availability of the fluoride in FPC has been estimated to equal 50 to 70 percent. The information available is still equivocal but in actual practice the approximate ingestion of 3.6 mg fluoride daily during formative tooth life from FPC (containing 100 ppm fluoride and having a 50 percent physiological availability) is expected to be beneficial in the reduction of dental caries.

Official specifications concerning the permissible level of fluoride based on physiological availability of the fluoride in FPC are subject to change. Commercial processing whereby the fluoride is reduced to as little as 8 to 10 ppm is possible by gravity separation of the fish bones, the main source of fluoride in the product. It appears desirable, however, that the fluoride content of FPC be maintained at a level which has a potential for a substantial reduction in dental caries. The problem of what quantity of fluoride may be permissible and optimum in FPC is similar to the unresolved question now being studied of the optimum quantity of fluoride to be added to common salt. The acute need for adequate protein in underdeveloped countries throughout the world, however, necessitates continued intensive investigation relative to processing and use of FPC. This has become an essential and productive phase of the war on hunger that exists today and may also become a factor in the improvement of dental health.

Home-Fluoridated Water

It was estimated in 1965 that 44 million persons, about 23 percent of the population of the United States, do not have a central water supply. An approach to the problem of providing supplemental fluoride for children reared in these homes is to fluoridate water in the home or at the school building. The design and perfection of home fluoridators has
been explored extensively but may seemingly unanswerable practical problems thus far have defied solution (15, 16). The first home fluoridators were more or less miniature versions of municipal fluoridation procedures, consisting essentially of a small solution feeder or pump to inject a fluoride solution into the home water system at a point near the well pump. However, these small home devices have mechanical problems and require maintenance and surveillance. In a municipal water plant the fluoridation equipment is under supervision of competent personnel whose job it is to see to it that the equipment functions properly and continuously. In addition fluoride analyses should be made at regular intervals and calculations are based on the fluoride compound used and the volume of water treated. None of these services is available in the home. The best home fluoridator devised can not be totally maintenance-free nor can its operation be so reliable that fluoride analyses would be unnecessary. To leave the functions of maintenance and surveillance to the homeowner is impractical since experience has shown that home fluoridators are almost completely neglected when their care is left to the householder. The only solution is to provide necessary service much as is done with water-softening devices. With this arrangement the home fluoridation unit could be leased from a service company which provides maintenance and surveillance on a regular basis. While such an arrangement adds to the cost of home fluoridation there seems to be no other way to assure safety and effectiveness of fluoridation of a home water system.

School Water Fluoridation

Administration of supplemental fluoride tablets to school age children at their school has had a substantial value in caries control. Fluoride provided in drinking water at the school may also have value in the prevention of dental caries, even though this waterborne fluoride is available but five days a week, only part of the day, and not all the year around. The quantity of fluoride added to school water should be increased above 1.00 ppm with the objective of providing at least 1.0 mg of fluoride daily. Several school fluoridation projects have been undertaken where the water was fluoridated to contain from 3.0 to 5.0 ppm. The fluoridating equipment is identical to that used in small community water plants with surveillance and maintenance provided by school personnel or by a local health agency.

In 1956 Horowitz, Law, and Pritzker (17) initiated a pilot study of the value of school water containing 3.0 ppm fluoride. In 1962 a survey of dental caries in children whose school attendance had been entirely at the test school, compared with a control group of children, indicated an overall 21.9 percent reduction in caries experience attributed to the fluoridated school water. Horowitz, Heifetz, Law, and Driscoll (18) have reported results of use of 5.0 ppm fluoridated school water in Elk Lake School, Pa., and in Phelps and Feds Creek Schools in Pike Coun-
ty, Ky. The water in the Kentucky schools contained 3.02 and 2.96 ppm fluoride, respectively. The caries diagnosis after four years indicated an overall reduction of 24.5 percent in Pennsylvania children aged 6 through 17. After five years the Kentucky children showed an average caries reduction of 28.6 percent. After four more years (1966), the Elk Lake children showed a 33.9 percent overall reduction in caries. In Pike County children, the reduction had increased to 32.8 percent. Results after eight years of this study continued to indicate an appreciable reduction in caries. Observations on dental fluorosis showed that use of fluoride water at these levels did not result in any form of objectionable dental fluorosis.

Notwithstanding the cariostatic improvement observed in the above trials, additional studies are needed to determine optimum quantities of fluoride to add to school drinking waters. These alternative water fluoridation procedures are not now widely applicable and cannot reproduce the magnitude and duration of benefits which accrue from a fluoridated communal water supply.

Topical Application of Fluoride

John W. Knutson and Wallace D. Armstrong were the first to undertake an extensive demonstration of the caries-preventive value of a fluoride solution applied directly to tooth surfaces. Earlier studies, one by Basil G. Bibby and another by V. D Cheyne, had indicated that topically applied fluoride would inhibit caries.

The comprehensive study by Knutson and Armstrong began in March, 1942, in North Mankato, Arlington, and St. Louis Park, Minn. (19). The study started in the pioneer days of fluoride and dental caries history, although already there had been some discoveries:

1. It was quite certain that fluoride in drinking water had a significant beneficial effect on dental caries.

2. Volker, Hodge, Wilson, and Von Voorhis (20) had discovered that fluoride in solution is absorbed by powdered enamel, a chemical reaction between fluoride and enamel which has proved to have major significance as an in vivo chemical phenomenon occurring on outer surfaces of teeth.

3. Limited preliminary data by Armstrong and Brekhus had indicated that fluoride present in sound enamel was greater than in enamel of carious teeth (21).

4. There was evidence that fluoride could be increased in the erupted molar teeth of white rats (22), and that some posteruptive enamel fluoride could be due to in vivo oral surface absorption.

5. B. F. Miller in 1938 had shown for the first time that experimental rat caries could be reduced by fluoride (23). Altogether there was every reason to determine the possibility of reducing dental caries by a topical fluoride treatment procedure.

At the end of one year, data on the incidence of caries in the perma-
nent teeth of 289 topically treated children were compared with the caries experience of 326 control children. During the first eight weeks the treated children had received 7 to 15 topical applications of a 2.09 percent solution of sodium fluoride in the left quadrants of the mouth. Armstrong and Knutson continued the treatments for three years and summarized the results as follows (24):

During the three-year period ending May, 1945, the number of permanent teeth initially attacked by caries was 36.7 percent less in fluoride-treated than in untreated teeth.

During the third study year, or the year ending May, 1945, initial caries attack was 22.2 percent less in fluoride-treated than in untreated permanent teeth. This yearly difference is substantially less than that observed for the second year, 46.6, and for the first study year, 39.8.

Among permanent teeth which were carious at the beginning of the study in 1942, the number of additional surfaces which became carious during the three-year period ending May, 1945, was 23.9 percent less in treated than in untreated carious teeth.

There was great interest in these results. The potential value of a topical procedure looked very promising and caries prevention was further evaluated in relation to the number of topical applications. Arnold, Dean, and Singleton made a single topical application to the teeth of U.S. Coast Guard cadets (25). This trial gave no evidence that a single topical application to the teeth of young adult men had improved their dental caries experience.

Knutson and his associates conducted additional extensive studies concerned with the overall preventive value of topically applied fluoride, particularly in the permanent teeth of children. Four applications of a 2 percent solution of sodium fluoride preceded by dental cleansing appeared to give best results, effecting a 40 percent reduction in dental caries incidence. This inhibitory value was not appreciably decreased during a three-year period following treatment (26). The results of many topical fluoride studies are now in the literature.

Finn Brudevold and co-workers at the Forsyth Dental Center in Boston (27) have been especially productive in this field. Studies of solutions of sodium fluoride in acid sodium phosphate have indicated that fluoride in a fluoride-acid phosphate solution was especially available and adsorbed, and that the enamel surface tolerated these low pH solutions. Highly concentrated fluoride solutions acidulated with acetic acid and hydrofluoric acid were not effective. Reactions between an acid phosphate-fluoride solution and tooth enamel appear to be highly complex (as is also the case with pure fluoride solutions) but in general the additional fluoride appears to be present in the enamel essentially as fluorapatite. The evidence suggests formation of only small quantities of calcium fluoride. Evidently the phosphate in solution has a dual effect, depressing enamel dissolution and the formation of calcium fluoride.

The desirable properties shown by the acid phosphate-fluoride solu-
tion for topical treatment of tooth surfaces prompted clinical trials of
the effect of this solution on dental caries. The solutions contained 1.23
percent fluoride as sodium fluoride and 0.1 molar orthophosphoric acid,
and the pH was approximately 3. As a result of one two-year study, 115
children who received a single topical application of this solution had
approximately 70 percent fewer carious surfaces than 113 children who
served as controls (28).

An excellent review of clinical trials utilizing acidulated phosphate-
fluoride topical agents was published recently by Paul F. DePaola, an
associate of Brudevold at the Forsyth Dental Center (29). Statements
concerning the current status of this important area of preventive den-
tistry include:

The clinical testing methods available today are relatively unrefined, espe-
cially when compared to the methods available in the physical sciences. It
follows that treatment effects can be estimated only grossly. With proper ex-
perimential design and good statistical support it is possible to determine
whether a test method is effective or not, or whether several test methods
employed in the same investigation differ significantly in effectiveness. An
accurate quantitative assessment of caries inhibition, however, seems to elude
current testing methods as indicated by the fact that independent tests of
the same agent frequently show markedly different percentage reductions in
caries. This is because the experimental conditions of different investigations
often vary widely, especially with respect to diagnostic criteria. In reviewing
clinical findings, therefore, percentage reduction figures should not be inter-
preted too literally, and reductions from one study should be compared to
those of another with caution in order to avoid unwarranted conclusions.

DePaola also noted that acidulated phosphate fluoride (APF) has
been tested in the form of a dentifrice, a brushing solution, a spray, a
gel, and a supplement (30), and commented:

The effectiveness in terms of percentage DMF surface reductions for all of
the different APF agents tested has ranged from 6 to 80 percent. Dividing
this range into thirds, methods producing reductions of 6 to 27 percent may
be considered as having a low order of effectiveness, while 28-47 percent
would represent moderate effectiveness and 48-80 percent would be high.
With this scheme two methods may be categorized as highly effective: the
daily six-minute use of a gel and tray and the daily use of chewable fluoride
supplements initiated prior to the eruption of the benefiting teeth. The
former method requires about 30 minutes of professional time for the fabri-
cation of trays and instruction to the patient. Thenceforth a high degree of
patient cooperation is essential to success. The use of fluoride supplements
requires virtually no professional time except for instruction but, again, ef-
fectiveness depends strongly upon the conscientiousness of the patient.

In the category of moderate effectiveness is the semi-annual topical appli-
cation and the semi-annual fluoride prophylaxis. In these instances, no patient
cooperation is required but professional time is considerable. There is no
reason, incidentally, why the APF prophylaxis and topical application could
not be combined in an effort to maximize the fluoride exposure of the teeth.
Clinical evidence relating to this approach has not yet appeared, but the
favorable results obtained from the combined use of stannous fluoride pro-
phylaxis pastes and topical solutions suggests a cumulative effect with multi-
ple agents.

There is general consensus that acidulated phosphate fluoride in all
of its forms is as effective as if not better than stannous fluoride. Phosphate-fluoride formulations permit use of a gel form which is not possible with a tin-fluoride combination. It is not the last word in topical treatment solutions, but at present it appears the most effective for adding maximal amounts of fluoride to the enamel rapidly and without demineralization.

Of major interest in the topical treatment procedure is the role of stannous fluoride as a caries-preventing agent. Topically as well as in a dentifrice, stannous fluoride continues to be extensively tested clinically and subjected to various laboratory and animal tests. In a majority of the numerous clinical tests there has been some caries-preventive effect.

Dr. Joseph C. Muhler and his group at the Indiana University School of Dentistry are major proponents of stannous fluoride as a caries preventive in topical treatments as well as in a dentifrice and prophylactic paste (31). They formulated a stannous fluoride dentifrice labeled "Crest," now a product of the Procter and Gamble Company and officially endorsed by the American Dental Association. But unusually significant cariostatic benefits of stannous fluoride have not been confirmed uniformly by other investigators. It remains doubtful if there is a particular value in this form of fluoride over sodium fluoride, sodium monofluoride phosphate (32), or perhaps other fluoride compounds now being added to dentifrices. Research on stannous fluoride at the Indiana University School of Dentistry continues unabated and practically all the results continue to indicate an unusually striking caries prevention. Recently, Muhler, Bixler, and Stockey reported results of a study on the clinical effectiveness of stannous hexafluoro-zirconate (33) and summarized:

A series of two independent clinical studies were conducted with children who used a new fluoride compound, stannous hexafluoro-zirconate. The data obtained in these studies indicate that a one-minute topical application of SnZrF₆ resulted in caries reductions in DMFT and DMFS of 99 percent and 96 percent and of 81 percent and 76 percent, respectively, in two independent clinical studies conducted by two different examiners. These data further indicate that the effectiveness of this new agent may be considerably greater than that of SnF₂.

Scola and Ostrom (34) have completed a two-year study of stannous fluoride as a constituent of a prophylactic paste (17.5 percent SnF₂) used for an annual topical application, an aqueous solution (10 percent SnF₂), and a dentifrice (0.4 percent SnF₂) for daily home use. The subjects were adult male Naval personnel on active duty. In summary, the authors stated, "After 2 years, the groups that received the three-agent SnF₂ treatment had the greatest reduction in dental caries." The anticaries effects were not particularly striking, considering all the sources of stannous fluoride that were involved.

A special issue of British Dental Journal for July 4, 1967, reports the results of five independent fluoridated toothpaste trials conducted in
Great Britain which were fully controlled by means of the double-blind technique. The size of the sample groups was adequate and the duration of the studies of sufficient length to demonstrate real differences between groups. The examiners were thoroughly familiar with the conduct of large-scale clinical trials and all teams included at least one member with extensive previous experience.

The trials indicated beneficial effects of fluoride-containing pastes. The reductions in caries were encouraging but "are nothing like so great as can be achieved when water is fluoridated. This must be fully realized, not only by the profession but the public as well, and there must be no relaxation of effort to secure water fluoridation throughout Great Britain."

All of these studies included a stannous fluoride dentifrice, and while caries reductions from use of all the dentifrices were significant, this dentifrice was not any more effective than one containing sodium monofluorophosphate. The consensus of all the trials was that staining of the teeth had resulted from use of the stannous fluoride.

Much research obviously remains to be done on the cariostatic value of fluoride applied topically to tooth surfaces. With continuing advances and improvements in therapeutic solutions and in techniques of application, it appears most likely that self-administration will become the most practical procedure for topical application of a cariostatic agent.

A comment by a secretary in our office seems apropos. This young lady ventured the remark that the endless displays of fluoride dentifrices together with radio and TV advertising have performed an unprecedented service by making "fluoride" a universal household word. Hopefully this publicity, false as it may be in some respects, will have favorable value in the promotion of water fluoridation.

NOTES AND REFERENCES


CHAPTER THIRTEEN

BIOLOGY AND SAFETY

NON-DENTAL physiological effects and safety of 1.0 ppm fluoride in drinking water was discussed in 1946 by McClure (1). While the intervening two decades have seen many significant advances in knowledge of fluoride, major basic concepts which appeared sound at that time and gave assurance of the safety of fluoridated water have remained essentially unchanged.

From the very beginning of fluoride biochemical research, clinical and experimental studies consistently confirmed the fact that the most pronounced characteristic of fluoride metabolism in all animal life is its retention in skeletal and dental structures. As a consequence the major health problem resulting from fluoride ingestion was to be identified with the accumulation of intolerable quantities of fluoride in bones and teeth. The essential protection against fluoride toxicosis is the avoidance of accumulation of fluoride in skeletal and dental tissues.

As stated in 1954 by Harold Hodge and Frank A. Smith (2):

Considerations of the metabolism of fluorides in the body increase our conviction of the safety of water fluoridation. The body possesses two potent detoxification mechanisms: (1) rapid excretion in the urine and (2) rapid storage in the skeleton. Deposition in bone mineral, although it increases the content of fluoride in the body, is harmless per se and is not permanent; mobilization and excretion continuously remove fluoride. Even if all the fluoride ingested in the drinking water (1 ppm) in a life-time were stored in the skeleton, no injury would thereby accrue.

Fluoride Ingestion Via Food and Water

Fluoride is a normal component of all food; its occurrence in human diets is unavoidable and a constant supply is assured. Dr. H. H. Mitchell and Marjorie Edman of the University of Illinois in 1953 discussed fluoride as a nutritional factor in the economy of man (3). They pointed out that although fluoride is invariably present in the diet and is a normal constituent of body tissues, it does not have the dimensions and properties which define an essential body nutrient. Numerous attempts have been made to obtain proof of an indispensable requirement for fluoride but this proof is still lacking. The ubiquitous occurrence of fluoride in nature has made it virtually impossible to prepare a diet which is entirely free of fluoride. It seems evident, however, that if
fluorine is essential for life its daily requirement is extremely small. Laboratory animals have been raised successfully on synthetic diets containing as little as 0.5 ppm fluoride, indicating that the required quantity is more than likely less than 0.5 ppm. As Dr. Mitchell and Miss Edman state, “An extremely small requirement indicates that if fluorine is toxic its toxicity would be evident in homeopathic doses.”

Fluoride has an indisputable beneficial role as a dietary nutrient. It is the most potent weapon known to combat dental caries.

Fluoride in Food

Where water supplies are low in fluoride and in constant domestic use, food is the major source of fluoride. The fluoride content of foods from various parts of the world is reported extensively in the literature and a compilation of such analytical data is shown in Table 1 (†).

**Table 1. The fluoride content of foods.**

<table>
<thead>
<tr>
<th>Food</th>
<th>Fluorine (ppm)</th>
<th>Food</th>
<th>Fluorine (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorine reported in food as consumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>0.07-0.22</td>
<td>Pork chop</td>
<td>1.00</td>
</tr>
<tr>
<td>Egg white</td>
<td>0.00-0.60</td>
<td>Frankfurters</td>
<td>1.70</td>
</tr>
<tr>
<td>Egg yolk</td>
<td>0.40-2.00</td>
<td>Round steak</td>
<td>1.30</td>
</tr>
<tr>
<td>Butter</td>
<td>1.50</td>
<td>Oysters</td>
<td>1.50</td>
</tr>
<tr>
<td>Cheese</td>
<td>1.60</td>
<td>Herring (smoked)</td>
<td>3.50</td>
</tr>
<tr>
<td>Beef</td>
<td>&lt;0.20</td>
<td>Canned shrimp</td>
<td>4.40</td>
</tr>
<tr>
<td>Liver</td>
<td>1.50-1.60</td>
<td>Canned sardines</td>
<td>7.50-12.50</td>
</tr>
<tr>
<td>Veal</td>
<td>0.20</td>
<td>Canned salmon</td>
<td>8.50-9.00</td>
</tr>
<tr>
<td>Mutton</td>
<td>&lt;0.20</td>
<td>Fresh fish</td>
<td>1.60-7.00</td>
</tr>
<tr>
<td>Chicken</td>
<td>1.40</td>
<td>Canned mackerel</td>
<td>26.89</td>
</tr>
<tr>
<td>Pork</td>
<td>&lt;0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluorine reported in dry substance of food</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>&lt;1.00</td>
<td>Honey</td>
<td>1.00</td>
</tr>
<tr>
<td>Corn</td>
<td>&lt;1.00</td>
<td>Cocoa</td>
<td>0.50-2.00</td>
</tr>
<tr>
<td>Corn (canned)</td>
<td>&lt;0.20</td>
<td>Milk chocolate</td>
<td>0.50-2.00</td>
</tr>
<tr>
<td>Oats</td>
<td>1.30</td>
<td>Chocolate (plain)</td>
<td>0.50</td>
</tr>
<tr>
<td>Crushed oats</td>
<td>&lt;0.20</td>
<td>Tea (various brands)</td>
<td>30.00-60.00</td>
</tr>
<tr>
<td>Dried beans</td>
<td>0.20</td>
<td>Cabbage</td>
<td>0.31-0.50</td>
</tr>
<tr>
<td>Whole buckwheat</td>
<td>1.70</td>
<td>Lettuce</td>
<td>0.60-0.80</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>&lt;1.00</td>
<td>Spinach</td>
<td>1.00</td>
</tr>
<tr>
<td>Whole wheat flour</td>
<td>1.30</td>
<td>Tomatoes</td>
<td>0.60-0.90</td>
</tr>
<tr>
<td>Biscuit flour</td>
<td>0.00</td>
<td>Turnips</td>
<td>&lt;0.20</td>
</tr>
<tr>
<td>Flour</td>
<td>1.10-1.20</td>
<td>Carrots</td>
<td>&lt;0.20</td>
</tr>
<tr>
<td>White bread</td>
<td>1.00</td>
<td>Potato (white)</td>
<td>&lt;0.20</td>
</tr>
<tr>
<td>Ginger biscuits</td>
<td>2.00</td>
<td>Potato (sweet)</td>
<td>&lt;0.20</td>
</tr>
<tr>
<td>Rye bread</td>
<td>5.30</td>
<td>Apples</td>
<td>0.80</td>
</tr>
<tr>
<td>Gelatin</td>
<td>0.00</td>
<td>Pineapple (canned)</td>
<td>0.00</td>
</tr>
<tr>
<td>Dextrose</td>
<td>0.50</td>
<td>Orange</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Particularly noteworthy for their fluoride content are seafoods, which may provide more fluoride than any other ordinary foodstuff. The quantity of fluoride in seafoods varies from 5 to 15 ppm depending largely on the amount of bone included in the product. The fluoride content of tea is exceptionally high and has been recorded extensively. Dry tea of average to best quality may contain 10 – 100 ppm of fluoride and cheaper grades contain even more fluoride. Some 10 to 12 cups of an infusion of average grade tea daily will provide approximately 1.0 mg of fluoride. In New Zealand where “the daily cup of tea” is very popular, urinary excretion of fluoride is correlated with the drinking of tea. Tea is the major source of fluoride in New Zealand, an area where the drinking water is practically free of fluoride. Fluoride analysis indicated that there was little or no increase in fluoride content of New Zealanders’ teeth due to drinking tea. Dental caries was not reduced by this extensive use of tea. A similar situation applies to Great Britain.

The occurrence of fluoride in food and water was reviewed by Cholak (5) in 1959 (Table 2). The estimated content of fluoride in the average diet exclusive of drinking water was 0.2 – 0.3 ppm.

**Table 2. Estimated quantities of fluoride consumed daily in drinking water and food.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Fluoride in drinking water (ppm)</th>
<th>Fluoride in food and water (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cincinnati, Ohio</td>
<td>0.1</td>
<td>0.34-0.80</td>
</tr>
<tr>
<td>Galesburg, Ill.</td>
<td>2.0</td>
<td>0.94-1.16</td>
</tr>
<tr>
<td>Ennis, Texas</td>
<td>5.0-6.0</td>
<td>1.32-1.55</td>
</tr>
<tr>
<td>Lake Beston, S.D.</td>
<td>6.0</td>
<td>0.99-2.19</td>
</tr>
<tr>
<td>Bartlett, Texas</td>
<td>8.0</td>
<td>2.38-3.13</td>
</tr>
<tr>
<td>Norway</td>
<td></td>
<td>0.22-3.1</td>
</tr>
<tr>
<td>Russia</td>
<td>0.6 - 1.2</td>
<td>0.18 - 0.3</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Switzerland</td>
<td></td>
<td>0.6 - 1.8</td>
</tr>
</tbody>
</table>

Included in Cholak’s report is a compilation of data obtained from various sources relative to fluoride in various foods (Table 3).

The evidence seems clear that in a raw state a specific food is consistent in fluoride content. Except for the tea plant, fluoride present in soil and water has no demonstrable effect on the intrinsic fluoride content of edible plants and vegetables. Cows’ milk contains 0.1 to 0.2 ppm of fluoride, but fluoride in the dairy cows’ drinking water and ration has little or no effect on the fluoride content of milk.

Fluoride waters used to process foods and beverages commercially and used in the course of home preparation may add fluoride to a food or beverage. Foods cooked in a fluoride water ordinarily do not acquire an appreciable quantity of fluoride. It is obvious, however, that a
Table 3. The levels of concentration of fluoride found in various items and classes of foods by various investigators in various countries.

<table>
<thead>
<tr>
<th></th>
<th>Fresh (ppm)</th>
<th>Dry (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meats</td>
<td>0.01-7.7</td>
<td>3.8-7.7</td>
</tr>
<tr>
<td>Fish</td>
<td>&lt;0.10-24</td>
<td>-0.45</td>
</tr>
<tr>
<td>Citrus fruits</td>
<td>0.04-0.36</td>
<td>1.4-2.2</td>
</tr>
<tr>
<td>Noncitrus fruits</td>
<td>0.02-1.32</td>
<td>0.45-12</td>
</tr>
<tr>
<td>Cereal and cereal products</td>
<td>&lt;0.10-20</td>
<td>0.0-0.64</td>
</tr>
<tr>
<td>Vegetables and tubers</td>
<td>0.10-3.0</td>
<td>0.0-28.3</td>
</tr>
<tr>
<td>Miscellaneous material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea</td>
<td>3.2-400</td>
<td>-1900</td>
</tr>
<tr>
<td>Wine</td>
<td>0.0-6.34</td>
<td>.........</td>
</tr>
<tr>
<td>Beer</td>
<td>0.15-0.86</td>
<td>.........</td>
</tr>
<tr>
<td>Milk</td>
<td>0.04-0.55</td>
<td>.........</td>
</tr>
<tr>
<td>Salt (table)</td>
<td>0.02-115.1</td>
<td>.........</td>
</tr>
<tr>
<td>Bone meal (edible)</td>
<td>246-770</td>
<td>.........</td>
</tr>
<tr>
<td>Coca-Cola</td>
<td>0.07</td>
<td>.........</td>
</tr>
<tr>
<td>Eggs</td>
<td>0.00-2.05</td>
<td>.........</td>
</tr>
<tr>
<td>Butter</td>
<td>0.4-1.50</td>
<td>.........</td>
</tr>
<tr>
<td>Sugar</td>
<td>0.10-0.32</td>
<td>.........</td>
</tr>
<tr>
<td>Baking powders</td>
<td>&lt;0.10-220</td>
<td>.........</td>
</tr>
<tr>
<td>Cheese</td>
<td>0.15-1.62</td>
<td>.........</td>
</tr>
<tr>
<td>Coffee</td>
<td>0.2-1.6</td>
<td>.........</td>
</tr>
</tbody>
</table>

processed food or beverage which includes fluoridated water in the final edible product does provide fluoride not otherwise present. Coca-Cola bottle with the fluoridated water of Washington, D.C., contains 0.7 – 0.9 ppm fluoride. These considerations may affect to some extent the quantity of fluoride ingested but in actual practice this may be a matter of having two bowls of soup or two cokes prepared with fluoridated water in place of two glasses of fluoridated water. It is important to evaluate any change in fluoride ingestion which occurs in the use of the many new processed and prepared foods, but it seems that current changes in eating and drinking habits may alter the fluoride source in the diet without an appreciable change in the actual total daily quantity of fluoride being ingested.

Fluoride in Drinking Water

Fluoridated water used for cooking and drinking is the major source of fluoride in the diet. Obviously it is difficult to estimate actual milligrams of fluoride which may be added daily to the average diet by a fluoride drinking water. The consumption of drinking water is influenced by physical activity and by variations in atmospheric temperature and humidity. In addition, in the case of children, the daily consumption of water is related to the quantity of liquid foods ingested, particularly milk, bottled beverages, and fruit juices.

Water consumption may be estimated on the basis of the daily energy requirement of calories, 1.0 cc of water per each of the total calories es-
established as the standard daily energy requirement for adequate nutrition. On this basis McClure (6) estimated the total daily intake of fluoride by children 1 to 12 years old from water containing 1 ppm and food containing from 0.1 to 1.0 ppm of fluoride based on dry weight of the food (Table 4). Numerous direct measurements of fluid consump-

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Body weight (kg)</th>
<th>From drinking water (mg)</th>
<th>From food (mg)</th>
<th>Total daily from food and drinking water (mg)</th>
<th>Total daily mg/kg of body weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 3</td>
<td>8 to 16</td>
<td>0.390-0.560</td>
<td>0.027-0.265</td>
<td>0.417-0.825</td>
<td>0.026-0.103</td>
</tr>
<tr>
<td>4 to 6</td>
<td>13 to 24</td>
<td>0.520-0.745</td>
<td>0.036-0.360</td>
<td>0.556-1.105</td>
<td>0.028-0.085</td>
</tr>
<tr>
<td>7 to 9</td>
<td>16 to 35</td>
<td>0.650-0.930</td>
<td>0.045-0.450</td>
<td>0.695-1.380</td>
<td>0.020-0.068</td>
</tr>
<tr>
<td>10 to 12</td>
<td>25 to 54</td>
<td>0.810-1.165</td>
<td>0.056-0.560</td>
<td>0.866-1.725</td>
<td>0.016-0.069</td>
</tr>
</tbody>
</table>

tion by infants and children through age 10 to 12 years (7, 8, 9, 10) show the variability of different fluid intakes in these early age groups. In general, actual measurements of daily fluid intake indicate that a somewhat lower quantity of water may be ingested than that calculated by McClure. On the average, however, the data support an estimate of 1.0 to 1.5 mg fluoride daily ingested in fluoridated water. Additional fluoride in food is estimated at 0.2 to 0.5 mg daily.

Since most of the food fluoride is of organic origin only about 50 percent of this fluoride may be available, except that the fluoride in tea infusions is largely assimilated at the usual levels of ingestion. A uniformity in quantity and the availability of food fluoride are indicated by an almost constant daily urinary excretion of fluoride by individuals whose drinking water is essentially fluoride-free, where food is the chief source of the fluoride intake.

The above quantities of waterborne and food fluoride are permissible during formative tooth life. After the age of 8 to 10 years larger quantities of fluoride may be ingested safely. No evaluation of the quantity of fluoride in foods should overlook the actual biochemical availability of this fluoride. The extent to which any food is used during the formation of teeth is especially important.

Fluoride ingested in food and drinking water may follow one or more metabolic fates. As it passes through the alimentary tract fluoride may be absorbed and thus enter directly into the bloodstream. If fluoride in food or drinking water is not absorbed, it is eliminated by fecal excretion. Absorbed fluoride is biochemically available. It is that quantity which is retained in body tissues or excreted in the urine and to
some extent in sweat. Retention in the body occurs mainly in skeletal tissues and to a lesser extent in dentin and enamel. Its ultimate fate in these latter events may bring about continuing accumulation, particularly in the bones. Soft tissues (liver, kidney, muscle, etc.) contain fluoride in insignificant quantities as compared to bones and teeth.

The fluoride-sequestering property of skeletal tissues plays an important role in disposing of fluoride which might otherwise become toxic. Fluoride acquired by skeletal tissues is directly related to the duration and quantity ingested, but even with continued prolonged ingestion of fluoride the bones remain at an almost constant level of fluoride. The urinary excretion of fluoride then accounts for elimination of practically all of the available fluoride present in the ingesta. Skeletal tissues thus remove excess fluoride from the bloodstream while urinary excretion removes fluoride continuously and permanently from the body. Fluoride has an additional unique fate: in an available ionic state, which is its state when present in drinking water, fluoride may be absorbed into the enamel surface of the teeth as the drinking water moves through the mouth. This is an interesting and significant chemical phenomenon and will be enlarged on later in this discussion.

Elimination of Fluoride From the Body

Urinary Excretion

Urinary fluoride excretion is the major avenue for the body's elimination of absorbed available fluoride. It is a significant criterion of physiologically available fluoride ingested in food and drinking water and by exposure to industrial and atmospheric sources of fluoride. When related to the quantity of available fluoride being ingested, urinary fluoride excretion indicates the rate and extent to which this fluoride is being retained by the bones and whether it is there in toxic quantities.

Edward J. Largent and his associates at the Kettering Laboratory in Cincinnati in the early 1930's conducted the first extensive studies on fluoride excretion. Dr. Largent converted to a human guinea pig for weeks on end—as many as twenty—during which time he measured his daily fluoride intake (food and fluid), fecal fluoride elimination, and urinary fluoride excretion. This personal dedication, patience, and fortitude provided a matchless early contribution to the knowledge of fluoride metabolism. Furthermore, as Dr. Largent advised in a letter of July 11, 1967, "My wife and my son also joined with me from time to time as experimental subjects." Largent wrote further:

In the mid-thirties, fluoride investigations began at the Kettering Laboratory in relation to fluorides generated by burning fluoro-refrigerants. Dr. Willard F. Machle was chief investigator. These studies are described in a series of reports related to exposure of animals to hydrogen fluoride. Later, Machle's attention was attracted to fluorides in foods (especially a dietary supplement)
for infants) and my stint as an experimental subject began in mid-1939. These investigations of fluorides continued into the 1950's. When Machle entered the Army in 1942, Dr. F. F. Heyroth assumed administrative responsibility at Kettering Laboratory for the fluoride program along with several other responsibilities there. My activities as an experimental subject ended with some HF inhalation studies in 1951.

Largent and his associates, Heyroth, Machle, Scott, and Ferneau, reported their extensive investigations in the *Journal of Industrial Hygiene and Toxicology* published between 1935 and 1949. In 1961 Largent wrote *Fluorosis: The Health Aspects of Fluorine Compounds* in which he also discussed these investigations (11).

In 1939 Machle, Scott, and Largent published an initial study on normal urinary fluoride excretion and the fluoride content of food and water (12). Subsequent investigations indicated that these initial fluoride analytical figures are unusually high. However, this study made it evident that fluoride was a normal constituent of the diet and was largely eliminated in the urine.

The results of the 20-week study with Largent as the subject showed that on a normal diet of his own choosing he maintained an equilibrium between intake and output of fluoride. Storage and an accumulation of skeletal fluoride did not occur at a daily intake of 0.5 mg fluoride. Another experimental subject ingested for a shorter period approximately 1.0 mg fluoride daily without fluoride retention. It was significant that "under normal dietary conditions over 80 percent of the fluoride in the ingesta is absorbed and that all of this absorbed fluoride is lost by way of the urinary excretion." This observation agrees with levels of normal urinary excretion obtained in North America and in Denmark.

No clinical roentgenological or other evidence of ill effects resulting from the ingestion of fluoride up to 1.5 mg per diem was observed in this or other subjects. It was concluded that "since 80 percent of the fluoride taken in with the food and fluids was absorbed, urinary excretion can be used as a measure of fluoride ingestion."

Following this initial balance study Machle and Largent investigated the balance of fluoride administered in different forms at higher levels of intake, with Largent again the experimental subject for approximately 80 days (13). In this case the quantity of fluoride administered was controlled at 6.0 mg daily. Absorption varied with the solubility of the compound, the presence or absence of large amounts of calcium in the enteric tract, and the form in which the fluoride salt was administered (as a solution or dry). Calcium fluoride solutions were absorbed as well as sodium fluoride solutions. Calcium fluoride administered as the dry salt was absorbed to a much smaller extent. Urinary excretion and fluoride storage again varied directly with absorption. Data are shown in Table 5.
<table>
<thead>
<tr>
<th>Experimental period number</th>
<th>Source of added fluoride</th>
<th>Duration of period wks</th>
<th>Average total intake mg/day</th>
<th>Average amount in feces mg/day</th>
<th>Average amount absorbed mg/day</th>
<th>Average amount in urine mg/day</th>
<th>Average amount stored mg/day</th>
<th>Average total output mg/day</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Sodium fluoride, solution</td>
<td>14</td>
<td>6.47</td>
<td>0.19</td>
<td>6.26</td>
<td>97</td>
<td>2.42</td>
<td>3.26</td>
<td>3.84</td>
</tr>
<tr>
<td>4</td>
<td>Calcium fluoride, solution</td>
<td>4</td>
<td>6.25</td>
<td>0.27</td>
<td>5.98</td>
<td>96</td>
<td>2.17</td>
<td>1.79</td>
<td>3.81</td>
</tr>
<tr>
<td>6</td>
<td>Calcium fluoride, solid</td>
<td>3</td>
<td>6.43</td>
<td>2.44</td>
<td>3.99</td>
<td>62</td>
<td>1.78</td>
<td>2.03</td>
<td>2.21</td>
</tr>
<tr>
<td>8</td>
<td>Bone meal</td>
<td>5</td>
<td>6.31</td>
<td>3.99</td>
<td>2.92</td>
<td>37</td>
<td>1.08</td>
<td>1.47</td>
<td>1.24</td>
</tr>
<tr>
<td>10</td>
<td>Cryolite, solid</td>
<td>3</td>
<td>6.61</td>
<td>1.52</td>
<td>5.09</td>
<td>77</td>
<td>2.66</td>
<td>2.74</td>
<td>2.43</td>
</tr>
<tr>
<td>11</td>
<td>None</td>
<td>5</td>
<td>0.40</td>
<td>0.03</td>
<td>0.37</td>
<td>93</td>
<td>0.42</td>
<td>0.5</td>
<td>S</td>
</tr>
<tr>
<td>12</td>
<td>Sodium fluoride, solution</td>
<td>2</td>
<td>12.40</td>
<td>0.45</td>
<td>11.95</td>
<td>97</td>
<td>6.34</td>
<td>5.4</td>
<td>5.61</td>
</tr>
<tr>
<td>13</td>
<td>None</td>
<td>2</td>
<td>0.40</td>
<td>0.04</td>
<td>0.71</td>
<td>0.8</td>
<td>S</td>
<td>0.75</td>
<td>S</td>
</tr>
<tr>
<td>14</td>
<td>Sodium fluoride, solution</td>
<td>2</td>
<td>19.4</td>
<td>0.73</td>
<td>18.67</td>
<td>96</td>
<td>9.75</td>
<td>11</td>
<td>8.92</td>
</tr>
<tr>
<td>15A</td>
<td>None</td>
<td>10</td>
<td>0.40</td>
<td></td>
<td></td>
<td></td>
<td>0.80</td>
<td>0.8</td>
<td>S</td>
</tr>
<tr>
<td>15B</td>
<td>None</td>
<td>8</td>
<td>0.40</td>
<td></td>
<td></td>
<td></td>
<td>0.47</td>
<td>0.7</td>
<td>S</td>
</tr>
<tr>
<td>16</td>
<td>Sodium fluoborate, solid</td>
<td>2</td>
<td>6.40</td>
<td>0.10</td>
<td>6.30</td>
<td>93</td>
<td>6.40</td>
<td>8.0</td>
<td>S</td>
</tr>
<tr>
<td>17A</td>
<td>None</td>
<td>1</td>
<td>0.40</td>
<td>0.07</td>
<td></td>
<td></td>
<td>1.22</td>
<td>1.1</td>
<td>S</td>
</tr>
<tr>
<td>17B</td>
<td>None</td>
<td>5</td>
<td>0.40</td>
<td>0.06</td>
<td></td>
<td></td>
<td>0.60</td>
<td>0.6</td>
<td>S</td>
</tr>
<tr>
<td>18</td>
<td>Cryolite, solid</td>
<td>6</td>
<td>18.4</td>
<td>5.50</td>
<td>12.90</td>
<td>70</td>
<td>7.04</td>
<td>7.8</td>
<td>5.86</td>
</tr>
<tr>
<td>19</td>
<td>None</td>
<td>3</td>
<td>0.40</td>
<td>0.25</td>
<td></td>
<td></td>
<td>0.93</td>
<td>1.1</td>
<td>S</td>
</tr>
<tr>
<td>20</td>
<td>Cryolite, solution</td>
<td>5</td>
<td>25.4</td>
<td>1.75</td>
<td>23.65</td>
<td>93</td>
<td>14.97</td>
<td>16</td>
<td>8.68</td>
</tr>
<tr>
<td>21</td>
<td>None</td>
<td>1</td>
<td>0.40</td>
<td>0.12</td>
<td></td>
<td></td>
<td>0.95</td>
<td>1.3</td>
<td>S</td>
</tr>
<tr>
<td>22A</td>
<td>Cryolite, solid</td>
<td>3</td>
<td>36.4</td>
<td>12.54</td>
<td>23.86</td>
<td>65.5</td>
<td>13.03</td>
<td>17</td>
<td>10.83</td>
</tr>
<tr>
<td>22B</td>
<td>Cryolite, solid</td>
<td>3</td>
<td>12.4</td>
<td>4.03</td>
<td>8.37</td>
<td>67.5</td>
<td>5.52</td>
<td>6.7</td>
<td>2.85</td>
</tr>
<tr>
<td>22C</td>
<td>Cryolite, solid</td>
<td>4</td>
<td>6.41</td>
<td>2.43</td>
<td>3.98</td>
<td>62.2</td>
<td>2.61</td>
<td>3.1</td>
<td>1.37</td>
</tr>
<tr>
<td>23A</td>
<td>None</td>
<td>5</td>
<td>0.48</td>
<td>0.07</td>
<td></td>
<td></td>
<td>0.96</td>
<td>1.2</td>
<td>S</td>
</tr>
<tr>
<td>23B</td>
<td>None</td>
<td>6</td>
<td>0.39</td>
<td>0.06</td>
<td></td>
<td></td>
<td>0.72</td>
<td>0.7</td>
<td>S</td>
</tr>
</tbody>
</table>

*S = spillage; the reverse of storage.*
The relative ease and convenience of obtaining urine specimens has made urinary fluoride studies a very practical means of estimating fluoride retention. Analytical data on spot specimens furthermore have agreed satisfactorily with the analysis of 24-hour samples. Our own reports of urinary fluoride studies indicate that spot urine samples are a reliable index of the retention of fluoride, particularly when the fluoride exposure is not excessive. This indication was evaluated by Largent's observations based on urinary fluoride excretion in men exposed to inhalation of fluorides in magnesium foundries. Grouped according to the work location of the men, urine specimens averaged 3.45 ppm fluoride in a "core spray" location, 2.13 ppm in the "pouring" location, and specimens from men engaged in other processing procedures varied from 1.37 to 1.97 ppm fluoride. Brun, Buchwald, and Roholm also studied the urinary excretion of fluoride by Copenhagen cryolite workers who were experiencing chronic fluoride toxicosis induced by an industrial exposure (14). The fluoride analysis of spot urine specimens was used routinely to evaluate the likelihood of fluoride toxicosis.

An additional experiment was reported by Largent and Heyroth (15) in which Largent again was the experimental subject. Fluoride at the high levels of 12 to 25 mg per day were ingested in aqueous solution. Absorption varied from 93 to 97 percent and urinary concentration of fluoride increased with the increased quantities absorbed. At these high levels body storage of fluoride was indicated. Urine concentrations averaged between 3 and 17 ppm.

Problems of occupational exposure to fluoride were the chief concern of investigators at the Kettering Laboratory. Their observations provide much basic information not only for appraisal of industrial fluoride hazards but for resolution of a public health hazard which might be associated with use of fluoride drinking waters.

Fluoride Content of Urine in Relation to Fluoride in Drinking Water

A predecessor to McClure and Kinser's survey of fluoride content of urine (16) was the study by Deatherage who, during World War II, used personnel who had physical examinations at Army induction centers in Illinois. His objective was an evaluation of dental caries experience in relation to exposure to fluoride waters. Obviously it was no small advantage and convenience to have large groups of young adult men available for an epidemiological study of the effects of naturally fluoridated drinking waters. With the assistance of induction center personnel McClure obtained urine specimens from young adult men reporting for physical examination at Army induction centers at Fort Myer, Va.; Manchester, N.H.; Indianapolis, Ind.; Chicago, Ill.; Oklahoma City, Okla.; and Lubbock, Texas. Specimens were also obtained from high school boys aged 15 to 17, residing in Washington, D.C., Little Rock, Ark.; Oklahoma City, Okla.; Lubbock and Amarillo, Texas; and in the Illinois cities of Waukegan, Quincy, Elgin, Aurora, Joliet, Mon-
mouth, and Galesburg. As a rule the specimens were obtained between 9 a.m. and noon. Equal volumes, usually 20 cc of each specimen, were pooled (15 to 20 specimens per pooled sample), according to age or duration of fluoride exposure. Preserved with toluene the samples were shipped to the National Institutes of Health for a fluoride analysis.

In the selection of men at induction centers the fluoride exposure from drinking water was evaluated on the basis of (a) previous studies on occurrence of endemic dental fluorosis, (b) water fluoride analysis, and (c) data on dental caries incidence in the residence area. In the survey of high school boys the local water supply was analyzed for fluoride at the time the specimens were obtained. Subjects were selected on the basis of continuity of residence in their particular community.

A graphic presentation of results of this study is shown in Figure 1.

Fig. 1.—Relation of fluoride in drinking water to fluoride content of urine.

The pronounced increase of fluoride in the urine which accompanies exposure to fluoride in drinking water provides strong evidence that domestic fluoride waters are the most important and universal source of fluoride in almost all human diets. The similarity which is apparent in the urinary fluoride figures for non-fluoride areas as widely separated as
those in the study indicates that the content of fluorine in the average human diet, exclusive of drinking water, is remarkably uniform regardless of the locality.

The fluoride balance studies by Machle, Scott, and Largent had indicated that fluoride in food providing about 0.3 to 0.6 mg daily is largely eliminated from the body. In our study an efficient urinary elimination of fluoride was evident. It could not then be inferred unequivocally, however, that storage of fluorine had not occurred in the body from these low concentrations of waterborne fluoride. Controlled experiments of fluoride balance and actual analyses of skeletal tissues would be required to prove this point and they were soon made.

Our summary concluded in part: "Where domestic waters are free of fluoride the fluoride present in urine averages 0.3 to 0.5 ppm. An increase of fluoride in urine was associated with the use of domestic waters containing as little as 0.5 ppm fluoride. Fluoride in urine specimens continues strikingly proportional to the fluoride content of the drinking water through the range of 0.5 to 5.1 ppm fluoride in the domestic water. The results furnish additional evidence of the importance of waterborne fluoride as a source of fluoride in human diets."

An efficient urinary elimination of fluoride was thereby demonstrated in young individuals residing in areas of the United States where the drinking water contained 0.5 to 5.0 ppm fluoride. The elimination of fluoride under these conditions is a normal body function and is a major factor in maintaining metabolic equilibrium.

The concentration of fluoride in urine specimens has been evaluated in relation to use of controlled fluoridated drinking water. Preceded by observations by Smith, Gardner, and Hodge in Rochester, N.Y., and by Blayney and his associates in the Evanston fluoridation trial, a definitive study was directed to residents of Montgomery County, Md., and Grand Rapids, Mich., following fluoridation of these community water supplies (17). As reported by investigators in the Laboratory of Biochemistry, National Institute of Dental Research, in the case of adults in Montgomery County, Md., the water-fluoride and urinary fluoride concentrations became approximately equal within one week after the introduction of the fluoridated water. In school children aged 5 through 14 years in Montgomery County and 6 through 17 in Grand Rapids, a considerably longer period of time elapsed (approximately 3 and 5 years respectively) before the concentration of fluoride in the urine reached that in the drinking water. This difference in the response of adults and children during the initial period of exposure to a fluoridated drinking water suggests that the maturity of human skeletal tissue influences its capacity to retain fluoride. As expected the results suggest no essential difference between urinary elimination of fluoride ingested in naturally fluoridated drinking water and in drinking water directly fluoridated with either sodium fluoride or sodium fluosilicate.
The fluoride concentration in urine specimens obtained in Grand Rapids is tabulated in Table 6.

### Table 6. Fluoride concentration (ppm) in urine specimens, Grand Rapids.

<table>
<thead>
<tr>
<th>Time after fluoridation</th>
<th>Age, in years</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 weeks ...............</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>7 weeks ...............</td>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
<td>0.7</td>
<td>0.8</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>3 years, 18 weeks ....</td>
<td>0.7</td>
<td>0.8</td>
<td>0.6</td>
<td>0.7</td>
<td>0.6</td>
<td>0.7</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>3 years, 43 weeks ....</td>
<td>0.7</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>4 years, 43 weeks ....</td>
<td>1.0</td>
<td>1.0</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>7 years, 37 weeks ....</td>
<td>0.8</td>
<td>1.0</td>
<td>0.8</td>
<td>0.9</td>
<td>0.8</td>
<td>1.0</td>
<td>1.3</td>
<td>0.9</td>
<td>0.9</td>
<td>1.1</td>
<td>0.9</td>
<td>1.1</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>9 years, 17 weeks ....</td>
<td>1.0</td>
<td>0.8</td>
<td>0.8</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.8</td>
<td>0.7</td>
<td>1.0</td>
<td>1.0</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>10 years, 19 weeks ...</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
<td>1.0</td>
<td>1.0</td>
<td>1.1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.9</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Additional data were accumulated to compare the analysis of spot specimens with 24-hour total urine volume. The results apply to exposure to 1.0 ppm fluoride in the drinking water and agree very well with data obtained by Largent and associates for other levels of fluoride. The fluoride concentration of pooled urine specimens for a group of individuals again was shown to reflect satisfactorily average fluoride concentrations in 24-hour specimens (Table 7).

### Table 7. Fluoride concentration (ppm) in spot and 24-hour urine specimens, Montgomery County, Md.

<table>
<thead>
<tr>
<th>Subject</th>
<th>9-12 a.m.</th>
<th>2-5 p.m.</th>
<th>8-11 p.m.</th>
<th>Mean of spot specimens</th>
<th>24-hour specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.3</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>B</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>C</td>
<td>1.5</td>
<td>1.1</td>
<td>1.3</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>D</td>
<td>1.2</td>
<td>1.3</td>
<td>0.8</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td>E</td>
<td>0.8</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>F</td>
<td>0.6</td>
<td>1.5</td>
<td>2.0</td>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>G</td>
<td>1.5</td>
<td>0.8</td>
<td>1.5</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>H</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>I</td>
<td>1.1</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Mean ........ 0.9 1.0 1.1 1.0 0.9

1 Corrected for spot specimen analysis.

**Urinary Fluoride and Defluoridation of Water**

A survey of the urinary excretion of fluoride was made in Bartlett, Texas, following defluoridation of that community's drinking water (18). The data are especially interesting in elucidating the mobilization of fluoride from fluorosed skeletal tissue following a reduction in the fluoride intake. This phenomenon of skeletal fluoride metabolism
was observed previously by Largent and Heyroth, and by Brun and Roholm. The study made in Bartlett added to information on the effect of age on the rate of mobilization of skeletal fluoride and its ultimate excretion in the urine.

Following reduction of the Bartlett communal drinking water from 8.0 ppm fluoride to a level of approximately 1.0 ppm, the urinary fluoride was determined in children from 7 to 16 years old and in adults 20 years and older. In 27 months the concentration of fluoride in urine specimens decreased from 6 to 8 to approximately 2 ppm. While urinary fluoride remained considerably higher than for a population with no prior exposure to high levels of fluoride, the data indicate beyond doubt that previously stored fluoride was being mobilized from bones. There was no apparent relation between age and urinary fluoride excretion except that the total fluoride mobilized appeared to be greater in children than in adults.

*The Balance of Fluoride in Five Men at the University of Illinois*

During World War II the nutrition of the U.S. Armed Forces living under arid and humid tropical conditions became an important problem because of the consumption of large quantities of fluid and the unusual elimination of body fluid by urine and excessive sweating. The extent of the loss of essential food nutrients, minerals, and vitamins under these conditions, particularly losses through the skin, were practically unknown. Just how this situation would affect the requirements, formulation of dietary standards, and proper rationing of the armed forces had to be investigated. Under contract with the Office of Scientific Research and Development (OSRD) the metabolism of essential trace minerals and vitamins was studied by Dr. H. H. Mitchell, Professor of Animal Nutrition at the University of Illinois. Additional arrangements were made between the OSRD and the NIH to have fluoride metabolism included in these studies. Five young men, conscientious objectors in good physical condition, cooperative, and intelligent, were subjected to the experimental regimens required for this study.

The results pertinent to fluoride were presented in 1945 by McClure, Mitchell, Hamilton, and Kinser (19). This phase of the study evaluated primarily the body's elimination of fluoride when ingested in different forms and amounts, with particular emphasis on paths of excretion, especially by dermal excretion (essentially sweat). The data provided information on the level of fluoride which could be ingested without an appreciable retention of fluoride in the body. The men were 19 to 27 years old, lived under strict supervision in a common domicile in Urbana, Ill., and reported to the University of Illinois Nutrition Laboratory each weekday for the metabolism studies. They spent 8 hours each day of a 5-day test period in an experimental chamber designed to control temperature and humidity. Two environmental conditions were maintained, one "comfortable" when the temperature was 84 to 85° F and relative humidity 49 to 52 percent; the other "hot-moist,"
when the temperature was 100 to 101° F and relative humidity 66 to 70 percent. The men sweated profusely during the first hours of "hot-moist" periods. During "comfortable" periods the body remained somewhat moist but there was little or no visible sweat.

The dermal excretion of fluoride was determined by a thorough washing of the body prior to entrance into the experimental chamber, the collection in pans or in prepared cheesecloths of all sweat running from the body during the experimental exposure, and a final thorough body-washing at termination of the exposure period. On Saturday mornings undiluted sweat was collected following a thorough body-washing.

Different fluoride supplements providing 1.5 to 3.0 mg fluoride daily were weighed into gelatin capsules, each capsule containing a third of the daily allotment. The supplements were sprinkled over the food at each meal and then the capsule itself swallowed. Urine was collected for 24-hour intervals during all test periods. When complete fluoride balances were determined all food was weighed and an aliquot taken for analysis. Daily fecal excretions were dried at 70° C, ground, and composited for each subject for each test period.

The diets during balance periods contained an average of 0.30 to 0.50 ppm fluoride. The high protein diets contained 0.70 to 0.90 ppm fluoride. The foods, cooked with Urbana water (0.30 ppm fluoride), had been increased slightly in fluoride content. The men ate above-average quantities of food so that 0.50 to 0.90 mg of food-fluoride was ingested daily, somewhat more than is ordinarily present in the average diet.

Quantitative data were obtained from 28 study periods. Absorption of fluoride from various fluoride compounds even at low levels of intake was influenced by their solubility, comparing favorably with results obtained by Machle and Largent. The elimination of absorbed (available) fluoride was distributed between urine and perspiration in accordance with environmental conditions. More than 80 percent of the fluoride ingested was being eliminated in urine and perspiration. The kidney excreted an average of 77 percent of the absorbed fluoride; the skin, through the insensible perspiration, 24 percent during "comfortable" periods. During "hot-moist" periods the kidney eliminated on the average 49 percent of the absorbed fluoride while the sweat during these eight-hour periods accounted for an average of 44 percent of fluoride elimination. A practically total elimination of absorbed fluoride in urine and perspiration combined occurred during "comfortable" periods, and 93 percent during "hot-moist" periods. Sweat contained 0.3 to 1.8 ppm fluoride during the fluoride ingestion periods. The week after terminating the fluoride regimen the sweat contained 0.4 to 0.6 ppm fluoride. Thus it seems evident that sweat may become an important avenue for the elimination of fluoride. The insensible perspiration also accounted for elimination of some body fluoride (Fig. 2).
**Fig. 2.—**Percent of ingested daily fluoride eliminated in the feces and urine daily and in perspiration excreted during an 8-hour period of the experimental day.

There was no significant body retention of fluoride by these young adult men when the total fluoride ingested did not exceed 4.0 to 5.0 mg daily. It appears that these may be the limits of fluoride which may be ingested daily without significant body storage. The state of practically complete fluoride equilibrium evident in these human experiments indicated that exposure to a fluoride water such as Galesburg, Ill., drinking water containing 1.8 to 1.9 ppm fluoride, or any drinking water which contributes an average of not more than 3.0 to 4.0 mg fluoride daily, could not bring about cumulative toxic fluorosis. The results of this study emphasized again the significance of the urinary fluoride excretion in preventing fluoride retention in the human body. For the first time it was shown that sweat could be an avenue of fluoride excretion.

**Fluoride in Bones**

The retention of fluoride in the skeleton has been noted in many experimental studies involving large and small animals. A considerable body of data relate to fluoride acquired by bones and other organs and tissues of the body through industrial contact with fluoride. The first
records of industrial skeletal fluorosis were reported by Roholm. Fluoride in the human skeletal system was studied in England by Glock, Lowater, and Murray (20) in the Evanston fluoridation study, and by Smith, Gardner, and Hodge (21) based on 158 autopsies in Rochester, N.Y. Data on human rib and vertebra indicate a fluoride relationship with age, a difference in the content of fluoride between rib and vertebra, some differences between males and females, and a considerable variation among individuals. Fluoride in bones of stillborn and newborn infants indicated a maternal transfer of fluoride.

More recently data became available from autopsy studies in Utah by Call, et al. (22), which are important in evaluating the status of toxic skeletal fluorosis. A former output of fluoride by certain industries in Utah has been significantly reduced in recent years and drinking water supplies average less than 0.5 ppm. The actual fluoride exposure of the subjects of the Utah study was variable and the fluoride exposure from the atmosphere, food, and drinking water was not unusual nor above normal. Eighty-eight of the autopsy cases came from geographic areas having elevated fluoride in forage and atmosphere, and some of the analytical data on certain autopsy bone specimens attest to an elevated fluoride exposure.

The bone specimens came from 127 male and female patients, 15 years old and older, who had resided in an industrial area where there was a probability of an excess of industrial atmospheric fluoride. The following skeletal tissues were analyzed for fluoride and ash: calvarium, sternum, rib, iliac crest, and vertebra. The average percentage of fluoride in these bones was, respectively, 0.0387, 0.0445, 0.0418, 0.0431, and 0.0501. The mean fluoride in bones of individuals presumed to have an increased fluoride exposure was 0.0568 percent in comparison with a control group with a mean of 0.0446 percent bone fluoride. These values are all within the normal range of skeletal fluoride and are concomitant with residence in a non-fluoride area. Determinations of fluoride were made on brain, heart, lung, thyroid, aorta, liver, spleen, pancreas, and kidney. Most of the tissues were examined histologically and the results agree with those previously reported by Geever, et al., who examined body tissues of individuals who had lived at least 10 years in communities where the drinking water contained 1.0 to 4.0 ppm fluoride (23).

A slight increase of fluoride in skeletal tissues was attributed to certain kidney diseases. Consistent with other data were the increases in fluoride content of osseous tissue with increase in age. In general, the data of this study apply to increases in fluoride exposure not equal to increases brought about by the use of fluoridated water. The fluoride exposure was not sufficient to cause abnormal histological changes in soft tissues and bones and caused no appreciable increase in fluoride retained by any body tissues.

Fluoride analyses of human skeletal specimens studied in direct relation to the quantity of fluoride in drinking water are still somewhat
limited. In the studies of Bartlett fluoride water, autopsy bone specimens were obtained from one individual and the analytical data compared with autopsy specimens obtained from a similar individual in Washington, D.C. (low-fluoride water) (24).

Bone specimens were made available for another study in Grand Rapids, Mich. (1.0 ppm), Colorado Springs (2.5 ppm), Amarillo, Texas (2.8 ppm), and Lubbock, Texas (4.0 ppm), through the assistance and cooperation of local pathologists (25). This series consisted of 37 persons who had resided 10 years or more in the communities. The majority of the cases had lived in Colorado Springs and provided 65 bone specimens for study and chemical analysis. The subjects, 17 men and 20 women, ranged in age from 36 through 90 years. For comparison as non-fluoride controls, 33 cases, 24 men and 9 women, were residents of communities where the drinking water contained less than 0.5 ppm fluoride. In addition to microscopic examinations the majority of these bone specimens, together with a few additional cases, were analyzed at the Laboratory of Biochemistry, National Institute of Dental Research, for their content of ash and fluoride. These same bones were analyzed for other primary bone chemicals and finally were subjected to X-ray diffraction.

The results of fluoride analyses of the iliac crest, rib, and vertebra are shown in Figure 3 which includes data obtained by analysis of skeletal

![Graph showing the relation between fluoride in drinking water and fluoride in human bone.](image)
tissues of the resident of Bartlett, Texas (8.0 ppm). From this survey on the fluoride content of human skeletal tissues it appears that the deposition of fluoride is directly related to the fluoride content of the drinking water up to 4.0 and perhaps 8.0 ppm fluoride. The fluoride concentration of the intervertebral cartilage was considerably less than that of the bones. The concentration of fluoride in the bones increased in an essentially linear fashion with an increase of fluoride in the drinking water up to 4.0 ppm.

These human calcified tissues did not approach their theoretical capacity to retain up to about 3.5 percent fluoride, although drinking water containing as much as 4.0 and 8.0 ppm fluoride was ingested. Prolonged exposure to the water of Colorado Springs, Colo., or Amarillo, Texas (2.6 ppm fluoride), and Lubbock, Texas (4.0 ppm fluoride), elevated the fluoride content of the bone to a maximum average of only 0.270 and 0.405 percent respectively. Bone fluoride in the one Bartlett case averaged 0.548 percent. The data from five subjects who had lived in Grand Rapids are of interest. Exposure to water containing 1 ppm fluoride did not exceed 12 years and the average age of the subjects at the time they started to use fluoridated water was about 63 years. Nevertheless, a mean concentration of 0.146 percent fluoride was found in these relatively old bones as compared with an average value of 0.049 percent in the bones of individuals of an average age of 56 years, ingesting water containing less than 1.0 ppm fluoride.

The fluoride data in this study coupled with microscopic findings constitute substantial evidence that a concentration of fluoride as high as 0.548 percent in bones may be present without producing tissue damage. According to Roholm's studies, the fluoride content of bones of cryolite workers who showed definitive subjective symptoms of chronic skeletal fluorosis contained upwards of 0.60 to 0.70 percent fluoride. Bone chemistry data from the Bartlett case indicate that 0.5 to 0.6 percent fluoride caused no gross systemic changes, impairment of health or general well-being, nor malformation or malfunctioning of the skeletal system.

In 1958 interesting data on skeletal fluoride in relation with age and fluoride present in the water supply were presented by Jackson and Weidmann of the University of Leeds, England (26). They analyzed rib-bone specimens from subjects of different ages who had lived in Leeds, South Shields, and West Hartlepool. The results of these studies are summarized in Figure 4.

Their figures are somewhat higher than comparable data obtained in the United States and suggested the possibility of an extra source of fluoride in the English diet, which they thought was tea. Their estimate of fluoride ingested in tea is somewhat higher than our figures for the United States, and they calculated that drinking six average cups of tea a day would provide 1.0 mg fluoride a day. Our estimate suggested 10 to 12 cups of tea per day for the same amount of fluoride.
The Chemistry of Bone Related to its Fluoride Content

Data on ash, calcium, and phosphorus content of bones previously analyzed for fluoride are shown in Table 8 (27). The quantity of bone fluoride varies from 0.045 to 0.556 percent, but as much as 0.40 percent fluoride has no effect on the percentage of ash, calcium, or phosphorus,

**Table 8. Comparison of composition of human skeletal tissues exposed to normal (<1.0 ppm) and fluoride waters.**

<table>
<thead>
<tr>
<th>Waterborne fluoride exposure</th>
<th>Dry, fat-free bone</th>
<th>Bone ash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fluoride (%)</td>
<td>Ash (%)</td>
</tr>
<tr>
<td>Normal</td>
<td>0.045</td>
<td>58.20</td>
</tr>
<tr>
<td>Normal</td>
<td>0.058</td>
<td>57.21</td>
</tr>
<tr>
<td>&lt;1.0 ppm</td>
<td>0.049</td>
<td>52.82</td>
</tr>
<tr>
<td>1.0 ppm</td>
<td>0.147</td>
<td>59.40</td>
</tr>
<tr>
<td>2.6 ppm</td>
<td>0.247</td>
<td>55.40</td>
</tr>
<tr>
<td>4.0 ppm</td>
<td>0.409</td>
<td>56.11</td>
</tr>
<tr>
<td>8.0 ppm*</td>
<td>0.556</td>
<td>64.91</td>
</tr>
</tbody>
</table>

*One autopsy case from Bartlett.
except that the one autopsy case available from Bartlett indicated a level of 0.556 percent fluoride in skeletal tissues was associated with a slight increase in ash, calcium, and phosphorus. The content of sodium and potassium was not significantly influenced by fluoride, but a major decrease in citrate was apparent in bones of individuals drinking water containing 4.0 ppm fluoride. There was also a slight increase in magnesium.

The role of fluoride in human bone continues to be a subject of major interest. It is wholly plausible that the quantity of fluoride retained in bone, specifically as a component of bone apatite, would cause physical and structural changes and might modify biochemical functions. Thus a number of the human bones previously analyzed for fluorine were subjected to X-ray diffraction analysis to evaluate the relation of fluoride content to physical characteristics of the bone. According to Posner, Eanes, Hesper, and Zipkin (28), "A rise in fluoride content was accompanied by an increase in bone apatite crystal size and/or a decrease in crystal strain in a direction perpendicular to the C-axis with the mean crystal size in the C-axis direction remaining at a value of 96 ± 9.6 Å—regardless of the fluoride content." X-ray methods are complex and lie within highly specialized areas of crystallography. But from a biological point of view it was postulated by investigators that "a more stable bone apatite is produced by (a) the improved crystallinity and (b) the isomorphous substitution of fluoride in the apatite structure." It appears at this time that this problem remains unresolved in the context of bone biology and function, and further study by crystallographic authority is needed.

Fluoride in Teeth

Fluoride in teeth as well as bones is increased by the use of fluoridated drinking water and this situation has motivated extensive research concerning the role of increased fluoride. When fluoride prevents dental caries, what is the mechanism of this action?

The occurrence of fluoride in teeth and bones of fossils was first noted in 1802. In 1805 the famous French chemists, Gay-Lussac and Berthollet, reported that fluoride was a natural component of normal teeth (29), and thereby raised many questions which continue to this day regarding the physiological role of fluoride in teeth as well as skeletal tissue.

The quantity of fluoride in dentin and enamel of teeth which are not mottled but have been exposed continuously to drinking waters containing 1.1 to 1.2 ppm of fluoride has been studied and comparisons made with teeth exposed to smaller as well as much larger quantities of fluoride (30). Data are shown in Figure 5. Special interest pertains to teeth developed in Aurora, Ill. (1.1 to 1.2 ppm fluoride). An increase of
fluoride due to use of water containing this permissible level of fluoride is evident. At the conclusion of this study the authors stated, "The importance of these data in connection with theoretical considerations of caries etiology lies in the fact that a reduction in dental caries due to consumption of a near optimal concentration of fluorine in drinking water is directly associated with an increase of fluorine in dentin and enamel. Thus the role of fluorine deposited during formative tooth life remains a prominent factor to be considered in solving the question of resistance to dental caries."

<table>
<thead>
<tr>
<th>RESIDENCE</th>
<th>FLUORIDE IN WATER (ppm.)</th>
<th>PERCENT FLUORIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chetopa, Kansas</td>
<td>7.6</td>
<td></td>
</tr>
<tr>
<td>Campagnano di Roma, Italy</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>West Texas Panhandle</td>
<td>2.5 – 5.0</td>
<td></td>
</tr>
<tr>
<td>Lubbock, Texas</td>
<td>2.5 – 5.5</td>
<td></td>
</tr>
<tr>
<td>Galesburg, Illinois</td>
<td>1.8 – 2.0</td>
<td></td>
</tr>
<tr>
<td>Aurora, Illinois age 0–4</td>
<td>1.0 – 1.1</td>
<td></td>
</tr>
<tr>
<td>Aurora, Illinois age 25–45</td>
<td>1.0 – 1.1</td>
<td></td>
</tr>
<tr>
<td>Aurora, Illinois age 0–25</td>
<td>1.0 – 1.1</td>
<td></td>
</tr>
<tr>
<td>North Central Illinois</td>
<td>1.0 – 1.1</td>
<td></td>
</tr>
<tr>
<td>Washington, D.C. and vicinity</td>
<td>0.2 – 0.3</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>0.2 – 0.4</td>
<td></td>
</tr>
<tr>
<td>Oslo, Norway</td>
<td>0.2 – 0.3</td>
<td></td>
</tr>
<tr>
<td>McDuffie County, Georgia</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 5](image)

Fig. 5.—Relation of fluoride in drinking water to fluoride in teeth.

Prior to this study when extensive data were accumulated on the fluoride content of dentin and enamel of sound and carious teeth, only inconclusive and variable data were available. Armstrong and Brekhus (31) had published data which attracted a great deal of attention because of what appeared to be a significant difference between the fluoride content of sound and carious teeth. Tables 9 and 10 show data obtained after 1933. Following this date the fluoride analytical procedure was more reliable, particularly the Willard and Winter technique as modified by Armstrong and others.

Fluoride was determined in enamel and dentin of sound and carious teeth obtained from 33 individuals (studied separately) and from two groups of 14 and 44 individuals each. The summary of the study states in part (32):
<table>
<thead>
<tr>
<th>Observer</th>
<th>Dentin (% F)</th>
<th>Enamel (% F)</th>
<th>Description and location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boissevain and Drea</td>
<td>0.0600</td>
<td>0.0250</td>
<td>Sound; New York City</td>
</tr>
<tr>
<td>Bowes and Murray</td>
<td>Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0250</td>
<td>0.0250</td>
<td>&quot;Normal&quot;</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0200</td>
<td>Sound; London, Eng.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0250</td>
<td>&quot;Normal&quot;</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0200-0.0320)</td>
<td>(0.0130-0.0180)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0252</td>
<td>Carious; non-F area; Knysna, S. Africa</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0140-0.0520)</td>
<td>(0.0070-0.0310)</td>
<td></td>
</tr>
<tr>
<td>Armstrong and Brekhus</td>
<td>Mean</td>
<td>0.0160</td>
<td>Sound; 36-year-old man</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0070</td>
<td>Carious</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0109</td>
<td>Sound; 28-year-old woman</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0063</td>
<td>Carious</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0112</td>
<td>Sound; sex and age unknown</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0067</td>
<td>Carious</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0114</td>
<td>Sound; mean of several individuals</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0169</td>
<td>Carious</td>
</tr>
<tr>
<td></td>
<td>Range</td>
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</tr>
<tr>
<td></td>
<td>(0.0073-0.0167)</td>
<td>(0.00668-0.0087)</td>
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</tr>
<tr>
<td>Restarski</td>
<td>Mean</td>
<td>0.0646</td>
<td>Sound; teeth from Samoan natives</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0418-0.1071)</td>
<td>(0.0100-0.0243)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0423</td>
<td>Carious</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0100-0.0903)</td>
<td>(0.0060-0.0246)</td>
<td></td>
</tr>
<tr>
<td>Roholm</td>
<td>Mean</td>
<td>0.0810</td>
<td>Normal incisors</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.0300</td>
<td>Normal molars</td>
</tr>
<tr>
<td>Table 10. Results of analysis of sound and carious teeth. Percent fluorine, ash, and fluorine in ash of enamel and dentin.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Dentin</td>
<td>Carious teeth</td>
<td>Enamel</td>
</tr>
<tr>
<td></td>
<td>Sound teeth</td>
<td>Carious teeth</td>
<td>Sound teeth</td>
</tr>
<tr>
<td>Number of sound teeth</td>
<td>Number of carious teeth</td>
<td>Number of analyses</td>
<td>Number of analyses</td>
</tr>
<tr>
<td>Analyses</td>
<td>Analyses</td>
<td>Analyses</td>
<td>Analyses</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>F (%)</td>
<td>F in ash (%)</td>
<td>Ash (%)</td>
</tr>
<tr>
<td>.0216</td>
<td>.0283</td>
<td>6</td>
<td>.0086</td>
</tr>
<tr>
<td>.0283</td>
<td>19</td>
<td>94.7</td>
<td>.0091</td>
</tr>
<tr>
<td>.0242</td>
<td>6</td>
<td>10</td>
<td>.0097</td>
</tr>
<tr>
<td>.0102</td>
<td>14 Individuals who were continuous residents of McDuffe City, Ga.—Nonfluoride area</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>22</td>
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<tr>
<td></td>
<td>124</td>
<td>80.0</td>
<td>.0240</td>
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<tr>
<td></td>
<td>160</td>
<td>79.8</td>
<td>.0220</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>96.4</td>
<td>.0103</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>95.5</td>
<td>.0093</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>.0097</td>
</tr>
<tr>
<td></td>
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<tr>
<td>33 Individuals from scattered areas with no indication of fluorine exposure</td>
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<td>224</td>
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</tr>
<tr>
<td>Total</td>
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<tr>
<td>262</td>
<td>248</td>
<td>132</td>
<td>142</td>
</tr>
<tr>
<td>Mean*</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>79.8</td>
<td>.0241</td>
<td>79.7</td>
<td>.0225</td>
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<td>.0003</td>
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<tr>
<td>P.E. mean±</td>
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<tr>
<td>.3</td>
<td>.2</td>
<td>.1</td>
<td>.1</td>
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<td>.0012</td>
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<td>.0003</td>
<td>.0003</td>
<td>.0003</td>
</tr>
<tr>
<td>Sound vs. carious—differences</td>
<td>Sound vs. carious—differences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>0.1 ± 0.4</td>
<td>0.2 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>Fluorine</td>
<td>0.0016 ± 0.0012</td>
<td>0.0004 ± 0.0005</td>
<td></td>
</tr>
<tr>
<td>Fluorine in ash</td>
<td>0.0020 ± 0.0015</td>
<td>0.0004 ± 0.0005</td>
<td></td>
</tr>
</tbody>
</table>

*In calculation of this mean and its probable error, the result for each individual of the group of 33 individuals was used as a separate item, and the means of the other two groups constituted two other items. Among the group of 33 individuals, from 1 to 14 analyses per individual were averaged to obtain the individual items.
Biology and Safety

The crowns of 262 sound and 248 carious teeth were separated into dentin and enamel and a little over 600 fluorine determinations made on pooled or individual dentin and enamel samples. The ash in enamel averaged 95.8 percent; in dentin, 79.8 percent; and no differences were apparent between sound and carious teeth. The fluorine in enamel averaged 0.0100 percent, in dentin 0.0253 percent, and differences between enamel and dentin of sound and carious teeth were not significant. Fluorine in ash of enamel averaged 0.0104 percent and in ash of dentin, 0.0292 percent. Differences between results for sound and carious teeth again were not significant.

These analytical data also indicated that fluoride in individual teeth of a single dentition as a general rule was not consistently less in the enamel of the carious teeth than in the enamel of the sound teeth. In some individuals fluoride in the enamel of the sound teeth alone differed as much as the fluoride in enamel between sound and carious teeth.

Thus a fluoride water used during formative tooth life will increase the fluoride content of both dentin and enamel of all the teeth, and account for an overall reduction in dental caries. An optimum quantity of fluoride in dentin and enamel of the entire dentition is associated with an overall reduction in dental caries.

At the time of this study it was realized that a more sophisticated approach should be made regarding fluoride in enamel and dentin of sound and carious teeth, as well as the relation of fluoride in drinking water (particularly at a level of 1.00 ppm) to the fluoride content of enamel and dentin. It was becoming increasingly evident that fluoride in the exposed oral surfaces of erupted teeth must be thoroughly evaluated as a possible major factor in explaining the caries-preventive action of fluoride. As a result fluoride in surface enamel has been explored especially in relation to topical applications, dentifrices, and mouthwashes. Surface enamel fluoride commands great interest also because it is acquired from fluoridated water as it passes through the oral cavity.

Jackson and Weidmann (33) published an investigation of the fluoride in enamel and dentin of sound premolar teeth provided by individuals living in Leeds, South Shields, and West Hartlepool, where fluoride in the drinking water averaged respectively 0.5, 1.0, and 2.0 ppm. "Premolar teeth were chosen for study because they constitute the only group of teeth which can satisfactorily be obtained over a wide age spectrum. The criteria for selection were that they should be free from caries, hypoplasia and blemishes of any kind, and should be obtained from patients who had been born and bred in one of the selected regions." The results of this study are shown in Figures 6 and 7.

This investigation demonstrated that considerable fluoride enters both enamel and dentin after eruption, even in a region where the drinking water is low in fluoride. Up to a level of 2 ppm fluoride in the drinking water the content of enamel fluoride may increase after eruption a maximum of 100 percent and in dentin a maximum of 200 to 300 percent.
Jackson and Weidmann stated, "If caries inhibition is associated with the external F concentration, then it is interesting to speculate on the benefits of acquired posteruptive F. One might expect, for instance, that on commencing fluoridation teeth already fully calcified would acquire some increased resistance to caries attack." This had become apparent in the Grand Rapids and the Newburgh-Kingston studies.

The consensus that the posteruptive uptake of fluoride by enamel and dentin can be an important factor in caries prevention gained further support from Brudevold and his associates (34, 35, 36) and seems to be a more and more convincing hypothesis. While the posteruptive uptake of fluoride by surface enamel takes place by the medium of oral fluids, dentin acquires its fluoride by metabolic tissue fluids in the pulp chamber. Bone and dentin both receive fluoride from the internal
Fig. 7.—Relation between age and fluoride concentration of human premolar enamel.

blood supply and a maximum uptake occurs when equilibrium is reached between fluoride of tissue fluids and bone and dentin crystal surfaces directly in contact with these fluids.

At the Forsyth Dental Center, Brudevold and his associates* continue to make distinguished contributions to knowledge of fluoride and its role in teeth. They have conducted an extensive series of elegant studies relating to the in vivo effect of fluoride drinking water, reactions between fluoride and enamel in vitro, and resolution of fundamental chemical reactions between fluoride and enamel. One of their most definitive studies involved analysis of a large number of teeth from individuals of different ages who lived in geographical areas with 0.1, 1.0, 3.0, and 5.0 ppm fluoride in their drinking water (Figure 8). The uptake of fluoride in surface enamel is rapid during first years of enamel formation and prior to eruption, but following eruption enamel is less active and accumulation of fluoride markedly decreases. This posteruptive uptake of fluoride by the enamel surface is significant, however,

and the quantity continues to increase slightly with age. This entire process is governed to a remarkable extent by the quantity of fluoride in drinking water. The data indicate that the fluoride concentration in surface enamel was increased as much as 200 to 300 ppm (on an ash analysis basis) as a result of 1.00 ppm fluoride in drinking water, compared with <0.1 ppm. Brudevold believes that surface enamel of teeth from areas with 1.0 ppm fluoride in the drinking water is not fluoride-saturated during the 10 years following tooth eruption but less additional fluoride is acquired in subsequent years. However, significant amounts of fluoride are acquired in subsequent years, occupy accessible positions on the surfaces of crystals which are exposed to the oral environment, and have the net effect of reinforcing the total enamel structure. Brudevold stated, "The inhibition in caries resulting from water
fluoridation (1.0 ppm) is related to the 200-300 ppm increase in fluoride concentrations in surface enamel over that found in surface enamel from low fluoride areas."

The studies of Brudevold and his group have had a distinct impact on our evaluation of fluoride acquired by teeth (particularly the enamel) and its relation to the inhibition of dental caries. Analysis of the fluoride content of the entire enamel had left something to be desired, particularly since the observed increases caused by 1.0 ppm fluoride in drinking water are relatively small. Fluoride in the outermost enamel is present in a much greater concentration than in total enamel.

Fluoridated water is especially effective as a source of fluoride acquired by local oral absorption in teeth. A facility for replenishing fluoride which may be lost from the oral tooth surfaces is provided also by fluoridated drinking water. These are major considerations which give fluoridated water a status for caries prevention not equaled by alternative fluoride procedures which are dependent on intermittent exposure of tooth surfaces to fluoride.

Fluoride in Soft Body Tissues

The data on the fluoride content of human soft body tissues are only approximate because of difficulties in fluoride analysis when applied to the minute quantities occurring in soft tissues. Experiments with small animals provide data on noncalcified tissues but the fluoride found usually relates to ingestion of greater quantities of fluoride than in the use of fluoridated water. The data are valuable evidence, nonetheless, of a wide distribution of fluoride in body organs. Radioactive fluoride $^{18}$F in experimental animal studies has indicated the relative distribution of fluoride in animal organs and tissues. Ericsson and his associates (37) have made valuable contributions to this problem by autoradiograph analysis of $^{18}$F, found especially in organs of the body other than bones and teeth wherein a minute degree of calcification may occur and account for deposition of fluoride. In this regard Smith and Gardner (38) suggested that the increased quantity of fluoride analyzed by them in the human aorta could be associated with the increased calcification frequently found in the aorta with advancing age.

The fluoride content of human blood has been studied extensively in recent years by Armstrong and his associates (39, 40). Data from various studies on blood fluoride thoroughly evaluated and summarized by Smith (41) indicate generally less than 0.5 ppm fluoride. Any increase of blood fluoride is rapidly removed by urinary excretion or absorption in skeletal tissues. Recent studies (42) have indicated that inorganic fluoride may be bound to a serum protein, perhaps albumin. While the nature of such binding remains speculative, there are indications of the presence of nonexchangable fluoride in blood serum.

Fluoride in saliva varies from $<0.10$ to approximately 0.14 ppm where
the drinking water is low in fluoride. Saliva specimens obtained in Amarillo (3.8–4.0 ppm fluoride in water) varied from 0.13 to 0.24 ppm fluoride (43). The consensus is that fluoride in saliva has no effect on dental caries.

Studies of Populations Drinking Fluoride Waters

Newburgh-Kingston Pediatric Findings After Ten Years

In 1956 Schlesinger and his associates (44) gave a detailed account of observations and results of medical examinations covering ten years of the Newburgh-Kingston study (during which time the Newburgh drinking water was adjusted to contain 1.2 ppm of fluoride) with emphasis on examinations performed ten years after the start of fluoridation. Closely similar groups of 500 children in Newburgh and 405 in Kingston were studied in the final series of examinations:

Each child was given a general medical examination by a qualified pediatrician. Height and weight were measured. Roentgenograms were taken of the right hand, both knees and the lumbar spine, and the bone density and bone age (maturation of the skeleton) were estimated. Laboratory examinations, including hemoglobin level, total leukocyte count and routine urine analysis, were also made. In addition, special studies were performed on smaller groups of children. These studies included detailed examinations of the eyes and ears, with determination of visual acuity, visual fields and hearing levels, and studies of the quantitative excretion of albumin, red blood cells, and casts in the urine.

Skin and mucous membranes, the hair, and the thyroid gland were also carefully examined.

No skeletal difference related to the use of fluoridated water was reflected on the roentgenograms. In agreement with our study of carpal bone calcification and fluoride, there was no difference in the rate of skeletal maturation between the children in Newburgh and Kingston (Table 11).

<table>
<thead>
<tr>
<th>Maturation</th>
<th>Newburgh</th>
<th>Kingston</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of children</td>
<td>Percent of children</td>
</tr>
<tr>
<td>Number of children</td>
<td>472</td>
<td>100.0</td>
</tr>
<tr>
<td>Within normal limits</td>
<td>461</td>
<td>97.7</td>
</tr>
<tr>
<td>Abnormally retarded</td>
<td>10</td>
<td>2.1</td>
</tr>
<tr>
<td>Abnormally advanced</td>
<td>1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Analysis of 12-hour urine specimens of 12-year-old boys included specific gravity, the pH, albumin, red blood cells, and casts. The objective
of the study was to determine if irritating effects on the kidneys had occurred. The differences found in the analyses of specimens from the two cities tended to favor the Newburgh boys who had used fluoridated water eight years.

After evaluating all the data accumulated by these extensive examinations it was concluded that "no differences of medical significance could be found between the two groups of children; thus further evidence was added to that already available on the safety of water fluoridation."

Eight PPM Fluoride in Bartlett, Texas, Drinking Water

Bartlett and Cameron are two small Texas communities located about 135 miles south of Dallas. Bartlett residents were desirable subjects for a study of the effects of prolonged exposure to a drinking water of high fluoride content (45). The municipal water contained 8.0 ppm fluoride, one of few such high-fluoride waters then in use in the United States; and there was substantial evidence that this water supply had been in use since 1901. Cameron was selected for a control population because of its close proximity to Bartlett and because its water supply (used since 1895) averaged 0.4 ppm fluoride (Table 12).

<table>
<thead>
<tr>
<th>Table 12. Composition of water in Bartlett and Cameron, 1943 and 1953.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Components</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Dissolved solids</td>
</tr>
<tr>
<td>Loss on ignition</td>
</tr>
<tr>
<td>Fixed residue</td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
</tr>
<tr>
<td>Iron (Fe)</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
</tr>
<tr>
<td>Sodium and potassium (calculated as Na)</td>
</tr>
<tr>
<td>Carbonate (CO₃)</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃)</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
</tr>
<tr>
<td>Nitrate (NO₃)</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
</tr>
<tr>
<td>Phosphate (PO₄)</td>
</tr>
<tr>
<td>Fluoride (F)</td>
</tr>
</tbody>
</table>
Individuals selected for this study had a history of continuous residence for 15 years before 1943, at which time a medical-dental team examined 116 selected individuals living in Bartlett and 121 in Cameron. Their ages ranged from 15 to 68 years. The 1953 survey included a reexamination of as many of the 1943 participants as possible. The procedures both years were essentially parallel, with a medical history, physical and dental examinations, X-ray, and blood and urine studies. In the 1943 survey all physical and laboratory examinations were done locally, except that participants were transported to the Scott-White Clinic in Temple, Texas, for X-ray. In 1953 practically all the examination procedures were at the Scott-White Clinic. The X-ray films were interpreted and then evaluated independently by Theodore F. Hilbush of the National Institutes of Health, and Merrill C. Sosman of the Peter Bent Brigham Hospital, Boston (46).

In the ten-year interval between 1943 and the 1953 follow-up studies, 47 participants had moved from Cameron and Bartlett. The number that left each town was almost equal: 22 from Bartlett and 25 from Cameron. They were predominantly of the younger age groups. Of these, 37 were examined by the usual procedures. Information on the deceased (approximately 8 percent) was obtained from the next of kin and from death certificates. Because of unusual success in accounting for 79 percent of the participants it was advisable to follow up the remaining 21 percent of the participants who had moved from the area. The ten living participants not examined were interviewed and a ten-year medical and residence history was obtained. All the participants of 1943, living and deceased, were accounted for in the 1953 study. Additional examination procedures in 1953 included rectal and pelvic examinations. Prostate examinations were routine. Hematocrit, sedimentation rate and blood calcium were determined. In addition, in 1953 the majority of the participants received complete dental examination including X-rays. These data showed the degree and prevalence of dental fluorosis, caries, gingivitis, and alveolar bone loss. There were no acute, chronic, serious, or debilitating diseases reported among the 1953 participants still living in Bartlett and Cameron or among those who had moved from the areas. Medical examination data are shown in Tables 13, 14, and 15.
<table>
<thead>
<tr>
<th>Characteristic studied</th>
<th>Bartlett</th>
<th></th>
<th></th>
<th>Cameron</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Number at risk</td>
<td>Number abnormal</td>
<td>Rate (%)</td>
<td>Number at risk</td>
<td>Number abnormal</td>
<td>Rate (%)</td>
</tr>
<tr>
<td>Arthritic change</td>
<td>96</td>
<td>11</td>
<td>11.5</td>
<td>110</td>
<td>15</td>
<td>13.6</td>
</tr>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys. 151 mm/hg and over</td>
<td>74</td>
<td>20</td>
<td>27.0</td>
<td>100</td>
<td>21</td>
<td>21.0</td>
</tr>
<tr>
<td>Dias. 100 mm/hg and over</td>
<td>89</td>
<td>11</td>
<td>12.4</td>
<td>104</td>
<td>11</td>
<td>10.6</td>
</tr>
<tr>
<td>Pulse pressure 75 mm/hg and over</td>
<td>86</td>
<td>11</td>
<td>12.8</td>
<td>108</td>
<td>16</td>
<td>14.8</td>
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<tr>
<td>Bone changes*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density*</td>
<td>89</td>
<td>7</td>
<td>7.9</td>
<td>101</td>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>Coarse trabeculation</td>
<td>89</td>
<td>4</td>
<td>4.5</td>
<td>101</td>
<td>2</td>
<td>2.0</td>
</tr>
<tr>
<td>Hypertrophic</td>
<td>89</td>
<td>10</td>
<td>11.2</td>
<td>101</td>
<td>6</td>
<td>5.9</td>
</tr>
<tr>
<td>Spurs</td>
<td>89</td>
<td>1</td>
<td>1.1</td>
<td>101</td>
<td>4</td>
<td>4.0</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>89</td>
<td>5</td>
<td>5.6</td>
<td>101</td>
<td>10</td>
<td>9.9</td>
</tr>
<tr>
<td>Bone, increased density (new cases)</td>
<td>81</td>
<td>1</td>
<td>1.2</td>
<td>99</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Cataract and/or lens opacity</td>
<td>95</td>
<td>10</td>
<td>10.5</td>
<td>106</td>
<td>13</td>
<td>12.3</td>
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<tr>
<td>Thyroid</td>
<td>90</td>
<td>3</td>
<td>3.3</td>
<td>101</td>
<td>10</td>
<td>9.9</td>
</tr>
<tr>
<td>Cardiovascular (except uncomplicated hypertension)</td>
<td>96</td>
<td>14</td>
<td>14.6</td>
<td>113</td>
<td>24</td>
<td>21.2</td>
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<tr>
<td>Hearing (decreased acuity)</td>
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<td>14</td>
<td>15.9</td>
<td>99</td>
<td>11</td>
<td>11.1</td>
</tr>
<tr>
<td>Tumor and/or cysts</td>
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<td>15</td>
<td>15.6</td>
<td>113</td>
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<td>13.3</td>
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<td>Fractures</td>
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<td>14</td>
<td>13.7</td>
<td>117</td>
<td>9</td>
<td>7.7</td>
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<tr>
<td>Urinary tract calculi</td>
<td>88</td>
<td>14</td>
<td>15.9</td>
<td>97</td>
<td>14</td>
<td>14.4</td>
</tr>
<tr>
<td>Gallstones</td>
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<td>0.0</td>
<td>100</td>
<td>1</td>
<td>1.0</td>
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</tbody>
</table>

* Bone changes determined by simultaneous reading of identical views of X-rays taken in 1943 and repeated in 1953.

* Bartlett: 4 increased density, 3 decreased density. Cameron: 2 increased density, 1 decreased density.
**Table 14. Prevalence of abnormal laboratory findings, 1943 to 1953 (participants residing in the study area for the 10-year period).**

<table>
<thead>
<tr>
<th>Laboratory determination</th>
<th>Year</th>
<th>Bartlett</th>
<th>Cameron</th>
<th>Significant difference (P = 0.05)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Number examined</td>
<td>Number abnormal</td>
<td>Rate (%)</td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>1943</td>
<td>116</td>
<td>34</td>
<td>29.3</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>79</td>
<td>20</td>
<td>25.3</td>
</tr>
<tr>
<td>Hematocrit</td>
<td>1943</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>79</td>
<td>5</td>
<td>6.3</td>
</tr>
<tr>
<td>Red blood count</td>
<td>1943</td>
<td>116</td>
<td>25</td>
<td>21.6</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>80</td>
<td>6</td>
<td>7.5</td>
</tr>
<tr>
<td>White blood count</td>
<td>1943</td>
<td>116</td>
<td>17</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>78</td>
<td>11</td>
<td>14.1</td>
</tr>
<tr>
<td>Differential count</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutrophiles</td>
<td>1943</td>
<td>71</td>
<td>15</td>
<td>21.1</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>78</td>
<td>23</td>
<td>29.5</td>
</tr>
<tr>
<td>Lymphocytes</td>
<td>1943</td>
<td>71</td>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>78</td>
<td>35</td>
<td>44.9</td>
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<td>Eosinophiles</td>
<td>1943</td>
<td>71</td>
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<td>0.0</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>78</td>
<td>6</td>
<td>7.7</td>
</tr>
<tr>
<td>Sedimentation rate</td>
<td>1943</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>79</td>
<td>31</td>
<td>39.2</td>
</tr>
<tr>
<td>Blood calcium</td>
<td>1943</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>79</td>
<td>9</td>
<td>11.4</td>
</tr>
<tr>
<td>Serology (S.T.S.)</td>
<td>1943</td>
<td>71</td>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>84</td>
<td>2</td>
<td>2.4</td>
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<tr>
<td>Urine albumin</td>
<td>1943</td>
<td>115</td>
<td>3</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>1953</td>
<td>77</td>
<td>5</td>
<td>6.5</td>
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<tr>
<td>Urine glucose</td>
<td>1943</td>
<td>115</td>
<td>2</td>
<td>1.7</td>
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<td></td>
<td>1953</td>
<td>77</td>
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<tr>
<td>Characteristics studied</td>
<td>Bartlett</td>
<td></td>
<td>Cameron</td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------</td>
<td>-------------</td>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>Number at risk</td>
<td>Number abnormal</td>
<td></td>
<td>Number at risk</td>
</tr>
<tr>
<td>Arthritic change</td>
<td>16</td>
<td>0</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys. 151 mm/hg and over</td>
<td>16</td>
<td>2</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Dias. 100 mm/hg and over</td>
<td>16</td>
<td>0</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Pulse pressure 75 mm/hg and over</td>
<td>16</td>
<td>2</td>
<td>19</td>
<td>0</td>
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<tr>
<td>Bone changesa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>15</td>
<td>0</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Coarse trabeculation</td>
<td>15</td>
<td>0</td>
<td>20</td>
<td>0</td>
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<td>Hypertrophic</td>
<td>15</td>
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<td>0</td>
</tr>
<tr>
<td>Spurs</td>
<td>15</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Osteoporosis</td>
<td>15</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Bone, increased density (new cases)</td>
<td>15</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Cataract and/or lens opacity</td>
<td>16</td>
<td>2</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Thyroid</td>
<td>16</td>
<td>0</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Cardiovascular (except uncomplicated hypertension)</td>
<td>16</td>
<td>4</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Hearing (decreased acuity)</td>
<td>16</td>
<td>0</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Tumor and/or cysts</td>
<td>16</td>
<td>3</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>Fractures</td>
<td>22</td>
<td>2</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Urinary tract calculi</td>
<td>16</td>
<td>0</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Gallstones</td>
<td>15</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

a At risk for that part of the ten-year interval in which the participant resided in the study area.

b Bone changes determined by simultaneous reading of identical views of X-rays taken in 1948 and repeated in 1953.

c Cameron: 1 decreased density.

Conclusions relative to the important X-ray observations are reported as follows:

1. The following types of roentgenographic bone conditions were seen in humans who used a water supply containing excessive fluoride (8 ppm F) for long periods: (a) increased bone density with or without coarsened trabeculation, with a "ground-glass" appearance; (b) coarsened trabeculation, showing lines of stress, without increased bone density; (c) increased thickening of cortical bone and periosteum with equivocal narrowing of bone marrow spaces. (This is positively demonstrated in cattle at toxic levels.)

2. The data, based on a study of 237 cases presented on a statistical basis in an earlier paper, clearly demonstrate that except for dental mottling, ingestion of water containing fluorides up to 8 ppm produces no deleterious bone changes: no unusual incidence of bone fractures, arthritis, hypertrophic bone changes or exostoses, or interference with fracture healing; no cases of "poker spine" and no evidence of associated functional or systemic effects.

3. Excessive fluorides in a water supply may produce roentgenographic evidence of bone changes, but the observable changes (a) occur in only a select few (approximately 10 to 15 percent of those exposed); (b) are
slight, often difficult to recognize, and in most instances equivocal in degree; (c) bear no resemblance to the bizarre findings described in some cases of long exposure to cryolite or rock phosphate dust, nor to those attributed by some investigators to excessive fluorides in domestic water supplies; (d) are not associated with other physical findings, except for dental mottling in persons who resided in the high-fluoride area during the tooth formative period (up to 8 years of age); (e) cannot be definitely ascribed to excessive fluorides alone; (f) do not necessarily occur even though the fluoride content of the bone may be six times that of "normal" bone.

4. There is some indication that the ingestion of excessive fluoride in water and the "fluoride effect" of the degree encountered in this study may, on occasion, have a beneficial effect in adult bone, as in counteracting the osteoporotic changes of the aged.

Specific systemic abnormalities and the prevalence of abnormal laboratory findings gave no evidence of a significant variation between Cameron and Bartlett. The only distinct variation was the high incidence and severity of mottled enamel in Bartlett. Cardiovascular abnormalities (except uncomplicated hypertension) were considerably higher in Cameron than in Bartlett. Differences in laboratory findings were recognized as clinically transient and to be evaluated in terms of clinical circumstances, without a pattern of association with fluoride effect. Age-corrected death rates of the two study areas were not significantly different. The authors' final conclusion was, "No clinically significant physiological or functional effects resulted from prolonged ingestion of water containing excessive fluoride except for dental fluorosis."

Leone, et al. (47), continued skeletal investigations in Framingham, Mass., where the drinking water contains less than 0.1 ppm fluoride, to compare with the effects of Bartlett's 8.0 ppm fluoride water. A total of 546 individuals between the ages of 30 and 70 years were examined by X-ray. In this non-fluoride area 220 cases of osteoporosis were diagnosed of which 77 were severe and advanced.

Effects of Fluoride Water in a Russian Community

V. A. Knizhnikov (48) reported that two towns in eastern Kazakh, Shchuchinsk and Kokchetav, situated 70 km apart, used drinking waters containing respectively 3.4 to 4.0 and 0.0 to 0.9 ppm fluoride. There were no essential differences between the two communities in climatic conditions, population number, nationality, or occupation. The people were largely native born, particularly in Shchuchinsk. Severe dental fluorosis in very old people of Shchuchinsk indicated the use of a fluoride water for many years before this study. This water supply was still obtained as it had been, from Lake Shchuchye.

Clinical observations were made on 222 native residents, 53 persons in Kokchetav (control) and 169 in Shchuchinsk (fluoride) with the objective of discovering any specific effect resulting from fluoride exposure. The authors were mindful of the effects of excessive fluoride on
bones and teeth and in addition paid special attention to any evidence of bradycardia, hypertension, somnolence, coagulation of blood, hemoglobin, paresthesia, and urticaria-type recurring rash. They attempted to learn whether the residents of Shchuchinsk had any other types of specific complaints or disorders. Mortality data were recorded for a 10-year period, including a number of chief causes for a 5-year period, and a study was made of illnesses for the years 1953–1954. All the illnesses listed were less in the fluoride area than in the control. There was an unexplained unusually low incidence of diseases of bones, muscles, and joints in the fluoride area. The authors concluded that there was no adverse action whatever on the part of water containing 4 ppm of fluoride except for dental fluorosis. Knizhnikov stated:

The present investigations as well as indications in the literature of a positive effect by fluoride, especially on dental caries and several other pathologic conditions, point to the importance of further investigations of the fluoride contained in water not only from the point of view of harmfulness, but also usefulness of this constituent in controlled concentrations.

The Osseous Development of the Hand and Wrist of Children

Films of children's hands from birth to 14 years of age have revealed a definite and uniform order of ossification in the carpal bones. Although the centers of calcification in these bones practically always appear in an orderly fashion it has been reported that progress of ossification may be influenced by factors such as environmental conditions, extremes of climate, systemic disorders, and endocrine functions. The skeleton of the growing girl is more mature than that of the boy of the same age.

It has become the general consensus that the hand is a good index of ossification of the entire skeleton. The first early observations in this regard have been confirmed and amplified by subsequent investigators who provided standards for the practical assessment of skeletal age by radiographic inspection of the hand. Calcification standards developed to assess skeletal age are based on large numbers of children radiographed at 6-month intervals from birth through the 18th year and have been used frequently in growth studies of children.

A study concerning the effect of fluoride in drinking water in the osseous development of the hand and wrist was conducted by McCauley and McClure (49), who were fortunate to have the assistance of school authorities and the use of darkrooms at St. Anthony's Hospital in Amarillo, Texas, Doctors Hospital in Lubbock, Texas, and Allegheny Hospital in Cumberland, Md.

Amarillo and Lubbock were the sites of this calcification study because of the high fluoride content of their drinking waters (approximately 3.5 ppm in 1948). Water supplies in the environs of these two cities for many years have contained 2.0 to at least 5.0 ppm fluoride and children living in this area could scarcely avoid exposure to these rela-
tively high fluoride drinking waters. Cumberland, Md., with 0.12 ppm fluoride, was selected as a control city. Continuously resident children (no more than 6 months' absence at one time) aged 7 through 14 years were selected for X-ray examination.

An X-ray picture showing the right hand and wrist of each child was taken and special care was exercised to maintain uniformity of position, distance, and exposure time. Radiographs of 2,050 children (965 boys and 1,085 girls) were taken in these three cities. The films were then used to establish an index of skeletal development for each child, employing the Carter technique to quantitate the calcified areas in the hand and wrist. Results are presented graphically in Figures 9 and 10.

Substantial evidence was found that continuous exposure to high levels of waterborne fluoride failed to influence the calcification of the carpal bones of boys and girls aged 7 through 14 years. The most significant non-dental effect of excessive quantities of fluoride is an advanced calcification in skeletal and ligamentous tissues and there was every reason to expect that if any effects of fluoride were found in this study they would be in the nature of hypercalcification and advanced skeletal maturity. There was no evidence in the radiographs, however, which

<table>
<thead>
<tr>
<th>F in water (ppm)</th>
<th>Sex</th>
<th>M</th>
<th>F</th>
<th>MEAN CARPAL OSSIFICATION RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
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<td>M</td>
<td>700</td>
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</tr>
<tr>
<td></td>
<td>F</td>
<td>700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumberland, Md.</td>
<td>M</td>
<td>368</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>401</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lubbock, Texas</td>
<td>M</td>
<td>330</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>360</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amarillo, Texas</td>
<td>M</td>
<td>267</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>324</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mottled Enamel Absent or mild Lubbock &amp; Amarillo</td>
<td>M</td>
<td>145</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>194</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mottled Enamel Moderate or severe Lubbock &amp; Amarillo</td>
<td>M</td>
<td>419</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>F</td>
<td>450</td>
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<table>
<thead>
<tr>
<th>F in water (ppm)</th>
<th>SEX</th>
<th>M</th>
<th>F</th>
<th>SKELETAL AGE RATING</th>
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<tr>
<td></td>
<td></td>
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<td>110</td>
<td>120</td>
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<tr>
<td>Univ. of Chicago Normals</td>
<td>M</td>
<td>350</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>350</td>
<td></td>
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<tr>
<td>Cumberland, Md.</td>
<td>M</td>
<td>368</td>
<td></td>
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<tr>
<td></td>
<td>F</td>
<td>401</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lubbock, Texas</td>
<td>M</td>
<td>330</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>360</td>
<td></td>
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<tr>
<td>Amarillo, Texas</td>
<td>M</td>
<td>267</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>F</td>
<td>324</td>
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<td></td>
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<tr>
<td>Mottled Enamel Absent or mild Lubbock &amp; Amarillo</td>
<td>M</td>
<td>145</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>194</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mottled Enamel Moderate or severe Lubbock &amp; Amarillo</td>
<td>M</td>
<td>419</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>450</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 9.—Mean carpal ossification ratios and skeletal age ratings for groups of children with and without exposure to fluoride waters.
Fig. 10.—Ossification ratios of boys and girls of different age groups in four communities.
would indicate any such adverse condition, although drinking waters had contained 2.0 to 5.0 ppm of fluoride during the growth and development of the Texas children. The results provided further assurance that fluoridated drinking water does not have a deleterious effect on skeletal growth development and calcification.

**Height, Body Weight, and Bone Fracture Experience**

Height, weight, and bone fracture experience data were collected from selected groups of 1,458 teen-age boys and 2,526 inductees, in the hope that body growth and skeletal function might show a relationship to use of a fluoride drinking water (50).

It had been suggested in 1929 by the French chemist, H. Christiani, that fluoride might cause bones to become fragile. Two animal experiments had also attributed a reduction in the breaking strength of long bones to fluoride, but one investigator had related an increase in breaking strength to a fluoride-induced enlargement of shaft walls of bones of dairy cows.

The men and boys selected for study lived in areas of the United States where the drinking waters used during growth and development varied from 0.0 to 3.8–5.1 ppm fluoride. By means of personal questioning their bone fracture experiences were recorded. Major breaks, it was felt, were quite accurately reported. Height and weight data were routinely obtained during the physical examination at induction centers. The bone fracture data tabulated in relation to the fluoride water exposure are shown graphically in Figures 11 and 12. There was no indication in these data that exposure to fluoride in drinking water in these boys and young men had changed the normal function of their skeletal system.

![Chart showing fluoride levels in different areas](chart.png)

**Fig. 11.—Distribution of bone fracture experience, number per 100 boys.**
The height-weight data also gave no indication of a relation to fluoride in drinking water.

Texas men exposed to highest water-fluorine concentrations and Oklahoma men averaged 69.6 and 69.4 inches in height (weight 149.0 and 142.4 pounds), respectively. Men from rural Indiana and Indianapolis averaged 68.1 and 68.3 inches in height, 146.8 and 146.2 pounds in weight, respectively. Washington, D.C., men averaged 69.4 inches and weighed 151.2 pounds on the average. New Hampshire men were 67.3 inches tall and weighed 149.6 pounds on the average.

The data of all the boys compared favorably with other investigations of height-weight data and with the standard figures for boys in this age group.

Endemic Skeletal Fluorosis—United States

Over a period of several years certain patients of the U.S. Public Health Service Indian Hospital in Phoenix, Ariz., were noted by Morris (57) as having unusually dense bones, especially of the spine and pelvis. These patients came from several areas on the Papago and Apache Indian Reservations in southern Arizona where drinking waters were known to vary from 0.5 to as high as 18.0 ppm fluoride or more. This is an area of Arizona where drinking waters have contained
excessive quantities of fluoride since early in this century. Between 1959 and 1963, among 9,726 admissions, 15 male and 5 female American Indian patients were found to have unusually dense bones. Twelve cases were over 40 years of age and five exceeded 60 years. Of the 20 patients suspected of having skeletal fluorosis, none had any symptoms of bone disease except one 22-year-old Apache male with severe renal rickets resulting from chronic pyelonephritis. There was no evidence of any deleterious skeletal changes with the possible exception of a 58-year-old Apache male who throughout his life had sustained multiple fractures, the cause of which was undetermined even at necropsy. Sixteen of these patients were from the Papagos tribe living in the Gila Bend where the water varied from 7.1 to 7.3 ppm fluoride. While there may have been a considerable migration among these patients they all came from areas known to have excessively high fluoride waters. Mottling of the teeth was a frequent observation. The fluoride analysis of rib bone, ilium, sternum, or vertebra made by I. Zipkin, of the National Institute of Dental Research, indicated well above normal fluoride in most of nine cases, varying from 0.126 to 0.699 percent fluoride.

The roentgenographic manifestations of fluorosis as recorded by Morris were similar to those first described in 1932 in cryolite workers by Møller and Gudjonsson (52). Morris reported:

It is evident that ingested fluorides may cause osseous sclerosis, but it is an enigma that people from the same area, drinking water from the same source, have considerable variability in the degree of sclerosis, and indeed may have no roentgenographic changes at all, even though it has been shown that fluoride concentration in bones of a human population has a linear relationship with the concentrations of fluorides in the drinking water up to concentrations of 4 ppm.

It was a matter of considerable concern to Morris that the degree of bone change did not correlate well with the amount of fluoride present in the bone.

It seems likely that unrecognized variables may have affected the fluoride content of these bone specimens. The observations indicate that this skeletal fluorosis was a benign condition, since none of the 20 patients had any symptoms relative to the osseous or ligamentous changes diagnosed by X-ray, with the doubtful exception of the one patient who had had multiple and repeated fractures. Participants in the Bartlett study (8.0 ppm fluoride in their water) also had shown no unusual symptoms of bone involvement nor any relation to incidence of arteriosclerosis, arthritis, stiffness of the back, renal disease, or biliary calculi. Hodges, et al. (53), had reported no skeletal sclerosis in two Illinois communities where the water contained 3 ppm fluoride. Mottled enamel was observed in the majority of the subjects examined, indicative of their use of this fluoride water. A further consideration is the consensus that skeletal tissue has a high degree of physiological tolerance to accumulation of fluoride. A physiological hazard to the individual may not arise even at a level of 0.5 to 0.6 percent fluoride in the
skeletal tissue. This quantity is greatly in excess of the less than 0.1 percent skeletal fluoride usually associated with the use of fluoridated drinking water. It is the consensus that there is no crippling skeletal fluorosis in the United States, because there is a wide margin of safety accompanying the use of fluoridated water.

Mortality Statistics

In 1957 at the 124th Meeting of the A.A.A.S., Thomas Hagan of the U.S. Public Health Service presented data from three studies concerned with the relationship between mortality and the use of fluoride drinking waters (54). Manifestly, as Dr. Hagan stated, "An examination of mortality experience provides only indirect evidence concerning general health effects resulting from the use of fluoridated water. The absence of a health hazard indirectly demonstrated by mortality statistics provides another link in the chain of evidence supporting the safety of water fluoridation."

The Illinois Department of Public Health published data based on 1940 census and mortality reports (55). Residents of certain areas of Illinois have used very low-fluoride drinking water provided by Lake Michigan and the Mississippi River for many years, while in other parts of the state deep wells have provided relatively high fluoride-bearing waters. The Illinois mortality data compared rates for deaths from all causes and specifically from heart disease, cancer, nephritis, and diabetes. Comparing communities using fluoride-bearing waters and fluoride-free waters it was concluded that "mortality experience in Illinois offers little or no support for claims of adverse effects being produced by limited ingestion of fluorides."

A second study published by Hagan, Pasternack, and Scholz (56) was concerned with comparisons of mortality data of cities in different parts of the United States. The populations included 892,625 persons in the fluoride cities and 1,297,000 in the non-fluoride cities.

This analysis was set up by listing all of the cities in the United States over 10,000 population in 1950, whose water supplies contained 0.70 ppm fluoride or more from natural sources. The criterion for inclusion of a city was met when the majority of its water analysis, for the entire period for which fluoride readings were reported, showed at least 0.70 ppm. Each fluoride city thereupon was paired with the nearest nonfluoride city over 10,000 population. The criterion for a nonfluoride city was a fluoride content of 0.25 ppm or less according to all available reports of water analysis.

This procedure resulted in an array of 82 pairs of cities, each pair consisting of one city whose water supply contained 0.70 ppm fluoride or more and an adjacent city whose water supply contained 0.25 ppm or less. The 1950 mortality rates of these cities for deaths from all causes, from heart disease, from cancer, or from nephritis showed no discernible differences related to the presence or absence of fluorides in their water supplies.

... heart disease mortality rates were higher in 17 of the nonfluoride cities than those in each paired fluoride city; ... for cancer and for deaths from
all causes half or 16 of the rates for the nonfluoride cities were higher; and for nephritis 19 of the nonfluoride cities were higher. It is evident that there is no real difference in mortality experience attributable to fluoride water usage between the 32 fluoride and the 32 nonfluoride cities for these causes of death.

Hagan also examined mortality experience in five cities before and after water fluoridation was instituted. These cities were Grand Rapids, Mich.; Sheboygan and Madison, Wis.; Evanston, Ill.; and Charlotte, N.C.; all having populations large enough to give stable mortality data suitable for comparing mortality experience and indicating an association of fluoridation with any change in number of deaths. Since controlled fluoridation was begun in 1945, the comparison provided an evaluation of the effects of 1, 2, 3, 4, and 5 years of fluoride ingestion on mortality. These mortality statistics gave no evidence of any effect of fluoridated water.

In addition to the above reports Knutson discussed statistics made available by the 1949–1950 U.S. Census Reports (57). These data reported deaths from nephritis, cancer, and heart disease per 100,000 population, adjusted for age, race, and sex, in 28 fluoride and 60 nonfluoride cities. Fluoride cities had 0.7 ppm or more fluoride in their drinking water. Knutson stated:

Examination of the data arranged according to death rates reveals a marked homogeneity. More specifically, for nephritis, 13 of the fluoride cities fall below and 15 above the median; for cancer 15 of the fluoride cities are below and 13 are above; and for heart disease 16 of the fluoride cities are below and 12 are above the median.

Mortality data have been compiled for Grand Rapids, Muskegon, and the United States for each of 8 successive years beginning in 1943. In addition to mortality rates for nephritis, cancer, and heart disease, mortality rates for intracranial lesions are included. Muskegon did not begin fluoridating its drinking water supply until 1951 so that for each of the years covered in these comparisons, 1943 through 1950, Muskegon's drinking water was not fluoridated.

The conclusion for this evaluation is, then, that absolutely no indications or suggestions of undesirable non-dental physiological effects can be attributed to the fluoridation of the drinking water in Grand Rapids during the past 8 years. The striking dental benefits have not been offset by any undesirable consequences.

Summary data from this study are shown in Tables 16 and 17.

Table 16. Mortality rates per 100,000 population (adjusted for age, race, and sex).

<table>
<thead>
<tr>
<th>Death</th>
<th>Fluoride cities</th>
<th>Control cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart disease</td>
<td>354.8</td>
<td>357.4</td>
</tr>
<tr>
<td>Cancer</td>
<td>195.4</td>
<td>189.1</td>
</tr>
<tr>
<td>Intracranial lesions</td>
<td>111.5</td>
<td>104.3</td>
</tr>
<tr>
<td>Nephritis</td>
<td>21.9</td>
<td>26.9</td>
</tr>
<tr>
<td>Cirrhosis of the liver</td>
<td>6.6</td>
<td>8.2</td>
</tr>
<tr>
<td>All causes</td>
<td>1010.6</td>
<td>1005.0</td>
</tr>
</tbody>
</table>
Table 17. Ratio of recorded to expected deaths in five cities ingesting a fluoridated drinking water.

<table>
<thead>
<tr>
<th>City and year of fluoridation</th>
<th>Year</th>
<th>Number of deaths</th>
<th>Ratio of recorded to expected deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Recorded</td>
<td>Expected</td>
</tr>
<tr>
<td>Grand Rapids, Mich. 1945</td>
<td>1940</td>
<td>1643</td>
<td>1674</td>
</tr>
<tr>
<td></td>
<td>1950</td>
<td>1803</td>
<td>1764</td>
</tr>
<tr>
<td>Sheboygan, Wis. 1946</td>
<td>1940</td>
<td>394</td>
<td>380</td>
</tr>
<tr>
<td></td>
<td>1950</td>
<td>383</td>
<td>416</td>
</tr>
<tr>
<td>Evanston, Ill. 1947</td>
<td>1940</td>
<td>611</td>
<td>660</td>
</tr>
<tr>
<td></td>
<td>1950</td>
<td>672</td>
<td>765</td>
</tr>
<tr>
<td>Madison, Wis. 1948</td>
<td>1940</td>
<td>546</td>
<td>612</td>
</tr>
<tr>
<td></td>
<td>1950</td>
<td>652</td>
<td>762</td>
</tr>
<tr>
<td>Charlotte, N.C. 1949</td>
<td>1940</td>
<td>806</td>
<td>782</td>
</tr>
<tr>
<td></td>
<td>1950</td>
<td>964</td>
<td>933</td>
</tr>
</tbody>
</table>

The Major Causes of Death in Relation to Length of Residence in Colorado Springs

An extensive mortality study in Colorado Springs, Colo., provided information concerning pathological effects in residents after prolonged use of the natural fluoride water (2.0–2.5 ppm) there. The material of the study consists of 904 necropsies performed in Colorado Springs between 1947 and 1953 by Dr. Erving F. Geever, senior author of this important report (58), who stated:

During the years that the necropsies were performed, the senior authors had no special interest in fluorides. Although this might be looked on as desirable in that necropsies were performed without prejudice in this controversial field, it had the disadvantage that no special attention was given to the bones, a known storehouse for fluorides. Thus, this study was complemented by another undertaken between 1955 and 1957 with detailed examination of bones.

The Colorado Springs necropsy protocols were classified according to the major cause of death, the contributing causes unrelated to the major cause, and the incidental pathological condition.

It was hoped that such classification and subsequent analyses might not only indicate whether there was evidence of serious cumulative toxic effects but also whether incidental pathologic processes impairing health were possibly related to the ingestion of fluorides. The material was classified according to residence history. The results were then tabulated and the figures analyzed statistically.

The results of reexamination of the protocols and classification of the data into the major cause of death, contributing causes and incidental pathologic conditions were tabulated.

The residence histories, after eliminating deaths among the newborn and among children under 10 years of age, revealed four groups: 334 persons who had resided in Colorado Springs for more than 20 years, 130 who had resided there from 5 to 20 years, 188 under 5 years, and 76 in whom the residence history was incomplete. This study of the pathologic findings was thus based on 728 necropsies.
Comparative statistical analyses of the pathologic findings revealed no significant differences which could be related to prolonged residence in this environment.

The second study by Geever, et al. (59), reported:

Necropsies were performed in Grand Rapids, Mich. (1 ppm); Colorado Springs, Col. (2.5 ppm); Amarillo, Tex. (2.8 ppm); and Lubbock, Tex. (4.0 ppm). Bone specimens were obtained through the cooperation of local pathologists: Dr. Joseph Mann and Dr. Harold Bowman of Grand Rapids, Dr. Morgan Bethrong and Dr. Raoul Urlich of Colorado Springs, Dr. Marie Shaw of Lubbock, and Dr. John Denko and Dr. C. P. Churchill of Amarillo. The series consisted of 37 persons who had resided for 10 years or more in the above communities. The majority, 24, were residents of Colorado Springs; they provided 65 bones for the study. The ages of the subjects, 17 men and 20 women, ranged from 36 through 90 years.

Residents of a non-fluoride area, 24 men and 9 women, ranging in age from 21 through 87 years, served as controls.

Most of the persons in this study died suddenly—the most common causes of death being trauma, coronary heart disease, and cerebral vascular accidents. Those with chronic illness and diseases known to affect bone structure were excluded. None had primary or metastatic bone cancer, long-standing cancer of other organs, renal, or parathyroid disease.

Generally, three bones were examined: the body of a lumbar vertebra, a portion of iliac crest, and the sixth rib. Lumbar intervertebral body joints were examined for possible changes in articular cartilage. "Less often, the sternum was also studied. A few bone or joint specimens proved unsatisfactory for some phase of the study, with the result that the totals vary."

These investigators discussed in detail the periosteal and marginal tissue, periosteum, compact cortical bone, the spongy bone of the medulla, bone marrow, and the intervertebral lumbar body joint.

The results of this study can be correlated to some extent with previous work on necropsy material in Colorado Springs, where the fluoride level is 2.5 ppm. In that study there was no significant difference in the occurrence of bone cancer between 334 long-term residents (more than 20 years) and 188 short-term residents (less than 5 years). There were 8 deaths attributed to bone cancer in the former group and 2 in the latter.

The microscopic examinations showed no significant differences between the fluoride-exposed group and the control group that could be related to fluoride intake. Microscopic changes in the bones and joints incidental to aging and due to non-fluoride-related conditions were observed in both series.

In addition to these mortality surveys mention should be made of two more recent publications concerning mortality statistics and use of a fluoride water. In 1961 a committee of Ontario Province reported on the fluoridation of municipal water supplies (60). Since 1957 fluoridation had been the subject of controversy in Ontario, when the Supreme Court of Canada, in the case of Metropolitan Toronto vs. Village of Forest Hill, decided that Metropolitan Toronto lacked the power to enact a by-law providing for fluoridation of its water. Prior to this
judgment, however, the legislature had amended the Public Health Act authorizing Brantford, Brockville, Deep River, Fort Erie, Oshawa, Thorold, Sudbury, and Tisdale to continue fluoridating their water supplies.

This committee reviewed the fluoride literature, held public hearings, evaluated available evidence, and listened to both opponents and proponents of fluoridation. Aware of the many areas in Ontario where water supplies contained 1.0 ppm or more fluoride naturally, the Medical Officers of Health of these counties were consulted. There were no reports of ill effects nor did perusal of death certificates and morbidity reports from hospitals and physicians reveal any deleterious effects of fluoride drinking waters. Mortality rates for all causes, stillbirths, and infant mortality in 18 cities using fluoride-free water were not different from similar statistics available in Brantford, Stratford, and Sarnia where 1.0 ppm or more fluoride was present in the water supplies.

The Ministry of Health, London, reported in 1962 mortality and morbidity statistics in areas where the drinking water contained fluoride naturally at levels of 0.5 to 5.8 ppm (67). In control areas the drinking waters contained less than 0.2 ppm fluoride. Statistics for 1950–1959 related to 428,960 individuals living in 18 fluoride areas and 368,580 in the control areas. These localities and their statistics were divided into southern and northern areas in an effort to improve variables other than fluoride in the matching of control and fluoride populations. In addition the concentrations of fluoride in the south were in many cases much higher than in the north. The southern towns are mostly small urban communities situated in predominantly rural areas; the northern towns are large and highly industrialized.

The data were difficult to assess but the combined experience of the southern and northern areas showed, "Mortality from coronary disease is significantly lower in the fluoride areas, but mortality from cancer of the stomach, pneumonia, bronchitis, and 'all other diseases' is significantly higher." It was thought that data on stomach diseases, pneumonia, and bronchitis could be safely ignored. At the same time the apparent excess of deaths from cancer of the stomach was given close inspection.

The most notable of the findings in this investigation is that there is no difference in the overall mortality between the two groups of areas examined.

When the individual causes of death are considered some differences are observed which are significant at the 5 percent level of probability, some conditions apparently having a higher mortality in the control areas.

With cancer of stomach it must be noted that the difference was based entirely on the comparison of three northern areas with their "controls." It was impossible to select areas which were exactly alike and it would be wrong to place too much emphasis upon this finding. It is concluded, on the evidence available, that the difference in the fluoride levels is most unlikely to have been the cause of the difference in mortality for the following reasons:

(a) There is a complete lack of association between fluoride levels and stomach cancer mortality in the southern areas.
(b) Two of the northern areas share a common water supply and yet the S.M.R. for stomach cancer is 117 in one (West Hartlepool) and 200 in the other (Hartlepool).

(c) Other areas, some of which are of a highly industrialised nature, but with little or no fluoride in their water, have higher mortality rates for stomach cancer.

(d) It is known that factors such as social class and geographical area play a part in the etiology of stomach cancer in a manner which is entirely unrelated to the consumption of fluoride.

A further pertinent fact may be noted. Tea contains fluorides at a level of approximately 1 ppm. Had fluoride been an etiological agent in the causation of cancer of the stomach one would have expected heavy tea drinkers to be unduly susceptible to this disease.

There was no evidence that cancer of the stomach was greater in heavy tea drinkers in comparison with those whose daily consumption was moderate.

NOTES AND REFERENCES

Fluoride in Tea

Investigators at the Boyce Thompson Institute reported recently on fluoride in tea (Contributions from Boyce Thompson Institute, 19:49). Tea with its high fluorine content presents an interesting exception to practically all other plant produce. Plants grown in small plots in proximity to the tea plant do not acquire a significant content of fluoride. The relationship of fluoride to the tea plant is real and unmistakable. The Boyce Thompson Institute investigators found, however, that different ornamental varieties of Camellia (C. japonica L.) which belongs to the same family as tea (Theaceae) also accumulate large amounts of fluoride. One sample of fresh leaves of greenhouse-grown Camellia sinensis E. contained 1,580 ppm of fluoride on a dry basis, while dry leaves of some domestic brands of tea contained from 72 to 178 ppm.

Fluoride in Processed Foods and Beverages

Recent investigations relative to the fluoride content of foods and beverages were reported by Marier and Rose (J. Food Sci., 37:941), who described a revised fluoride microanalytical procedure. Using only a 10 g sample of food, the method was reported to have unusual accuracy, the data having a standard deviation of 0.195 ppm fluoride, but the success of this new procedure in the hands of other analysts has not been reported. Marier and Rose analyzed a number of foods processed with both fluoridated and unfluoridated water. The actual quantity of fluoride in the waters used was reported for one foodstuff although fluoride is present in all commercial water supplies. The original content of fluoride in the foods prior to processing also was not reported. According to Marier and Rose the data “indicate that the use of artificially fluoridated water in the processing of foods and beverages increased the fluoride content of these products by 0.34–0.75 ppm.” These increases obviously are significant but the data are very limited and the analytical procedure should be verified. The processing procedures are not clearly defined and control data are lacking.

Kidney Function and Fluoridated Water

The indispensable function of the kidney for elimination of fluoride from the body has focused special attention on that organ in relation to effects of fluoridated water. Many observations on kidney structure and function support the fact that the kidney is sensitive to excessive amounts of fluoride. Renal injury has been induced in
swine, cattle, sheep, monkeys, dogs, and experimental rats in varying degrees of severity, depending on the fluoride dose. Toxic quantities of fluoride are estimated at 80-100 ppm in animal rations administered for long periods, depending on the animal species. Evidence concerning the permissible threshold with respect to the experimental white rat is extensive albeit equivocal. In 1957 Ramseyer (J. Gerontol., 12:14) reported pathological kidneys in rats given 1, 5, and 10 ppm fluoride in drinking water for over a year, only to be refuted in 1962 by Bosworth and McKay (J. Dental Res., 41:949). These later investigators studied effects of 1, 5, and 10 ppm fluoride in water of experimental rats for periods of 520 days. Histological examination made in three laboratories agreed that the changes observed were the normal effects of age. There was no evidence of fluoride injury at these low levels of intake. Pindborg placed the threshold of production of chronic kidney injury in the rat at the high level of 125 ppm fluoride (Odontol. Rev., 8:177).

Beginning with the thorough studies of Roholm and the later observations on industrial exposures to fluoride in both man and animals, there has been no evidence of kidney damage resulting from relatively excessive fluoride. The Bartlett, Texas, study (8 ppm fluoride in the water) gave no evidence of an effect on kidney function or disease. Analyses for occult blood, albumin, and glucose in urine specimens from young men, aged 19.4 to 21.8 years, living in non-fluoride areas (0.0—0.3 ppm fluoride) as opposed to those living in the west Texas Panhandle area (2.0—5.2 ppm fluoride), revealed no variations indicative of any effect of the high fluoride waters. Children using Newburgh's fluoridated water were shown to be unaffected when compared with those using Kingston's non-fluoridated water, according to microscopic examinations of urine specimens. In the extensive mortality studies and necropsy studies reported in this chapter there was no evidence that fluoride in drinking water even in excess of 1.0 ppm had a detrimental effect on kidneys.

Kidney impairments, short of chronic complete renal insufficiency, do not reduce the urinary fluoride excretion, a conclusion having substantial support in experiments on rabbits and rats as well as observations on man. Comparing the use of fluoridated water with urinary fluoride excretion, Hodge and Smith stated a general consensus: "Even were all renal excretion of fluoride blocked in an individual consuming 1 ppm of fluoride in the water for 70 years, the skeletal storage capacity is great enough to accept and deposit all the fluoride taken in without alterations in structure or function of the skeleton." In the event that skeletal damage becomes a concomitant of kidney malfunction, this generality might not be tenable, except that 70 years is a prolonged period to survive a kidney failure of any consequence.

Excessive storage of fluoride as a concomitant of subnormal renal function was claimed in 1945 in a frequently quoted case history (Radiology, 40:474). A young soldier suffering from a fatal kidney disease was reported to have 0.64 to 0.75 percent of fluoride in his bones. Although his drinking water during part of his lifetime contained 4 to 12 ppm fluoride, there was no evidence that this fluoride exposure induced the kidney damage. This quantity of bone fluoride, in the case of an 84-year-old resident of Bartlett, Texas (8 ppm fluoride in drinking water), was not a health hazard.

Hemodialysis and Fluoride

Treatment of severe renal insufficiency by use of the artificial kidney may require as much as 200 liters of water per treatment. The presence of fluoride in the dialysate bath has given rise to interest regarding a potential hazard (or benefit) of this fluoride. Taves, Terry, Smith, and Gardner (Arch. Intern. Med., 115:167) studied a 41-year-old nurse with a past history of proteinuria, hypertension, and periodic urinary tract infection. Renal function having failed, hemodialysis was performed. Clearance of fluoride from the bloodstream was followed during hemodialysis. After one hour of dialysis blood serum fluoride averaged 0.65 ppm, as compared with an initial serum content of 0.40 ppm fluoride, indicating abnormal clearance of fluoride. The dialysate for a two-hour period contained 0.71 to 0.95 ppm of fluoride indicating that the water used was fluoridated.
A vertebral bone specimen taken at autopsy was found to contain 0.55 percent fluoride in the vertebral bone ash. "The pathological diagnosis of the bone was that of a mild to moderate degree of osteoporosis, plus a severe degree of osteomalacia and dissecting osteitis, compatible with moderately severe renal osteodystrophy. No changes or abnormalities in the bones were noted on the radiographs taken during the two years prior to death." It was estimated that this patient received 10 mg of fluoride at each dialysis period. Clinical fluoride treatment of osteoporosis, however, may prescribe as much as 1,000 to 2,100 mg of fluoride to some patients in a period of time similar to kidney dialysis. Among five such patients, only two had serum fluoride concentrations higher than the initial values of the dialysis case. Regarding fluoride retained in their patient's vertebral bone. Taves and his associates suggest that she had retained more fluoride than was usual for some time prior to the periods of dialysis. In concluding, they stated,

It is possible that extra fluoride was beneficial for this patient's bone as is suggested in osteoporotic patients, so further experimental work would be justified. However, where no effort can be made to learn more about its possible effects it would seem prudent to use nonfluoridated dialysate baths for long-term hemodialysis.

It is generally agreed that a desirable fluoride content of water to be used in dialysis has not been determined.

Retention of Fluorides in Animals

Experimental animal studies on the physiological effects of fluoride have contributed quantities of valuable data pertinent to the effects of fluoridated water. Many experiments have evaluated the chemical and physical properties of fluoride in relation to enamel and dentin and to the agreement between the level of fluoride ingested in food and water and the quantity acquired by dentin and enamel. Extensive evidence demonstrates a post-eruptive uptake of fluoride by fully developed teeth and the effect of the age of teeth and bones on their capacity to retain fluoride. A study of a mature dog showed that dentin and to a limited extent enamel acquired fluoride after tooth eruption (Science, 95:256). The post-eruptive deposition of fluoride in enamel and dentin of erupted molar teeth of rats has been demonstrated. Zipkin gave experimental rats aged 30 to 350 days equal quantities of fluoride over specified periods (J. Nutr., 47:611). As the rats aged there was a striking reduction in capacity to acquire fluoride by both bones and molar teeth. The results are quite dramatic in regard to the teeth and agree with the extensive evidence showing the effect of age of human teeth on their capacity to acquire fluoride.

In vitro studies on the chemistry of enamel and dentin have described numerous complex reactions with fluoride as well as basic physical properties, some of which have been mentioned. A major objective of all these studies is to clarify the chemistry and mechanism of the caries-preventive effect of fluoride, particularly as dentin and enamel are involved. This continues to be a difficult and unresolved problem.


studies in man after prolonged ingestion of fluoride in drinking water. II. Findings in bones in communities with water levels from 1.0 to 4.0 ppm fluoride. Public Health Rept. (U.S.), 73:721.


CHAPTER FOURTEEN

APPROVAL

The five years following the start of fluoridation studies were marked by an acrimonious controversy which arose between those who pressed for immediate acceptance and official promotion of fluoridation, and a more conservative group who advised withholding approval pending longer periods of observation. Pressure for immediate acceptance centered particularly in a number of dentists and health officials in Wisconsin. Many details of these events are interestingly documented by Donald R. McNeil in his book *The Fight for Fluoridation*.

In 1945 the Wisconsin State Dental Society had passed a resolution recommending that public water supplies which were deficient in fluoride should have their fluoride concentration raised to 1 ppm for the purpose of reducing dental decay. The same year the Wisconsin Board of Health, composed of eight prominent physicians, had passed a resolution also encouraging fluoridation. In 1947 the Board restated this policy and amended the resolution to permit a 1.5 ppm maximum content of fluoride. In February, 1946, the drinking water of Sheboygan was fluoridated. Favorable effects of this fluoridation on the deciduous teeth had been reported in 1948, and as Dr. Francis A. Bull, a Wisconsin dentist, wrote in August, 1950:

The question now arises, "Is the evidence for the fluoridation of public water supplies sufficiently conclusive to warrant its general recommendation to the public?" Like all questions pertaining to public health, there are two viewpoints. One group believes that the evidence is sufficiently conclusive to make this recommendation. The Wisconsin State Dental Society and the Wisconsin State Board of Health, the Colorado State Dental Society and the Colorado State Board of Health, and several research workers support this viewpoint and have been making this recommendation for some years. The other viewpoint is that, while all the evidence for the artificial fluoridation of public water supplies looks good, this evidence is presumptive, and scientific skepticism should be applied to all of this data and no recommendation be given to the public until this evidence is conclusive.

In all fairness, it must be stated that scientific skepticism is a healthy condition. However, this skepticism must be based on logical deductions. When there is overwhelming epidemiologic evidence to support any public health measure, skepticism not founded on logical bases should not constitute a valid reason for withholding that measure from the public. The history of
public health is filled with examples of great harm done to the public because skepticism was maintained long after it had ceased to be scientific or logical.

This policy led to the intensive, persistent character of the Wisconsin fight for fluoridation. Public resistance to this health measure was compared to that which had occurred in the chlorination of drinking water, use of iodine in goiter prevention, and use of silver nitrate in the eyes of the newborn for the prevention of gonorrheal blindness. As a result of the persistence of their drive, at an early date (1949), 85 percent of the urban population of Wisconsin had adopted fluoridation. But before long, dissent and opposition were to erupt in their home state as well as in other states. Nationwide, antifluoridation forces were to begin their fight to thwart all efforts to fluoridate public drinking waters, and in Wisconsin the first real opposition developed in a small village named Stevens Point. The battle of Stevens Point is described in detail in McNeil's *The Fight for Fluoridation*. The political remonstrance and resistance in Stevens Point became typical of what was to develop later in so many communities throughout the United States.

The Wisconsin fluoridation fight was conducted to a major extent by four prominent Wisconsin dentists, Drs. Francis A. Bull, John G. Frisch, A. H. Finke, and Timothy A. Hardgrave. Typical of the activity of one of these men is McNeil's description:

> Relentlessly, tirelessly Frisch pursued the trail. He prodded, pushed, and often created interest where there was none. As requests for him to speak increased, he began to discriminate. Though he refused to "go on wild goose chases," he asked only that the proposal to fluoridate actually be in the form of an ordinance before the council or board. Summer or winter, he never refused an invitation when the local citizens proved to him they "meant business." He rejoiced when he was able to "knock off" a town, as he called it, and despaired when the community leaders rejected the idea or settled for placing the issue on the ballot. "This is getting warmer every minute," he once confided to Fred McKay as he told of an impending battle, "and I am enjoying it."

As a member of the state Fluorine Study Committee from the time of its inception in 1943, Frisch had shown greatest interest in the promotional rather than the scientific side of fluoridation. Determined to "sell" the idea to Madison, he began, in the fall of 1944, laying plans for the campaign. Frisch toured the city obtaining signatures of dentists favoring fluoridation. All but two of Madison's 108 dentists signed. The city health officer, Dr. Frank F. Bowman, conducted a survey of doctors in the city and received 154 favorable replies and 23 opposed.

But very soon two Madison aldermen, strenuously opposing this proposal, privately published a pamphlet entitled *Why the City of Madison Should Not be Hasty in its Decision to Introduce Fluorine into its Municipal Water Supply*. These two aldermen had received but one affirmative answer to three leading questions: (a) Is it non-poisonous? (b) Can it be controlled to a safe quantity in water? and (c) Can it be unequivocally stated that it is safe without any scientific objection or reservation? McNeil commented:
Only one person answered yes to all three questions. Dr. Edward J. Largent of the Kettering Laboratory in Cincinnati said that 1 ppm fluorine was "too small to cause harmful effects." On the other hand, Dr. A. J. Carlson of the University of Chicago medical school urged delay until completion of the ten-year experiments at Grand Rapids and Newburgh. Other scientists, obviously objecting to such words as "unequivocally," and "without reservation," either hedged or advocated delay.

At the University of Wisconsin, several faculty members raised questions in their replies which the aldermen reproduced in their booklet. Otto L. Kowalke, professor of chemical engineering at the University, expressed doubt about its engineering feasibility. As fluoridation entailed an "exceedingly difficult engineering operation" involving proper and automatic proportioning of the added fluoride compound, Kowalke said it was "unlikely that the additions of fluoride could be made so that the concentration of it would be near 1 ppm and not rise to 2 ppm. Kowalke also blasted Frisch's Union Grove statistics. Because Frisch compared Madison with a population of 67,000 and Union Grove with a population of 1,000, Kowalke maintained that Frisch's statistical procedure was "open to serious criticism."

From Dr. E. B. Hart, emeritus professor of biochemistry and former head of that department at the University, the two aldermen received a blunt warning: "Fluorine is a distinctly dangerous and toxic element." It was a known fact that fluorine at higher levels was toxic and would progressively accumulate in bony tissues, Hart wrote. As there was no "unequivocal evidence" that 1 ppm fluorine was safe, Madison would be wise to wait for completion of the long-term Michigan and New York studies.

Henry T. Scott, director of biological research of the Wisconsin Alumni Research Foundation—established to receive and give grants to the University—concurred. "Why subject the entire community to something that benefits only a small percentage of the population," asked Scott, "especially until 'additional evidence' is collected?"

These were but the beginnings of efforts to have Madison city water fluoridated. The battle was finally won on June 1, 1948, when the Madison Water Department began fluoridation of water from one well (No. 6). By June, 1950, the entire city water supply was fluoridated. In 1951 it was reported that kindergarten children using fluoridated water from Well No. 6 averaged 4.23 decayed surfaces per child as compared with 8.14 decayed surfaces before the water was fluoridated.

In 1948–1949 the investigators in the fluoridation studies in Newburgh, Brantford, and Grand Rapids were cautiously advising that their data were preliminary and that the studies should continue to at least 1954 or 1956.

At the same time pressure continued for definitive policy statements from influential dental and health organizations, and the first of these was the American Water Works Association. During May, 1950, at a meeting of the State and Territorial Dental Directors of the U.S. Public Health Service in Washington, there was a climate of urgency calling for an official Public Health Service policy statement on fluoridation. The major pressure for official approval still originated from the enthusiastic Wisconsin proponents. Drs. H. Trendley Dean and Francis A. Arnold, Jr., of the NIDR remained conservative and were inclined to delay an official pronouncement. Shortly following this meeting, how-
ever, the Chief Dental Officer of the Public Health Service, Dr. Bruce D. Forsyth, released a policy statement to the American Dental Association, published in an editorial of the August, 1950, issue of the Journal of the Association:

Preliminary data indicate a lowered amount of dental decay following fluoridation of the public water supply. Although evidence is rapidly accumulating, the control study now being carried on (in Grand Rapids) should be continued and others as may be necessary inaugurated.

In order to utilize this preventive at the earliest possible moment, therefore, fluoridation of public water supply as a procedure for the partial control of dental caries can be encouraged subject to the approval of the state and local health authorities and the dental and medical professions.

The editorial continued:

It appears certain from the data compiled from the few controlled fluoridation studies now under way that the addition of 1 ppm of fluoride to community drinking water inhibits dental decay. In fact the reports warrant the assumption that the fluoridation of drinking water may, at the end of ten years, reduce significantly the incidence of caries.

Certainly the opinions of such authoritative bodies as the American Water Works Association, the State and Territorial Dental Health Directors and the United States Public Health Service should dispel any lingering doubt about the advisability of fluoridating communal drinking water, and they should open the way for all communities having a central water system to provide a simple, inexpensive measure which will partially protect their children from the ravages of caries.

The artificial fluoridation of drinking water, however, is not a cure-all; it will not protect children completely from dental decay, but it is a tremendous step forward in the profession’s fight against dental disease and it will stimulate further investigation which will lead to a more complete solution of the caries problem.

The secretaries of the Councils on Dental Health and Dental Therapeutics of the American Dental Association subsequently polled their members and received favorable reactions, swayed particularly by the official approval given by the U.S. Public Health Service and the State and Territorial Dental Health Directors. At its November, 1950, meeting the House of Delegates of the American Dental Association passed a resolution recommending fluoridation of community water supplies “when approved by the local dental society and utilized in accordance with the standards established by the responsible health authority, . . . the American Dental Association recommends the continuation of controlled studies of the benefits derived from the fluoridation of water supplies.”

In 1953 the House of Delegates of the association again approved fluoridation with:

Resolved, that the American Dental Association reiterates its recommendation that all local communities be urged to adjust the fluoride content of their public water supplies to the level recommended by responsible state and local health authorities.

The American Dental Association thus enthusiastically supported
flouridation, and the organization's activities in support of this procedure include numerous publications available to all interested individuals and communities. Officials of the association have participated in numerous court cases and Congressional hearings. The authoritative status of the association has been a great boon to the acceptance and adoption of fluoridation.

State and Territorial Dental Health Officers had announced on June 8, 1950, their support of fluoridation by the following resolution passed at their May meeting:

Resolved, that the State and Territorial Dental Health Directors recommend the fluoridation of public water supplies for the partial control of dental caries, where the local dental and medical professions have approved this program and where the community can meet and maintain the standard required by the state health authority.

Surgeon General Leonard A. Scheele reaffirmed fluoridation as an official policy of the Public Health Service in testimony before the Senate Subcommittee on Appropriations, April, 1951. At that time it was stated, "During the past year our studies progressed to the point where we could announce an unqualified endorsement of the fluoridation of public water supplies as a mass procedure for reducing tooth decay by two-thirds."

In 1952 Assistant Surgeon General Bruce D. Forsyth restated this unqualified position before the U.S. House of Representatives Select Committee to Investigate the Use of Chemicals in Food Products. The chairman of this committee was Rep. James J. Delaney of New York. Public hearings devoted almost entirely to fluoridation continued for seven days before this committee. The major testimony was concerned with safety and efficacy of fluoridation.

Flouridation has been given official approval by virtually all national and international health and professional organizations:

American Dental Association (1962)

The fluoridation of public water supplies is a safe, economical and effective measure to prevent dental caries. It has received the unqualified approval of every major health organization in the United States and of many in other countries.

American Medical Association (1957)

On December 6, 1951, the House of Delegates of the American Medical Association adopted the following resolution with respect to fluoridation of community water supplies:

Whereas, Carefully controlled studies have demonstrated that fluoridation of water supplies has been definitely beneficial in the reduction of dental caries in the younger age group; and

Whereas, The Council on Pharmacy and Chemistry has reported that fluoride is nontoxic in community water supplies up to one part per million; and

Whereas, The addition of fluoride to community water supplies seems to have merit; therefore be it
Resolved, That the House of Delegates of the American Medical Association endorses the principle of fluoridation of community water supplies.

In 1956, the AMA House of Delegates instructed the Board of Trustees to have the Council on Drugs and the Council on Foods and Nutrition review this matter.

A joint report of these councils concluded:

1. Fluoridation of public water supplies so as to provide the approximate equivalent of 1 ppm of fluorine in drinking water has been established as a method for reducing dental caries in children up to 10 years of age. In localities with warm climates, or where for other reasons the ingestion of water or other sources of considerable fluoride content is high, a lower concentration of fluoride is advisable. On the basis of the available evidence, it appears that this method decreases the incidence of caries during childhood. The evidence from Colorado Springs indicates as well a reduction in the rate of dental caries up to at least 44 years of age.

2. No evidence has been found since the 1951 statement by the Councils to prove that continuous ingestion of water containing the equivalent of approximately 1 ppm of fluorine for long periods by large segments of the population is harmful to the general health. Mottling of the tooth enamel (dental fluorosis) associated with this level of fluoridation is minimal. The importance of this mottling is outweighed by the caries-inhibiting effect of the fluoride.

3. Fluoridation of public water supplies should be regarded as a prophylactic measure for reducing tooth decay at the community level and is applicable where the water supply contains less than the equivalent of 1 ppm of fluorine.

The American Medical Association is of the opinion that fluoridation of public water supplies is a safe and practical method of reducing the incidence of dental caries.

American Association for the Advancement of Science (1954)

Reaffirmed its 1952 recommendation of fluoridation and:

Resolved, That . . . the Association . . . go on record as endorsing the fluoridation of community water supplies as a method for advancing dental public health, at this 121st meeting of the AAAS.

American Federation of Labor and Congress of Industrial Organizations (1963)

Whereas, The AFL-CIO Community Service Activities has developed a program to bring to union members and their families knowledge and information necessary to prevent illness. Such program includes union sponsored courses on the prevention of heart disease, cancer, mental illness, alcoholism, arthritis and so on; the development of mass vaccination and inoculation programs against tetanus, polio, diphtheria and so on; support of fluoridation; the intensified use of rehabilitation facilities by those injured in industrial accidents and those with non-industrial injuries and handicaps; the development of mass multiple screening programs; therefore, be it

Resolved, That this Convention affirms its support of this community health education program and urges all national and international unions, and state and local central bodies to support and assist in the development of this effort to safeguard the health of American workers.
American Water Works Association (1963)

In communities where a strong public demand has developed and the procedure has the full approval of the local medical and dental societies, the local and state health authorities, and others responsible for the communal health, water departments or companies may properly participate in a program of fluoridation of public water supplies.

American Institute of Nutrition (1966)

Whereas, The addition of appropriate amounts of fluoride, to those municipal water supplies which are deficient in fluoride, has been shown to improve the durability of dental enamel and to decrease the rate of dental decay, and

Whereas, This well-tested public health measure has the support of the U.S., Public Health Service, the American Medical Association, the American Dental Association, and many other science-oriented groups, therefore

Be It Resolved, That the American Institute of Nutrition at its annual meeting April 15, 1966, recognizes fluoridation as a safe, effective and low-cost means of improving dental health by improving nutrition.

Additional approving American organizations:

- American Academy of Pediatrics
- American Association of Dental Schools
- American Association of Industrial Dentists
- American Association of Public Health Dentists
- American Cancer Society
- American College of Dentists
- American Commission on Community Health Services
- American Dental Health Society
- American Dental Hygienists' Association
- American Heart Association
- American Hospital Association
- American Legion
- American Nurses Association
- American Osteopathic Association
- American Pharmaceutical Association
- American Public Health Association
- American Public Welfare Association
- American School Health Association
- American Society of Dentistry for Children
- American Veterinary Medical Association
- Association of Public Health Veterinarians
- Association of State and Territorial Health Officers
- Commission on Chronic Illness
- College of American Pathologists
- Federation of American Societies for Experimental Biology
- Conference of State Sanitary Engineers
- Industrial Medical Association
- Child Study Association of America
- National Congress of Parents and Teachers
- United States Junior Chamber of Commerce
- Heads of Departments of Preventive Medicine at 68 accredited medical colleges
- Inter-Association Committee on Health
- National Education Association
- National Institute of Municipal Law Officers
Approving British organizations:

Standing Dental Advisory Committee (England and Wales)
Standing Dental Advisory Committee (Scotland)
Joint Sub-Committee of the Standing Medical Advisory Committees (England and Wales and Scotland)
Standing Medical Advisory Committee (England and Wales)
Central Health Services Council
Scottish Health Services Council
General Dental Council
British Medical Association
British Dental Association
Society of Medical Officers of Health
Royal Society of Health
County Councils Association
Association of Municipal Corporations
Central Council for Health Education
Executive Councils Association

Approving Canadian Organizations:

Canadian Dental Association (1963)

Whereas, tooth decay, by affecting the vast majority of people in Canada, has come to be recognized as one of the major health problems of our time, and

Whereas, studies covering a period of over 30 years under the widest variety of controlled conditions have marked fluoridation as one of the most widely studied of public health procedures, and

Whereas, such studies reveal that fluoride in the recommended amount of 1 part of fluoride to 1,000,000 parts of water is safe from any ill-effect and is effective in reducing tooth decay by approximately two-thirds, and

Whereas, fluoridation benefits children and the benefits extend into adult life, therefore be it

Resolved, that the Canadian Dental Association reiterate its recommendation to the people of Canada that communities having a public water supply adopt a procedure for adjusting the fluoride content of their water supply to a level considered optimal for the maximum prevention of dental decay, and for this purpose seek competent dental, medical and engineering advice.

Canadian Medical Association
Health League of Canada
Canadian Nurses Association

Additional Statements

John L. Thurston, Acting Administrator, Food and Drug Administration, Federal Security Agency (1952)

(a) The program for fluoridation of public water supplies recommended by the Federal Security Agency, through the Public Health Service, contemplates the controlled addition of fluorine at a level optimum for the prevention of dental caries.

(b) Public water supplies do not ordinarily come under the provisions of the Federal Food, Drug, and Cosmetic Act. Nevertheless, a substantial number of inquiries have been received concerning the status of such water
under the provisions of the act and the status, in interstate commerce, of commercially prepared foods in which fluoridated water has been used.

(c) The Federal Security Agency will regard water supplies containing fluorine, within the limitations recommended by the Public Health Service, as not actionable under the Federal Food, Drug, and Cosmetic Act. Similarly, commercially prepared foods within the jurisdiction of the act, in which a fluoridated water supply has been used in the processing operation, will not be regarded as actionable under the Federal law because of the fluorine content of the water so used, unless the process involves a significant concentration of fluorine from the water. In the latter instance the facts with respect to the particular case will be controlling.


The United States Public Health Service unequivocally endorses the fluoridation of community water supplies. Fluoridation can be classed with the pasteurization of milk, the purification of water, and immunization against disease as one of the great disease prevention measures of all time.

Good dental health is essential to total health. Techniques of modern dentistry, however advanced, cannot in themselves ensure good dental health. Fluoridation of public water supplies assures a reduction in dental decay of up to 65 percent and, in combination with preventive dental practices, offers the opportunity for children to keep their teeth for life.

The Public Health Service urges every community to make the benefits of fluoridation available to its citizens as soon as possible.

Seymour J. Kreshover, Director, National Institute of Dental Research

The National Institute of Dental Research encourages the fluoridation of drinking water. My two predecessors as Directors of this Institute, Dr. H. Trendley Dean and Dr. Francis A. Arnold, Jr., gave unqualified official endorsement to fluoridation.

The National Institute of Dental Research has had to counter much criticism from unrelenting opponents of fluoridation. The Institute has investigated numerous claims of injurious effects of fluoridated water but has not found a basis of fact in any of the claims. The amount of fluoride in fluoridated drinking water remains permissible because it is not a public health hazard. It is a valuable element in drinking water because it reduces dental decay and prevents loss of teeth.

I earnestly hope that the many communities who have not accepted water fluoridation may soon join with thousands of other cities now using fluoridated water. In so doing they express their confidence in the competence, integrity and dedication of the many individuals whose work has made this major dental health program possible.

Viron L. Diefenbach, Director, Division of Dental Health, Bureau of Health Professions, Education and Manpower Training, National Institutes of Health

Tooth decay is a painful, costly, and disfiguring disease that attacks 95 percent of the American people. Most of this decay can be prevented by fluoridation of community water supplies. With over 25 years of experience behind us, we know that water fluoridation is safe; it is effective; it is practical; it is economical. It is really the ideal health measure available today for preventing tooth decay.
The safety and effectiveness of fluoridation are backed by sound scientific evidence. The legality of fluoridation has been established and confirmed in the higher courts.

Millions of people live in communities enjoying the benefits of controlled fluoridation. Children in these areas have up to 65 percent less tooth decay, and this protection carries over into adult life. But many other children—and adults as well—are still without this protection although it is well within the capabilities of their communities to provide.

Local civic leaders must take the initiative in developing broad citizen support for this completely safe and effective public health measure.

Food and Nutrition Board of the National Research Council (1968)

Standardization of fluoride in public water supplies by addition of fluoride to bring the concentration to 1.0 ppm has proved to be a safe, economical, and efficient way to reduce the incidence of tooth decay—a very important nutritional public health measure in areas where natural water supplies do not contain this amount.

Extensive medical and public health studies have clearly demonstrated the safety and nutritional advantages that result from fluoridation of the water supply.

World Health Organization (1958)

The effectiveness, safety, and practicability of fluoridation as a caries-preventive measure has been established.

Fluorides penetrate cells and in sufficiently high concentrations inhibit certain enzymes, but no evidence of enzymal inhibition has been found in persons drinking fluoridated water containing concentrations of fluoride optimal for dental health.

Most of the fluoride absorbed into the system is rapidly excreted, principally in the urine; the rest is deposited in the minerals of the bone and teeth.

Drinking water containing about 1 ppm fluoride has a marked caries-preventive action. Maximum benefits are conferred if such water is consumed throughout life. There is no evidence that water containing this concentration of fluoride impairs the general health. Controlled fluoridation of drinking water is a practicable and effective public health measure.

Pan American Health Organization (1964)

Resolution XXIII—Flouridation of Public Water Supplies—The Directing Council,

Having considered the report of the Director on the fluoridation of public water supplies (Document CD15/29):

Considering that dental problems cannot be solved or dental disorders brought under control with the available professional resources and that the relative shortage of dental resources will become more pronounced as the population of Latin America increases;

Considering that the fluoridation of public water supplies is an effective means of preventing dental caries; and

Bearing in mind that, in order to hasten the extension of water fluoridation to areas that are not yet benefiting from this measure, there must be close collaboration and coordination between dentists and sanitary engineers,
RESOLVES:

1. To take note of the report of the Director on the fluoridation of public water supplies (Document CD15/29) and to endorse the policy outlined in it.

2. A number of personnel at the water treatment plant at the local laboratory and at the state laboratory would become immediately cognizant of dosage levels that could prove toxic over a reasonable length of time. We have had experiences of 50 years or more with several hundred communities whose water supplies have consistently carried a natural fluoride content of more than five times the amount prescribed in the fluoridation program without any evidence of shorter life or of a physical impairment other than mottling of teeth. Thus the rate of use would have to be so increased that it could not escape detection.

Ministry of Health, United Kingdom (1962)

No harmful effects from the addition of one part per million of fluoride to drinking water have been demonstrated in any of the extensive medical evidence collected and reviewed by the Research Committee.

The Research Committee is of the same opinion, therefore, as the World Health Organisation's Expert Committee on Water Fluoridation, which, in 1958, reported, "The most convincing evidence of the safety of water fluoridation comes from the numerous population groups (3 million in the U.S.A., 0.5 million in England) who have drunk naturally fluoridated water containing 1 ppm, or more during their lifetime. In these groups water drinking has been, of course, uncontrolled and there have been well and ill babies, as well as healthy young adults and frail elderly people. Medical practitioners and specialists in these areas have never detected or defined a systemic aberration in health of any kind related to the fluoride consumed."

After detailing the more important evidence the World Health Organisation's Expert Committee concludes, "All these findings fit together in a consonant whole that constitutes a great guarantee of safety—a body of evidence without precedent in public health procedures."

The Ministry's Research Committee agrees with these conclusions. In its opinion the raising of the fluoride content of drinking water to a level of 1 ppm is safe.

The Minister of Health and the Secretary of State for Scotland on December 10, 1962, announced in the House of Commons Government support for fluoridation.

On December 14, 1962, local authorities were informed of the Minister's announcement and that he was ready to approve the making of arrangements for addition of fluoride to water supplies deficient in it naturally. Local authorities were also advised that the Ministry of Housing and Local Government would be issuing a circular to all water undertakers and that in the event of court proceedings both local health authorities and water undertakers would be indemnified.

No public health measure has received such universal scientific support as has fluoridation of drinking water.
State Laws Regulating Fluoridation

Fluoridation has entered a period of statewide legislative action which is expected to give major impetus to fluoridation. Connecticut, Minnesota, Illinois, Delaware, Michigan, South Dakota, and Ohio have enacted fluoridation acts which provide for legal action in one form or another.

Connecticut in 1965 became the first state to pass a fluoridation act. Wherever the content of fluoride in a public water supply serving twenty thousand or more persons contains less than 0.80 ppm fluoride, the act requires that sufficient fluoride be added so as to maintain between 0.8 and 1.2 ppm fluoride. In May, 1968, it was reported that all but eight towns had complied with this law.

Minnesota’s fluoridation law, enacted in 1967, requires fluoridation of all municipal water supplies on or before January 1, 1970. In a manner specified by the law, the State Board of Health shall promulgate rules and regulations governing fluoridation.

The Illinois law of 1967 provides for the addition of fluoride to public waters so that they contain a fluoride not less than 0.9 nor more than 1.2 ppm fluoride.

A Delaware law passed in May, 1968, gives the State Board of Health the responsibility of requiring and regulating fluoridation of all public water supplies.

The Michigan state law, signed by Governor George Romney in July, 1968, provides that every public water supply in which fluoride is not presently added, shall add fluoride as prescribed by the Department of Public Health within five years, unless objected to by the local governing body or by a majority of the local electors.

Kentucky has a state regulation issued in 1966 requiring the presence of an optimum 1.0 ppm fluoride in communal water supplies in order to meet the water standards of the State Health Department. An injunction against a water supplier in Somerset has been initiated by a local chiropractor who raised issues and claims previously rejected by other courts. In late 1968 the Fluoridation Reporter, a current publication of the American Dental Association, stated that this case had reached the Kentucky court of appeals and a decision was impending.

In March, 1969, the Governor of South Dakota signed into law a statewide fluoridation bill. Another state fluoridation bill prepared by the Ohio Citizens Committee for Fluoridation was introduced in the Ohio Senate in February, 1969. This bill would require fluoridation of all public water supplies serving 20,000 or more persons in Ohio by January 1, 1971. Communal water for 5,000 to 20,000 persons would have to be fluoridated by January 1, 1972. Thus more than 90 percent of the approximately 11 million people in Ohio would be using fluoridated water within three years. An estimated 42 to 45 percent of Ohio's population now drinks water containing 0.8 ppm or more of natural or
controlled fluoride. In late 1969 this bill had been passed by the legislature and signed by the governor.

The Irish Free State Mandatory Law.

A comprehensive fluoridation act, applicable to public water supplies which served more than 800 to 900 people, was passed by the Oireachtas (Irish Parliament) and signed by President de Valera on December 28, 1960. Prior enactment proceedings, and the court case which followed, were discussed by Michael Stanley, Assistant Principal Officer of the Irish Free State Department of Health, at a seminar on fluoridation held at Rutgers University, New Brunswick, N.J., in December, 1965 (1).

The act empowers the Minister for Health to make regulations as to the manner in which health authorities shall arrange for the fluoridation of water supplied to the public by sanitary authorities. Before making such regulations the Minister must survey the incidence of dental caries in the areas where the regulations relate, and report on the survey to each House of the Oireachtas. The first set of regulations under the act, when applied to Dublin, Kildare, and Wicklow, was made by the Minister for Health in May, 1962. After a lawsuit which was successfully defended by the government, fluoridation of the Dublin Corporation water supply, which serves over 700,000 people, was started in July, 1964.

Fluoridation regulations have been made applicable to every county in the Irish Free State. The act lays down certain conditions to be met by local authorities and the equipment is specified or approved by the Minister for Local Government; only sodium fluoride, sodium silico-fluoride, or hydrofluosilicic acid, complying with approved specifications, may be used; the fluoride content of the water must be tested daily, with check tests every two to four weeks; and the fluoride content must be kept at 0.8 to 1.0 ppm.

Fluoridation is a recognized health service in Ireland and 50 percent of the expenditures are met by the central Exchequer, by grants paid by the Department of Health. According to Stanley the Health Department expected that by the end of 1966 every public piped water supply serving more than 800 or 900 people with few exceptions would be fluoridated.

Fluoridation Census

The most recent fluoridation census of the United States, published in 1968, applies to the year 1967 (2). The figures were obtained from

*Late in 1969 almost 83 million people were using communal waters containing 0.7 ppm or more fluoride. Of these, some 74.5 million were in communities where the water had been fluoridated at the level of 1 ppm. The others had access to water where the natural concentration of fluoride was at least 0.7 ppm.
official reports made available from the Departments of Health of each state. The publication lists all communities by state using controlled fluoridated water prior to December 31, 1967, and the date each community was known to have started fluoridating its water. The most significant data presented in this report show the populations on public water supplies in the United States and Puerto Rico using controlled fluoridated water and water containing naturally 0.7 ppm or more fluoride. The occurrence of fluoride naturally in drinking water was reported in a previous Government publication (3). These data are illustrated in Figure 1.

![Map of United States showing towns using naturally fluoridated water (0.7 ppm or more of fluoride)](image)

This recent tabulation shows that almost 82 million people or 52.8 percent of those on public water supplies are using communal waters containing 0.7 ppm or more fluoride. Based on the 1960 United States Census, the population figures are:

<table>
<thead>
<tr>
<th>Description</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>155,218,500</td>
</tr>
<tr>
<td>Using controlled fluoridated water</td>
<td>71,916,700</td>
</tr>
<tr>
<td>Using water containing naturally 0.7 ppm or more fluoride</td>
<td>10,009,000</td>
</tr>
<tr>
<td>Total using fluoride waters</td>
<td>81,925,700</td>
</tr>
</tbody>
</table>

Figure 2 shows the percentage of the population using a fluoride water in each state and the relative status of each state. Of the total population in the United States which has a communal water supply, 52.8 percent have access to a water containing 0.7 or more fluoride. Maryland, Michigan, Virginia, Wisconsin, and Washington, D.C., lead in...
Fig. 2.—The first number in each state refers to the percentage of its population on public water supplies with natural or controlled fluoridation. The second number shows states' rank according to percentage of water fluoridated (1967).

the use of this fluoride water and 90 percent of the people on public water have access to this fluoride water.

The communities and populations served with water to which fluoride has been added have increased rapidly since 1951 (Fig. 3). In 1965, the water of New York City was fluoridated, adding 11.5 million people to those who use fluoridated water. Fluoridation of Detroit water in 1965 added 3.5 million. An increase of over 9.5 million in the people having access to fluoridated water was reported in 1967. The last five-year period added a little over 20.2 million persons and 938 communities.

A National Opinion Research Center survey on fluoridation attitudes in 1968 found that 76.7 percent of the people surveyed favored fluoridation of the public water supply. In a 1959 survey, 65 percent favored the measure. In the later survey, about 10 percent considered fluoridation undesirable and about 12 percent had no opinion.

Further findings of the 1968 survey suggest that people prefer to have fluoridation treated as a health issue rather than a political issue. A little more than half, 55 percent, believed that the decision to fluoridate should be made by the health department. Almost 40 percent favored a special vote.

The survey also found that 34 percent of the people surveyed felt the decision to fluoridate should be made at the state level. About 62 percent favored a local level decision.
Fluoridated cities with over 200,000 in population and the dates of initiation of fluoridation are:

New York City ______ 1965  Indianapolis ______ 1951
Chicago ________ 1956  Louisville ________ 1951
Philadelphia _______ 1954  Fort Worth ________ 1965
Detroit _________ 1967  Oklahoma City ________ 1954
Baltimore _________ 1952  Rochester __________ 1952
Cleveland _________ 1956  Toledo ____________ 1955
Washington, D.C. ___ 1952  St. Paul ___________ 1952
St. Louis __________ 1955  Norfolk ___________ 1952
Milwaukee __________ 1953  Miami ____________ 1952
San Francisco _______ 1952  Tulsa ____________ 1953
Dallas ____________ 1966  Richmond ___________ 1952
Pittsburgh __________ 1952  Des Moines _________ 1959
Buffalo ____________ 1955  Providence __________ 1952
Denver ____________ 1954  Mobile ____________ 1958
Minneapolis _________ 1957  Charlotte, N.C. ______ 1949
In late 1969 Atlanta, Seattle, and Memphis had approved, but had not yet fully implemented, fluoridation programs.

Major fluoride-deficient cities are: Los Angeles, Houston, Boston, New Orleans, San Antonio, San Diego, Cincinnati, Columbus, Phoenix, Newark, Portland, and Honolulu.

Fluoridation in Foreign Countries

The status of fluoridation in Europe was reported by Forrest in 1967 (4). Progress has been delayed, pending results of local studies which appeared necessary because of differences in the European's dietary and drinking habits. There are differences in the design of these various dental studies, in the age groups studied, in the method of examination, and in the criteria used. Nevertheless all studies which have been in operation long enough for a reliable assessment to be made show a substantial reduction in caries which is of the same order as that found in America.

While introduction of fluoridation in Europe has not been rapid, Forrest estimated that more than four million people were receiving fluoridated water in 1967, and that when all the other projects being planned are in operation, this figure will be more than doubled. Fluoridated water is in use in Belgium, Czechoslovakia, East Germany, Finland, West Germany, Great Britain, Ireland, the Netherlands, Sweden, and Switzerland. It is reported to have been introduced in the U.S.S.R. and is expected to be in operation soon in Hungary and Yugoslavia.

During 1965, twenty municipalities started fluoridation in Canada, bringing the Canadian population using fluoridated water to five million. The highest percentage (60 percent) of the population using fluoridated water is in Manitoba. Five percent use it in Alberta, and Prince Edward Island and New Brunswick had no controlled fluoridation as of 1966.

Fluoridation has progressed slowly in South America. In this area and in other countries throughout the world a deterrent is that many public water supplies have no water treatment facilities currently in operation.

REFERENCES

THE progress of fluoridation as a public health measure has not been a triumphant procession. Dr. Luther Terry, former Surgeon General, said without doubt that no public health procedure has had to endure more severe obstruction than fluoridation. More than two decades have passed since fluoridation had official approval, but only about half of the potential beneficiaries are drinking fluoridated water today.

The organized antifluoridation movement, although never large in active members, has proved to be shrewd, vigorous, often ruthless, and well financed. Many referenda for fluoridation have been voted down. Public health officials, civic leaders, political scientists, sociologists, and legal scholars search for the answers to why a public health measure which is cheap, safe, easily implemented, and beneficial to so many creates such public controversy.

The proponents of fluoridation have endeavored to end the fear and misunderstanding, aroused perhaps inadvertently or by an accident of circumstances. No public health proposal has been so revealing of what can happen to the political process of democracy when it is called upon to pass judgment on a hard question of scientific fact. Confronted with a vital personal decision, the wary are caught in a trap, the cautious are left in a maze of confusion, and the proponents sometimes despair.

The struggle for fluoridation began in Wisconsin early in 1941 and has been documented in great detail by Donald R. McNeil (1). These events started when a small group of Wisconsin dentists were inspired with the idea of widespread fluoridation. They were active proponents 9 years before the Public Health Service or the American Dental Association officially endorsed fluoridation, and they were persistent in urging that these two organizations officially recommend fluoridation as a national policy. At the same time they engaged in a fight for fluoridation in numerous communities in their home state.

The American Dental Association published authenticated comments on organizations and individuals who were especially active as opponents of fluoridation (2). The comments included statements appearing in local newspapers, magazines, books, and in the opponents'
own major publications, particularly *The National Fluoridation News.* Two of the best-known extremist organizations which oppose fluoridation have been the Ku Klux Klan and the John Birch Society. The American Association for Medico-Physical Research has opposed fluoridation with a superficial gloss of authority, although it is usually identified as a proponent of somewhat unorthodox medical treatments. Two leading opponents of fluoridation are Drs. George L. Waldbott and Frederick B. Exner. Waldbott has pursued a medical career in Detroit as an allergy specialist. He is a prolific writer and collaborated with Exner on a major publication, *The American Fluoridation Experiment* (3). Waldbott, in his book, *A Struggle with Titans—Forces Behind Fluoridation* (4), mentioned cases of fluoride poisoning caused by water fluoridation. This threat has been the theme of most the antifluoridationists' efforts to discredit the findings of recognized scientists and health organizations. Prestigious scientific groups have offered to evaluate the material on which Waldbott bases his position. In 1955, the Milwaukee City Health Department offered to admit one of Waldbott's "cases of fluoride poisoning" to a hospital, free of charge, in order to conduct extensive tests and make an evaluation of the patient's condition. Waldbott did not accept the invitation.

That same year the Michigan State Health Department invited Waldbott to submit his evidence on fluoride poisoning for an evaluation, but he refused, stating that "because of the methods used by health officers regarding fluoridation, nothing could be gained by submitting my material."

In 1957, Waldbott submitted his material to the American Medical Association's Councils on Food and Nutrition and on Drugs. He was unable to convince either council that drinking water containing one part of fluoride per million parts of water was a hazard to health.

Waldbott was similarly unconvincing when visited in Detroit in 1955 by Dr. Heinrich Horning of Kassel-Wilhelmschohe, Germany. An experienced public health officer, dedicated to the promotion of dental health in Germany, Horning had a personal interest in being advised objectively by Waldbott concerning his reasons for arguing against fluoridation. In a letter to Dr. Frederick McKay, published in the *Journal of the American Dental Association* (5), Horning disclosed some of the frustrating experiences he encountered as a result of his visit with Waldbott:

During our conversations, he mentioned frequently the 70 cases of poisoning caused by fluoridation and repeatedly stated that the U.S. Public Health Service "had been bribed by the sugar and aluminum industry," and, therefore, did not find it necessary to investigate these cases scientifically. I then explained that I was a public health officer and that I was visiting the United States mainly to obtain all information available on fluoridation of drinking water.

*Fluoride, Quarterly Reports* has recently been issued by the International Society for Fluoride Research; Dr. Waldbott is the editor and Dr. A. W. Burgstahler, co-editor.
Horning reported that the first question asked by Waldbott implied that Dr. Horning was getting money from the aluminum industry in order to initiate a fluoridation study in Germany. Horning wrote further to McKay:

The American Dental Association and the public health authorities are fully justified in their contention that Dr. Waldbott presented no proof to substantiate his belief that chronic poisoning had been caused by water fluoridation, and those organizations, therefore, should proceed with their program.

In *A Struggle with Titans* Waldbott accused Dr. Horning of quoting him erroneously in the letter to McKay. Together with his wife, Waldbott was for many years a mainstay for the antifluoridationists' publication, *The National Fluoridation News* (6). Frederick B. Exner is a prominent physician of Seattle, Washington, and limits his practice to radiology. His career, like Waldbott's, has taken him the length and breadth of the nation. Their efforts against fluoridation have made them better known than in their own medical specialties. Few community debates on fluoridation have been held without the presence, personal or written, of Waldbott and Exner. Neither of these men appears to have engaged personally in a constructive program of research on the dental or physiological effects of fluoridated water. Neither are dentists, and apparently have only limited interests in basic physiology and biochemistry, essential for clinical and epidemiological research. The charges of these physicians regarding health hazards of fluoridated water are lacking in substantial evidence and are rejected by the majority of physicians, scientists, and public health authorities.

**The Loud Voice of Fear**

People are unaware, the antifluoridationists state, of a current movement which is headed toward dictatorship and which is inherent in fluoridation. Fluoridation is little more than a hoax engineered by the U.S. Public Health Service. If not an exercise of dictatorship, fluoridation is a communist plot, states an organization calling itself the Paul Revere Associated Yeomen, Inc. (PRAY). Organized to "wake up Americans" this association noted in 1965 that "we are convinced that the MAIN communist plots by the internal traitors in the United States are as follows—fluoridation, disarmament of American citizens, federal aid to education." Its detailed list of charges against fluoridation was signed by H. S. Riecke, Jr., and read (7):

This will positively degenerate "Christian" Americans by dulling their brains and crippling their bodies! Fluoridation causes an increase of 30% to 125% in anemia, Diabetes, Heart Disease, Strokes and Cancer! Fluoridation also CAUSES abortions and mongoloid births . . . Do you want your children to become progressively dull—and morons? Do you want your grandchildren to be born MONGOLOIDS AND CRIPPLES?!! THEN GET OUT AND FIGHT FLUORIDATION—DAY AND NIGHT . . . Fluoridation is endorsed by some branches of the League of Women Voters, and some
Branches of the JAYCEES and Lions Clubs. Of course, also by the HEW, USPHS AND ADA. Enough said.

We are convinced that the Department of Health, Education and Welfare (HEW) and its subsidiary—the U.S. Public Health Service (USPHS)—are now the most dangerous threats to our constitutional form of Republican government.

We are convinced that HEW is the Frankenstein Monster that threatens to completely CONTROL . . . not only our Schools, Colleges, Textbooks, Teachers and our Children . . . but also YOU—day and night!

**URGENT!**

Flouridated-water Cities Have 30%, to 125% MORE Heart Disease, Diabetes, Strokes, Cancer & Aneurism

* GOD WILL SURELY, REWARD TEN THOUSAND TIMES OVER!

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**Professor Says Fluoride Brings Idiocy Increase**

(N.O.D.—1949-7-14)

Pure Water Supporter Interviewed Here

BY ROBERT PAUL

New Orleans will experience a "significant increase" in the rate of birth of "morbid" infants if the city fluoridates its water, said Dr. Jonathan Frances, prominent pediatrician at Ohio State University.

Interviewed Thursday afternoon at the Jesuit Hotel, Dr. Frances, who was in New Orleans to speak with the New Orleans Public Water Commission, said that the increase would be "enormous.

There are in favor of fluoridation, said Dr. Frances, because they are ignorant of the facts relating to it. He said the rate of fluoride to water given by proponents of fluoridation is based on a myth "enormous error," he said.

"In fact," he continued, "the ratio of one cubic foot of fluoride to water given by proponents of fluoridation is based on a myth and enormous error," he said.

"But," he continued, "more water goes to a baby who is fluoridated than to one who is not. What happens, said Dr. Frances, is that fluorine becomes more concentrated in the water which makes the water more toxic and makes the baby more susceptible to diseases."

"If," he said, "the facts show only that fluorine makes teeth decay, then perhaps it will help."

He cited the facts from charts which he said showed that, although there are no children in cities with fluoridation who have less tooth decay, there are children in the same cities who have fewer children in cities without fluoridation who have less tooth decay.

"Fluoridation has many dangers," he said, "and a rising cost, and all that has been proven to be that it robs a baby of tooth decay."

"No one has proven that..."

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**Fluoridation Called Poison by Doctor**

North East—"Fluoridation is one of the most certain evidences of what is best for children's health."

Dr. J. H. McK. of Long Beach, Calif., who was a chief proponent of fluoridation, however, is one of its strongest critics.

"As a general rule," he said, "it is a matter of fact that the water in where I live is not fluoridated."

"I learned that the U.S. Public Health Service, Dental Branch, had conducted a year's research to show that fluoridation had no relation to dental decay."

"He said that the U.S. Public Health Service conducted experiments with sourland conditions and that, under the conditions of experiments, were abandoned.

"For some of the most successful reasons for more than 30 years, previous to Long Beach, I have been a fluoridation advocate."

It was probably one of the first people to refuses fluoridation in the world who, until he became convinced of the facts, fluoridation had no relation to dental decay."

"In 1949, Dr. McK. said that there were 30 states who have state public health representatives and representatives of the American Dental Association attended that institution."

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**The American Medical Assn. Does Not Endorse Fluoridation Anymore**

NEITHER DOES THE AMERICAN DENTAL ASSN. MEMBERSHIP

We urge you to reproduce this article by 1000s per thousand, and distribute them in YOUR CITY—PLEASE!

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An antifluoridation newsletter.
On February 6, 7 & 8th, the HEW and USPHS held a BIG meeting in Washington . . . to lay plans for a massive campaign to FORCE fluoridation of the drinking water in ALL states . . .

You might say: Well . . . I—ME—I'll drink BOTTLED water!! Oh, yes? And how long before fluoride will be made 'mandatory' in bottled water! And why wouldn't the "Establishment" buy up all the Bottled Water companies! . . .

Our health departments are potential DICTATORS. DO NOT let them go unbridled and Rampant. They can run you down like a stampede, once they break loose!

Such shrieks of fright and claims of impending disaster could be documented further and at great length. Fluoridation proponents have learned that it is virtually impossible to engage in a straightforward rational discussion with the radical opponents. It usually turns out that when mongolism is disproved nephritis will be charged, and when nephritis is disproved cancer will be brought up. Irrelevant medical and dental data may be demanded by uninformed, unrelenting writers or local Leagues for the Promotion of Pure Waters. The struggle seems never-ending.

Political and Social Scientists View the Puzzles of Fluoridation Referenda

In late 1961 an annotated bibliography on the social science aspects of fluoridation revealed that some 50 articles, books, and reports had been compiled (8). Wide-ranging surveys indicated that education, income level, and notions of alienation and fear were factors which often influenced a vote for or against fluoridation. In 1953 J. M. Burns, then a faculty member of Williams College in Williamstown, Mass., wrote informally on these influences (9). He was in Williamstown in 1952 when fluoridation was started by order of a town meeting. Within a year antifluoridationists had collected enough signatures to require a referendum. About half the eligible voters turned out, and fluoridation was defeated. The significance of the defeat, Burns felt, was not in the specific failure:

The real question is quite different—how account for the mass irrationality and hysteria sweeping over a community of people who are ordinarily thoughtful, responsible and hard to "sell?"

I think the answer can be found not in our town but in our time. This is an age of fear and suspicion, of big lies and little lies. We are used to irrationality in areas of morals and politics. It seems to have spread now to areas where science usually holds sway . . . .

The episode does not speak well for the famous New England town meeting. Only a minority of voters showed up to hear the debate and to vote on fluoridation. Balloting by an open show of hands is a serious weakness. Many of the merchants in town either stay away from town meetings or duck out before a controversial measure comes up . . . .
Running through the anti-fluorine feeling was a pervasive fear that powerful people were trying to take away the rights of "little people." Fluoridation became an assault on civil rights. . . If [people] would fight a local attack on freedom of speech or freedom of worship as hotly as they fought fluoridation, civil liberties would be secure in our town. But that is a big "if."

The tentative conclusions reached by Burns concerning the "anti-intellectual" aspects of antifluoridation thinking, as well as the fear that it was being forced on a helpless populace by "powerful people," were taken up and elaborated by other social and political scientists who looked at the issue more formally.

Some eighteen months after the Burns article, *Scientific American* published a study which read, in part (10):

Many people, particularly scientists, believe that we are suffering in the U.S. from a national epidemic of irrationality—what Senator J. W. Fulbright of Arkansas has called the "swinish blight of anti-intellectualism."

The article went on to call fluoridation "an excellent example of the careful application of scientific knowledge to a problem." It also recounted an investigation of public attitudes that had been undertaken among citizens of Northampton, Mass., while that town was disputing the subject.

Who were against fluoridation? They were predominantly people of the older age groups, people without children under 12, people of the lower income brackets and middle- or lower-class occupations. Support for fluoridation came mainly from the younger groups and those in professional, managerial and other white-collar occupations. One of the most striking differences was in education. A large proportion of the antifluoridation voters had failed to finish high school. Among high school and college graduates, the majority favored fluoridation. Yet there was a large number of graduates, even with some postgraduate education, who accepted the antifluoridation arguments.

Thus the demographic factors show two independent trends: (1) the younger people are more likely to be for fluoridation than older ones, probably in part because they are more likely to have children under 12, and (2) the people of higher education, occupations and incomes are more likely to be for it than those of lower social status . . .

The anti voters overwhelmingly refused to accept reports of its success or to accept scientific organizations as the best authorities on fluoridation. Many of them felt that public health officials, dentists and the chemical industry were in a conspiracy to impose the measure on the public. . . .

Almost 95 percent of those approving fluoridation accepted scientific organizations as reliable sources of information. . . . Among the anti voters those with little education tended to reject scientific authority. However, in the anti group two-thirds of those with better than high school education professed to accept the authority of the scientific organizations. Their opposition to fluoridation suggests either a failure of communication for the scientists . . . or an unconscious rejection of these sources. . . .

We were struck by the pervasive attitude of suspicion among those who opposed fluoridation. . . To them . . . it seems perfectly reasonable to suppose both that scientists would lend themselves to a conspiracy with enemies of our country and, at the same time, they would permit themselves to be used by a giant monopoly. . . .
The fear of conspiracy, which has been such an important component of the antifluoridation case, is often strengthened by the manner in which fluoridation is introduced. . . . In Northampton, for instance, 82 percent of the antis, and even 32 percent of the pros, agreed with the statement that the water commissioners had taken advantage of their position to start fluoridation without consulting the public. This despite the fact that there had been public hearings and an appropriation by the town council before treatment of the water began. The same sequence of events apparently occurred in Williamstown, Mass., in Seattle and in Cincinnati. . . .

In time a somewhat tougher attitude arose, condemning politicians for throwing the issue to an ill-equipped electorate, and despairing of physicians and dentists who saw themselves as educators rather than community leaders and consequently did not exert their full influence. In addition, two investigators (11) noted that a likely hypothesis is that specific events occurring within a community are more crucial determinants of fluoridation outcome than any relatively fixed attribute such as median age or education. Studying who does what, when, and how in the course of a fluoridation controversy appears to be a better investment of resources than a continued search for fixed demographic attributes of the community significantly associated with fluoridation outcome.

Social scientists (12) have dealt with the hypothesis that on any political issue those on one side are likely to have a "natural advantage" over those on the other side, an advantage which will enable them to win if they simply hold their own in an influence contest. This natural advantage falls to those who do not carry the burden of proof. In a relatively stable, nonrevolutionary situation this advantage is held by those who would maintain a present arrangement against those who would alter it.

In answering such objections, one proponent has said that: "The phenomenon cited in the experiment is likely to be stronger in the fluoridation case than on other issues. . . . "For one thing, the very admission that there is disagreement on the issue, that 'doctors disagree,' is enough to cause many to join the antifluoridation camp. The public seems to demand unanimity of professional opinion on this issue; but on a school bond issue, for example, the mere existence of debate is not so likely to have such an important effect. Additionally, water fluoridation has not proved to be subject to compromise. Alternative methods of mass distribution have generally been rejected as unworkable, dangerous or both. Thus, opposition cannot be partly undercut in advance by reducing the demand . . . as a proposal to substitute a modest school building program for a large one can sometimes satisfy moderate opponents. It might also be noted that a somewhat similar procedure was used in other parts of the experiment to probe the resilience of civil liberties attitudes. It was found that argumentation altered attitudes on this issue very little."

Others have added further elaboration. One, in arguing that the voters "reject fluoridation not because they are alienated, but because they are confused," noted in support of this that: "In their effort to defeat fluoridation, the opponents have formed or have obtained support from many organizations having particularly impressive names. The American Academy of Nutrition, the Association of American Physicians and Surgeons, the Medical-Dental Ad Hoc Committee and the National Health Foundation have all attacked controlled fluoridation and have participated in campaigns against its
adoption. To the informed citizen, as well as to the public health official, the
National Academy of Sciences, the American Association for the Advance-
ment of Science, and the American Dental Association are distinctive, re-
pected and prestigious organizations whose opinions and endorsement in sci-
ence and health matters carry great, if not decisive, weight. To the average
voter, however, they are probably not particularly familiar groups, and their
purposes and endorsement are likely to be confused with less solid organiza-
tions.

"The proponents do not enhance their chances when they act as though
there is no legitimate opposition to fluoridation. Voters are socialized to ex-
pect two sides in every election issue. In fluoridation referendums the other
side is vigorously argued. To be told that a certain doctor or scientist has
not the right (meaning competence) to speak on what is obviously a health
or science issue would only increase the voters' suspicions and fears."

A recent analysis by C. T. Shaw of a fluoridation referendum defeat
seems to pinpoint major contributing factors (13). Discussed in other
similar reports, the characteristics of the two groups in his study, con-
ducted in Amherst, Mass., agree with other observations. Although the
social and economic status and educational and cultural milieu of the
Amherst residents were regarded as above average, this environment
did not result in an active profluoridation citizenry. Shaw noted that
an increase of social and economic status apparently diversified individ-
ual interests to the detriment of interest in basic community problems.
"Greater effort should have been made to get the better educated,
higher socio-economic group out to vote on the issue." Only 42 per-
cent of the eligible voters participated and only 34 percent favored fluorida-
tion.

The survey data pointed to the following. Profluoridationists in gen-
eral had more than a high school education, an annual income of at
least $6,000, and at least one member of the family had an occupation
in one of the top three categories according to U.S. Census standards.
Radio, television, and newspapers seemed to have had little or no influ-
ence. Many individuals, however, recalled having received antifluorida-
tion literature. This technique seemed most effective in influencing vot-
ers to cling to a status quo for their drinking water. Those with no
fixed opinion voted against fluoridation. People voting against the mea-
sure were generally over 40 years of age, unmarried, or with no children
under 12. They were in the lower income bracket and worked in the
lower classified occupations.

Thus, a mass of findings, hypotheses, and data have been accumu-
lated in an attempt to explain the confusion, discord, and conflict be-
tween science, politics, and the public. It remains clear that fluorida-
tion is by no means a simple "doctor-patient" or a "scientist-student"
affair. The procedure has faced frustration not only in local politics,
but also at the national level.
Courtroom Adversaries, Decisions

Attacks against fluoridation in courtroom hearings acquire a more rational quality than antifluoridation newsletters which excite fear and mistrust. There are legal briefs, precisely written documents, contending that the fluoridation of community water goes beyond the powers of elective and appointive public officials and that it is a deprivation of individual freedom within the meaning of the Fourteenth Amendment and a violation of the First Amendment guaranteeing religious freedom. The opponents are usually more decorous and respectful in the courtroom because they know that on constitutional grounds their objections are not unprecedented. Vaccination against smallpox, chlorination of water, and pasteurization of milk have experienced similar opposition.

The Supreme Court of the United States has not yet taken a fluoridation case, although it has had six chances to do so. Each case was either dismissed or the appeal was refused (14). Legal scholars regard this as indicative of a consistency of judgment in favor of the view that fluoridation is clearly constitutional. The highest courts of thirteen states have upheld the constitutionality of fluoridation ordinances. Two states have voiced reservations about validity, their decisions being designed to permit the issue to go to trial (15).

Regarding the broad question of the state's right to pass statutes bearing on public health, the Supreme Court has spoken. One landmark case, Jacobson vs. Massachusetts, occurred in 1905, the defendant refusing to submit to compulsory vaccination. In upholding the constitutionality of the statute the Supreme Court said:

But the liberty secured by the Constitution . . . to every person . . . does not impair an absolute right in each person to be, at all times and in all circumstances, wholly freed from restraint. There are manifold restraints to which every person is necessarily subject for the common good. On any other basis organized society could not exist with safety to its members. . . . Real liberty for all could not exist under the operation of a principle which recognizes the right of each individual person to use his own, whether in respect of his person or his property, regardless of the injury that may be done to others.

In similar cases, the Supreme Court and other judicial bodies have stated that the state's right to provide for health, safety, and general welfare of the community is inherent in the concept of state sovereignty (16):

Legislation for the promotion of these ends has generally been upheld where it is reasonable. If the legislative objective is within the reach of the police power and the means adopted reasonably related to achieving that objective, the measure is valid. . . . That the health and physical well-being of the community is a public need and hence a proper object of the police power is beyond question.

Within the framework of this judicial philosophy, the health needs
of children were given a just and rightful attention. The Supreme Court of Louisiana ruled in 1954 on Chapman vs. City of Shreveport:

Children of today are adult citizens of tomorrow, upon whose shoulders will fall the responsibilities and duties of maintaining our government and society. Any legislation, therefore, which will equip them by retarding or reducing the prevalence of disease, is of great importance and beneficial to all citizens.

In 1965, the Supreme Court of New York (not the state’s court of highest appeal) said in Paduano vs. City of New York:

However, the health of our children is a legitimate area of public and governmental concern, whether under the police power of the state, or in the exercise of the State's power to protect the general welfare. It is not shocking to realize that the State, acting in the interest of children, too young to be sui juris, may intervene in the parental area.

While the broad questions of the state's powers in public health appear settled, the legality of fluoridation has been attacked on the grounds that municipal governments are lacking in authority, or abuse their authority because fluoridation is unnecessary, or wasteful, or unsafe, or a breach of contract, or class legislation. It is argued that there are other and better alternatives; fluoridation is socialized medicine; it is an illegal use of public funds or even a public nuisance. Other objections are the claim of violation of religious freedom and more specifically that of statutes of pure food and drug acts which prohibit unauthorized practice of medicine, dentistry, and pharmacy.

On the question of municipal authority the courts have found for fluoridation. The reasoning has been in general that although the statutes do not specifically authorize fluoridation, they do authorize municipalities to pass health measures. Since fluoridation is a health measure, even though not directed at a contagious disease, the city has implied authority to pass a fluoridation ordinance. A court decision in Wisconsin adopted this reasoning and pointed out that the merits of fluoridation did not come directly to judicial notice. Rather the court's question was the reasonableness of this extension of the power of the state. In 1965 an appellate court put the matter to rest by saying, "We think, contrary to plaintiff's contentions, that these constitutional, statutory, and charter provisions constitute adequate authority for enactment of the ordinance in question."

Opponents have declared that this is an abuse of power, contending that fluoridation is a public health hazard. No final court that has tried this issue has adopted this view, however, ruling either that the opponents failed to make a case for lack of safety or that if a legitimate issue could be construed to exist, it is the legislative branch of government, not the judicial, that must thrash out the issue and decide on a policy for the community in question. Courts have also dismissed arguments that the addition of fluoride to drinking water violates such existing statutes as those relating to pure water or those regulating the practice of medicine and dentistry.
When a question of religious freedom is raised under any circumstance, courts have always moved with utmost caution and sobriety. In hearing cases where this question arises the Supreme Court of the United States, followed by other courts, has found a "double aspect" to be considered. The First Amendment guaranteeing freedom of religion, according to a classic decision handed down in 1940, embraces two concepts, "freedom to believe and freedom to act." Freedom to act remains subject to regulation for the protection of society. "In every case the power to regulate must be so exercised as not, in attaining permissible ends, unduly to infringe the protected freedom."

The problem of religious freedom and fluoridation is related to doctrines of the Christian Science Church. This issue was raised in a Missouri court and the response was a ruling that fluoride is not a medicine but a nutrient found naturally in food and water. It was ruled that in some areas the content of fluoride in water is not sufficient for optimum caries prevention. This ruling is realistic. Fluoride is a nutrient trace element and its status in preventive dentistry is not regarded as medication. The question of compulsion imposed on an individual, nevertheless, is still alive, so that all courts of appeal including the United States Supreme Court may of necessity have more to say in the future.

There are thousands of pages of court testimony on fluoridation, and hundreds of pages devoted to judicial summaries and opinions. Two of the most important judgments documenting basic rights to implement fluoridation came in 1965, one from the Circuit Court for Wayne County, Mich., and the other from the Illinois Supreme Court. The first court had this to say:

In a democratic society, universality of opinion is seldom achieved. Governors and even presidents serve the whole of the people although almost half of the voters have registered a vote for the opposite candidate. Scarcely any public policy, however fundamental, or any measure of public health, receives complete acceptance or overwhelming support. But popular government would be frustrated and ineffective in the protection of the rights and liberties of the people if, under our constitutional system, a legislative body on judicial review was told that it could not enact a measure unless it be one of absolute certainty in the accomplishment of the desirable public object. Such a result would be intolerable. It would fly in the face of our fundamental constitutional plan of separation of powers.

And the Illinois Supreme Court, rejecting constitutional claims made by the opponents of fluoridation, noted:

These constitutional claims have both their source and their unanimous rejection in the decisions of our sister States. . . . Suffice it to say that those well-reasoned precedents, with which we are in accord: (1) sustain the right of municipalities to adopt reasonable measures to improve or protect the public health even though communicable or epidemic diseases are not involved; (2) hold that the benefits of fluoridation which carry over into adulthood absolve such programs of the charge of being class legislation; and (3) conclude that fluoridation programs, even if considered to be medication in the true sense of the word, are so necessarily and reasonably related to the common good that the rights of the individual must give way.
The Irish Court Trial, 1963-1964

In December, 1960, the President of Ireland signed into law a bill which had passed the lower House of Parliament and the Senate. This act imposed a legal obligation on health and sanitary authorities to fluoridate public piped water supplies. With the passage of this law Ireland became the first nation of the world to make water fluoridation a legal compulsory public health procedure. Major events leading up to passage of the law's legal proceedings and hearings in the high courts were related by Michael Stanley, Assistant Principal Officer, Department of Health, Dublin (17).


The Minister of Health for the Dublin, Kildare, and Wicklow areas had completed dental examinations in May, 1962, preparatory to fluoridation, but, in June, notice was served on the Chief State Solicitor on behalf of a Dublin housewife that she would challenge the constitutionality of the act in the High Court. Stanley has recorded the subsequent course of events:

Shortly afterwards the Honorary Secretary of the Pure Water Association wrote letters to newspapers, and inserted advertisements in some of them, appealing for funds to defray the expense of bringing witnesses from abroad to give evidence against fluoridation in the High Court. On 15th October, 1962, a statement setting out the plaintiff's objections to the Act was submitted to the High Court. Briefly this statement alleged that the proposed fluoridation of public water supplies under the Act was unconstitutional because it was, or could be, injurious and harmful to the health of some members of the public, including the plaintiff and her family, that it violated personal and family rights, and interfered with the rights of education guaranteed by the constitution.

Although legal objection was raised by the Attorney General, medical evidence on toxicology and dental merits of fluoride were admitted to be presented on behalf of the plaintiff. Witnesses called to testify at these hearings included Drs. Galagan, Arnold, Schlesinger, Armstrong, Hodge, Leone, and Shupe from the United States, and Dr. O. Backer-Dirks, Professor Ingve Ericsson, Dr. G. Wynne Griffith, Professor V. Demole, and Dr. J. H. Fremlin from other countries. The opposition was represented by Dr. Waldbott, United States; Dr. Steyn, University of Pretoria, South Africa; Dr. Sinclair, a fellow of Magdalen College; Dr. T. Gordonoff, Bern University, Germany; and Professor Andrea Benagiano and Professor Sergio Fiorentini of the University of Rome. Waldbott wrote in his book, A Struggle with Titans, that he was

the only witness who could report about actual observations of humans poisoned from drinking artificially fluoridated water. On this pivotal point that water fluoridated at 1.0 ppm can and had poisoned people, the one and only fact which would unequivocally defeat fluoridation, I stood alone against the numerous voices assuring the court that fluoridated water was absolutely safe
for humans and that my data were unreliable. Other physicians who have observed ill effects from fluoridated water were not available to testify.

It was impossible to bring to the surface during the trial the inner workings of this Struggle with Titans, namely, how valid research is being prevented from reaching the medical profession; how proponents create an unfavorable image of opponent scientists; how industry, using vast research grants, originated the fluoridation idea and influenced the thinking of the scientific community. Since not any of these facts were presented to Justice Kenny's court, his decision is understandable.

In July, 1963, Justice Kenny delivered judgment in the case, which stated in part:

I accept the whole of the evidence given by Professors Hodge and Ericsson and by Dr. Galagan. Both Professor Hodge and Dr. Galagan were in the witness box for six days and were cross-examined at considerable length on the literature on this subject. In the course of cross-examination Dr. Galagan was accused of perpetrating a scientific fraud in one of the articles which he wrote; I am satisfied that he completely vindicated himself of this charge. I also accept the evidence of Dr. Schlesinger, Dr. Arnold, Dr. Armstrong, and Dr. Dirks. If their evidence in any way contradicts that of Professors Hodge and Ericsson or that of Dr. Galagan, I prefer the evidence of Professors Hodge and Ericsson and Dr. Galagan. I reject the evidence of Professor Gordonoff, of Dr. Rozelik, of Dr. Waldbott and of Dr. Dillon. There was a marked note of fanaticism and passionate conviction about their evidence. I got the impression that they were determined at all costs to make a case against fluoridation. Typical of this was the evidence of Professor Gordonoff. He was asked in cross-examination whether he thought that the fluoridation of public water supplies would reduce the incidence of dental caries; his guarded answer was "perhaps" although his own writings showed that he held the view that it would. The plaintiff's witnesses (except Professor Steyn) also had a habit of prefacing their more sensational charges with the words "it has been suggested" without giving any authority for the suggestion or indicating its source (the evidence in connection with the distressing condition of mongolism in children was a particularly glaring instance of this). There is absolutely no support in the literature or in the evidence for many of these suggestions.

Professor Steyn, who came from the Union of South Africa to give evidence, was a most impressive witness. He favoured the use of fluorine in the battle against dental decay but thought it should be used topically, that is by application, and that it should not be put into the water supply. He also said that at a concentration of 1 ppm fluorine does not produce severe mottling of the teeth. His objection to the use of fluoride ion in the water supply was that he thought that there was a connection, in the Union of South Africa at least, between the presence of the fluoride ion in water and a high incidence of goitre.

Dr. Sinclair, a Fellow of Magdalen College, gave evidence for the plaintiff: most of his evidence was a statement of what may happen if the fluoride ion is introduced into water. He conceded during cross-examination that many of the ill effects mentioned would not arise when the fluoride ion in water was 1 ppm. I do not think that any of his evidence supports the view that the fluoridation is dangerous or that there is a reasonable possibility that it may be dangerous. If any of his evidence supports this view, I reject it.

In my judgment the fluoridation of the public water supplies in this country is not a violation of any of the plaintiff's constitutional rights and this action must be dismissed.
An appeal was lodged against the High Court's judgment and was heard by the five Supreme Court Judges for eight days. In February, 1964, the High Court announced its decision which upheld the judgment of Justice Kenny.

The Delaney Hearings

Fluoridation became a concern of American politics almost at its inception, when a House of Representatives committee directed to explore the use of chemicals in foods and cosmetics devoted seven days in 1952 to hearings on fluoridation. Chairman of the committee was Rep. James J. Delaney of New York. Mr. Delaney remains a member of Congress as of 1969 and retains his antipathy to fluoridation. The Committee member most active in the hearings and most opposed to fluoridation was Rep. A. L. Miller of Nebraska. A graduate physician of Loyola University Medical School, Rep. Miller had practiced medicine for nearly 25 years. A supporter of fluoridation in 1951, he had introduced the bill authorizing fluoridation of the water of the District of Columbia. Sometime between then and the Delaney hearings, he changed his mind. Prior to the issuing of a report by the committee, Dr. Miller attacked the public health measure in a speech in the House.

The opponents of fluoridation at these hearings included Mr. H. V. Smith and Dr. Margaret Cammack Smith of the University of Arizona; Dr. Robert Harris, Massachusetts Institute of Technology; and Dr. E. B. Hart, University of Wisconsin. Since that time Mr. Smith, Dr. Smith, and Dr. Harris have reversed their stand and are no longer opposed to fluoridation. Other opponents at the hearings were Dr. V. O. Hurme, Forsyth Dental Infirmary for Children; Dr. H. H. Neumann, Hewlett, N.Y.; and Dr. A. T. Taylor, University of Texas, Austin.

Testimony in favor of fluoridation was presented by Drs. Forsyth and Knutson of the Public Health Service; Dr. Blayney, Director of the Walter G. Zoller Memorial Dental Clinic, Chicago (and director of the Evanston fluoridation study); Drs. Arnold, Dean, and Zipkin, National Institute of Dental Research; Dr. Andervont, National Cancer Institute; Drs. Doty and Conway, American Dental Association; Dr. Porterfield, representing the Association of State and Territorial Health Officers; Dr. Ast, Director of the Newburgh-Kingston study who represented the American Public Health Association; and Dr. Heyroth, representing the National Research Council ad hoc Committee on Fluoridation of Water Supplies.

In evaluating the Delaney Report it is well to note that the overall objective of this Select Committee was to investigate the use of chemicals in foods and cosmetics. Prior to the fluoridation hearings, much scientific data had been compiled and expert testimony had emphasized dire effects which might result from certain chemicals added to food, usually as a preservative. It is not surprising that the committee would
embark on the fluoridation hearings skeptical and quite unsympathetic
to any proposal to add fluoride—a chemical already widely known as a
poison—to drinking water. As the hearings progressed it was evident
that the committee was more impressed by the overwhelming evidence
of the dental health benefits of fluoridated water than by the evidence
to disprove practically every fear of a health hazard that had been ex-
pressed. The committee was prepared nonetheless to reject any evidence
of public health safety which could not be supported by every conclu-
sive demonstration conceivable.

Fluoridation of water would probably not have become a subject for
this committee's investigation had not the Congress taken a view con-
trary to that of its Select Committee. In May, 1952, Congress appro-
priated funds for the fluoridation of the water supply of the District of
Columbia.

It is difficult to show that the Delaney Report has had any significant
impact on the subsequent history of fluoridation. In the years since
Congress has not figured heavily in the fluoridation controversy. Mr.
Delaney has remained in Congress and has introduced bills that can be
characterized as antifluoridationist, but Congress itself has been neu-
tral. The two Congressmen who were active proponents of the public
Hill of Alabama did not make a crusade out of their acceptance of fluo-
ridation but neither did they ignore many opportunities to speak out in
its favor. The late Rep. Fogarty on one occasion noted that he and Rep.
Delaney were good friends: "He and I have discussed this over break-
fast many times. We have never agreed. . . . Mr. Delaney has been an
ardent opponent of fluoridation for many years in Congress and he is
very outspoken. He knows how I feel about it."

A report of the Delaney Hearings in 1952 stated:

The Delaney Committee report on fluoridation acknowledges that the pre-
ponderance of scientific evidence supports the conclusion that fluoridation is
a safe and effective procedure for the control of dental caries. The Commit-
tee itself concludes that the efficacy of the procedure is amply demonstrated
but expresses vague apprehensions concerning possible toxic action from a
cumulative effect of the fluoride. . . .

It is our opinion that the Congressional Committee report suffers from a
lack of adherence to the proper standards of investigative procedure as evi-
denced especially by its failure to substantiate many statements which it ac-
cepted as fact. The Committee also accepted misgivings of a few individuals
who appeared as witnesses, in spite of the weight of the evidence furnished by
such organizations as the American Dental Association, the American Medical
Association, the United States Public Health Service, the National Re-
search Council, the American Public Health Association and the Association
of State and Territorial Health Officers. The Committee, through its statement
that "dental decay is not contagious nor can it be said to constitute a serious
danger to health," implies that a disease is not a community problem unless
it is contagious and fails to recognize the fact that dental caries (decay) is
the most prevalent disease of mankind.

Representative Miller stated his additional views on fluoridation:
In my opinion, the United States Public Health Service has been premature in urging universal use of fluorides in water. They have gone beyond the scope of their duties, or what is expected of them by Congress and the people, in urging communities to adopt the universal fluoridation of water without knowing the results of experiments that are now in progress.

The Public Health Service should concern itself with good public health measures and the prevention of disease. If it goes into the propaganda field, it will lose its effectiveness and the confidence of the public.

The Wier Bill

A bill introduced in the 83rd Congress (1954) by Rep. Roy W. Wier of Minnesota stated:

... no agency of the Government of the United States (including the government of the District of Columbia and of each territory and possession of the United States) and no agency of any State or of any municipality or other political subdivision of a State shall treat any public water supply with any fluoride compound or make any water so treated available for general use in any hospital, post office, military installation, or other installation or institution owned or operated by or on behalf of any such agency.

Before official comment on the bill by the Department of Health, Education, and Welfare had been stated by Secretary Oveta Culp Hobby, letters disapproving passage of the bill were written by the Secretary of the Army, Acting Secretary of the Interior, the President of the Board of Commissioners of the District of Columbia, and the Assistant Director, Executive Office of the President.

Fluoridation opponents included the Board of Directors of the National Committee against Fluoridation, which made a plea for the rights of an individual to accept or reject fluoridation. The statement of Miss Florence Birmingham, President, Massachusetts Women's Political Club, Boston, Mass. (numbering 50,000 women) included:

In 1944 Oscar Ewing was put on the payroll of the Aluminum Company of America, as attorney, at an annual salary of $750,000. This fact was established at a Senate hearing and became a part of the Congressional Record. Since the Aluminum Co. had no big litigation pending at the time, the question might logically be asked, why such a large fee? A few months thereafter Mr. Ewing was made Federal Security Administrator with the announcement that he was taking a big salary cut in order to serve his country. As head of the Federal Security Agency (now the Department of Health, Education, and Welfare) he immediately started the ball rolling to sell "rat poison" by the ton instead of in dime packages. How?

By using the pressure of the Federal Government he induced the city fathers of Newburgh, N. Y.; Grand Rapids, Mich.; and Evanston, Ill.; to try a 10-year experiment with fluoridation, to actually determine the effects of this "rat poison" upon the dental caries of growing children. This was in 1945. The Nurenb erg trials against Nazi criminals for experimenting on humans started in 1946.

Thus we see the paradox in which one department of the Government is prosecuting 23 Nazis as arch-criminals for illegally experimenting on human beings without their consent. In said trials the fact that humans were used
as "experimental" guinea pigs outraged the conscience of the civilized world as being a crime against the fundamental laws of God and the inalienable rights of man. Some were hanged, others received long time sentences. But, at about this same time, we see another department of our Government deliberately committing the same illegal criminal act en masse against its own people in the name of "medical therapeutics."

The report of these hearings includes a statement by J. Watt, Washington Office of the Christian Science Committee on Publications:

The Christian Science Church and Christian Scientists individually protest the compulsory medication involved in the treatment of public water supplies with fluorides. We welcome the opportunity to appear in support of H. R. 2341, and it is our hope that the bill will be favorably considered by the Congress.

This tendency to pass over the people and let the experts decide is all too frequent these days in matters pertaining to health. It is an attitude of "the government knows best" that, while well intentioned, dilutes self-reliant self-government. Moreover, paternalism involves an unconscious tyranny over individuals.

Dental health is a private affair, and there are many who prefer to keep the freedom to decide for themselves how to deal with it. This they cannot do if public water is medicated as recommended, for then they must either submit to the fluoride treatment or go thirsty.

In effect, this is state medicine with the government forcing its concept of dental hygiene upon everyone in the community. Certainly, no group of experts, however well qualified they may be technically, is really competent to decide such an issue, especially when, as in the case with fluoridation, they cannot even agree among themselves that what is recommended is safe or effective.

A fundamental freedom is involved here. The right of individuals who depend on prayer rather than drugs to maintain health is infringed by blanket medication. This basic religious freedom is precious and cannot be conveniently ignored every time a new cure-all is suggested. Certainly it is within the scope of technical possibility as well as conscience to provide medication for those who want it without forcing it upon everyone. Certainly such a course is more in accord with democratic ideas and constitutional practices.

Dr. Exner said:

We don't ask: "Is this thing true?" "Does it make sense?" "Does it conform to common knowledge?" Instead, we ask: "What does Dean say?" "What does Arnold say?" "What does McClure say?" Or "What does the A.D.A. or the A.M.A., the A.W.W.A., the National Research Council, or the Public Health Service say?" And we fail to notice that when any of these organizations speaks on the subject, it is merely Dean, Arnold, or McClure in a different hat.

Dean, Arnold, and McClure have done much work on fluorides, mottled enamel, and tooth decay; but instead of examining their methods, or looking at their data, we merely ask: "What do they say?" Let's look at what they say.

We are now confronted with a gigantic steamroller, fabricated by the Public Health Service, powered with unlimited Federal funds, and directed from Washington. It is designed to put over the greatest hoax in history, and to destroy, once and for all, the constitutional protections of the citizens. It gives control over our bodies to a group of men who believe that "physical
fitness is a duty owed the Nation," that they are under no obligation to tell the truth but should rather tell people whatever will lead them to do as they "ought;" to men who think fuzzily in terms of "average people," and are willing to sacrifice up to 20 percent of individuals to improve something they call "the public health" and can't define.

Other prominent opponents contributed testimony. Lt. Col. Robert J. H. Mick, then attached to the U.S. Army Medical Corps serving in Germany, was unable to be present in person but his covering letters were entered in the Record.

Rep. Fogarty had requested that the Congressional Record contain a bibliography of references on the safety and efficacy of fluoridation to "lay this thing to rest." The American Dental Association obliged by submitting data covering more than 70 pages of small type in the Congressional Record.

Fluoridation Controversy in the Press

Among numerous publications which have entered the fluoridation controversy, the Saturday Review is perhaps most notable. Its vigorously expressed antifluoridation bias has been in marked contrast to the attitude displayed by most of the national press. While not always accurate or complete, articles in newspapers and periodicals have in most instances tended toward either a non-committal attitude or outright support of fluoridation. Thus, in covering a successful referendum in New Canaan, Conn., Look magazine referred to the "anti" arguments as running a "shaky gamut" and countered each enumerated objection with an answer supplied by the proponents. Some magazines, like Changing Times, return to the subject periodically with articles featuring such favorable titles as "What's Holding up Fluoridation?" Time and Newsweek have made fairly frequent mention of the subject, always basically in favor of fluoridation. In covering the Dallas referendum in 1966, Newsweek noted: "More than anything else, time has helped to get fluoridation moving. After 21 years, Americans have learned that fluoridation is safe and effective; over the same period, the dire warnings of the antifluoridationists have not come true."

Some specialized magazines, especially those connected with health naturalism or eccentric dietary theories, have attacked fluoridation just as they have other public health measures. One of the most prominent of these magazines is Prevention, published in Pennsylvania and distributed nationally.

But when Saturday Review entered the fluoridation fray, proponents were faced with a challenge from a publication of considerable stature, with influence in literary circles.

The controversy began suddenly, and rather forthrightly, with an editorial in the issue of December 7, 1963, by Science Editor John Lear. The two-page editorial, "The Real Danger in Fluoridated Water,"
began invitingly enough with the admonition, "Come let us reason together." Lear dealt at some length with the extensive problem of dental decay, and outlined the controversy over proposals to fluoridate. Then he labeled the U.S. Public Health Service's attempt "to force fluoridation . . . throughout the country" as "outrageous." He raised ancient arguments of class legislation; contrasted unfavorably the brochures and pamphlets of the proponents with the opposing publication edited by Mrs. Waldott; decried the fact that he could find few "unequivocal, rigorously controlled experiments" on the benefits of fluoridation; and ended by encouraging "the simple act of toothbrushing."

In the issue of January 4, 1964, Lear noted that most of the letters responding to his first article assumed that "fluoridated water's protection of teeth from decay had been established absolutely, and the danger to health in small amounts of fluoride was nonexistent." In six pages Lear denied the veracity of their assumptions. Among some thousands of studies that had been made up to 1964, he cited only one, essentially a review article by three members of the National Research Council of Canada. Although Lear was later to say that "his readings on fluoridation had been wide," it was this one Canadian report to which he continued to cling.

Proponents of fluoridation flooded the magazine with countering letters, and the magazine carried a considerable number of them in the 1964 issues of February 1, February 15, and March 7. Many well-known men of science who had been professionally involved with fluoridation sent in disclaimers. Mr. Peter C. Goulding of the American Dental Association characterized the controversy in noting:

> . . . there is little that can be termed new in Mr. Lear's article. All of his conjectures have been laboriously investigated long since, and if Mr. Lear wishes to assure himself of the safety of fluoridation, he need only look through the abundant scientific literature with an open mind and the assistance of several qualified scientists.

The attack mounted by Mr. Lear was probably more astonishing than damaging. That such an attack would come from the Saturday Review made proponents incredulous. Their reaction was aggravated even further when, in defense of his Science Editor, Publisher Norman Cousins raised the spectre of mongoloid births, a fearsome unverified assertion of opponents. Not even Lear had gone that far.

The first attacks in the Saturday Review had little if any impact on subsequent acceptance of fluoridation, any more than the Delaney Report or the hearings on the Wier Bill. The controversy seemed to end on April 3, 1965, when the Saturday Review published an article attempting to raise doubts about the constitutionality of fluoridation. The embers, however, were to be fanned some four years later.

In the Saturday Review of March 1, 1969, Lear again argued his case against fluoridation. "New Facts on Fluoridation" was his lead article, followed by "Biography of a Bandwagon" by Michael Wollan. A report by Taves, Terry, Smith, and Gardner (18) became the major basis for
Lear's critique. This report suggested that an excessive and possibly harmful quantity of fluoride had been retained in a patient's skeletal tissue after long-term hemodialysis. Lear cited other sources of information not yet published in the medical literature. One was a paper presented in November, 1968, at a meeting of the American Society of Nephrology, the other a lecture given at a meeting of the Canadian Society for Clinical Investigations by Dr. J. Marier which included the observation that use of the artificial kidney on patients in Ottawa, Canada, had created problems not experienced in Montreal. The water in Ottawa is fluoridated; Montreal water is not fluoridated. The investigators expressed the wish for more research regarding the role of fluoride in the dialysate used in the artificial kidney.

The National Institute of Arthritis and Metabolic Diseases, which conducts a national research program on artificial kidneys, commented that fluoride might be harmful, but this could also be the case for other trace elements naturally present in water. This Institute pointedly emphasized that hemodialysis units now routinely use deionized water to remove not just fluoride but other elements as well. Studies on the most desirable dialysate do not preclude the possibility that a trace amount of fluoride could be beneficial to the skeletal tissues of the patient.

In March, 1969, the Surgeon General of the Public Health Service, Dr. William H. Stewart, stated:

Consumers of public water supplies enriched with minute quantities of fluoride in order to prevent tooth decay should not be misled by news articles which mention medical problems that may arise from using tap water in the artificial kidney. There is no relationship between the daily consumption of fluoridated water and the use of such water in artificial kidneys for the treatment of patients with total kidney failure.

It should be pointed out again that the need to process some water supplied before therapeutic use in large quantities in artificial kidneys has no bearing on the ingestion by anyone of optimally fluoridated water from community water supplies, recommended by health authorities as a medically safe procedure for the reduction of dental caries.

The United States Public Health Service endorses water fluoridation as a safe and effective public health measure and urges all communities to make its benefits available to people at the earliest possible time.

There is little need to comment on the article credited to the late Michael Wollan. The text in Saturday Review was taken from an article published by Wollan in 1968 in the George Washington Law Review and no new facts on fluoridation were presented.

While investigations of political and social scientists multiply, and the press and politicians have their say, referenda continue and fluoridation moves on, however slowly. It is a compelling commentary on the critics of fluoridation that they have not been able to persuade any professional scientific organization to disapprove fluoridation or to disavow any earlier endorsement.

Donald R. McNeil summed it up best: "The fight for fluoridation is a case study of our American democracy in action."
CONTEST AND VICTORY

NOTES AND REFERENCES


(3) EXNER, F. B., and WALDBOTT, G. L., 1957. The American Fluoridation Experiment, edited by J. Rorty, Devin-Adair, New York. The commitment of this volume is immediately evident in the introduction, written by James Rorty: "At this writing, some 28 million Americans have been using artificially fluoridated public water supplies. . . . They are willing or unwilling guinea pigs in what many American scientists and most Europeans regard as a huge, unprecedented, and possibly disastrous national experiment. . . . This is the first time that the official sponsors of a public health measure have censored, intimidated, and regimented the interested health professions. It is the first time that public health officials have deliberately falsified, distorted and suppressed scientific evidence tending to impugn the safety of a public health measure. It is the first time that the sponsors of such a program have systematically slandered its profession and lay critics and opponents."

(4) WALDBOTT, G. L., 1965. A Struggle with Titans—Forces behind Fluoridation—A Scientist's Look at Fluoridation. Carlton Press, New York. The preface reads, "For eleven years I have been engaged in medical research on the effect of fluoride on the human organism. Some of my data have been published in medical journals. They include three monographs which encompass original observations and much of the world's medical literature on fluoride with emphasis on research which is difficult of access. . . . Because of the constantly increasing interest in this subject and because of the many conflicting data, I decided to make some of the information, thus far gleaned, available to the general public. . . . While exploring this subject, I have observed many practices usually not encountered in medical research. My original plan was to confine myself to presentation of purely scientific data in a book of encyclopedic proportion. This has been temporarily laid aside in order to narrate personal experiences in an unending struggle and the trials and tribulations of one who found himself swimming against the stream."


FLUORIDE LITERATURE

Scientific literature relating to the biology and physiological effects of fluoride is voluminous. The recent Hodge and Smith publication, Biological Properties of Inorganic Fluorides and the Effect of Fluoride on Bones and Teeth, for example, lists approximately 3,400 references. The preface of that text makes note of the fact that more papers on the biological effects of fluorides have been published during the past thirty years than in all the preceding literature. Roholm's bibliography lists references as of 1931. Research on dental caries alone has produced thousands of articles. There are 2,274 papers listed in a Canadian publication of 1950, Bibliography on Caries Research, prepared by Dr. J. Stanley Bagnall. In 1964, Jane F. Brislin and Gerald J. Cox, School of Dentistry, University of Pittsburgh, prepared Survey of the Literature of Dental Caries, 1948-1960 and listed 3,755 abstracts. In addition to volumes of scientific publications dealing directly with the relationship of fluoride to dental caries, many popular articles have discussed the pros and cons, acceptability, and health safety of fluoridated drinking water. A major increase of interest in biological effects of fluoride came about with the advent of water fluoridation. Following World War II, as Frank A. Smith noted in his preface to Pharmacology of Fluoride, this interest was augmented by the expanding industrial use of both inorganic and organic fluorine compounds.

The splendid fluoride bibliographic service of Mrs. Irene Campbell at the Kettering Laboratory in Cincinnati, Ohio, has inestimable value for the scientific fluoride community, as well as dental, medical, and public health professions. The first of the annotated publications of this bibliographic service appeared in 1958 under the title The Occurrence and Biological Effects of Fluorine Compounds, Vol. I., The Inorganic Compounds. Containing approximately 8,700 abstracts, this vast compilation was prepared by Mrs. Campbell and Evelyn M. Widner with the assistance of Irene P. Kukanis. Mrs. Campbell has reported that by 1962 there was a backlog of around 2,000 additional references and in 1967 alone approximately 1,200 publications on this subject accumulated. There is no limit to the gratitude and appreciation to be paid Mrs. Irene Campbell and her associates for this contribution to fluoride history and research.

Mrs. Campbell prepared a selected fluoride bibliography, The Role of Fluoride in Public Health—The Soundness of Fluoridation of Communal Water Supplies, published by The Kettering Laboratory, University of Cincinnati. This compilation was selected particularly to be helpful in promoting water fluoridation. Its objective is stated by Mrs. Campbell:

An important phase of the present work is the preparation and issuance of abstracts of selected reliable and critically evaluated publications pertaining
to fluorides that would be of interest and value to people who are interested in the fluoridation of communal water supplies. A compilation of the entire extensive literature on the subject would be of little assistance to those who are concerned with the welfare of their community, because the scientific reliability of some is highly questionable. This is true of any literature concerning environmental health which often provokes controversy. An evaluation by competent people of the literature pertaining to biological processes, and particularly the biological response to chemical or physical agents in the environment, is therefore necessary.

The abstracts (or digests of the publications) included in this bibliography which will be supplemented periodically, were selected with the assistance of an Advisory Editorial Board consisting of members who have themselves investigated and followed the physiology and pharmacology of fluorides and their effects on dental health, and those who have been concerned with the educational, legal, engineering, and chemical matters. The first compilation considers the literature through 1962 and is designed to establish the basic principles of the role of fluoride in dental health, and of the soundness of the use of water containing fluoride at a concentration of one part per million parts (1 ppm) of water. The references are limited to those concerning the inorganic compounds, since the fluoride ion exists chiefly as such. (Two organic compounds, fluorocacetate and a fluoro-oleic acid, are known to occur naturally in a genus of plants, but their action or that of any other organic compound containing fluoride is not due to the fluoride ion per se.)

Abstracting and organization of current fluoride literature is continuing under the very competent direction of Mrs. Campbell at the Kettering Laboratory.

BOOKS


Fluoride Literature


A symposium held in Berne, Switzerland, October, 1962.


Reviews


Reports


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