SUGAR RESEARCH FOUNDATION, INC.
NINETY-NINE WALL STREET
NEW YORK 5, N. Y.

ODY H. LAMBORN
EXECUTIVE DIRECTOR

June 27th, 1945

TO OUR MEMBERS:

Sugar has been the "whipping boy" for dental caries for generations. It has borne the major share of culpability for this unfortunate defect of the body although there has been no convincing scientific proof of its guilt.

An examination of the research work done to ascertain the causes of dental caries indicates that this subject has received little attention as compared with studies of the causes of other ailments of the human body. Of course the enlightened, progressive scientist knows that there is an infinite number of factors which contribute to the development of dental caries.

In the face of this it is extremely encouraging to observe the studies being made by the dental profession to ascertain how much the lack of fluorine in the body may contribute to dental caries. In this connection we enclose a copy of a booklet recently printed by the New York Institute of Clinical Oral Pathology, entitled "Fluorine in Dental Public Health". You will find this of great interest and we recommend that you not only read it but preserve it. Incidentally, we understand that this booklet is going to all the dentists in the Nation.

Sincerely yours,

OHL:be
Encs.

Ody H. Lamborn

FLUORINE

IN DENTAL PUBLIC HEALTH

A Symposium

AT A MONTHLY CONFERENCE OF THE
NEW YORK INSTITUTE OF CLINICAL ORAL PATHOLOGY
NEW YORK CITY, OCTOBER 30, 1944

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The New York Institute of Clinical Oral Pathology, Inc.
101 East 79th Street
New York 21, N.Y.

TO THE DENTAL PROFESSION

At the New York Academy of Medicine, on October 30, 1944, a meeting was held that was notable in the annals of American dentistry. More than a thousand people were present — dentists, physicians and laymen. Every seat in the large auditorium, including those in the gallery, was occupied and many auditors remained standing throughout the meeting. The occasion was a symposium, arranged by the New York Institute of Clinical Oral Pathology, to discuss the relationship of fluorine to dental caries. Five of the leading authorities in the United States presented papers on different aspects of the subject, followed by a period of questions and answers.

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.

June, 1945

Arthur L. Merrill

Chairman

FLUORINE
IN DENTAL PUBLIC HEALTH

A Symposium

At the ninety-fourth monthly conference of the New York Institute of Clinical Oral Pathology, in the main auditorium of the New York Academy of Medicine, New York City, Monday evening, October 30, 1944

By

FREDERICK S. MCKAY, D.D.S.

H. TRENDLEY DEAN, D.D.S.

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NEW YORK CITY • 1945

Contents

Preface: W. J. G. 5

Introductory remarks by President Kaletsky and Chairman Merritt 9

Addresses:

Frederick S. McKay, D.D.S.: Fluorine and mottled enamel; historical survey 10

H. Trendley Dean, D.D.S.: On the epidemiology of fluorine and dental caries 19

Wallace D. Armstrong, M.S., PH.D., M.D.: Fluorine content of enamel in relation to resistance of teeth to decay 31

Basil G. Bibby, B.D.S., PH.D., D.M.D.: Effects of topical application of fluorides on dental caries 36

David B. Ast, D.D.S., M.P.H.: A plan to determine the practicability, efficacy, and safety of fluorinating a communal water-supply, deficient in fluorine, to control dental caries 40

Questions and answers:

Addressed to, and answered by,

Dr. McKay 46

Dr. Dean 46

Dr. Armstrong 46

Dr. Bibby 47

Dr. Ast 50

Supplementary bibliography on mottled enamel and other dento-fluorine relationships (1931-1944) 51

PREFACE

THIS booklet presents a valuable and timely summary of data on a subject of growing significance in the development of dental science and in the advancement of oral health-service. The five addresses on pages 10-45, by leaders in research on dento-fluorine relationships, outline the successive steps in these discoveries:

(1) Intake of excessive amounts of fluorine-containing substance in solution in communal water-supplies (*more than* 1.0 part per million of F) —during the period of tooth formation—causes production of *mottled* enamel (endemic dental fluorosis).

(2) In communities where the proportion of such fluorine-containing substance in the domestic water-supplies is *not far below* the minimal threshold of endemic dental fluorosis (1.0 ppm. of F), the caries-rates are comparatively low.

(3) Wherever the potable water-supply has *much less* than 1.0 ppm. of such fluorine, or none, the caries-rates are relatively high.

(4) The proportion of fluorine in combination in dental enamel—in which fluorine is a normal constituent—is greater in enamel of sound teeth than in enamel of carious teeth.

(5) Caries-experience can be decreased by topical application of fluoride solutions to the teeth (the enamel of which presumably did not acquire a normal fluorine-content during the period of formation).

These important discoveries (1-5), and related findings, show or suggest that

(A) during the period of tooth development, fluorine—in *physiological* form and proportion in the diet (food and water)—is essential for the formation of normal enamel (teeth), such enamel having a high degree of resistance to caries;

(B) *excess* of such fluorine, during tooth development, causes formation of mottled enamel; *deficiency* of such fluorine during that period causes production of enamel having low resistance to caries;

(C) topical application of fluoride solution to teeth induces protective incorporation of fluorine in enamel that is deficient in this element, and thus increases the resistance of the treated enamel to caries; and

(D) *addition of fluoride* (*e.g.*, sodium) in *physiological* proportions to *domestic water-supplies* assures daily ingestion of amounts of fluorine that are needed in children for the development of normal enamel, *without causing formation of mottled enamel.*

Dr. Ast's address (pages 40-45) states the basis for, and the procedure in,

the effort in the State of New York to determine, in a comprehensive and extended research, whether mass prevention (control) of dental caries (under the conditions stated in the preceding paragraph) is attainable *without inducing toxic effects elsewhere in the body.* Available evidence seems to indicate that there are no undesirable collateral influences.

The very hopeful prospect that mass prevention of dental caries—or great decrease in its incidence—can be accomplished by addition of *physiological* proportions of sodium fluoride to communal water-supplies raises many related questions, the answers to which will require much further research. Thus, does ingestion of the recommended amounts of fluoride prevent, or decrease the incidence of, caries by

(a) destruction, or by impairment of the activity, of the oral microörganisms that conduct the carious process?; or by

(b) increasing the amount of fluorine within the enamel, in this way physiologically fortifying the enamel against the disintegrative (solvent) action thereon of products of fermentation by oral microörganisms?; or by

(c) both influences, and/or others?

Does a *physiological* intake of fluoride prevent or arrest *caries in enamel defects,* such as pits and fissures? If either occurs, does the fluoride act by bringing about

(d) direct chemical reconstructions that protect enamel defects against decay?; or by

(e) stimulating or supporting endocrine influences that repair enamel defects?

Does a *physiological* intake of fluoride prevent the *formation, or reduce the number, of enamel defects,* such as pits and fissures? Does it have effects, beneficial or harmful, on any periodontal condition?

In 1926, in the Carnegie Foundation's *Bulletin on Dental Education in the United States and Canada,* in a discussion of some urgent problems for dental research—five years before the discovery in 1931 that fluorine is the cause of mottled enamel—the present writer stated some phases of his biochemical philosophy in dentistry that may be quoted here as pertinently suggestive in current perplexities (pages 174-5):

> *"The exact elementary composition and the mineralogical constitution of the inorganic matter in enamel, with particular reference to variations in the resistance to chemical change. . . .* Nearly all of the mineral matter in dental enamel is disposed in microscopic hexagonal rods or prisms. In the light of accordant data of incomplete chemical analysis, this particular physical state, which is unusual under biological conditions, suggests that enamel consists chiefly of apatite (ἀπατᾶν, to deceive), a phosphatic mineral that is widely distributed in many varieties and which *for centuries was mistaken for others.* Among the common forms of apatite are hexagonal crystals, which, colorless or varicolored, transparent or opaque, according to differences in the nature of associated materials, are *suggestive of analogies with normal enamel in some respects and with 'brown stain' or mottled enamel in others.* Although dental enamel is composed mainly of tri-basic calcium phosphate, it also contains

magnesium, manganese, chlorine, fluorine, and carbonate. The ordinary types of apatite include forms consisting of three parts of the phosphate and one of calcium chloride in one instance [$3Ca_3(PO_4)_2.CaCl_2$], and *three parts of the phosphate and one of calcium fluoride in another* [$3Ca_3(PO_4)_2.CaF_2$]. In familiar kinds of apatite, calcium is replaced by magnesium or manganese, and *chlorine or fluorine by hydroxyl or carbonate, indicating great responsiveness of the mineral to external influences during its formation.* All of these elements or radicals are common to animals and plants, and are present in an ordinary diet.

"The adjustment of the constituents of enamel during its normal development depends not only on sufficiency and balance of the diet but also on equilibrium of special processes of coordination. The particular forms of apatite that may be produced in enamel are presumably affected by such glands as the parathyroids and thymus, fluctuations in their adaptive influences doubtless causing significant variations in its quality. If these deductions should be verified and extended by research, *it might be possible physiologically to strengthen enamel against the action of such external chemical agents as those produced by bacteria, for its resistance may vary with the proportions of the units in the mineralogical structure, or with the nature of the structure itself, and these may be controllable.* Although the recent discovery of protein in enamel complicates these views, it also emphasizes the importance of a thorough study of enamel, with special reference to elementary percentage composition, chemical character, mineralogical constitution, histological structure, resistance to solution and disintegration, and relation to the prevention of decay of teeth, the most general and urgent problem in dentistry." [Italic not in original.]

The two editions of *Dental Caries*—issued by the American Dental Association in 1941 and 1943, respectively—present so many disagreements among the large number of active and competent investigators in this field in all parts of the world, not only on causes of caries but also on ways and means to prevent it, that there will be world-wide rejoicing if current hopes that "fluorine solves the problem" will be fully realized. Meanwhile constructive scientific skepticism should be applied to every finding, to facilitate thorough research and also to prevent the consequences of misjudgments.

The important scientific presentations in this booklet were parts of the proceedings of the ninety-fourth monthly conference of the New York Institute of Clinical Oral Pathology, which—the first of its kind—was organized in 1932 "for the study and advancement of oral pathology, particularly of the correlation of clinical findings, x-ray examination and histopathological evidence, and the dissemination of such knowledge to the members of the Institute and to the medical and dental professions." To promote its various purposes—in study, research and teaching—the Institute conducts, at its headquarters (101 East 79th Street), its own pathological laboratory under the direct supervision of a diplomate of the American Board of Pathology. There the Institute also has a comprehensive library of medical, dental, and scientific books, journals and reprints; also large collections of case-histories, wet and dry anatomical specimens of the head and jaws, plaster casts, moulages, lantern slides,

microscope slides, pathological specimens, photographs of patients, mounted x-ray- and micro-photographs, etc., all of which—related to interesting and instructive conditions in oral pathology—are increasing in number and significance.

At monthly conferences (October to May, inclusive), in the building of the New York Academy of Medicine, the Institute gives special attention to cases showing unusual conditions and related methods of treatment; cases for diagnosis and recommended treatment; papers on subjects of timely interest, such as those in this booklet; etc. These conferences are open to members and invited guests, and are frequently attended by teachers in the local dental schools, by dental interns in the hospitals of Greater New York City, and by visitors from other parts of the United States and foreign countries. In the Institute's pathological laboratory, examinations are made for patients, regardless of ability to pay.

Benefactors, Donors, Fellows and Members contribute funds for the maintenance of the Institute and its laboratory. The present governing board (Council) of the Institute consists of ten members: Drs. Alfred Walker, Waldo H. Mork, Isador Hirschfeld, Theodor Blum, Herman L. Reiss, Frederick F. Pfeiffer, Edwin G. Van Valey, Percy T. Phillips, Meyer L. Rosoff, and Theodore Kaletsky.

The success of the Institute suggests that its usefulness should be emulated in other centers where the advancement of clinical oral pathology can be furthered by active research and special instruction.—*W.J.G.*

FLUORINE IN DENTAL PUBLIC HEALTH

A Symposium

AT THE NINETY-FOURTH MONTHLY CONFERENCE OF THE NEW YORK INSTITUTE OF CLINICAL ORAL PATHOLOGY, IN THE MAIN AUDITORIUM OF THE NEW YORK ACADEMY OF MEDICINE, MONDAY EVENING, OCTOBER 30, 1944

IN OPENING the conference, the President of the Institute, Dr. Theodore Kaletsky—after welcoming the audience that filled the large auditorium to overflowing—presented, as Chairman of the conference, Arthur H. Merritt, D.D.S., M.S., SC.D.

Chairman Merritt: I too am happy to extend to you a very cordial welcome to this meeting. It has been my privilege throughout a long period of years to attend many dental meetings. I think I can say, without qualification, that I have never attended a meeting which aroused the interest that this program has developed in the minds not only of members of our own profession but also of the medical profession—and of laymen. I have received requests from men as far away as Winnipeg for information regarding our program. I have been called to the telephone by laymen asking if they might attend. It is a matter of great satisfaction to those of us who are members of the dental profession that there is so much interest in this meeting among many of our colleagues in other fields.

I am not here tonight, as Chairman, to make an extended address. You are here to listen to the distinguished men whose names appear on the program. At the conclusion of the symposium, questions will be received from the audience. I ask those of you in whose minds questions arise, as the different speakers address you, to make note of your questions and be prepared to present them at the conclusion of the formal program.

(Chairman Merritt appropriately introduced the successive speakers, whose addresses follow in the sequence of their delivery.)

Fluorine and Mottled Enamel

Historical Survey

Frederick S. McKay, D.D.S.
Colorado Springs, Colorado

AT A MEETING of the American Association for the Advancement of Science held at Dallas, Texas, in December 1941, a symposium was presented in the Subsection on Dentistry under the title: "The Public Health Aspects of Dentistry, with Special Reference to Fluorine." That was the first symposium in the field of dental science to be held by the Association and the first anywhere on that subject. The same Association held a second symposium on the same general theme, entitled "Fluorine and Dental Caries," at the meeting in Cleveland, Ohio, only last month. This symposium tonight—the third within three years—is a further indication of the growing importance that this subject has acquired in relation to the public health.

Knowing as we do now the widely scattered distribution of dental fluorosis over the earth, it may seem strange that serious attention to it was so long delayed. Aside from a few scattered small areas in the East, this lesion has its most pronounced expression in the western part of our country. The occurrence of sporadic cases did not present a problem that required special attention; but when it became apparent that a mass occurrence existed in communities of considerable population, the condition thus revealed demanded investigation. This was the situation in the city of Colorado Springs when, in 1908, the newly organized Dental Society undertook an investigation to determine the cause of what was then known as the "Colorado Brown Stain." This was a name that recognized only a concomitant but unfortunately the most conspicuous phase of the lesion—a brown discoloration on the labial surfaces of the upper front teeth.

Dentists practising in Colorado Springs had recognized this condition as something entirely different from any known lesions of the teeth, and comparable only to what was then termed "atrophy." There was a persistent tendency to attribute its cause to the common pathologies of childhood. It was only natural that there should be various theories as possible explanations, of which the most widely held was a deficiency of calcium in the city water-supply, which was known to have a very small content of that element. Aside from a very brief mention in *Dental Cosmos* in 1902, of what seemed like a similar condition near Naples, Italy, there had been no reference to, nor description of, this lesion in the dental literature. This reference to Naples did not come to our attention until ten years after it was published and so, as far as we knew at the time, this lesion had no existence anywhere in the world outside our own locality. This was the situation when our investigation was begun.

In a way there was an advantage in not having false theories or published opinions to overthrow; neither was there any guide whatever to direct the path of the investigation. The slate was clean. The one feature generally recognized was the occurrence of the lesion in children and young adults. Colorado Springs having been founded in 1871, these young adults represented the first generation to have been reared in the city. An examination of the public-school children revealed that the lesion existed only in natives and those children who had become residents during infancy or early childhood. This was the first differentiating fact established in the investigation.

It is apparent now that, in these early examinations, the screening process—that is to say, the careful separation of those individuals who had a continuous residence from those who had been in any considerable sense migratory during their early years—was not as carefully done as in the more recent examinations. The early examinations did show, however, that a very high proportion, considerably above 80 percent of those classed as natives of Colorado Springs, were in some degree afflicted. It also became evident that teeth that had completed calcification elsewhere never acquired the lesion thereafter through residence in the community. Since this lesion is continuously produced through successive generations of natives, it is correctly classed as endemic.

Following the examinations in the city schools, similar examinations in all schools within a radius of 30 to 40 miles revealed that these small communities were generally endemic, the only conceivable difference between them and the nearest immune community being that, whereas the former —like Colorado Springs—received their water supplies from the Pike's Peak watershed, the immune district received its supply from a totally different source. This seemed to establish a relation between the Pike's Peak watershed and the production of the lesion.

With the foregoing as a basis, it was important to determine whether a similar relationship to the water supply occurred in other afflicted districts in the State, which by that time were being observed and reported. Accordingly during the following two or three years, examinations were made in all the known afflicted districts of Colorado, and in these the lesion was found only in the native individuals. It was not possible to establish an association in these various communities with any one particular source of water supply: there was water from mountain streams, from surface wells, and from deep wells, but no difference among these waters as to clarity, taste or odor.

During the course of this state-wide examination, a point was established bearing on the differentiation between water supplies that was to become important later. Attention had been called to a certain small coal-mining community, where the domestic water-supply was being drawn from the mine and examination of the children revealed the most disastrous occurrence of this lesion the writer has ever seen. Water from this mine—because of its supposed purity—had in previous years been hauled in barrels to a

nearby town, where it accounted for pronounced cases of the lesion in adults examined there who had used this water extensively as children. This town otherwise was not generally endemic. Here was revealed for the first time an association between water drawn from deep sources, which included artesian wells and hot springs, and the production of the lesion.

The association of Dr. G. V. Black with this investigation is one of its most important episodes. No one up to that time had written so voluminously on enamel lesions. Prior to the investigation as thus far indicated, a general description of the situation in Colorado Springs was conveyed to him. His interest was immediately aroused. No such mass occurrence of an identical lesion—in an entire class (native children) of the population of any community—had ever before been recorded, and Dr. Black pronounced it a new lesion in dental pathology. In order to study it he came to Colorado Springs, in 1909, as the guest of the State Dental Society. In his studies of tooth structure in relation to the liability to decay, as published during the 1890's, he had reached what at that time was considered the revolutionary conclusion that the degree of hardness, or of perfection of the calcification of the enamel, was not the principal factor that determined its liability or its resistance to decay. This dictum of Black's was strongly corroborated, as the research proceeded, by observations which warranted the conclusion that mottled enamel was not by its defective calcification thereby rendered more liable to decay. It later became apparent that mottled enamel was actually *less* liable to decay. The data supporting this conclusion were published by the present writer in *Dental Cosmos* (August, 1929).

The first article on mottled enamel in dental literature was published in *Dental Cosmos,* in 1916, under the joint authorship of Dr. Black and the present writer. In this article Dr. Black described the histology as showing absence of the cementing substance between the enamel rods, which accounted for the grayish, spotted—and in some cases the dead white—appearance of the teeth. Because of this grayish splotched appearance he gave it the name "mottled enamel," which name was used until—after the discovery of the cause—the more comprehensive term, "dental fluorosis," was substituted. The present writer's contribution to the article consisted of a description of the conditions found in the communities examined throughout Colorado and in other states. Dr. Black, up to the time of his death (1915), maintained a vigorous interest in this problem, and it is worthy of note that the last paper of the great number he wrote was on this subject.

It was early recognized that, in gathering the data in the endemic districts, the most essential feature was accuracy—at least to the greatest degree possible—in treading this new and unexplored ground. For this reason opinions could not be accepted; hence it was necessary that all examinations be made personally. In addition to the general survey of Colorado, communities in South Dakota, Idaho, California, Arkansas, Arizona, Kansas, Illinois, Virginia and Massachusetts in our own nation, and in Italy and Holland in Europe, were personally examined. Extensive data were obtained from correspondents in Argentina and South Africa. By the

time these field surveys had been completed, it had become evident beyond any doubt that the cause of this enamel dystrophy was in the domestic water-supplies. Routine analyses of the water from endemic districts early in the research showed nothing that was conclusive. No constituents were revealed that had not been common to domestic waters for generations, and none that were known to be deleterious to tooth structure. The present writer was thereby convinced that a completely different kind of chemical analysis would be necessary: one that would search even for traces of the rarer elements not sought for in the standard analysis. How sound this conclusion was is now apparent.

Among all the communities examined, certain ones were outstanding not only in their almost dramatic interest, but more so in the conclusive evidence they furnished toward establishing the water hypothesis. In *Britton,* a small community in *South Dakota,* the original source of domestic water was from individual surface or dug wells. In later years, primarily for fire protection, the town had installed a water system in which the source was from deep or drilled wells. The water was pumped into a high tank for pressure, and distributed for household use. Following this change, the succeeding generations of children have been universally afflicted with mottled enamel whereas formerly that lesion had been unknown there. Further than this, in the generation of children that overlapped the change, those teeth that had been calcified prior to the change were normal; those calcified after the change were mottled—both kinds of teeth in the mouths of the same individuals in many cases. The fact of the change of domestic water was indelibly recorded in the teeth. Outside of the artesian district, adjacent to Britton, mottled enamel was completely absent.

It is evidence such as this, substantiated by animal experimentation, that has demonstrated that dental enamel, of all body tissues, is the most sensitive index of the action of fluorine. This may be explained in two ways: first, because of the intense affinity of fluorine for calcified tissue; second, because of the total absence of capacity for self-repair, any damage inflicted on enamel during its formative period is permanent.

Reports from field dentists, in the Indian Service of the United States Public Health Service, indicated that conditions among the Pima Indians were worthy of investigation. At the reservation at *Sacaton, Arizona,* a severity of mass affliction among the children was encountered that, in the experience of the writer, had scarcely been approached theretofore. Here was the new feature of the occurrence of mottled enamel in an arid sun-baked desert, a condition entirely different from the timbered mountainous and agricultural regions previously examined. The striking absence of decay in view of the extreme severity of the enamel defect was recorded and published following the examination (*Dental Cosmos,* August, 1929).

The small agricultural community of *Oakley, Idaho,* presented one of the most significant episodes in the course of the investigation, in that the accomplishments there were entirely without precedent. A few years earlier

the people of the town began to notice that something was happening to the teeth of their children, which was entirely different from anything in any of the adjacent communities. The matter was given vigorous attention by the town's organization of women and the writer was urged to make a survey of the situation. This showed that the tooth disfigurement had made its appearance following the installation of the then existing water-supply. Several years before, water from a warm spring in the hills a few miles away was piped into the town to supplant the individual shallow wells. From that time the production of mottled enamel was universal and continuous in the native children. Children living on adjacent ranches, hence beyond the town's warm-spring supply, were free from the defect.

With the evidence so conclusive, a special bond-election voted funds to install a new water-supply that would be free from the damaging potentialities of the existing supply. But, as the water supply was very limited, where was a new source to be found, and what was the evidence that any proposed new water would be satisfactory? The only known possible source of sufficient volume was a cold spring not far from the old warm spring. Someone recalled that the children of a certain family had used that water for a considerable period of years. Here was a possible source of evidence that could determine the suitability of that water. This family having been located on a neighboring ranch, the children were examined and their enamel found to be normal. On this slender evidence the cold-spring water was turned into the pipes a few weeks later. This episode at Oakley is unique in being the first instance in dental history where a municipal project of such a magnitude had been undertaken solely to prevent a dental disorder. It should be noted in addition that not only was the old water-supply discarded, but also the new water was selected on dental evidence alone.

Naturally the result of this action could not be known until after the next generation of children had been born, and enough of their permanent teeth had erupted to reflect the change. Eight years afterward Oakley was again visited and examined. By that time enough teeth were visible to show that new production of the lesion had been completely prevented. Again the cases that had overlapped the change of water were of compelling interest. In some of these a line of demarcation showed what portion of certain teeth had been calcified under the influence of each type of water. It was again apparent that the mottled teeth in the older children had not in any degree been improved by the change of water during the eight years.

This is believed to be the most conclusive evidence ever presented of the inability of enamel to respond to any nutritional influence after its calcification has been completed. Having seen the devastating effect of fluorine, one of the most active of all elements, in disrupting the orderly process of enamel production and its total inability in the same proportions to damage formed enamel, is it not pertinent to inquire how such comparatively inactive substances as calcium or vitamins can be expected—when administered therapeutically—to improve the structure of *formed* enamel? With-

out cellular activity how can there be metabolism in the enamel? Mottled enamel remains unchanged throughout life regardless of any dietary influence.

This episode at Oakley can best be interpreted as an application of laboratory-research methods to an entire population, where conformity to the experimental procedure was voluntary—but at the same time compulsory, in that there was no other supply of water. In its major aspects the episode at *Bauxite, Arkansas,* was like that at Oakley. At Bauxite, shortly after the installation of a water system derived from three deep wells, endemic mottled enamel made its appearance. In 1928 the present writer was commissioned with Dr. Grover Kempf, epidemiologist of the United States Public Health Service, to survey conditions at Bauxite. Precisely as in other endemic regions mottled enamel was found to exist only in native persons. No teeth were affected that had completed calcification prior to the change of water. Children who lived outside of the town had normal enamel. This examination marked the active entrance of the Public Health Service into this research. As a check against the situation in Bauxite the school children of the neighboring town—Benton, about four miles away—were examined and found to be completely free from this enamel defect. Benton derived its water from the nearby Saline River.

Bauxite, which is engaged in mining aluminum-bearing ore, is wholly owned by a company subsidiary to the Aluminum Company of America. As affecting the welfare of the community, the parent Company, following our examination, promptly substituted water from the Saline River by building a four-mile pipe-line and by sealing off the artesian wells. In 1938, ten years later, the present writer returned to Bauxite, assisting Dr. H. T. Dean of the Public Health Service in a re-examination. The results were an exact duplicate of those at Oakley in every detail—there had been no further production of the enamel defect since the change of water. But it was evident that the teeth which had been normally calcified since the change to the "new" fluorine-free water *exhibited a rate of caries attack that was higher than that which existed in the fluorosed teeth.* This may have been the first definite consciousness in both examiners that these findings contained a much deeper significance than either had anticipated.

What took place at Bauxite marks the climax of the investigation, in that it led to a strong indication that fluorine was the cause of the lesion. How this came about is extremely interesting. A chemical study of the water from the deep wells at Bauxite, made at the laboratories of the Aluminum Company of America at New Kensington, Pa., indicated presence of fluorine. Recognizing that fluorine had not been considered a usual constituent of domestic waters, the first analysis was rejected and another ordered; for the same reason the second analysis was rejected and a third made with the same result. The finding was then accepted. Under date of January 20, 1931, a letter was received from Mr. H. V. Churchill, Chief Chemist of the Company, which set forth the possible relation between fluorine and mottled enamel. Although no conclusion was reached, the

writer deems it entirely appropriate to say here that this announcement brought the feeling that the long search over twenty-five years had reached its goal.

That letter went on to propose that water from several endemic districts be sent to the laboratory for analysis for fluorine and, as a control, waters from some thirty non-endemic cities in different parts of the United States would also be analyzed. Arrangements were made by the present writer to have a gallon of water from each of six widely separated endemic districts shipped to New Kensington. Stated briefly, fluorine was found in varying amounts in the waters from all the endemic districts and none in the waters from the non-endemic places. These findings were published by Churchill, in the *Journal of Industrial and Engineering Chemistry,* in the issue for September, 1931.

Conclusions even more definite had been reached at practically the same time by Margaret Cammack Smith, of the University of Arizona, through work done at St. Davids, the small endemic community about sixty miles east of Tucson. Her series of experiments on laboratory animals, in feeding and injecting fluorides, produced dental fluorosis of a most fantastic type as to its distribution over the tooth surfaces. A notable contribution to the literature is a series of *Bulletins,* published by the University of Arizona, describing these experiments, in certain of which Dr. Isaac Schour of Chicago collaborated in histological studies of the fluorosed teeth. The application of fluorides by intermittent injections during the calcification period, as a means of measuring the rate of apposition of enamel and dentin—as developed by Schour—is the most unique achievement of this research, in providing definite knowledge not obtainable in any other way.

As between Churchill and Margaret Cammack Smith, this is another instance of workers apart and unknown to one another contributing to the same discovery at about the same time. Later the Smiths (Margaret C. and H. V.) made a state-wide survey of Arizona to locate and describe the endemic districts, which was a notable achievement.

As a final correlation between the fluorine hypothesis and Oakley: it was found that the former warm-spring water had 8 parts per million of fluorine, and the "new" water had none. The deep-well water at Bauxite had 13 to 14 p.p.m. of fluorine. The highest fluorine content encountered by the writer is 18 p.p.m. in a very small hamlet in a warm-spring district in Idaho. Referring back to the Pike's Peak watershed: it is known to have extensive deposits of cryolite, a fluoride mineral.

The confirmation of the fluorine hypothesis brought the field investigations, as previously conducted, to a close. It ushered in a new era, in the work of Dr. H. Trendley Dean and his associates, in the most significant phase of this research—relating a reduced caries experience with dental fluorosis, which brings this subject to its present focal point. The by-product has thus achieved the major importance.

Not only to our own profession has this subject brought a new concept;

it has also extended into other phases of human activity and welfare. The quantitative determination of such minute amounts of fluorine as 1 part per million of water brought a new problem to the chemist. Similarly the water-works engineer has been confronted with the problem of safeguarding municipal water-supplies when new sources are needed, for which it has become routine practice to make fluorine determinations. The entomologist is now required, by government restrictions, to limit the amount of fluoride in insecticide sprays on fruits going into the open market. In animal husbandry the stock raiser considers the possible damage to bones and teeth of animals by the feeding of rock phosphates, all of which have a high fluorine content. The pathologist is similarly charged with the responsibility of safeguarding the health of industrial workers who may be exposed to the fumes of fluorine in certain industries.

A sharp line often has been drawn between the theoretical and the practical, even though it is true that everything that is practical was at one time only theoretical. In the present instance the one-time abstract question as to the cause of mottled enamel has acquired an intensely practical value in human welfare. The field studies of Dean and his associates have shown clearly that so low a fluorine content as 1 part per million in domestic water-supplies is sufficient to decrease substantially the incidence of caries. It is a fortunate circumstance that so low a fluorine content is associated with only the very mildest expression of dental fluorosis: so mild as to be difficult in most cases to detect, which means that the protective action against caries is available without the sacrifice of esthetics.

When a vision appears it remains only that until some far-seeing individual, recognizing the reality, translates it into accomplishment. It is a noteworthy achievement to marshall the facts and evidence, and convincingly present them to the responsible officials of a community, as was done in Newburgh, N. Y. There might have been much objection to adding fluoride to a communal water-supply pending demonstration that it can be done without causing toxic effects. The removal of fluorine from water for the prevention of one defect, and its addition for the prevention of another totally different lesion, is one of the most curious reversals in the whole history of science, and is certainly without precedent in dental history. It is wholly a question of amount whether the influence of fluorine is good or bad.

After fluorine has been added to a communal water-supply, as at Newburgh, the acceptance of the project is compulsory. Hence in the most perfect sense it is a mass participation, devoid of the necessity of individual effort, which is always a slender reed upon which to lean. At present such a project would seem to be the only possible or practical method for mass application of an anti-caries therapy. In the search for some method of mass control of caries, could it ever have been conceived to be as simple, economical, or as universally applicable as the treatment of communal water-supplies? And addition of fluorine to individual water-supplies, in regions remote from a city system, is just as applicable.

There is no intention to regard fluorine therapy as a complete answer to the problem of caries, but when that answer has been found, it need not necessarily be in conflict with the findings for fluorine. Based on the convincing evidence already available, there is ample reason to believe that the project at Newburgh will justify itself; and if so, the same method could be applied anywhere: there would be no limit. In that event, Dr. David B. Ast, its principal sponsor, will have achieved a distinction for humanitarian service that will have few parallels in dental history.

As direct evidence on the actual conditions in my own endemic community, I can state that there rampant dental decay is almost unknown, and that a surprisingly large proportion of individuals have passed through the teen-ages and even into middle life with no decay whatever. The prevailing experience is to find decay only in occlusal fissures and in pits. The ultimate effect on the practice of dentistry of a mass reduction of the caries experience by 50 percent, which is a reasonable expectation, can be foreseen. This would effect an enormous release of working hours of dentists, which could be made available for such greatly needed health-service as the prevention and treatment of periodontal destruction. Newburgh has become another "biological experiment station," in which the rationale is applied directly to humans without previous laboratory experiments on animals.

In conclusion the present writer submits that the achievements of these researches have had a profound effect in helping to raise dentistry from the "general level of skilled technology to that of the exact sciences."

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On the Epidemiology of Fluorine and Dental Caries[1]

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I. Introduction

While occasional references to a possible relationship of fluorine to dental caries may be found in the 19th century literature, the epidemiology of the fluorine-dental-caries relationship finds its tenuous beginning in the first mottled-enamel study (1, 2) in 1916. During the 1920 decade the mottled-enamel-dental-caries relationship was investigated by McKay (3, 4) and by Bunting and his associates (5)—studies conducted during a period when the all-important factor, fluorine, was still unknown. In 1931, with the discovery of the cause of mottled enamel, these earlier studies took on an added significance.

As in the study of many other natural phenomena, the necessary technical methods for accurate and fruitful measurement in this relation were slow in developing. The clarity of the epidemiological pattern, as now known, is closely dependent upon the utilization of several technics conjointly applied—methods which proved invaluable in tracing out this particular natural phenomenon (fluorine and dental caries) from amidst the welter of many other phenomena associated with population groups in general and the dental-caries process in particular. The four methods which were most useful in finally identifying and sifting out this natural phenomenon were:

1. Refinements in measuring dental-caries experience involving prevalence-rates specific for age, sex, and color (6, 7).

2. Elimination of the "circulation factor," or limiting all observations to individuals continuously exposed to the specific environmental factor under investigation—the common water-supply (8).

3. Development of analytical chemical methods permitting water analyses accurate to 0.1 part per million of fluorine (F)— (9).

4. Development of quantitative methods for estimating the number of *Lactobacillus acidophilus* in saliva, used as an index of dental-caries activity (10).

The conjoint application of these technics permitted study of the association of the two variables, fluorine and dental caries, by quantitative epidemiological methods, with results that are now well known.

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Many of the basic data of the fluorine-dental-caries relationship were recently summarized in a series of papers read at the 1944 meeting of the Subsection on Dentistry of the American Association for the Advancement of Science. As these papers will appear shortly in a monograph, readers interested in a detailed exposition of many of the epidemiological aspects of this question are referred to this source of information. For a readily available review of much of the epidemiological data, reference might be made to an article by the present writer in the issue of the *Journal of the American Water Works Association* for September 1943 (11). The student who desires critically to analyze and evaluate the basic data, and to acquire a clear concept of many of the underlying variables, should examine a number of original articles (references 12 to 29, inclusive, pages 29-30).

The historical review of fluorine and mottled enamel having been presented by Dr. McKay (pages 10-18), this discussion will be limited to the more recent studies. Prior to six or seven years ago, dental research on fluorine centered largely on one or another of the various phases of endemic dental fluorosis. The effects of using domestic waters containing excessive amounts of fluorides were thoroughly studied. With a precision almost mathematical it was determined that, with each increase in proportion of the antecedent cause (fluorine), there was concurrent increase in the consequent effect (dental fluorosis)—(8). Domestic waters containing less fluoride than 1.0 part per million of fluorine (F), being below the mottled-enamel threshold, were considered of no dental public-health importance; and, with the control of mottled enamel uppermost in mind, little attention was paid to them.

During the "1937-1939 period" this concept changed rather dramatically. Inadequate amounts of fluoride in a domestic water-supply assumed an importance far overshadowing the earlier studies of effects of excessive quantities. Any domestic water, in so far as its fluoride content influences dental health, may now be thought of as falling into one of three classes:

1. Those carrying naturally the *optimal* concentration of fluoride (F), i.e., about 1.0 part per million, no treatment of the water being required.

2. Those carrying an *excessive* concentration of fluoride, requiring removal of the excess in order to protect the population against endemic dental fluorosis (mottled enamel).

3. Those *deficient* in fluorine, to which fluoride might be added to bring the concentration up to the optimal in order to lessen the amount of dental decay in the community.

Or, as stated pithily in a recent editorial in the *American Journal of Public Health* (30):

> . . . "It seems clear that we have, in this case, an intriguing example of the desirability of maintaining in the human body an optimal concentration of a particular chemical element—a value below this optimum tending to favor one diseased condition and a value above this optimum to cause another disease of a different type" . . .

II. Some Epidemiological Considerations

While the main portion of this paper will be limited to a discussion of the study of twenty-one cities in four states, some reference will be made to certain earlier studies from which was gleaned the unfolding pattern of this natural phenomenon. In subjecting a disease or condition to a searching epidemiological inquiry, it is often desirable—at times essential—to proceed from a study of broad distributional characteristics of the phenomenon in Nature to selected local investigations where some particular circumstance, condition, or set of conditions, can be examined. The epidemiological studies at the National Institute of Health followed in general this pattern, the successive steps in chronological order being: (a) The broad epidemiological differences, (b) the Galesburg-Quincy (Ill.) study, and (c) the study of twenty-one cities in four states.

The South Dakota studies in 1938 (12) showed sharp differences in dental-caries prevalence, dependent upon whether or not the populations were affected with dental fluorosis. After the broad association between mottled enamel (objective evidence of fluorine intake) and low dental-caries prevalence was obvious, succeeding studies were designed to check this relationship with a number of other associations and relationships which would either confirm or modify the inferences drawn from the observed broad association. Before passing from the 1938 article, attention should be given to another observation contained in that report: a finding which became increasingly important as successive studies developed. Among the data included in that article was a report on 236 nine-year-old children with a *verified continuity of exposure* to the fluorine domestic-waters of the cities in which they lived. It was noted that there was relative freedom from dental caries (a) in deciduous teeth as well as permanent teeth of these children, (b) *whether or not their teeth showed macroscopic evidence of mottled enamel.* Were the tendency to escape dental-caries attack dependent upon the existence of mottled enamel, the practical worth of fluorine in dental-caries control would obviously be of little real utility.

The next step was a detailed local study: Galesburg and Quincy (Ill.). The startling disclosures of this study (13) are now so well known that a detailed description would be repetitious. Briefly, the children of Galesburg—using a domestic water containing 1.8 parts per million of fluorine (F)—experienced less than a third of the amount of dental caries observed in a comparable age-group of Quincy children using practically fluorine-free water from the Mississippi River. At Galesburg an unusual opportunity was presented to test the previous observation that "the limited-immunity-producing-factor," presumably fluoride in the water supply, was operative whether or not the individual had mottled enamel. The Galesburg water-supply contains fluorides (1.8 ppm. of F)—enough to produce the milder forms of endemic dental fluorosis in about 50 percent of those continuously using the public water-supply during the period of tooth

development, the other 50 percent showing no macroscopic evidence of dental fluorosis. Of 243 Galesburg children with continuous-residence histories, 114 (47%) had some form of dental fluorosis, mainly of the very mild type. The remainder, 129, were classified as not having dental fluorosis. Among the 114 with dental fluorosis, the dental-caries experience-rate was 200 per 100 children; among the 129 children with no dental fluorosis, a rate of 186 per 100 children was recorded. Then, as now, this observation remains one of primary epidemiological importance.

From these studies began to evolve a new concept in environmental regulation: the possibility of partially controlling dental caries through the communal water-supply. Before serious thought could be given to such procedures, however, it seemed that the next logical step was to learn whether or not a fluoride concentration sufficiently low to eliminate the problem of dental fluorosis was still sufficiently high to inhibit the initiation of dental caries to a degree sufficient to warrant serious public-health consideration.

III. Study of Twenty-One Cities in Four States

The next step was a study that included twenty-one cities in four states: eight in the suburban-Chicago area [Elmhurst, Maywood, Aurora, Joliet, Elgin, Evanston, Oak Park, and Waukegan (Ill.)]; Kewanee (Ill.); Zanesville, Portsmouth, Middletown, Marion, and Lima (Ohio); Elkhart and Michigan City (Ind.); Colorado Springs and Pueblo (Colo.); Galesburg, Quincy, and East Moline (Ill.). (See *Fig. 1.*) These cities presented wide differences in types of domestic water-supplies, varying in content not only of fluoride but also of other mineral constituents. Included among these twenty-one cities were communities obtaining their respective water supplies from Lake Michigan; from the Mississippi, Ohio, or Arkansas River; from deep wells of different fluoride concentration and mineral composition; and, in one instance, from water from snow melted high on Pike's Peak (Colorado Springs, Colo.). All dental examinations were made by one or the other of two dental officers using a mouth mirror and explorer. In each city an equal number of children were examined by each dentist.

In these studies (16, 19) a total of 7257 white, urban, school children, age 12-14 years, were examined. All children had been *continuously exposed throughout life to the variable under investigation* (common water-supply). Study of the intensity of dental-caries attack, as shown by the dental-caries experience of the population, disclosed striking differences. Children using domestic waters containing as little as 1.0 part per million of fluorine experienced only about a third as much dental caries as comparable groups using water that contained no fluorine. Briefly, 647 children continuously using domestic water containing more than 1.4 ppm. of F averaged 2.4 decayed, missing, or filled teeth[2] per child; 1403 children in cities having water supplies containing between 1.0 and 1.4 ppm. of F

[2] All teeth referred to in this study are permanent teeth.

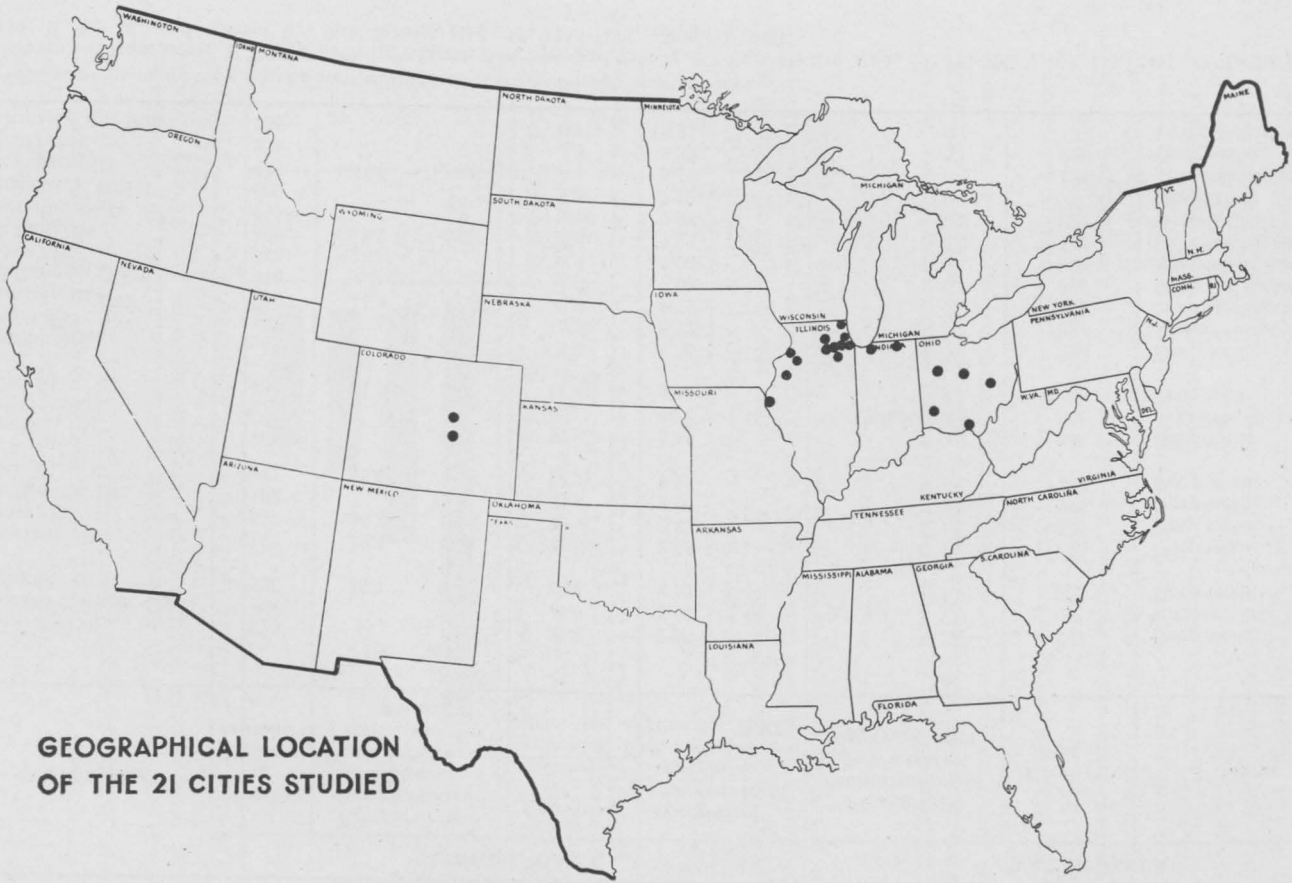


FIG. 1. Geographical location of the 21 cities studied.

TABLE 1

Summary of dental-caries findings in 7257 selected, white, school children, age 12 to 14 years, in 21 cities of 4 states in relation to the fluoride (F) content of the public water-supply

City and State	CLINICAL DATA					WATER DATA			
	Number of children examined	Percent of children examined,[1] with oral L. acidophilus in saliva; number per cc.		Percent of children examined, caries free	Number of permanent teeth per child, with dental-caries experience (DMF)	Fluoride (F) concentration, of public water-supply, in ppm.	Total hardness, in ppm.	Source
		Neg. and < 100	30,000 and >					
Galesburg, Ill.	273	.....	.....	27.8	2.36		1.9	247	Deep wells
Colorado Springs, Colo.	404	.....	.....	28.5	2.46 } 2.44	> 1.4	2.6	27	Surface (Pike's Peak)
Elmhurst, Ill.	170	35.7	24.7	25.3	2.52		1.8	323	Deep wells
Maywood, Ill.	171	39.6	20.9	29.8	2.58		1.2	75	Deep wells
Aurora, Ill.	633	38.2	25.6	23.5	2.81		1.2	329	Deep wells
East Moline, Ill.	152	.....	.....	20.4	3.03 } 2.94	1.0-1.4	1.2	276	Deep wells
Joliet, Ill.	447	35.6	26.6	18.3	3.23		1.3	349	Deep wells
Kewanee, Ill.	123	.....	.....	17.9	3.43		0.9	445	Deep wells
Pueblo, Colo.	614	.....	.....	10.6	4.12 } 4.16	0.5-0.9	0.6	302	Arkansas River
Elgin, Ill.	403	21.2	33.2	11.4	4.44		0.5	103	Deep wells
Marion, Ohio	263	.....	.....	5.7	5.56		0.4	209	Deep wells
Lima, Ohio	454	.....	.....	2.2	6.52		0.3	223	Surface, impounded
Evanston, Ill.	256	15.4	41.8	3.9	6.73		0.0	131	Lake Michigan
Middletown, Ohio	370	.....	.....	1.9	7.03		0.2	329	Deep and shallow wells
Quincy, Ill.	330	.....	.....	2.4	7.06		0.1	88	Mississippi River
Oak Park, Ill.	329	18.2	43.8	4.3	7.22 } 7.40	< 0.5	0.0	132	Lake Michigan
Zanesville, Ohio	459	.....	..	2.6	7.33		0.2	291	Deep wells
Portsmouth, Ohio	469	.....	.....	1.3	7.72		0.1	80	Ohio River
Waukegan, Ill.	423	14.9	54.6	3.1	8.10		0.0	134	Lake Michigan
Elkhart, Ind.	278	.....	.....	1.4	8.23		0.1	220	Deep wells
Michigan City, Ind.	236	.....	.....	0.0	10.37		0.1	141	Lake Michigan

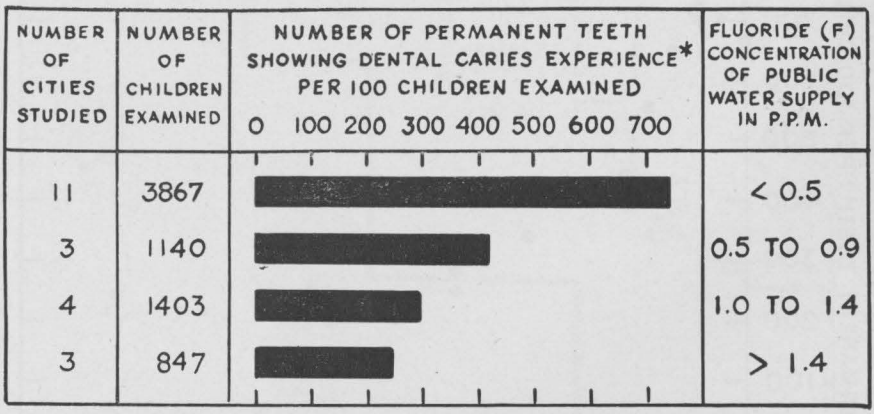
[1] Estimations made only on children of eight suburban-Chicago communities.

[Compiled from Dean, H. T., Jay, Philip, Arnold, F. A., Jr., and Elvove, E.: *Pub. Health Rep., 56:* 761-792, (Apr. 11) 1941; and Dean, H. T., Arnold, F. A., Jr., and Elvove E.: *Pub. Health Rep., 57:* 1155-1179, (Aug. 7) 1942.]

showed 2.9 affected teeth per child. In the 1140 children in cities where public water-supplies contained 0.5 to 0.9 ppm. of F, an average of 4.2 teeth per child showed evidence of past or present caries attack. In the 3867 children in cities having common water-supplies containing less than 0.5 ppm. of F, an average of 7.4 teeth per child showed evidence of caries experience. The most outstanding of these differences was in the upper incisors. In the 3867 children residing in cities having water supplies containing less than 0.5 ppm. of F, 3106 out of 30,528 surfaces showed evidence of caries experience, or a rate of 10.2 per 100 surfaces. In sharp contrast: in the 3390 children who resided in cities wherein the public water-supply contained 0.5 ppm. of F, or more, only 292 out of 26,618 surfaces had any caries experience, or a rate of 1.1 per 100 surfaces. When comparisons are made between children using fluorine-free water and those using water containing 1.0 ppm. or more of F, the contrast is even greater, differences of as much as 20 to 1 or more being observed. (See *Table 1* and *Fig. 2.*)

IV. Discussion

Probably the outstanding finding of these investigations is the wide difference in dental-caries experience (prevalence) associated with the use of fluoride domestic-waters in the 0.0 to 1.0 ppm.-F range. The influence on dental health of domestic waters containing such minute amounts of fluoride was undreamed of a few years ago. (*See Fig. 3*). On the basis of the



* 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. 2. Amount of dental caries (permanent teeth) observed in 7257 selected 12-14-year-old, white, school children in 21 cities of 4 states; classified according to the fluoride concentration of the public water-supply. [Dean, H. T., Arnold, F. A., Jr., and Elvove E.—*Pub. Health Rep., 57:* 1155-1179, (Aug. 7) 1942.]

order of the epidemiological events, and knowledge from laboratory studies, one seems fully justified in inferring that the inhibitory agent is the fluoride present in the water supply. The evidence of concomitant variation is particularly impressive; the fluoride variable cannot in general be changed in quantity (between 0.0 and 1.0 ppm. of F) without affecting the phenomenon (dental-caries prevalence). Fluoride seemingly constitutes an indispensable condition of this particular phenomenon. Other studies in England (28), South Africa (29), and India (21), report similar findings respecting the influence of small amounts of fluorides on the amount of dental caries in the community.

Utilizing the observations made in the suburban-Chicago area, Arnold (23) has estimated the beneficial results that might occur after the requisite lapse of time, were the fluoride-free Lake Michigan water-supplies at Evanston, Oak Park, and Waukegan (Ill.) raised to about 1.0 ppm. of fluorine. A comparison of the dental-caries prevalence in the 633 Aurora

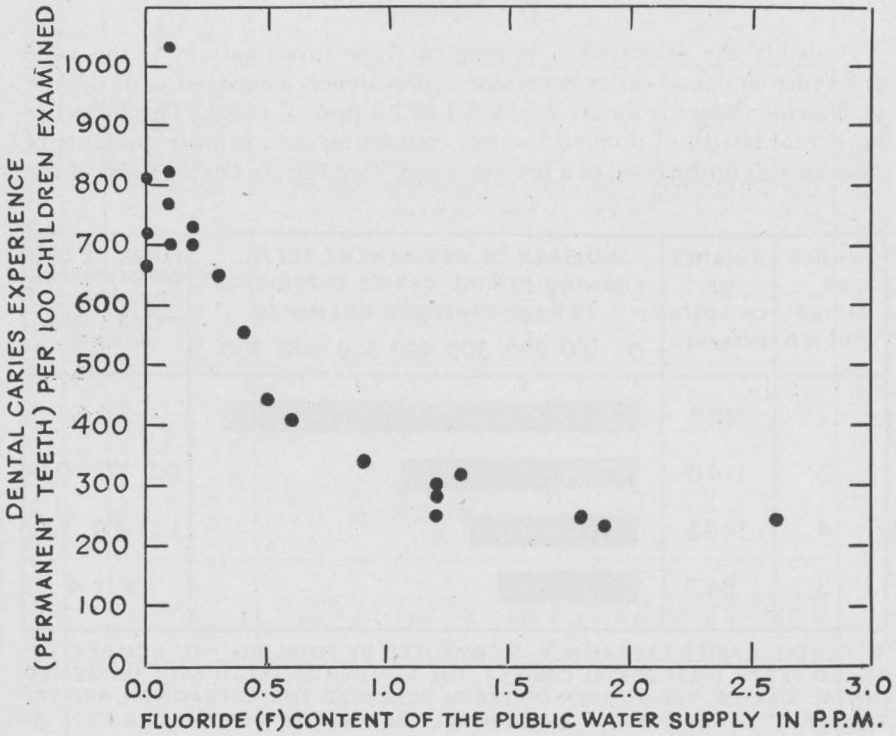


FIG. 3. Relation between the amount of dental caries (permanent teeth) observed in 7257 selected 12-14-year-old, white, school children in 21 cities of 4 states, and the fluoride (F) content of public water-supply. [Dean, H. T., Arnold, F. A., Jr., and Elvove, E.—*Pub. Health Rep., 57:* 1155-1179, (Aug. 7) 1942.]

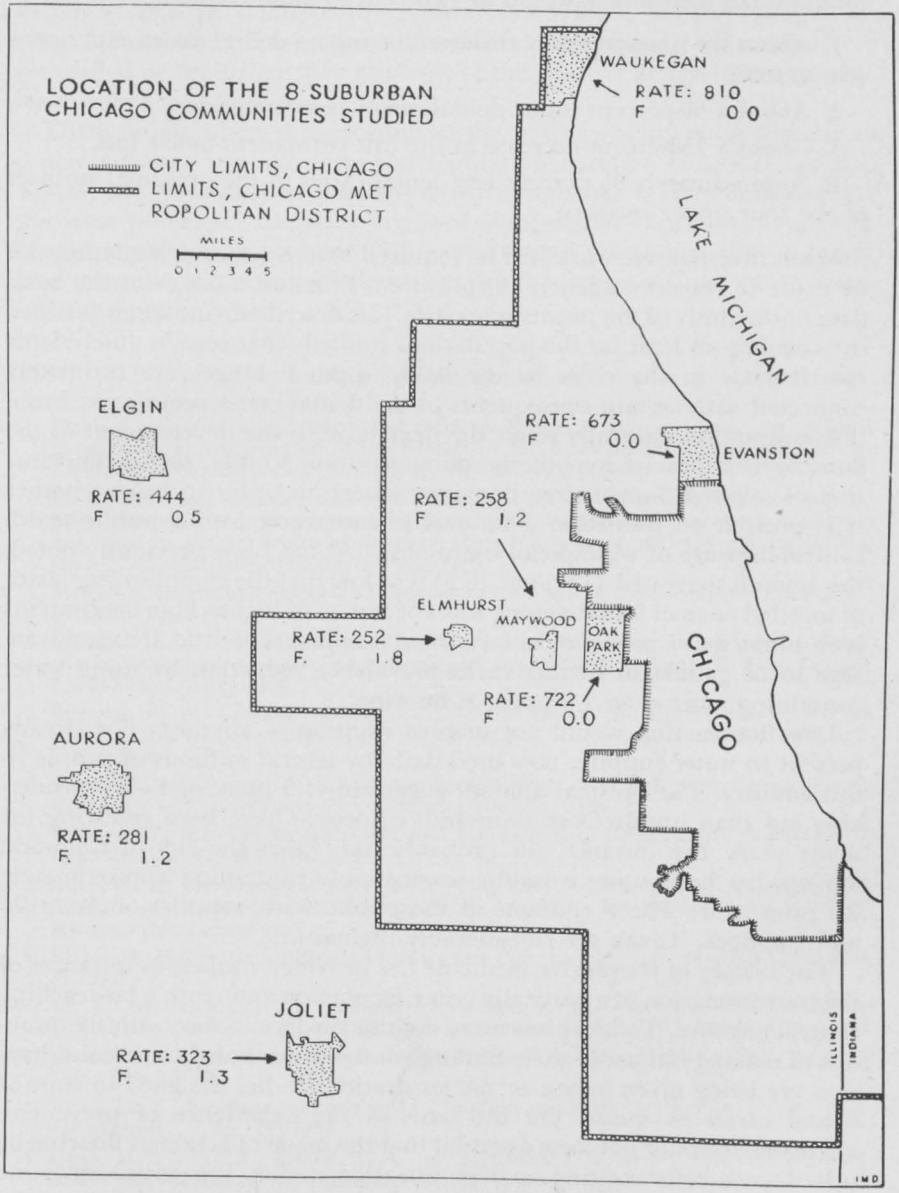


FIG. 4. Location of the 8 suburban-Chicago communities studied. [Dean, H. T.—*J. Am. Water Works Ass'n, 38:* 1161-1186, (Sep.) 1943.]

(Ill.) children, with that of the 1008 children in the three fluorine-free communities mentioned, would be expected to show (*Fig. 4*):

1. About six times as many children having no dental-caries experience (caries free).
2. About a 60-percent lower dental-caries experience-rate.
3. About a 75-percent decrease in the first-permanent-molar loss.
4. Approximately 95 percent less dental caries in the proximal surfaces of the four upper incisors.

Much investigative work will be required before a recommendation can be made in respect to general application. From an analysis of the basic data in the study of the twenty-one cities, just described, one seems justified in assuming—at least for the populations studied—that certain antecedents (particularly in the cities in the 0.0-1.0 ppm.-F range) are intimately connected with certain consequents in the dental-caries prevalence. From this assumption naturally stems the next stage in the development of the fluorine-dental-caries hypothesis: domonstration studies, or low fluorination of selected fluorine-free domestic waters, in order to learn whether it is possible to transform a natural phenomenon into a public-health control-measure of widespread usefulness.[3] As has been previously noted, the amount suggested (1.0 ppm. of F) is so low that the complicating factor of mottled enamel found among users of waters of higher fluorine-contents is eliminated as a problem. In fact, there is apparently little, if any, advantage to be gained in further caries-prevalence reduction by using water containing more than 1.0 ppm. of fluorine.

Low fluorination would not involve addition of anything not already present in water supplies now used daily by several millions of people in this country. The optimal amount suggested—1.0 ppm. of F—is considerably less than hundreds of thousands of people have been receiving for many years. For instance, for probably sixty years the city of Colorado Springs has been using a public water-supply containing approximately 2.5 ppm. of F. The F contents in the public water-supplies of Amarillo and Lubbock, Texas, are considerably higher (31).

The history of preventive medicine has provided numerous instances of the transformation of a naturally occuring phenomenon into a far-reaching control-measure. Today, preventive dentistry is face to face with the problem of making full use of these findings, and serious thought and consideration are being given to test or demonstration studies designed to control dental caries *en masse*. On the basis of the experience of preventive medicine, it would not seem essential that the mode of action of fluorine be fully known before setting up demonstration studies. Preventive medicine controlled smallpox, scurvy, and malaria for generations before the

[3] Demonstration studies, designed to test the effectiveness of low fluorination in respect to partial control of dental caries, are at present under way at Grand Rapids, Michigan, Newburgh, New York, and Brantford, Ontario. [Grand Rapids began low fluorination of its fluorine-free Lake Michigan public water-supply in January, 1945.]

laboratory provided the "scientific explanation" of the respective phenomena. The conversion of Jenner's observation of the protective influence of vaccinia virus in smallpox-prevention rested for a century wholly on empirical grounds. For generations scurvy and malaria were effectively controlled before either their etiology, or the mode of action of the prophylactic agent, was known.

These unprecedented disclosures of the past few years point directly to a new advance in environmental regulation through chemical control. Today, the possibility of partially controlling what is frequently termed the most prevalent disease of civilized man, dental caries—at a cost of a few cents per person per year (32)—constitutes a pressing challenge to the best scientific leadership in dentistry, sanitary engineering, water chemistry, and public health.

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Fluorine Content of Enamel in Relation to Resistance of Teeth to Decay

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CONSIDERATION has long been given to the hypothesis that differences in composition of teeth account in part for the susceptibility of some teeth to decay, and for the resistance of others to this disease. However, demonstration of the validity of this hypothesis had to await, as does so much of scientific progress, the development of refined methods of investigation. The accident of the fact that I had some part in the development of methods for the separation of enamel and dentin (1), and for the determination of small quantities of fluorine in biological materials (2), accounts in a very large measure for my contributions to the subject of this symposium.

For studies of the said hypothesis, it seemed obvious that the enamel and dentin should be separately examined, since otherwise variations in the proportions of these anatomical divisions of teeth might obscure significant differences of composition occurring only in the enamel or only in the dentin. The problem of quantitative separation of the enamel and dentin of a single tooth was solved by suspending the finely powdered whole-tooth in a liquid of density intermediate between those of enamel and dentin—and having no effect on the composition of either—whereupon the heavier particles of enamel sink and the lighter particles of dentin float. The investigator of the composition of carious teeth is faced with a dilemma at the outset. If the carious debris were left undisturbed, the analytical variations would be largely those resulting from the carious process and not those which might have contributed to the development of the lesion. If, on the other hand, the decayed material were removed before separating the enamel and dentin, there would remain only sound enamel and dentin. Since a choice of procedure had to be made, I selected the lesser horn of the dilemma and removed the decayed material from the carious specimens before separating the enamel and dentin. It is obvious that, under these conditions, it is possible to discover differences in composition of carious teeth—which might be correlated with their susceptibility to decay—only if these differences extend outside of the limits of the lesion.

Our study of the composition of sound and carious teeth began with an investigation of the major components of enamel and dentin. By 1937 the results summarized in *Table 1* had been obtained (3). No discussion is required to show that the results for the sound group are not significantly different from those obtained for the carious specimens, but they indicated one positive fact; namely, that no change in the calcium, phosphorus,

magnesium and carbonate contents of enamel occurred outside of the carious lesions. Thus, the presence of the carious lesion does not affect the composition of the sound enamel of the remainder of the tooth. This fact will be employed in the argument below.

Having failed to discover any significant variations of composition with respect to the major constituents, our attention was then directed to those elements which occur in small amounts in teeth. Since we had available a micro-method for fluorine analysis, in which some confidence could be reposed, an investigation of the fluorine content of enamel and dentin in relation to the susceptibility of teeth to decay was undertaken. The results of the first few analyses encouraged continuation of the work until 50 specimens each of enamel of sound and of carious teeth were analyzed (4). The data are shown in *Table 2*. On an average, the fluorine content of the enamel of the carious teeth is only 62 percent of that of the sound teeth. Statistical analysis of these mean results, in the light of their standard deviation, showed that there is much less than 1 chance in 5,000,000 that the higher amount of fluorine in the enamel of the sound teeth in comparison with that of carious teeth is accidental. If time permitted inspection of the data of individual analyses (4), it would be demonstated that, in the same persons in general, the enamel of carious teeth contained less fluorine

TABLE 1

Composition of enamel of sound and carious teeth

Constituents	ENAMEL OF SOUND TEETH			ENAMEL OF CARIOUS TEETH		
	Mean %	*Standard deviation* %	*Number of analyses*	*Mean* %	*Standard deviation* %	*Number of analyses*
Calcium	35.35	0.977	43	35.63	0.638	15
Phosphorus	17.43	0.360	43	17.21	0.145	15
Magnesium	0.30	0.041	34	0.32	0.026	15
Carbonate (CO_2)	3.00	0.187	41	3.01	0.129	14

TABLE 2

Fluorine content of enamel and dentin of sound and carious teeth

Tissue	*Mean fluorine content* %	*Standard deviation* %	*Number of analyses*
Enamel of *sound* teeth	0.0111	0.0020	50
Enamel of carious teeth	0.0069	0.0011	50
Dentin of *sound* teeth	0.0169	.....	*
Dentin of carious teeth	0.0158	.....	*

* The samples of dentin were prepared by pooling 50-mg. quantities of dentin from each of 26 teeth.

than the enamel of sound teeth; also that the enamel of teeth of persons suffering from rampant caries contained *much* less fluorine than the average amount in the enamel of sound teeth.

None of the teeth included in this study was obviously mottled and it is doubted, from a consideration of the fluorine content of the individual specimens, that many were so affected even to a moderate degree. The sound teeth examined in this study possessed a considerable degree of caries-immunity, since the average age of the persons from whom they were obtained was 40 years. Some degree of confirmation of these results has been obtained by Ockerse (5), who found the fluorine content of both enamel and dentin of people living in a low-caries area in South Africa to be greater than of people living in a high-caries area. The difference between the two areas, in incidence of caries, may be attributed to the larger amount of fluorine in the communal water-supply of the area of low-caries incidence.

When I first reported on this subject, high amounts of fluorine in drinking water had only recently been indicated as the cause of mottled enamel, and the general concept that fluorine has a deleterious effect upon teeth was not easy to abandon. At that time the hypothesis as to the beneficial rôle of fluorine in the preservation of the integrity of the teeth was supported only by the observations of McKay (6), who noted that mottled teeth were apparently more resistant to decay than teeth that were not in this condition. Now there is a plethora of support derived from the investigation relating the incidence of caries to the fluorine content of the communal water-supplies and from the results of animal experimentation.

It has been emphasized that these results represent the fluorine content of the entire sound enamel from sound and from carious teeth. How then can it be explained, if a low fluorine-content of enamel contributes to susceptibility of a tooth to decay, that the lesion is not diffuse over the entire surface of the crown? It is reasonable to suppose that the agent causative of caries is able, because of the configuration of the tooth, stagnation of food debris, etc., to exert its maximum force at the well-known sites of predilection to caries. The smooth surfaces are able to resist decay, in spite of low fluorine-content, owing to the factors that favor immunity to caries—or because of local lack of vigor of the attacking forces. When resistance to caries is reduced over the entire surface of a tooth, because of a low fluorine-content, caries naturally develops first in those areas at which there is local increase in the vigor of the caries-producing factors or because of local decrease in factors that favor resistance to decay. One of the most attractive features of the fluorine-caries relationship, whatever the mechanism of the process may be, is the fact that their association does not controvert the generally accepted ideas as to the causation of caries or disagree with the evidence indicating that factors other than fluorine are concerned.

It might be assumed that the low fluorine-content of the enamel of carious teeth is secondary to the carious process. It will be recalled that

the data in *Table 1* showed that there is no change in the calcium, phosphorus, magnesium and carbonate contents of enamel outside of the site of decay. It would be unreasonable to suppose, in view of these facts, that fluorine is unique in this respect. While there is considerable evidence that the apatite molecule of calcified tissues can acquire fluorine, there seems to be none indicating that this element can escape from enamel or dentin under any condition which might exist in the mouth.

A few specimens of obviously mottled teeth have been examined in the present writer's laboratory (6). The fluorine contents shown in *Table 3*, for enamel, are two to three times that for enamel of the average sound non-mottled tooth; and the amount of this element in the dentin is likewise definitely greater than that in dentin of normal teeth. *Patient A* was a girl, aged 16, who exhibited no caries. The specimens from *Patient B*, a woman aged 41, were very markedly mottled, and there was little doubt that they were affected so severely as to be definitely harmed from a structural standpoint. The enamel was pitted, broken, and eroded. Thus only a relatively slight amount of fluorine in enamel produces, or is accompanied by, profound changes in the quality and character of this tissue. Therefore it is not illogical to conclude that the higher fluorine-content in the enamel of sound teeth, compared with that of carious teeth, gives to enamel properties which are associated with an increased resistance to caries. These data are of interest in another respect. Although *Patient B* lived in Minneapolis for 22 years preceding the extraction of her teeth, and there regularly consumed water low in content of fluorine, her teeth maintained an unusually high content of this element. Thus we are able to conclude that fluorine—once deposited in enamel—does not quickly leave this structure, and it is doubtful if its amount is ever decreased. These results also demonstrate that the production of mottled enamel is accompanied by increased deposition of fluorine in affected teeth, and support the evidence that extra fluorine-intake is the cause of the mottled condition.

The Island of Tristan da Cunha has long been known as a classical

TABLE 3

Fluorine content of enamel and dentin of mottled teeth

Mottled teeth	*Enamel: Fluorine (%)*	*Dentin: Fluorine (%)*
Moderately mottled—*Patient A:*		
Upper right second bicuspid	0.0250	0.0375
Upper left second bicuspid	0.0248	0.0415
Severely mottled—*Patient B:*		
Upper right and left second incisor	0.0357	.....
Upper right and left cuspids	0.0333	0.0504*
Upper left first incisor	0.0361	.....
Upper right first incisor	0.0343	.....

* Pooled dentin of teeth of Patient B.

example of localities characterized by low incidence of dental decay. Sognnaes (7) noted the occurrence of mild degrees of mottled enamel in 15.8 percent of the population. Without being aware of this observation, the writer (8) found that the enamel and dentin of teeth of Tristanites contained amounts of fluorine that were higher than those in teeth collected in Minnesota.

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Effects of Topical Application of Fluorides on Dental Caries

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THE EVIDENCE presented by Dr. Dean and Dr. Armstrong indicates that, where there is an increased fluorine-content in the water supply, there is greater resistance to dental decay. It also shows that, where there is an added resistance to dental decay, there is an increased content of fluorine in the teeth, particularly in the enamel. Other evidence from laboratory studies shows that, when fluorine is added to drinking water of animals, reduction in experimental dental-decay results. Thus evidence from three different fields shows that fluorine acts in some way to reduce the prevalence of dental decay.

To take advantage of these observations, as a basis for using fluorine therapeutically to control decay, it is necessary to understand the manner in which fluorine acts to prevent caries. My own interest in the subject of fluorine began at this point. Much high-grade research has been carried out to determine the mechanism by which fluorine acts to prevent decay. Dr. Armstrong, and a group of workers with whom I was associated at the University of Rochester, have been active in this field. The details of this extensive work need not be discussed here. It is probably enough to say that the accumulated evidence has convinced me—and I offer this only as my individual conclusion—that fluorine prevents dental caries principally, but perhaps not entirely, as the result of an increased content of fluorine in the tooth substance. This increased fluorine-content may result either from incorporation of fluorine into the tooth during the period of tooth formation, or by acquisition of fluorine from the external surface of the tooth after eruption.

The evidence that it is possible to increase the fluorine content of erupted teeth is fairly complete. It ranges from evidence collected in the fertilizer industry, and in anthropology through the use of bone phosphates to remove fluorine from drinking water, to studies with a radioactive isotope of fluorine. All this work seemed to show that fluorine reacts rapidly with enamel, bone, or basic calcium phosphates, and that this interaction results in a calcium compound having a somewhat increased fluorine-content and a decreased solubility in organic acids. This suggested that, since the solubility of enamel and dentin in acids could be significantly reduced as the result of a short reaction in a test-tube, it should be possible to produce a reduction of the solubility of the teeth by applying fluorides to their external surfaces. An increased resistance to dental decay should also result. A test of this hypothesis would not only

answer the primary question, but also cast a side-light on the causation of dental decay. If treating teeth in a way to reduce their solubility in acid lowers the activity of dental decay, there would be additional evidence that dental decay results from the solubility of the tooth in some type of acid.

Having concluded that fluoride applications should reduce tooth solubility and dental decay, the logical next step was to test the deduction. This was first done in Brockton, Massachusetts (1), where a group of 100 children were studied for this purpose. One quadrant only of the teeth in each mouth was treated with fluoride solution. The tooth surfaces were painted with 0.1 percent solution of sodium fluoride, three times during the course of a year. The quadrant on the opposite side of the same jaw was used for control purposes. At the end of one year it was found that the teeth which had been painted with fluoride solution had only about half the amount of *new* dental decay which had appeared on the untreated side. Here we had evidence that painting teeth with fluoride solutions, or in a broad sense bringing fluoride-containing solutions in contact with teeth, reduced susceptibility to decay.

Since that time there have been five other tests of a similar sort in various parts of the country. The largest test was the one by *Knutson and Armstrong* (2), in Minnesota, in which one side of the mouth was treated with fluoride solution. In this instance from seven to fifteen treatments were given during a period of eight weeks, and nothing was done for the remainder of the year. At the end of the year, a 40-percent reduction in dental decay was found in the treated sides. A test by *Arnold, Singleton and Dean* (3), in the Coast Guard Academy, failed to produce similar results. In this instance one application was made at the beginning of a test-period of one year. At the end of the year no reduction in dental caries was discerned in the treated mouths. A study by *Cheyne* (4) in Indiana—in which the teeth of one group of children were treated with fluoride solution, and those of another group of the same age were not treated—resulted in a 50-percent reduction of decay in the treated group. We have just completed studies of the effect of incorporating fluorides in the cleaning mixtures used by dental hygienists in ordinary prophylaxes (5, 6). The usual treatment was not modified in any way except by incorporating in the peroxide-pumice mixture sufficient 4-percent sodium fluoride solution to give a 1-percent concentration of fluoride in the final mixture. In these tests we obtained approximately 25-percent and 43-percent reductions in dental decay as the results of two or three cleanings per year. The data of these studies are summarized in *Table 1,* which shows the results of the Brockton test (caries reduction of 46 percent); the Minnesota test (40-percent reduction); the Coast Guard test (no reduction); the Cambridge (5) and Millville (6) studies, with fluoride in prophylactic mixtures (25- and 43-percent reductions); and the Indiana study (50-percent reduction).

Why the treatments were less effective in the Cambridge and Millville studies, and completely ineffective in the Coast Guard test, is an inter-

TABLE 1

Summary and results of tests of topical applications of fluorides

Test	CHILDREN		TREATMENTS		*Caries reduction* %
	No.	*Age: years*	*No. per yr.*	*Fluoride solution* %	
Brockton (Bibby)	90	10-13	3	0.1 NaF	46
Indiana (Cheyne)	46	4-6	2 (in 4 mo's)	0.05 KF	50
Minnesota (Knutson and Armstrong)	289	7-15	7-15 (in 8 wk's)	2.0 NaF	40
Coast Guard (Arnold *et al*)	188	17-22	1	Acidulated 1.0 NaF (approx.)	None
Cambridge (McKelleget and Bibby)	47	6-14	3	1.0 NaF	43
Millville (Labunsky and Bibby)	91	6-14	2	1.0 NaF	25

esting question. It points to the possibility of analyzing the effectiveness of the various treatments, and perhaps ascertaining the manner in which fluorine acts. Probably the most that can be said at this time regarding the Coast Guard study is that perhaps one important reason why caries reduction did not occur was the fact that the subjects were older than in the other groups. This result suggests that perhaps fluoride treatments are effective in newly erupted teeth but not in older teeth. The Millville and Cambridge studies suggest that smaller reductions of decay occur when fluoride is incorporated in the cleaning mixtures used in the ordinary dental prophylactic procedure, and that this is not quite as effective a way for topical application of fluoride as is the method in which fluoride solution is rubbed onto freshly cleaned tooth-surfaces.

What significance do these findings have in terms of the use of fluorine to prevent dental decay? Does the procedure of topical application of fluoride have any potential usefulness as a means of providing mass therapy? For this purpose it will probably be inferior to adding optimal quantities of fluoride to water supplies—a method that will not be time-consuming, and will be effective in the mouths of people whether they do anything about it or not. But it must be borne in mind that methods which depend upon the incorporation of fluoride in water supplies are limited by the fact that at least one-third of the population of the United States does not use communal water-supplies, and therefore would not be benefited by treatment of such water. It seems, then, that it is the responsibility of the dental profession to see that methods to reach this third of the population are developed. It should also be borne in mind that the method of fluorine therapy by means of topical applications is still in the stage of preliminary study, and that it may be developed to a much greater degree

of efficiency. It may be important chiefly as an indication of a type of therapy for which agents other than fluoride may ultimately be used to reduce dental decay. Therefore, while I think it likely that topical application of fluoride may never be as widely useful in caries-control as addition of fluoride to drinking water, the benefits of the method can be given to a population-group which would not otherwise be helped by fluorine-therapy. Another of its advantages is the fact that it places fluorine-therapy in the hands of the dental profession to use, or not, as the need is indicated.

Finally, it should be reemphasized that the work on caries-control by means of topical applications of fluoride is still in the most preliminary stage. Before the most effective method of fluoride treatment can be established, tests must be carried out with different concentrations of fluoride solution, different fluoride mixtures, and different methods of application. The effects on patients of different ages must be examined, as must the influence of different levels of caries susceptibility. Only after such tests have been completed will it be possible to evaluate the worth of this approach to caries-control. Because of the opinion I have just expressed, it is obvious that I must disappoint those who are interested in receiving a specific recommendation in the line of treatment with fluoride. I can make no specific recommendation. I feel that a great variety of solutions, and many concentrations, of fluoride will work. Not enough evidence has yet accumulated to indicate that one method of topical application would be more effective than any other such method. I am convinced that the method has great potential usefulness and deserves much further investigation.

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A Plan to Determine the Practicability, Efficacy, and Safety of Fluorinating a Communal Water-Supply, Deficient in Fluorine, to Control Dental Caries

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THE PREVIOUS speakers have related their experiences, both clinical and in the laboratory. Their results seem to indicate that there is a very definite correlation between the amount of fluorine in drinking water and the degree of occurrence of dental caries. All previous investigations regarding water supplies have been conducted where the fluorine occurs naturally in the water. There are, however, many communities in which the water supplies do not contain fluorine. The subject of my paper indicates an attempt to find a method to control the most prevalent of all diseases—dental caries—by fluorinating a communal water-supply that is deficient in content of fluorine. This conception was the starting point for the study, in this field, now in progress under the auspices of the Department of Health of the State of New York.

There is no group of persons in this country which is more cognizant of the dental-caries problem than the dental profession. Yet the dental profession, to whom is entrusted the duty to endeavor to solve this problem, is almost helpless before the onrush of accumulating increments of dental decay. The best means thus far evolved by the dental profession, to prevent tooth mortality, is for the dentist to give the patient regular periodic attention. From studies by Klein and Palmer (1) we learn that there is a wide disparity between yearly increments of dental defects and the number of corrections completed. We are therefore faced with the following factual circumstances which account for the seemingly insurmountable dental-caries problem:

1. Dental caries is practically universal, starting early in life and affecting all age-groups, regardless of race, sex or economic status.

2. Dental caries is a progressive disease and, unless corrected through surgical intervention, ultimately causes the loss of affected teeth.

3. Diseased teeth and their investing tissues may become foci of infection.

4. Because of the widespread prevalence of this disease and the inadequacy of present-day methods to control it, dental caries is a public-health

problem and should be treated as such. This calls for its study along broad epidemiological lines, and its control by the application of means which can reach large masses of the population.

The dental-caries-fluorine hypothesis, which has been so ably presented by the preceding speakers, states that there is an inverse ratio of dental caries to fluorides ingested in drinking water *during the years of tooth development.* This hypothesis takes into account the fact that, beyond certain limits, fluorides are toxic and that the first evidence of toxicity manifests itself in the form of mottled enamel. The epidemiological studies of Dean and his co-workers (2) appear to be so correct mathematically that the effectiveness of trace-quantities of fluorine in drinking water, to protect the teeth against dental caries, is fairly well established. The optimum concentration of fluorine in potable water, which apparently will afford this protection without the known deleterious effects of dental fluorosis, is about 1.0 part per million. The concentration of 1.0 ppm. of fluorine in potable water has been specified as the maximum permissible concentration, according to the standards for drinking water established by the United States Public Health Service (3).

Following careful study, and consultations with a Technical Advisory Committee on the Fluorination of Water Supplies appointed by Doctor Edward S. Godfrey, Jr., State Commissioner of Health, the New York State Department of Health has approved—and has begun[1]—the basic examinations specified in the following outline of the dental-caries-fluorine investigation:

Objective: To conduct a research program to determine the efficacy, practicability, and safety of reducing the prevalence of dental caries by treating with sodium fluoride the potable water-supply of one community; and also studying analogous conditions, as a control, in a similar community having fluorine-free water.

Need. Present methods of treating and controlling dental caries are inadequate. Practically the entire population is suffering from this disease. Up to the present time, no satisfactory method has been advanced to prevent the occurrence of dental caries. If the suggested demonstration proves successful, a safe and useful method will be available to reduce the prevalence of this almost universal disease on a mass basis at a very low per-capita cost.

Estimated duration of study. The study will continue for 10 to 12 years. To date available data indicate that the benefits derived from ingested fluorine-water accrue during the years of tooth development; that is, through age 8 (excluding third molar). After the teeth have calcified, fluorine ingested in potable water is apparently not effective.

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[1] The comprehensive examinations that are outlined in succeeding paragraphs, and which provided a basis for the systematic fluorination tests, were begun in June, 1944.

Outline of method. The cities of Newburgh and Kingston, each with a population of approximately 30,000—with comparable water-supplies, population groups, climatic conditions, economic status, and common sources of food supply—have agreed to serve as demonstration and control areas respectively. The groundwork for this approach was established through consultations with members of the local medical and dental professions, the local and district health-officers, and school and water-works officials. When cooperation from these sources was assured, the plan was laid before each City Council. In line with the progressive attitudes of both cities, the authorities saw the potential benefits which might accrue to their people and to the public in general, and wholeheartedly approved the plans. Newburgh, as the study area, will have its potable water-supply treated with sodium fluoride to bring the fluorine content continuously within the limits of 0.9 to 1.0 ppm. (4). Kingston, where the water supply is fluorine-free, will continue to use fluorine-free water and will serve as a control in this research. To the Newburgh water-supply sodium fluoride will be added, in measured amounts, with dry-feed equipment. This equipment feeds white, 95 percent, dense sodium fluoride in quantities as small as one-half pound per hour at its minimum capacity—at its maximum capacity, 8.9 pounds per hour—with an average deviation of 0.7 to 1.0 percent. The Newburgh water-supply normally contains fluorine varying in concentration from 0.05 to 0.15 ppm., according to seasonal changes. It will therefore be necessary to add approximately 0.8 to 0.9 ppm. of F. To add 0.9 ppm. of F would require use of 2.08 ppm. of 95 percent commercial sodium fluoride, or about 17 pounds of the fluoride per million gallons of the water thus treated. Newburgh requires 3 million gallons of water per day for all purposes, which will necessitate daily use of about 51 pounds of sodium fluoride. This will be added to the filtered water because alum-coagulation may lead to partial removal of the fluoride.

Fluorine is a potentially toxic substance. However, there is ample evidence of satisfactory use of potential poisons—in therapeutic doses—to provide life-saving and health-improving measures. No better example of such a public-health procedure could be cited than the use of chlorine, which like fluorine is a halogen and a potentially toxic element; yet chlorine is almost universally added to public water-supplies to make them safe. Another example is iodine, also a halogen and potentially poisonous; yet iodine has been used for many years, in potable water—and in food, such as common table-salt—as a prophylactic to prevent goiter.

While it is conceded that the quantity of water consumed, especially in children, varies according to muscular activity and atmospheric conditions, McClure (5)—using Adolph's method (6) of determining the daily water-requirement as 1 cc. per calorie of energy in the daily diet—has estimated that, when the drinking water contains 1 ppm. of F and the solid (dry) substance of the food contains 0.1 to 1.0 ppm. of F, the total fluorine intake for children from the age of 1 to 12 years would be of about the following order:

Age	1-3	yrs.	0.417-0.825 mg.
"	4-6	"	0.556-1.105 "
"	7-9	"	0.695-1.380 "
"	10-12	"	0.866-1.725 "

To summarize these figures: under the conditions indicated, the total daily fluorine-intake for children 1-12 years old ranges from 0.4 to 1.7 mg.

The lethal dose of sodium fluoride is about 4 grams (7). On the assumption that an adult daily consumes about 1600 to 2000 ml. of water, made up of potable water and water added to food in the cooking process (which may be considered high in this part of the country), it would be necessary—in order to attain a lethal concentration—to add about 25 tons of sodium fluoride daily to the Newburgh water-supply. The sub-lethal dose is about 230 mgs. which, under like conditions, would require daily addition of 2847 pounds of sodium fluoride in this water supply—in marked contrast with the 51 pounds per day needed for *optimum* concentration, and also with the *maximum* capacity of the feeding equipment, which is only about 9 pounds per hour.

Determination of the fluorine content will be made, from tap-water samples, according to procedures developed and published by a Committee of the American Water Works Association (8). Samples will be analyzed weekly at the filtration plant, and will be checked from time to time by the Division of Laboratories and Research of the State Department of Health in Albany.

Dental examinations. All 5- to 12-year-old children in the schools of Newburgh and Kingston will be examined annually for dental-caries experience. These examinations will be made by a member of the staff of the Dental Bureau of the State Department of Health. Approximately 3200 children in each city will be examined with the use of a mouth mirror and sharp explorer. The same examiner will be used, if possible, throughout the study to minimize errors in interpretation. Children showing defects will be referred to their private dentists for needed corrections. Included in the dental study will be annual bacteriologic examinations of the salivas of about 500 children for *L. acidophilus* counts.

Pediatric examinations will ascertain the effects, if any, of fluorine on growth and development, and determine conclusively the safety of daily ingestion of 1 ppm. of F in water. In Newburgh, physical examinations will be made at regular intervals on a group of 500 children equally distributed as to sex, and from birth to 12 years of age. Up to 2 years the physical examinations will be repeated every three months; thereafter they will not be oftener than every six months, unless indicated. In Kingston, the control area, a similar group of children will be examined at the outset of the research. These children will be reexamined only if findings in Newburgh should indicate the need.

The initial physical examination will be accompanied by a complete history, with past history and system-review in detail. Special attention will

be given to the questions of physical and mental development and emotional stability. All subsequent examinations will be accompanied by an interval note, with emphasis on alertness, fatigability and irritability. X-ray studies of the bones and centers of ossification, and laboratory tests including blood and urine analyses, will supplement the physical examinations.

Adult examinations will determine the effects, if any, of fluorine in small concentrations on older age-groups (past 50 years). Physical examinations will be made at regular intervals on a group of 150 adults over 50 years of age, equally distributed as to sex in both study and control areas. This group will be examined annually unless more frequent review seems desirable. As in the examinations of children, skeletal x-rays and laboratory tests will supplement the physical examinations.

Cost. The cost of this research will be approximately $25,000 a year for ten years. However, if this plan proves to be practicable, then any city having a satisfactory water-treatment plant will be able to fluorinate its water supply at the very nominal cost of (a) the chemical feeding-equipment, which for a city the size of Newburgh is about $350 (a non-recurring item), and of (b) the sodium fluoride which, at the present market price, is $7.75 per hundred pounds. For a city like Newburgh, using 3 million gallons of water daily for all purposes, the cost of the sodium fluoride would be approximately $1500 per year, or a per-capita cost of only five cents. No additional personnel will be necessary.

Conclusions

While there is much statistically significant evidence that low concentrations of fluorides occurring naturally in potable waters diminish appreciably the prevalence of dental caries in persons who ingest such water during the years of tooth development, it is necessary to determine conclusively the effects of several important related conditions before the principle of fluorinating water supplies, deficient in fluorine, can be generally advocated.

1. Will artifically fluorinated water produce in humans the results, in kind and degree, that are caused by waters in which fluorine is found naturally? There is every reason to believe that it will, but this remains to be demonstrated.

2. Are there any cumulative effects—beneficial or otherwise, on tissues and organs other than the teeth—of long continued ingestion of such small concentrations as 1.0 part per million of fluorine in water? Again, there is much presumptive evidence that there are no such effects; but, until that is demonstrated, the procedure outlined in this paper must be regarded as an investigation.

3. Safe and practical methods of fluorinating potable water-supplies must be developed and demonstrated.

When these three factors will have been well established, as physiological conditions, then indeed will we have taken a long step in the control of dental caries.

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Questions and Answers

Chairman Merritt: I am sure we have all been inspired and encouraged by this spendid symposium. Now we are ready for the questions you may wish to ask, and to which the speakers who have addressed you will respond.

[The questions (*Q*) asked by auditors, and the answers (*A*), are grouped below under the names of the speakers to whom individually the questions were presented.]

Dr. McKay

Q. Does Dr. McKay know what happened to the skeletal systems of the children in the small district in Idaho where the fluorine concentration was 13 to 14 parts per million? Was there any osteopetrosis or spondylosis, or any such skeletal dyscrasia?

A. I do not know whether this unusually high fluorine-content of the water had any effect on the bony structures of these children. So far as I could see, there were no changes in the osseous tissues. I believe there have been no reports from any fluorine district of any injurious effects on any tissue other than dental. *Dr. Ast* has indicated that, in the study now in progress in this State—on the value of the potable water containing the optimal proportion of fluoride for the prevention of caries—very close attention will be given to questions of possible collateral toxicity.

Dr. Dean

Q. I should like to ask either Dr. Dean or Dr. Ast whether, in their studies, any differentiations have been made of the various specially vulnerable tooth-surfaces?

A. Interproximal caries of the four superior anterior teeth shows the widest variation. In comparisons of the number of surfaces affected, in populations using fluoride-free water in contrast to those using water having, say, 1.0 part per million or over, the difference in favor of the latter sometimes ran as high as 15 or 20 to 1. Caries of the anterior teeth was very low in the fluoride areas.

Dr. Armstrong

Q. We hear much about the solubility or insolubility of enamel. Will Dr. Armstrong state what dissolves enamel?

A. Enamel is dissolved by acids. By increasing the fluorine content of a calcium phosphate of the nature of apatite—of which that in enamel is an example—we believe that the solubility of that material is decreased in the fluids that occur in the mouth. The rate at which enamel having a protective fluorine-content dissolves, in an acid of a given concentration, is

much slower than that of enamel of teeth that become carious. Tests were carried out by selecting an acid medium which had a pH of 4 and determining how fast given weights of enamel, including some in which the fluorine content had been increased, dissolved in that medium.

Q. Some fluorine enters metabolism every day from ingested food. Is this fluorine utilized to increase resistance to caries? Will Dr. Armstrong, as a biochemist, state how fluorine in drinking water or food can prevent dental caries?

A. During the symposium you were told that fluorine reduces susceptibility to dental decay, if the fluorine is taken in potable water in sufficient quantity—for a period long enough—to favor production of resistant enamel during the *formation* of a tooth (childhood), but that the same amounts of fluorine are without such effects on enamel after the formation of that tooth has been completed. It has also been stated that the greater resistance to caries thus induced is probably due to the fact that enamel which contains the increased amount of fluorine is less soluble, than other enamel, in the fermentation acids that initiate the process of decay. The fluorine ion, which is incorporated in the mineral salts of the skeletal tissues and is replaceable detrimentally by other ions, occupies a special position in the structure of these salts. They are identical crystallographically in bone, enamel, and dentin. The *mature* tooth is unable to acquire extra fluorine by way of the vascular system; at least the amount thus acquired is infinitesimally small. The mechanism for transporation from the blood through the dentin to the enamel in an erupted tooth is so feeble that only negligible quantities of fluorine can pass into the enamel by that route. Some can get into the dentin, but not in the proportions that enter bones.

The fluorine content of an *erupted* tooth can be increased only by direct contact with relatively strong solutions, and when the surface layers of the enamel can exchange hydroxyl for fluorine in the apatite formations in that tissue. When the proportion of fluorine in applied solutions is not above the physiological limits, such exchange of hydroxyl for fluorine occurs without disorganization of the enamel but with ensuing increase in insolubility in acid solutions.

Dr. Bibby

Q. Does Dr. Bibby have any histologic evidence showing that there has been a definite deposition of fluorine in teeth to which he has made topical applications?

A. The deposition of fluorine in a tooth cannot be determined by histological means. The only evidence I have is indirect; namely, that increase of fluorine-content reduces the solubility of enamel. *Dr. Armstrong* has found that, after immersing extracted teeth in sodium fluoride solu-

tions of approximately the same composition as those used in our topical studies, the fluorine-content of the enamel was increased.

Q. Did Dr. Bibby have any experience with "Flak," which is intended for internal use—fluoride in ethyl alcohol? Does fluoride solution applied topically affect erosion?

A. I have had no experience with internal administration of fluoride. Beneficial effects have been claimed for internal dosage. One such claim is associated with the ingestion of bone-meal, which I discount because the number of subjects tested was inadequate. The available evidence as to the influence of fluoride on erosion is not convincing. A greater number of observations are needed.

Q. Most general practitioners would like to have the answers to these questions: Can topical application be used in the average dental office? How is the solution applied, and what percentage is preferred?

A. The first question is very difficult to answer. I am convinced that the margin of safety is so great that the application can be safely employed in the "average dental office." We have not, I am convinced, gotten anywhere near the ultimate efficiency. I think we can make topical-application mixtures which will be much more effectual than those we are now using. In that sense the method is not ready for use in the "average dental office." How long you are going to wait to test it will have to depend on your own judgment, as in the use of any other reagent. I am sure you are safe in using it—just as safe as using phenol or any other toxic substance, provided that due care is exercised.

As I indicated in my paper, the solution has been applied by three or four different methods. The results have varied. The greatest effect was that reported in the first-year Brockton study, in which the fluoride was applied by a dentist. There the teeth, having been cleaned by hygienists, were isolated with cotton rolls, dried with alcohol and air, and then moistened with sodium fluoride solution in a pledget of cotton-wool and kept moist for seven minutes. Others have used shorter periods of application, with practically the same results. As yet no particular method can be advocated. Intimate contact with a clean tooth-surface is necessary—the tooth surface must be clean to get the greatest effect. The fluoride solution must be brought into "working contact" with the enamel. If you attain these objectives by your own technic, you will probably get good results.

It should be pointed out that the results of these topical applications show a reduction in caries over one- and two-year periods. How long this reduction will continue—whether it is cumulative or will break down—we don't know. The evidence covers only a short period of time and is definitely only preliminary in character. These conditions should not be overlooked. It would be a mistake to get patients into a state of expectancy and then disappoint them. That would be unfavorable for fluorine-therapy as a whole, and would also be disadvantageous for the practitioner.

Q. Will Dr. Bibby state whether saliva is a normal carrier of fluorine?

A. The evidence relating to saliva is fairly complete and quite negative. Analyses of salivas, from areas where there are relatively high contents of fluorine in the drinking waters and concomitant reductions in dental decay, have failed to show any increase in the fluorine contents of these salivas. Experiments on animals, using various substances including radioactive isotopes or tracer elements, have shown that whereas chloride and other substances—after their injection—appear in saliva, injected fluoride is not passed into saliva in proportionate amounts. Very little fluoride seems to "spill over" into saliva. The present state of our knowledge leads me to believe that the rôle of saliva, as a mechanism by which fluorine is effective in reducing dental decay, is quite unimportant.

Q. Will Dr. Bibby indicate whether there would be any deleterious effect—or any useful or beneficial influence—in using sodium fluoride solution in cavity preparation?

A. Experiments on this point have not yielded convincing evidence of any benefit. High concentrations of sodium fluoride—4 percent or thereabouts—do have obtunding effects, and some dentists have been using them for this purpose, with what I believe are questionable results in reducing sensitivity during cavity preparation. Whether such treatment reduces tendency to further decay we cannot say. Theoretically I would expect some effect, but there is no satisfactory evidence to show what happens.

Q. Dr. Bibby's response to this question would be appreciated: If fluoride could be carried into and through enamel electrically, and a suitable apparatus measured the exact quantity transmitted, would it be a better procedure than simple topical application?

A. I take it that your question is essentially this: Could cataphoresis be employed to carry fluorine into enamel more efficiently than by topical application alone? We have an apparatus set up to test this possibility. The apparatus works. We have not yet obtained significant results. The preliminary tests indicate that fluorine is being carried into the tooth in increased quantities, as determined solely in terms of increased resistance. We have not yet devised methods to test the results. These various possibilities are now under active experimentation.

Q. Did Dr. Bibby have any experience with a mouth-wash containing, say, 5 parts per million of sodium fluoride?

A. A group of our students are using a mouth-wash having a much higher concentration of fluoride. They have been using it for a period of nearly a year. We are also conducting parallel control-tests with other dentifrices. As yet we have no evidence that the fluoride in the mouth-

wash exerts beneficial effects. Possibly topical application—I think this point should be stressed—is effective only in newly erupted teeth rather than in older ones, such as teeth in our mature students. In these students the *L. acidophilus* counts and clinical examinations fail to give evidence of beneficial effects from using, over a period of a year, mouth-washes having quantities up to 1 part in 10,000 of sodium fluoride.

Q. One of the pharmaceutical houses is distributing a calcium tablet which they claim contains a small amount of fluorine. Does Dr. Bibby regard such a preparation as possibly useful in the fight against caries?

A. I am quoting *Dr. Dean* in saying that there is no acceptable evidence that that would be an effective method. The English have been using a salt mixture for some time and claim, also without satisfactory evidence, that it is beneficial. I think that, in the present state of our knowledge, we cannot assume that ingestion of trace-quantities of fluoride—particularly in conjunction with large quantities of calcium—would be effective in reducing dental decay. I lean very definitely to the idea that, to be most effective, fluoride must be taken in ample amounts throughout the period of tooth formation, or be brought in suitable concentration into direct contact with the tooth surfaces. The calcium tablets under discussion do not fulfill these requirements.

Dr. Ast

Q. Dr. Ast made the statement that an average of 0.4 to 1.7 mg. of fluorine is ingested daily by children from 1 to 12 years of age. How much of this is ordinarily assimilated? How much is excreted?

A. There are no data on the proportion of ingested fluorine that is stored in children, but there is very good evidence on what happens in young adults. Thus, Machle, Scott and Largent (of the Kettering Laboratories)[1] found that, after the ingestion of approximately 0.5 to 1.5 mg. of fluoride (Ca or Na) per day, the output in the urine, feces and sweat just about balanced the intake. After ingesting larger doses of fluoride, there was some storage. Largent,[2] using himself as a subject, took 6 mgs. of fluoride per day in addition to what he ingested in food and water—which was about 0.5 mg. He found that the absorption of fluoride varied with the solubility of the salt and with the form in which the salt was administered; i.e., whether in the dry state or in solution. With NaF which is highly soluble, and with CaF_2 in solution, the daily output was about 2.5 mgs.; about 4.0 mgs. were retained. With CaF_2 in the dry state, bone-meal, or cryolite, the daily output was about 4.0 to 4.5 mgs.; about 2.0 mgs. were retained.

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