Some Epidemiological Aspects of Chronic Endemic Dental Fluorosis*

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THE endemic hypoplasia of the permanent teeth known in this country as mottled enamel was first reported by Eager[1] in 1901. The first investigation in the United States was the extensive one of Black,[2] and McKay,[3] published in 1916. At present in this country alone there are more than 200 areas where endemic mottled enamel has been confirmed by survey; in addition there are approximately 100 areas where the endemicity has been reported but not confirmed by survey. These approximate 300 areas are distributed among 23 different states.

The incidence of affection in an endemic area is relatively high, often 90 per cent, and in some instances all children exposed throughout the period of calcification of the teeth are affected. In the light of present knowledge, mottled enamel is a water-borne disease associated with the ingestion of toxic amounts of fluoride present in the water used for drinking and cooking during the period of tooth calcification. The minimal threshold has not yet been definitely established but studies to date would suggest that amounts below 1 p.p.m., expressed in terms of fluorine (F), are of no public health significance.

There is apparently no race, color, or sex differential. With respect to the teeth, the causative factor is operative only during the period of calcification, which, with the exception of the third molar represents approximately the first decade of life. There is some indication[4] that the skeletal system might likewise be affected; if this is true, it would be necessary to extend the time range to include adults.

The macroscopic pathology in the human has been classified according to severity thus: normal, questionable, very mild, mild, moderate, moderately severe, and severe. These various gradations have previously been described.[5] This classification, depending on the degree of severity of the affection, permitted in turn the development of the following "mottled enamel indexes" of a community[6, 7]: negative, border-line, slight, medium, rather marked, marked, and very marked. Several detailed studies[8, 9, 10] concerning the histopathology of this disease have been reported. An analogous hypoplasia developed under natural conditions has been observed in certain domestic animals.[11, 12] The sole hope in the solution of this problem lies in prevention. Since the ameloblasts cease functioning at the time of eruption of a tooth, such

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ameliorative treatment as is possible is naturally very limited in scope and generally unsuccessful. Bierring[13] in referring to this disease recently has recorded that "although different in nature from typhoid fever, [it] represents a permanent physical defect of distressing character."

Mottled enamel has direct relationships to other forms of oral pathology, some of these relationships being at times paradoxical. In spite of their defective structure, mottled enamel teeth, according to McKay,[14] exhibit no greater liability to caries than do normally calcified teeth, an inference apparently sustained by the investigations of Masaki,[15] Ainsworth,[9] and Erausquin.[16] Masaki [15] and Ainsworth,[9] in addition, maintain that the eruption of the secondary dentition is delayed.

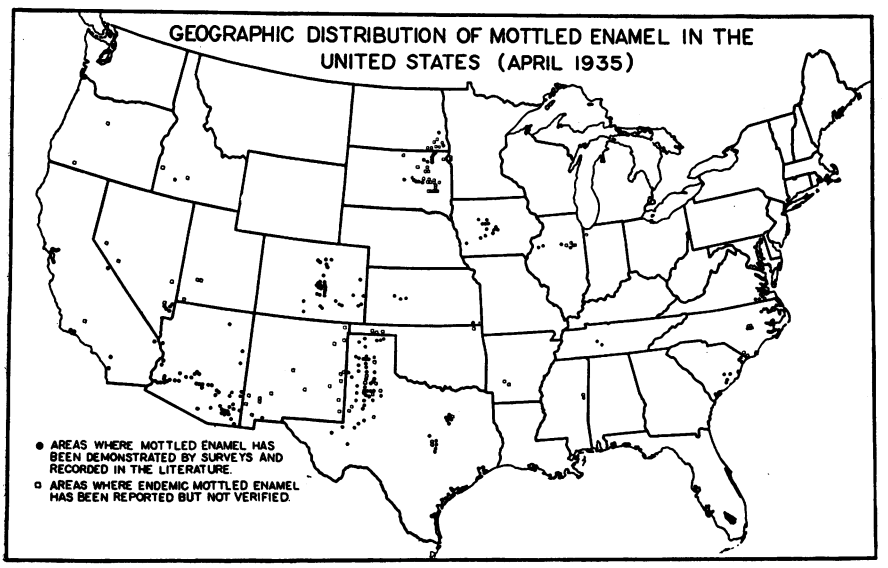
From observations made by one of us (HTD) in areas of relatively high fluoride concentration (more than 4.0 p.p.m.) there is, likewise, sufficient evidence to suggest an apparent tendency to a higher incidence of gingivitis (Figure I).

POSSIBILITY OF ERROR IN NON-QUANTITATIVE STUDIES

A review of the literature indicates that surveys of the past have been largely non-quantitative. In many instances data of little value are submitted relative to two important conditions, namely, (a) the number of children in the group studied, together with the length of time of their constant exposure, and, (b) possible changes in the chemical composition of the water used during the life period of the group examined.

The number in the group examined should consist of at least 25 children 9 years of age or older who had used the water under investigation continuously since birth for both drinking and cooking. Breaks in continuity totaling less than 30 days in any one calendar year are excepted. In instances where the examination of the first 25 children discloses an incidence of less than 75 per cent, the number in the group examined should be increased to at least 50, if possible. In other words, when more than 25 per

FIGURE I



cent are diagnosed as "normal" or "questionable," the size of the group examined should be increased to compensate for fluctuations in sampling and their possible effect on the computation of the community mottled enamel index.

Studies of the past have, in most cases, failed to take into consideration what has recently been revealed by carefully conducted surveys which included the individual water histories of each child re-checked by an interview with the child's parent. These surveys [7] have shown, at least with respect to the 9 year old group in the 4 cities studied, that only about 20 per cent used the city water continuously from birth.

The need for an adequate clinical sample is obvious when we consider that the causative factor of mottled enamel is probably operative during the entire period of calcification of the permanent teeth; and an observed effect may be the result of a comparatively low fluoride concentration operating during the entire period, or a relatively high concentration for a shorter period. In endemic areas where the domestic water contains a fluoride concentration only slightly above the minimal threshold, the production of visible signs of mottled enamel in the susceptibles of the group examined would probably depend upon the continuous use of the water during the entire period of calcification. On the other hand, in areas where the domestic water contains a comparatively high fluoride concentration, its use during a part of the period of calcification is sufficient to produce observable mottled enamel. A careful analysis of the data from the Bauxite survey [17] makes this latter point apparent.

Because of possible changes in the fluoride content of water supplies, it is obvious that an attempt to correlate clinical observations with a single fluoride determination of a municipal water associated with endemic mottled enamel introduces the possibility of questionable correlation. In respect to water from deep wells, the fact that the mineral content usually varies within comparatively narrow limits might be misleading until it has been definitely ascertained that there have been no changes in the physical set-up of the water supply during the lifetime of the children. Hence the amount of fluoride in a water sample taken at the time of the clinical examination may mean little unless a complete history of the water supply concomitant with the life of the children examined, has been obtained.

It must also be borne in mind that some municipalities using deep wells for their common water supply have more than one source of deep well water. For instance, the largest city in the United States known to be affected with mottled enamel regularly uses water from one group of wells for 6 months of the year, and from an entirely different group for the other 6 months. This rotation has been followed for the past 4 years, and since one supply has about twice as much fluoride as the other, it is evident that a single sample representing only one of these supplies would be valueless in correlating chemical findings with clinical observations. Moreover, the addition of new wells, or the abandonment of old ones during the lifetime of the group examined may introduce variable factors that would make it impossible to draw reliable conclusions from the chemical findings disclosed at the time of the examination. Furthermore, in dealing with surface waters or shallow wells, the seasonal and annual rainfall or other meteorological conditions become factors of importance. In this study, therefore, consecutive monthly water samples were obtained for 1 year and a fluoride determination was made on each sample.

TABLE I

FLUORIDE (F) CONTENT OF MONTHLY SAMPLES

(PARTS PER MILLION)

Month and Year	Lubbock Texas	Amarillo Texas	Conway South Carolina	Plainview Texas	Mullins South Carolina	Big Spring Texas
November, 1933		2.4	4.0		0.9	
December		2.5	3.9		0.9	
January, 1934	4.3	2.5	4.0	2.7	0.9	0.3
February	4.3	2.5	4.1	3.0	1.0	0.3
March	4.0	2.4	4.1	2.8	0.9	0.3
April	4.3	5.0	4.1	2.9	0.9	0.3
May	4.3	5.3	4.0	2.8	1.0	0.7
June	4.4	5.3	4.1	2.9	0.9	0.9
July	4.5	5.6	4.0	3.0	0.8	0.9
August	4.4	5.6	3.9	2.8	0.8	1.0
September	4.7	2.7*	4.1	2.9	0.9	1.1
October	4.4	5.0*	4.1	2.9	1.0	1.0
November	4.2			2.9		1.1
December	4.5			2.8		1.0
Mean annual fluoride content	4.36	3.9	4.03	2.87	0.9	0.7

* The Amarillo municipal water is obtained from two sources: October to March, inclusive, each year from the McDonald wells. April to September, inclusive, each year from the Palo Duro. In September, 1934, the city water was obtained from the McDonald supply on account of a break-down in the lines of the Palo Duro supply. In October, 1934, the water used in the city was from the Palo Duro; in November, the supply was again obtained from the McDonald wells.

PRESENT STUDY

This paper presents a comparison of the results obtained in the investigation of the following 10 cities: Monmouth and Galesburg, Ill.; Colorado Springs and Pueblo, Colo.; Lubbock, Amarillo, Plainview, and Big Spring, Tex.; and Conway and Mullins, S. C.

The detailed results, including chemical analyses, noted in the study of the Illinois and Colorado areas have been reported.[7] An approximate mottled

TABLE II

ANALYSES OF THE WATERS * USED

(PARTS PER MILLION)

	Lubbock Texas	Amarillo Texas	Conway South Carolina	Plainview Texas	Mullins South Carolina	Big Spring Texas
Residue on evaporation	882.0	468.0	633.1	390.0	172.0	314.0
Loss on ignition	77.0	73.7	16.6	37.0	18.2	27.0
Fixed residue	805.0	394.3	616.5	353.0	153.8	287.0
Silica (SiO_2)	64.0	51.8	17.0	62.0	43.0	19.0
Iron (Fe)	0.1	0.08	0.06	0.1	0.08	0.03
Aluminum (Al)	0.2	0.3	0.06	0.3	0.25	0.50
Calcium (Ca)	60.7	43.9	2.3	48.5	1.3	73.2
Magnesium (Mg)	72.6	47.8	0.5	35.8	0.8	6.6
Sodium and Potassium (calculated as Na)	131.4	54.1	255.1	41.9	49.3	31.1
Carbonate (CO_3)			36.0			
Bicarbonate (HCO_3)	342.8	389.2	256.0	331.8	124.2	226.9
Sulphate (SO_4)	255.0	52.0	3.4	32.5	4.3	31.9
Nitrate (NO_3)	1.0	4.4	1.0	2.2	0	4.0
Chloride (Cl)	111.8	13.5	49.5	31.8	7.9	34.0
Fluoride (F)	4.2	5.6	4.1	2.9	1.0	1.1
Phosphate (PO_4)	0	0	0	0	7.1	0
Boron (B)	0.5	0	2.5	0	0	0

* These samples of water from Lubbock, Plainview, and Big Spring were received in November, 1934; the sample from Amarillo, in August, 1934; and those from Conway and Mullins, in October, 1934. Assistant Chemist C. G. Remsburg carried out the determinations other than fluoride and boron, using mostly the methods given in the *Standard Methods of Water Analysis* of the American Public Health Association. The boron determinations were made essentially by the method of Foote.[19]

enamel index of each of the 4 Texas cities has already been reported,[6] but the chemical data are included in the present paper. Furthermore, there are included in this report, for comparative purposes, chemical findings of and certain relevant clinical observations from a recently made study in South Carolina.

The fluoride content of the monthly samples of water was estimated colorimetrically by means of the zirconium-alizarin reagent.[18] The results obtained are given in Table I.

As has been pointed out previously,[7] it may be reasonable to suppose that the mottled enamel index will be found to depend entirely on the fluoride concentration of the drinking water; but it is possible, on the other hand, that other constituents of the water may have some influence on the activity of the fluoride. For this reason it appears desirable that a careful survey of a community for chronic endemic dental fluorosis should include also, for the present at least, a chemical analysis of the drinking water for constituents other than fluoride. Results of the chemical analyses of the waters from the South Carolina and Texas cities are given in Table II.

The water histories, especially with respect to variation, and other comparative data obtained in the study of the 10 cities referred to are given in Table III.

DISCUSSION

An analysis of the history of the common water supply respecting continuity clearly indicates the extreme caution necessary in attempting to correlate clinical observations including verified water biographies, with a single fluoride determination or even an annual arithmetical mean of the fluoride content when the communal water supply itself contains one or more extrinsic variables. In more than half of the cities in the group there are sufficient interruptions to warrant caution

FIG. II

SEVERITY OF MOTTLED ENAMEL IN CHILDREN OF TEN SELECTED CITIES AND THE MEAN ANNUAL FLUORIDE (F) CONTENT OF THE MUNICIPAL WATER SUPPLY 1933-34.

CITY	SIZE OF SAMPLE	MEAN ANNUAL FLUORIDE (F) CONTENT PPM	PERCENTAGE DISTRIBUTION OF SAMPLE ACCORDING TO SEVERITY OF AFFECTION 0 10 20 30 40 50 60 70 80 90
LUBBOCK, TEXAS	176	4.4	
AMARILLO, TEXAS	168	3.9	
CONWAY, S.CAR.	59	4.0	
PLAINVIEW, TEXAS	78	2.9	
COLORADO SPR. COLORADO	79	2.5	
GALESBURG ILLINOIS	57	1.8	
MONMOUTH ILLINOIS	38	1.7	
MULLINS SOUTH CAROLINA	47	0.9	
BIG SPRINGS, TEX.	68	0.7	
PUEBLO, COL.	83	0.6	

MODERATE TO SEVERE — MILD — VERY MILD — QUESTIONABLE — NORMAL

TABLE III

WATER HISTORIES AND OTHER COMPARATIVE DATA OF THE CITIES STUDIED.*

City and State	Population (1930)	Description of Water Supply with Respect to Variation	Quantitative Evaluation		Clinical				Mottled enamel index of the community	Mean annual fluoride (F) content (1933–1934) (parts per million)
			Presence or absence of requisites	Classification	Age group or school grade examined	Number of children examined who stated they had used municipal water continuously	Number showing mottled enamel	Incidence		
Colorado Springs, Colo.	33,237	Surface supply; melted snow from Pike's Peak stored in 7 mountain reservoirs 9,300′ to 12,000′ in altitude. No changes in present supply during past 20 years.	Present	A	9 year old	79	53	67.0	slight	2.5
Monmouth, Ill.	8,666	Since 1925 from two 2,445′ wells drilled to the "Potsdam" stratum of the Cambrian sandstone. Upper water-bearing strata cased off.	Present	A	9 year old	38	16	42.1	slight	1.7
Mullins, S. C.	3,158	Municipal water supply obtained from 2 deep wells, 350′ and 360′ deep and drilled in 1913 and 1921, respectively.	Present	A	9, 10, 11 years old	47	5	10.6	negative-border line	0.9
Pueblo, Colo.	50,096	Surface supply; Arkansas River. Samples taken from North Pueblo supply; clinical examinations likewise limited to children in northern half of city. North Pueblo supply from same source during past 46 years.	Present	A	9 year old	83	2	2.4	negative	0.6
Lubbock, Tex.	20,520	Municipal supply obtained from 8 wells, #1 (1925), #2 (1917), #3 and #4 (1924), #5 (1928), #6 (1930), #7 (1931), and #8 (1934). City water in general is a composite of these various wells distributed from 5 reservoirs in which water from specific wells is impounded. No. 4 well furnishes about 25% of the supply; Nos. 1, 2, 5, and 6 about 15% each, and Nos. 3, 7, and 8 about 5% each. Depth ranges from 140′ to 150′; all wells have perforated casings through each water bearing stratum. About half of the time only 2 pumps are operated and one section of the city may be served by one or two wells and another section by another well or group of wells.	Absent	B	4th 5th 6th grades	176	174	98.8	marked	4.4
Amarillo, Tex.	43,132	Prior 1927 from 35 wells, 250′ deep, located in various parts of city. In 1927 Palo Duro supply, 20 mi. SW of city consisting of 10 wells, 180′ deep, installed, and used exclusively until 1931 when McDonald supply consisting of 5 280′ wells, 7 mi. SW of city was installed. Since 1931 municipal supply from two sources: Oct.-March inclusive each year from McDonald wells; April-Sept. inclusive each year from the Palo Duro.	Absent	B	4th 5th 6th grades	168	162	96.4	rather marked	3.9

* Clinical examinations at Monmouth and Galesburg, Ill., were made during October, 1934; those of the 4 Texas cities during November, 1934, Colorado Springs and Pueblo, Colo., during April, 1935, and Mullins and Conway, S. C., during September, 1935.

TABLE III—Continued

WATER HISTORIES AND OTHER COMPARATIVE DATA OF THE CITIES STUDIED.*

City and State	Population (1930)	Description of Water Supply with Respect to Variation	Quantitative Evaluation		Clinical				Mottled enamel index of the community	Mean annual fluoride (F) content (1933–1934) (parts per million)
			Presence or absence of requisites	Classification	Age group or school grade examined	Number of children examined who stated they had used municipal water continuously	Number showing mottled enamel	Incidence		
Conway, S. C.	3,011	Municipal water supply is obtained from 3 artesian wells, a 3½" well drilled in 1896, 450' deep; a 10" well drilled in 1918, 400' deep, and a 3" well drilled in 1927, 305' deep. All wells cased entire depth. Casings of the 400' and 450' wells have "slots" at the higher water bearing levels and water from these 2 wells represents a composite of more than one water bearing stratum. About 85% of the city water is obtained from the 10" well; the remainder from the 305' well. Well drilled in 1896 supplies negligible amount. Analysis of a sample from each of the 3 wells shows slight variation in the fluoride (F) content; approximately 0.2 p.p.m.	Absent	B	9, 10, 11 years old	59	52	88.1	rather marked	4.0
Plainview, Tex.	8,834	Prior to 1926 from 2 wells, 95' and 175' deep (old supply); 1926–1928 from one well 275' deep (new supply). From 1928 to date supply is a composite one, 75% from "new" supply and 25% from "old" supply. All wells within city limits are "gravel backed" thus permitting water from different strata to mix.	Absent	B	5th 6th 7th 8th grades	78 †	76 †	97.4	rather marked	2.9
Galesburg, Ill.	28,830	Since 1928 from 2 2,414' wells drilled to the "Potsdam" stratum of the Cambrian sandstone. During 1924–1928, 60% of municipal supply from first 2,414' well and 40% from 2 wells in St. Peters sandstone, 1,245' and 1,252' deep.	Absent	B	9 year old	57	20	35.1	slight	1.8
Big Spring, Tex.	13,735	Municipal supply obtained from 23 wells. One-third of supply from 13 wells, 260' deep drilled in 1923. Two-thirds of supply from 8 wells, 280–300' deep, drilled in 1927. During 1894–1923 all municipal water from "Old Park" supply, which was supplemented until 1927 by 1923 group of wells. During 1927–1933, "Old Park" supply shut down. Between Nov., 1933, and May, 1934, 1927 group of wells also shut down. Wells located 2, 6, and 9 miles, respectively, south of Big Spring.	Absent	B	5th 6th grades	68	2	2.9	negative	0.7

* Clinical examinations at Monmouth and Galesburg, Ill., were made during October, 1934; those of the 4 Texas cities during November, 1934, Colorado Springs and Pueblo, Colo., during April, 1935, and Mullins and Conway, S. C., during September, 1935.

† Large part of 1934 sample calcified their teeth while using "old" water supply, the "F" content of which is unknown. Recent survey (March, 1936) shows incidence of 87.6 and index of "medium."

in attempting to correlate clinical observations with the composition of the water at the time of the clinical survey.

The application of epidemiological principles for the purpose of determining a minimal threshold of toxicity produced under natural conditions presupposes that inferences shall not be drawn from studies of cities in which there is an interfering relevant variable in one or both of the factors which are to be correlated. The magnitude of the population of these 10 cities makes possible a clinical examination of a sufficiently large sample in each community having the essential characteristic of continuously using a common water supply for domestic purposes. But when an attempt is made to correlate the mottled enamel index of the community with the mean annual fluoride content, only 4 of the cities are appropriate for quantitative evaluation; in the others, an approximate evaluation only is possible.

With respect to an adequate clinical sample, it has been found desirable, if not necessary, in instances where the examination of the first 25 children discloses an incidence of less than 75 per cent, to increase the minimal number of the group, whenever possible, to at least 50. In other words, when more than 25 per cent are diagnosed "normal" or "questionable," the increase in the number examined naturally tends to compensate for the fluctuation in sampling and its corresponding influence on the computation of the community mottled enamel index.

The data obtained in the study of these 10 cities and the fact that many reports in the literature generally omit inherent basic data required for epidemiological purposes suggest the classification of endemic areas under three heads:

Class A—Communities where the requisites for a quantitative evaluation are present and have been analyzed

Class B—Communities where changes in the source of water supply and/or population preclude quantitative evaluation. In some instances, however, a careful analysis of the variable factor or factors may suggest an approximate evaluation

Class C—Communities which have been reported in the literature as affected with chronic endemic dental fluorosis (mottled enamel) but where the requisites for a quantitative evaluation were not stated.

In this study, Colorado Springs, Colo.; Monmouth, Ill.; Mullins, S. C., and Pueblo, Colo., are illustrative of Class A. Lubbock and Amarillo, Tex.; Conway, S. C.; Plainview, Tex.; Galesburg, Ill., and Big Spring, Tex., would come under Class B. A high percentage of endemic areas previously reported in the literature would be classified under C.

SUMMARY

1. The requisites for a quantitative evaluation of an area showing chronic endemic dental fluorosis (mottled enamel) are: (a) a common water supply whose history discloses no relevant changes in either its physical set-up or its source during the period concomitant with the life of the group examined; and (b) clinical examinations, the observations recorded quantitatively, of a minimum of 25 children, 9 years of age or over, who have used a common water supply continuously since birth for both drinking and cooking. Breaks in continuity totaling less than 30 days in any one calendar year are excepted. Moreover, in instances where the examination of the first 25 children discloses an incidence of less than 75 per cent, an attempt should be made to increase the number of children to 50 or more in order to compensate for fluctuation in sampling.

2. For the purpose of quantitative study, affected communities are classified on the basis of the presence or absence of the requisites for quantitative evaluation, as follows: Class A in-

cludes communities where the requisites for a quantitative evaluation are present and have been analyzed; Class B includes those where changes in source of water supplies and/or population make impossible the determination of a quantitative evaluation; and Class C includes communities which have been reported as affected with mottled enamel without stating whether the requisites for a quantitative evaluation are present or absent.

3. The percentage distribution of severity permits the computation of an actual or approximate "mottled enamel index" of an affected area. This index in turn may be correlated with the fluoride content of the water supply, expressed as an arithmetical mean of 12 consecutive monthly determinations.

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