Partial Defluoridation of a Community Water Supply and Dental Fluorosis

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DENTAL FLUOROSIS, or mottled enamel, is a unique waterborne disease caused by the ingestion of water containing excessive amounts of fluorides during the period of enamel calcification. Widespread occurrence of dental fluorosis has been reported in investigations conducted in many areas of the world (*1–5*).

The disease alters the structure and appearance of enamel to varying degrees, depending primarily upon the concentration of fluoride in the drinking water (as the fluoride level rises, the severity of mottling increases) and individual variation in the amounts of the water consumed. The magnitude of the disfiguring effect is such that practically every child born and reared in an endemic area who regularly consumes the water containing excessive amounts of fluoride will be afflicted to some degree.

Even before the confirmation that endemic dental fluorosis was caused by excessive amounts of fluorides in domestic water supplies, a few communities attempted to alleviate the condition by changing their sources of drinking water. In doing so, these communities switched by chance from a source of water containing a fluoride concentration sufficient to produce endemic mottled enamel to one practically free of fluorides. The effectiveness of this approach was proved when subsequent fluorosis surveys in these communities revealed marked reductions in the prevalence and severity of the enamel defects (*6–8*). It is not always feasible or practical, however, for a community to replace or dilute its existing water supply.

Gerrie and Kehr (*9*) reported data on the use of low-fluoride bottled water during the period of enamel calcification in areas where endemic fluorosis occurs. Although the prevalence of fluorosis was reduced in children who regularly consumed the bottled water, the method has limited application in a community because of cost and inconvenience. A more desirable method of preventing dental fluorosis, benefiting all children growing up in a community with a high fluoride level, is to treat the water supply by chemicals to remove only the excessive fluorides, retaining adequate levels of fluoride to provide protection against dental caries.

At present, three methods have proven effective and practical for the chemical removal of excessive amounts of fluorides from water (*10–12*). Two of these methods involve the use of activated alumina and bone char, insoluble mediums which remove fluorides as the water percolates through them. As these mediums become progressively saturated with fluoride, they also become less efficient. Therefore, they must

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be periodically regenerated to remove the accumulated fluorides. The third method uses magnesium compounds which remove the fluorides by absorption. The magnesium and the absorbed fluorides are subsequently removed by sedimentation and filtration and are discarded.

The method using activated alumina has been employed successfully for 14 years in a Public Health Service demonstration project in Bartlett, Tex. A report concerning the practical elimination of dental fluorosis by partial defluoridation in Bartlett after 11 years of treatment was published in 1964 (*13*).

The Britton Defluoridation Plant

After a preliminary investigation, the Public Health Service selected Britton, S. Dak., in 1947 as an appropriate site for demonstrating a feasible means for removing excessive amounts of fluorides from a community water supply. The principal water supply for Britton, a community of approximately 1,430 persons, is derived from three wells with an average fluoride content of 6.7 parts per million (ppm). Some residents occasionally consume water from several shallow private wells that do not contribute to the city water supply. Although no recent information is available relative to the fluoride content of the private wells, it is believed that their fluoride level is less than that of the deeper, more mineralized wells that provide water for the city supply. We assumed that the infrequent consumption of water from private sources would not influence the evaluation of the effectiveness of the defluoridation procedure.

The design, construction, and operation of the defluoridation plant have been discussed in detail (*14–16*). The plant began operating on November 20, 1948, using a synthetic hydroxy apatite material as the defluoridating agent. Use of this material was abandoned in November 1952 because excessive amounts of the chemical (42 percent per year) were lost from attrition during the defluoridation process. During the 4 years that the apatite was employed, 497 cycles (the period between two consecutive regenerations) were recorded, an average of about one every 3 days.

Daily samples of the water were analyzed to determine the fluoride levels delivered throughout the period. The average fluoride level achieved with the hydroxy apatite during this period was 3.6 ppm, roughly half that of the natural water before treatment (6.7 ppm), but well short of the target level of 1.5 ppm.

Defluoridation was recessed for the period November 13, 1952, to January 17, 1953, to permit removal of the apatite and its replacement with bone char. In the period between January 17, 1953, and September 1, 1954, the average fluoride level was reduced to 2.5 ppm. From September 1, 1954, to April 1, 1965, the fluoride level averaged 1.6 ppm. There were 828 cycles recorded from January 17, 1953, to April 1, 1965, an average of about one every 5½ days. Thus, a greater reduction in fluoride level was achieved through use of the bone char than previously with the hydroxy apatite, and regeneration was required less frequently.

The fluoride concentration of the treated water is not constant throughout each cycle, but rather varies with the condition of the medium. Immediately after regeneration of the medium, the fluoride level is relatively high, but it rapidly falls to a minimum point well below the target level. Thereafter, as the cycle progresses the fluoride concentration gradually increases until the point is reached where the weighted average of all the water delivered in that cycle approaches the target level. Because the periods between regenerations average less than 1 week, the variation in fluoride level during the cycles should have little or no effect either on producing fluorosis or interfering with caries inhibition.

Within practical limits, the duration of a cycle can be adjusted to approach an average fluoride level that is desirable for a particular community. In approaching the target level of 1.5 ppm for Britton, approximately 1.1 million gallons of water are treated before the bone char requires regeneration.

The cost of equipment for the Britton defluoridation plant in 1947 was $12,245, including the medium (hydroxy apatite). The type of bone char now required currently sells for 4½ cents a pound. At present total chemical costs for regeneration amount to about $28 per million gallons of water treated. The building that houses the equipment and the cost of installing pipelines to join two of the city's wells were financed by the city of Britton as its contribution to the project. Initially the Public Health Service agreed to pay for the equipment, its installation, and expenses of operating the plant for 10 years. However, because of the switch in mediums and the difficulty in achieving a desired average fluoride level during the first 6 years of the project, the period of Public Health Service support was extended, and Britton did not assume the full cost of the operation until July 1965.

Dental Fluorosis Study

Method. In October 1948, immediately prior to the initiation of partial defluoridation, baseline examinations were carried out on Britton school children to determine the extent of dental fluorosis. The study group comprised 71 children who met certain requirements for residence and source of water for drinking. For this study, children who had lived in Britton almost continuously from birth to age 8 were classified as residents. This age span was specified because enamel calcification of all permanent teeth except the third molars is completed during this period, and enamel once calcified is no longer susceptible to fluorosis. For all children included in the survey, the town's water supply was their major source of drinking water and of the water used in preparing their food.

A followup survey conducted in May 1960 included 97 children, and one in April 1965 included 114 school age children who met the same requirements as the baseline group for residency and source of the water they consumed.

All examinations for the three surveys were made by Public Health Service dentists. Children, seated in portable dental chairs under good artificial light, were examined with mouth mirrors and explorers. Examiners in the 1960 and 1965 surveys assigned a score to each permanent tooth according to the standards described by Dean in 1942 (*17*). According to these standards, teeth are given the following scores depending on the degree of fluorosis.

Degree of fluorosis	*Score*
Normal	0
Questionable	0.5
Very mild	1
Mild	2
Moderate	3
Severe	4

Classification of an individual child for the 1960 and 1965 surveys was based on the condition of the two teeth in the mouth that showed the same, most severe form of fluorosis. For example, if a child had one tooth scored as severe—4, five teeth as moderate—3, and his remaining teeth as having milder forms of fluorosis, he was classified as having moderate fluorosis—3.

The examiner in 1948, while basically using Dean's classification system, introduced two additional intermediate rating categories. When confronted with a situation in which he believed the degree of severity fell about midway between mild and moderate or moderate and severe, the examiner chose not to make a decision that placed the tooth into one or the other of these categories. Rather, he classified the tooth as either mild to moderate (score 2.5) or moderate to severe (score 3.5). Classification of an individual child in the 1948 survey was also based on the condition of the two teeth in the mouth that had the most severe form of fluorosis.

Findings. Community fluorosis indexes for children examined in each survey are shown in table 1. The fluorosis index, developed by Dean and McKay (*18*) as a means of comparing one group or population with another on the basis of average severity of fluorosis, is computed by averaging the individual classifications of the children.

For analytical purposes, the age groupings in table 1 were established on the basis of the number of years that had elapsed since September 1954 when the average fluoride content of the water supply approached the target level and at which it was maintained thereafter. Thus, in 1965 the children who had used the water defluoridated to a level of 1.6 ppm since birth were essentially those 10 years old or younger. (A few of the 10-year-olds were born within a 5-month period before the beginning of maximum defluoridation.) The 1965 examinees 11 years old or older were children who had lived through various stages of incomplete defluoridation, as well as a few who were born before the alteration of the water was begun in 1948.

Table 1 shows a community fluorosis index of 2.63 for all children examined on the baseline. In 1960, 12 years after the initiation of partial defluoridation and only 6 years after a level of 1.6 ppm had been achieved, the fluorosis index of all examinees was reduced to 1.37. By 1965 the fluorosis index had fallen to 0.99.

Children 6–10 years of age in 1965, almost all of whom had consumed water at a level of 1.6 ppm exclusively, had an average fluorosis index of 0.68, about 72 percent lower than the score of 2.44 recorded for this age group on the initial survey. A less substantial reduction was observed in children older than 10 years, most of whom had lived through various stages of partial defluoridation and some of whom were born prior to the start of defluoridation. Figure 1 shows the fluorosis indexes according to age group at each examination.

Percentage distributions of the fluorosis classifications of the children examined in 1948, 1960, and 1965 are shown in table 2 according to age group. These percentages have been grouped to show the proportion of children exhibiting positive signs of fluorosis as opposed to those with no fluorosis or with questionable borderline signs. Perhaps the most conspicuous feature of the data is the complete lack of children with no fluorosis in the group examined in 1948. The natural fluoride content of almost 7 ppm before treatment of the water was initiated in 1948 had some measurable effect on 100 percent of the children examined on the baseline survey. In contrast, a rating of negative or questionable fluorosis was assigned to 42 percent of those examined in 1960 and 58 percent of those examined in 1965.

Table 1. Fluorosis index of children in Britton, S. Dak., according to age group in 1948, 1960, and 1965

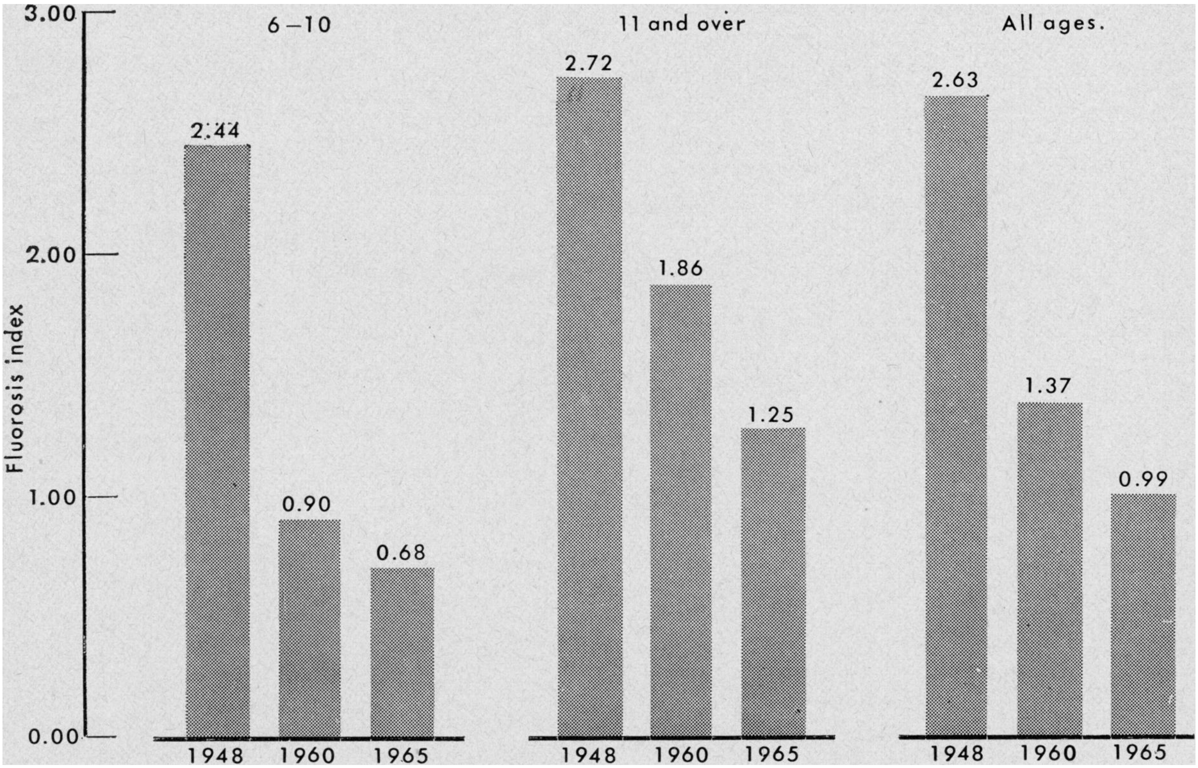
Age group (years)	Number of children	Fluorosis index
1948	71	2.63
6–10	24	2.44
11 and over	47	2.72
1960	97	1.37
6–10	50	.90
11 and over	47	1.86
1965	114	.99
6–10	51	.68
11 and over	63	1.25

If comparisons are made among children 6–10 years of age, even more striking improvements are apparent; whereas 100 percent of the children in this age group exhibited positive signs of fluorosis in 1948, the corresponding percentage dropped to 42 percent in 1960 and, additionally, to 29 percent by 1965. Even though the changes are not as striking for children 11 years old and older, considerable improvement is evident. Approximately 75 percent of these children had positive signs of fluorosis in 1960, compared with 100 percent in 1948. By 1965, this percentage had been reduced further to 52. The complements of these percentages are shown graphically in figure 2.

Table 2. Percent distribution of children in Britton, S. Dak., according to age group in 1948, 1960, and 1965

Year	Fluorosis absent		Total with no fluorosis	Fluorosis present						Total with fluorosis
	Normal	Questionable		Very mild	Mild	Mild to moderate	Moderate	Moderate to severe	Severe	
All ages:										
1948	0	0	0	7.0	16.9	33.8	26.8	9.9	5.6	100.0
1960	22.7	19.6	42.3	17.5	15.5		20.6		4.1	57.7
1965	19.3	38.6	57.9	20.2	8.8		10.5		2.6	42.1
6–10 years:										
1948	0	0	0	8.3	25.0	33.3	29.2	4.2	0	100.0
1960	30.0	28.0	58.0	22.0	8.0		10.0		2.0	42.0
1965	25.5	45.1	70.6	17.7	7.8		3.9		0	29.4
11 years and over:										
1948	0	0	0	6.4	12.8	34.0	25.5	12.8	8.5	100.0
1960	14.9	10.6	25.5	12.8	23.4		31.9		6.4	74.5
1965	14.3	33.3	47.6	22.2	9.5		15.9		4.8	52.4

Figure 1. Fluorosis index of children in Britton, S. Dak., according to age group and year of examination



With regard to the more severe classifications of fluorosis, 42 percent of all children examined in 1948 were determined to have at least moderate fluorosis. By 1960, only 25 percent were so classified and, by 1965, this percentage was further reduced to 13. Among children 6–10 years old, the percentages of children with at least moderate fluorosis were 33 in 1948, 12 in 1960, and 4 in 1965. Thus, signs of overt forms of fluorosis had almost disappeared in 1965 among children born and reared in the area who regularly consumed the water partially defluoridated to near the target level.

Discussion. The findings clearly show that the prevalence of objectionable fluorosis has been greatly reduced among Britton children whose permanent teeth have calcified subsequent to defluoridation. The results are particularly striking among those children examined in 1965 who essentially had consumed only water containing approximately 1.6 ppm fluoride.

It should be pointed out that basing the classification of a child on his two teeth affected most severely by fluorosis is only a crude measure of the practical significance of the amount of fluorosis in a community. A child may have only a few teeth affected by fluorosis. Moreover, if only his posterior teeth are affected, the condition is of little or no esthetic concern. Yet by use of Dean's index, the child is classified the same as another child with fluorosis generally throughout the mouth or prominently on his maxillary anterior teeth. Thus, scores derived from Dean's index can underestimate the practical significance of the defluoridation process.

Despite the progress in reducing fluorosis shown in this study, the results of the 1965 survey suggest that a still lower level of fluoride in the water may be indicated than the 1.6 ppm average maintained since September 1954. In 1965 all children 9 years old or younger and approximately half the 10-year-olds were born after the fluoride level was controlled to an average of 1.6 ppm. Yet 29.4 percent were judged to have some fluorosis; 17.7 percent were rated as very mild, 7.8 percent as mild, and 3.9 percent as moderate (table 2).

These younger children demonstrated an

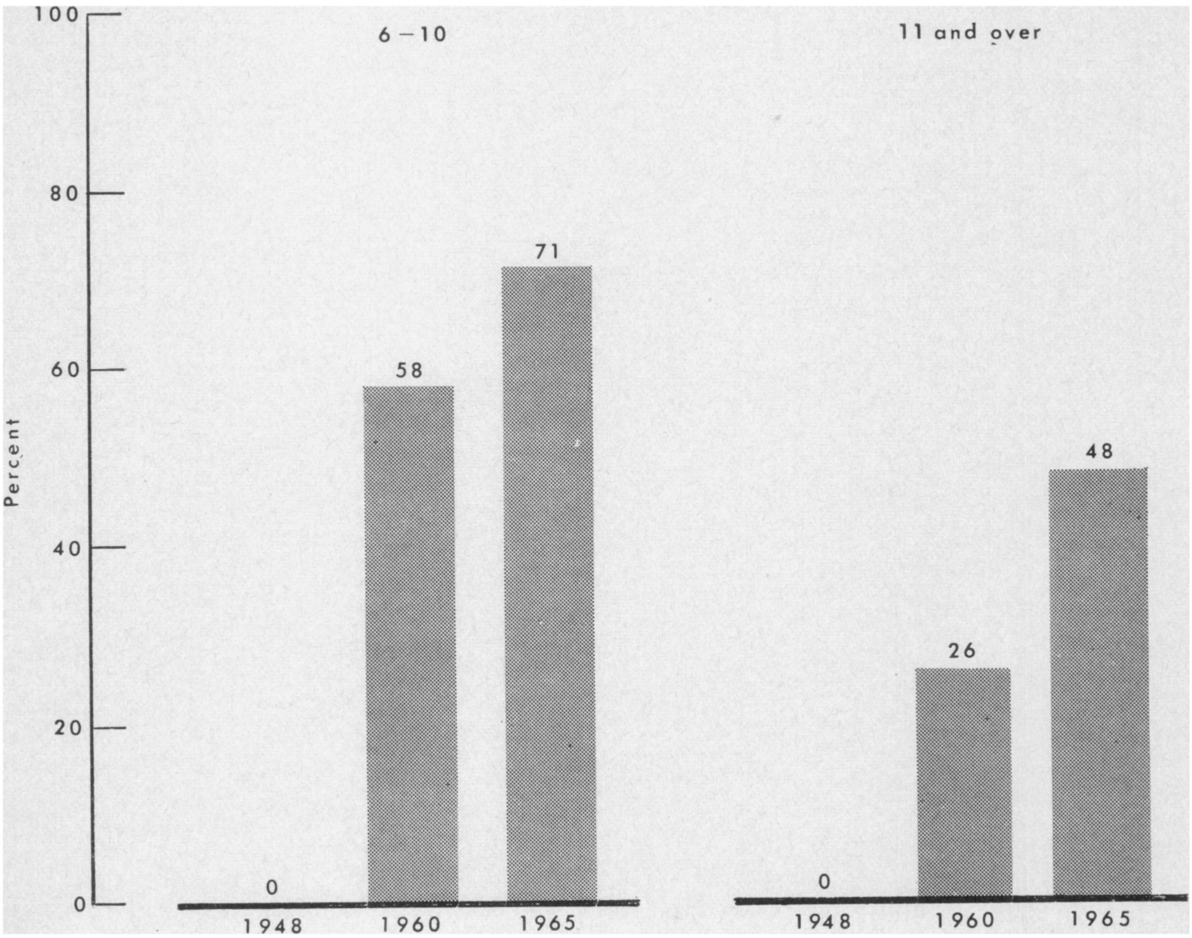
average fluorosis index of 0.68, a figure somewhat greater than the 0.4 index suggested by Dean (*17*) as the level below which fluorosis is of little or no public health concern. He considered indexes ranging from 0.4 to 0.6 to be of borderline public health significance and recommended removal of excess fluorides when the fluorosis index was above 0.6.

According to fluoride concentrations recommended in "Public Health Service Drinking Water Standards" (*19*), the optimum fluoride concentration for Britton, according to its annual mean maximum daily temperature, should be 1.1 ppm, with an upper control limit of 1.5 ppm. Between September 1954 and April 1965 the average concentration of fluoride in the water supply in Britton was 1.6 ppm, slightly above the upper control limit. If the fluoride concentration had been maintained at a level closer to the optimum, it would be expected that a greater proportion of children born subsequent to the defluoridation process would have been free of fluorosis.

For older children whose permanent teeth developed during a period overlapping the changes in water supply, the reduction was less than for those exposed mainly to the low level of 1.6 ppm. In 1965, 30 percent of the children 11 years of age and older still demonstrated mild or more severe forms of fluorosis compared with a corresponding percentage of 94.0 in 1948. In contrast, only 12 percent of the children 10 years of age and under demonstrated mild or more severe forms of fluorosis compared with 92 percent of this age group on the baseline.

Results achieved in Britton can be compared

Figure 2. Percent of children in Britton, S. Dak., with fluorosis absent according to age group and year of examination



with the findings in Bartlett, Tex., after 11 years of defluoridation in that community (*13*). The fluorosis index for children 6–10 years of age in Bartlett in 1963, after the fluoride level had been reduced from 8 ppm to 1.17 ppm, was 0.42. This value compares with an index of 0.68 in Britton for the same age group. In Bartlett, 78.8 percent of the children reared entirely on the treated water supply demonstrated no positive signs of fluorosis compared with 70.6 percent of the children free of fluorosis in Britton.

The experience with partial defluoridation in Britton, S. Dak., furnishes another demonstration of the successful removal of excessive fluorides from a community water supply. This and similar projects show what can be accomplished in other communities served by water sources containing fluorides in excess of the optimum range. According to best estimates by the Community Fluoridation Section of the Public Health Service's Division of Dental Health, there presently are approximately 4.2 million people living in 1,142 communities served by public water supplies that exceed the upper control limits for fluoride recommended in "Public Health Service Drinking Water Standards" (*19*). In 712 of these communities with a combined population of 1.8 million, the fluoride levels are at least twice the optimum, which constitutes grounds for rejection of the water supply (*19*).

The striking difference in the prevalence of fluorosis between Britton children ages 10 and younger in 1965 and their counterparts in 1948 reared in the area who regularly consumed the untreated water offers additional evidence that disfiguring dental fluorosis can be nearly eliminated by controlling the fluoride content of a community water system.

The removal of excessive fluorides has been found to be a practical and economical procedure; the results in Britton furnish additional justification for the adoption of partial defluoridation as a public health measure by other communities.

Summary

Since November 1948, excessive fluorides have been removed chemically from the community water supply of Britton, S. Dak. The water supply originally contained an average of 6.7 ppm fluoride. Hydroxy apatite was used as the defluoridating agent for the first 4 years of operation, but since January 1953 bone char has been used instead because it is more effective and efficient in reducing the fluoride content to the desired target level (1.5 ppm).

A baseline survey, using Dean's classification, was conducted in 1948, just prior to the initiation of partial defluoridation, to determine the prevalence and severity of fluorosis among school children who had used the city's water supply since birth. Followup surveys were made in 1960 and 1965 to determine whether or not there had been any changes in the extent of fluorosis after partial defluoridation.

The findings showed less fluorosis among Britton children in 1960 than in 1948 and still greater improvement in 1965. The results in 1965 were particularly striking for those children less than 11 years old, essentially all of whom were born subsequent to the use of bone char as the defluoridating medium. Originally children in this age group had had a fluorosis index of 2.44; by 1960 the corresponding index had fallen to 0.90; and by 1965 it had reached 0.68, a 72 percent reduction compared with the baseline figure. Whereas all of these younger children had been classified as having fluorosis in 1948, only 29 percent were so classified in 1965, and nearly all of these demonstrated the milder forms of fluorosis.

Because more than 4 million persons live in communities served by water supplies containing excessive fluorides, dental fluorosis remains a serious dental public health problem. The successful removal of excessive fluorides in Britton with the use of bone char and in Bartlett, Tex., with activated alumina, plus the concomitant improved appearance of the teeth of children reared on the partially defluoridated water, should stimulate public health leaders in other communities with excessive fluorides to adopt similar measures to improve the appearance of their children's teeth.

REFERENCES

(*1*) Dean, H. T.: Geographical distribution of endemic dental fluorosis (mottled enamel). *In* Fluorine and dental health, edited by F. R. Moulton. American Association Advancement Science Publication No. 19, Washington, D.C., 1942, pp. 6–11.

(2) Pu, M. Y., and Lilienthal, B.: Dental caries and mottled enamel among Formosan children. Arch Oral Biol 5: 125–136, November 1961.
(3) Rosenzweig, K. A., and Abkewitz, I.: Prevalence of endemic fluorosis in Israel at medium fluoride concentration. Public Health Rep 78: 77–80, January 1963.
(4) Ludwig, T. G.: The Hastings fluoridation project. V. Dental effects between 1954 and 1964. New Zeal Dent J 61: 175–179, July 1965.
(5) Forrest, J. R.: Mottled enamel. Brit Dent J 119: 316–319, Oct. 5, 1965.
(6) McKay, F. S.: Mottled enamel: The prevention of its further production through a change of water supply at Oakley, Idaho. J Amer Dent Assoc 20: 1137–1149, July 1933.
(7) Dean, H. T., McKay, F. S., and Elvove, E.: A report of a mottled enamel survey of Bauxite (Ark.) ten years after a change in the common water supply. Public Health Rep 53: 1736–1748, Sept. 30, 1938.
(8) Dean, H. T., Elvove, E., and Poston, R. F.: Mottled enamel in South Dakota. Public Health Rep 54: 212–228, Feb. 10, 1939.
(9) Gerrie, N. F., and Kehr, F.: Experience in preventing dental fluorosis by using low-fluoride bottled water. Public Health Rep 72: 183–188, February 1957.
(10) Fink, G. J., and Lindsay, F. K.: Activated alumina for removing fluorides from drinking water. Industr and Engin Chem 28: 947–948, August 1936.
(11) Smith, H. V., and Smith, M. C.: Bone contact removes fluorine. Water Works Engin 90: 1600–1603, Nov. 10, 1937.
(12) Scott, R. D., et al.: Fluoride in Ohio water supplies: Its effect, occurrence, and reduction. J Amer Water Works Assoc 29: 9–25, January 1937.
(13) Horowitz, H. S., Maier, F. J., and Thompson, M. B.: The effect of partial defluoridation of a water supply on dental fluorosis—Results after 11 years. Amer J Public Health 54: 1895–1904, November 1964.
(14) Maier, F. J.: Defluoridation of municipal water supplies. J Amer Water Works Assoc 45: 879–888, August 1953.
(15) Maier, F. J.: Partial defluoridation of water. Public Works 91: 90–92, November 1960.
(16) Maier, F. J.: Manual of water fluoridation practice. McGraw-Hill, Inc., New York, 1963, vol. 5, pp. 209–213.
(17) Dean, H. T.: The investigation of physiological effects by the epidemiological method. *In* Fluorine and dental health, edited by F. R. Moulton. American Association Advancement Science Publication No. 19, Washington, D.C., 1942, pp. 23–31.
(18) Dean, H. T., and McKay, F. S. Production of mottled enamel halted by a change in common water supply. Amer J Public Health 29: 590–596, June 1939.
(19) U.S. Public Health Service: Public Health Service drinking water standards, 1962. PHS Publication No. 956. U.S. Government Printing Office, Washington, D.C., 1962, p. 8.

To Develop Simple Test for Urinary Tract Infections

Development of a simple "dip-stick" screening test to help detect millions of undiagnosed urinary tract infections is the purpose of a contract awarded to Georgetown University by the Public Health Service's National Center for Chronic Disease Control.

The contract will support efforts of the university's urologists to develop a simplified chemical test to show signs of bacteriuria. Such a test would help reduce the number of undetected urinary tract infections.

Urinary tract infections occur more often than any except those of the respiratory tract. Studies indicate that more than 3 million undetected urinary tract infections, a large majority of them in women, exist at any given time in the United States. Infections of the urinary tract often result in serious kidney disease, a major concern of the Center's Kidney Disease Control Program.

Present methods of screening for urinary tract infections when there are no symptoms require bacteriological culturing of urine specimens. The number of colonies of bacteria that appear on the culture medium indicate the possibility of urinary tract infection. If, for example, 100,000 colonies or more appear, the probability of urinary tract infection is about 85 percent; if 10,000 to 100,000 colonies appear, the possibility of infection is about 35 percent; and with less than 10,000 colonies the chance of infection is less than 5 percent.

The goal of the project at Georgetown University is to develop an inexpensive material that will reflect the presence of significant bacteria after being dipped into urine.