Fluorine Toxicosis
A Public Health Problem*

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The widespread occurrence of mottled enamel, a defect of the teeth which is caused by the action of fluorine present in many public and private water supplies, makes fluorine poisoning a public health problem.

We recognize at least 3 types of mottled enamel as may be seen in Plate I, the mild chalky white type, the more severe stained type, and the pitted, corroded type.

It is obvious that mottled teeth are very disfiguring and ugly, for the stain which commonly filters into the porous areas is usually rust colored. In addition, mottled teeth are defective in formation and calcification and are, therefore, structurally weak. The defect is irreparable and permanent. It has been estimated by the Tucson Dental Association that it would cost $1,000 for dental care of the teeth of the average person with mottled enamel, up to adulthood, at which time the teeth must usually be replaced by false ones.

Fluorine is very common in nature, occurring in many rocks and soils, and ranks 20th in quantity in the earth's crust. It is natural, therefore, that fluorine should find its way into many water supplies, and when it is realized that drinking water containing as little as 1 p.p.m. of fluorine will cause mottled enamel, it is not surprising that there are sections in every country in the world and in 24 states of the United States * in which mottled enamel is reported and most of the native born inhabitants are afflicted. It is perhaps most prevalent in the arid states of the Southwest. Our survey of Arizona

* Arizona
Arkansas
California
Colorado
Florida
Idaho
Illinois
Iowa

Kansas
Louisiana
Minnesota
Nevada
New Mexico
North Carolina
North Dakota
Oklahoma

Oregon
South Carolina
South Dakota
Tennessee
Texas
Virginia
Washington

Plate I—Typical cases of mottled enamel in human beings who drink water containing fluorine.
made in 1931 has revealed more than 45 scattered communities in which mottled enamel is endemic. The fluorine content of the water supplies in these communities varied from 1 to 6 p.p.m. The only other extensive state survey which has been made is that of Colorado. Boisevain² reports the occurrence of mottled enamel in 25 communities in Colorado. In all probability, mottled enamel is equally as prevalent in other states, especially Texas and New Mexico.

Mottled enamel has been produced experimentally in albino rats, in guinea pigs, and in dogs (see Plates II and III)³ by the feeding of fluorides or the residue of water from a community which contains fluorides. A number of lines of evidence indicate that the fluorine passes into the bloodstream and interferes with the calcification of the unerupted teeth of children. It does not act in the mouth upon the enamel of the erupted portion of the teeth. The teeth of children or adults who do not begin drinking water containing fluorine until after their second sets of the teeth have erupted do not later show mottled enamel.

In humans, the enamel organ disappears as soon as the enamel of the permanent teeth is completely formed and calcified. The enamel does not regenerate itself and behaves, therefore, like dead tissue. For this reason the enamel of the teeth of adults is un-

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Plate II—A. Normal rat incisors. B. Mottled incisors of a rat which received sodium fluoride. Note loss of luster and pigment and corrosion of enamel.

Plate III—Effect of fluorine feeding upon the permanent teeth of a dog. Note corrosion and chipping of the enamel.
affected by the drinking of water containing fluorine. It is almost possible to tell at what age a child moves into a community whose water supply contains fluorine, by the teeth which show mottled enamel. If the person has lived from birth in a community in which mottled enamel is endemic, all of the teeth will be mottled. If a child moves into such a community after the age of 12 to 13 years, only the wisdom teeth will be mottled, for they will all have erupted before he drinks the fluorine containing water. Again, a child who begins to drink fluorine containing water at the age of 5 to 6 years will have no mottled enamel on the 6 year molars, central incisors, and probably the laterals, but will have mottled cuspids, bicuspid, and second molars, for these teeth are in the process of formation at this age.

Experiments on rats whose incisor teeth are continually growing also have demonstrated that the feeding of fluorides does not mottle the erupted portion of the incisors, but it is only the new incisor growth which erupts 2 to 3 weeks after the beginning of the feeding of fluorine which shows the characteristic defect.

We have injected sodium fluoride subcutaneously, and again the evidence indicates that the injected fluorine goes to the site of enamel formation and interferes with the calcification of the enamel of the unerupted portion of the incisors. In rats with intermittent injections of fluorine, the results appear in about 3 weeks after the first injection (Plate IV). The lower incisors of the rat completely renew themselves every 30 days. Normal enamel areas alternate with the areas of defective calcification, the extent of which corresponds with the interval between the injections. The mottled appearance of human teeth may well be explained by an intermittent use of fluorine containing water, or a daily variation in the amount of the drinking water consumed.

Although it is true that the enamel of adult teeth is unaffected by fluorine, the dentine of adult teeth which does receive nutrients from the blood stream continually and whose composition is subject to change, may suffer. Histologic examination \(^4\) suggests that this may be the case. A microphotograph (Plate V) of the incisor of a rat which received 8 injections of sodium fluoride showed 8 stripes in the dentine which was

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**Plate IV**—Effect of intermittent injections of sodium fluoride. Different effects can be produced by varying the interval between the injections and the amount of fluoride injected.
FLUORINE TOXICOSIS

PLATE V—Microphotographs of incisors of rats receiving injections of sodium fluoride. A. Eight injections given on alternate days resulted in 8 decalcification stripes in the dentine. B and C. Transverse ground sections showing stratification in both the dentine and the enamel of the incisors of a rat which received 4 injections of sodium fluoride given at 48 hour intervals. Formed during the period in which the injections were given, whereas the dentine formed before and after the injections were begun was normal. Plate Vb shows a cross-section of the incisor of a rat which had received 4 injections of sodium fluoride. Stratification in both the enamel and dentine may be observed.

It may perhaps be concluded, therefore, that the dentine portion of the teeth of adults who drink fluorine containing water may be adversely affected, resulting in a general weakening of the tooth structure, although the change will not be externally visible.

The question naturally arises then as to the effect of fluorine upon bone. High fluorine feeding (0.1 per cent NaF in the ration) produced a short, square, and stocky appearance in the skeleton of the rat, with the enlarged, deformed bones and bowing of the legs typical of severe rickets. In addition, the bones of the fluorine fed animals, like the teeth, were chalky and fragile. A measurement of the storage in the body of the bone forming elements, calcium and phosphorus, as determined by measurement of the balance between the intake and the output showed that the young fluorine fed animals retained only slightly more than half as much of these elements as did the normal litter mate rats which served as controls (Table I). The fluorine increased the loss or elimination of calcium, and bone

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<th>Fluorine Fed</th>
<th>Per Cent Intake Retained</th>
<th>Daily Retention per Kilo Body Wt.</th>
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<tr>
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development was accordingly retarded. Addition of calcium to the diet, however, prevented this loss to a large extent but at the same time the teeth remain severely mottled.

Similar experiments performed on girls of 10 and 13 years who had mottled teeth, due to the fact that their drinking water contained fluorine, did not show a disturbance in their ability to metabolize either calcium or phosphorus (Table II). No signs of bone defects or other indications of defective mineral metabolism have been observed in children whose teeth are severely mottled. It may be concluded that although the drinking of water containing from 1 to 6 p.p.m. of fluorine will severely impair the teeth, the calcification of the bones is probably not upset to any great degree. The teeth are extremely sensitive to fluorine which seems to exert a more specific effect upon them.

Our work has also shown that the interference of fluorine with the calcification of the teeth cannot be prevented by increasing the calcium content of the diet or by a liberal intake of vitamin D in the form of cod liver oil or viosterol. Supplemental feeding of vitamin D concentrates to rats, dogs, and children over a period of years has in no case prevented the action of fluorine or made its effect upon the teeth less severe.

Mottled enamel is usually found only on the second or permanent set of teeth. We have examined thousands of children and noted that the deciduous teeth were free from mottled enamel, whereas all the erupted permanent teeth were mottled. It is believed that the formation of the temporary teeth begins about the 3rd week of fetal life and they are largely calcified at the time of birth. The eruption is usually complete at the age of 2 to 2½ years. In explanation of this almost complete freedom of deciduous teeth from mottled enamel, McKay said “It must be remembered that the temporary teeth are formed largely before birth and are sheltered against outside influences, with a nutritive supply dialyzed through placental osmosis.” It is true that thousands of cases have shown that even though mothers drink water containing sufficient fluorine to cause severe mottled enamel (as much as 6 p.p.m.), the deciduous teeth of their children are free from this defect. If the children drink this water from birth however all of their permanent teeth are severely mottled. It would appear that a toxic concentration of fluorine does not find its way through the placental membrane or into the milk supply of the mother.

In support of this, our experiments with rats have shown that even though we feed a high concentration of fluorine (0.05 per cent NaF in the diet) to pregnant females, their offspring have normal teeth at the time of weaning which later become mottled when the young rats have access to the food of the mother animals. Phillips  has
shown that feeding a large amount of a
mineral supplement to lactating cows
containing enough fluorine to produce a
toxic effect upon the cows themselves,
did not appreciably increase the fluorine
content of their milk. From this evi-
dence it seemed likely that the milk of
cows raised in regions in which the
water supply contained fluorine could
be considered safe from the fluorine
standpoint and that pregnant and nurs-
ing mothers could drink the fluorine
containing water without endangering
the temporary teeth of their children.

However, our more recent findings
make this conclusion somewhat unten-
able. A district has been recently
visited in which the native born chil-
dren have mottled enamel of the
severest type upon their temporary
teeth. This extreme condition was not
suggestive of mottled enamel at first
glance, for the characteristic chalky
whiteness of the enamel could not be
observed as the teeth were almost devoid
of enamel and ground down almost to
the gum line. Analysis of the private
water supplies in this section of the state
revealed fluorine contents varying from
12 to 18 p.p.m., the highest fluorine
concentration yet reported for potable
water supplies. It would appear there-
fore that deciduous teeth are not exempt
from the toxic action of fluorine and
that they will become mottled if the
water supply contains an extremely high
concentration of fluorine.

Fortunately, the occurrence of mot-
tled enamel is sectional. Colorado
Springs is perhaps the largest city
where the water supply contains
fluorides. There is an agricultural
practice which, unless controlled, will
make mottled enamel more prevalent
and no longer sectional in distribution.
I refer to the growing use of fluorine
compounds as insecticide sprays against
agricultural pests. Fluorine compounds
are being more and more extensively
used as a substitute for arsenicals whose
toxic action is known and feared. Cryo-
lite, barium silicofluoride and sodium
silicofluoride are among the compounds
now rather commonly used for spray-
ing apples in the Northwest, and vege-
tables such as cabbage, cauliflower,
broccoli, celery, etc., especially in
Florida and California. The fact that
these compounds of fluorine are rela-
tively insoluble has raised the question
as to their toxicity. Our study 7 on rats,
of the comparative toxicity of fluorine
compounds has shown that from the
standpoint of the initial damaging
effect upon the teeth all are equally
poisonous. One mg. of fluorine per
kilo of body weight per day, or a con-
centration of 14 p.p.m. of fluorine in
the ration of rats, regardless of the
source of the fluorine, will prevent the
normal development of the incisor teeth.

Fluorine is even more toxic to the
teeth of human beings than to rat in-
cisors which grow at a more rapid rate.
A concentration of only 1 p.p.m. in
water supply will produce mottled
enamel in humans. If we assume an
average water intake of from 4 to 8
glasses a day, the average fluorine intake
per day from this source will be from 1
to 2 mg. per person.

Analyses of the fluorine residues on
food material have been made by the
U. S. Department of Agriculture 3
months after the foods were sprayed
with various commercial fluorine sprays.
Apples sprayed with barium silicofluo-
ride showed an average fluorine content
of 5.6 p.p.m. before washing. One of
these large apples would therefore pro-
vide as much fluorine as 4 glasses of
water containing 1 p.p.m. of fluorine.
The fluorine residue on cabbage varied
from 1.6 to 11 p.p.m., on celery from
9.9 to 28, on cauliflower, from 1 to 3.

Experiments upon the removal of
spray residue by washing have been
made by Smith and his coworkers of the
U. S. Department of Agriculture. They
report that fluorine residue removal
amounts to only 85 to 90 per cent by the best washing process available so that "it was impossible satisfactorily to clean fruit originally carrying 0.1 gr. or more of fluorine per lb." They also state that the fluorine residue on fruits sprayed with cryolite or barium silico-fluoride plus fish oil was practically impossible to remove to meet the fluorine tolerance set by the U. S. Department of Agriculture even when the most efficient methods were used. It seems logical to suppose also that it would be even more difficult to remove fluorine from the leafy vegetables than from apples.

With the human tolerance level for fluorine so low, it seems a dangerous practice to use the compounds of fluorine for spraying purposes. The ugliness of mottled teeth alone causes untold misery to the afflicted persons.

REFERENCES

Cure for Stubborn Wounds

FROM a clue provided by an insect, entomologists of the U. S. Department of Agriculture have discovered a new way to heal stubborn wounds quickly, painlessly, and cheaply. The new treatment is the application of a solution of allantoin, a bland, odorless, harmless, and easily obtained product found in both insects and plants.

The insect that gave the clue to this discovery is one of the flies—in the maggot stage—that gained fame as a medical aid on World War battlefields, where an Army doctor found that wounds infested with maggots healed better and faster than wounds without them. Since then surgeons all over the world have used maggots in treating deep infections difficult to cure by ordinary surgery.

Dr. William Robinson, of the Bureau of Entomology and Plant Quarantine, now finds that allantoin, which is given off by the maggots as they work their way through a wound, is responsible for part of this power. Dr. C. J. Macalister, who used it successfully 23 years ago for ulcers, reported that European peasants had long applied the roots of comfrey, which contain allantoin, to sores.—Press Release, U. S. Dept. of Agriculture, Apr. 23, 1935.