

*A survey undertaken in areas of Tanzania where the water has a very high fluoride content showed mottling of the teeth. Some skeletal fluorotic changes were found in some older people. The problem of reducing the fluoride content of the water to acceptable levels is discussed.*

## THE EFFECTS OF EXCESSIVE FLUORIDE INTAKE

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A PRELIMINARY report of a fluorosis survey carried out in Tanzania in East Africa was recently published.<sup>1</sup> That paper was designed mainly to report the high incidence of fluorotic bone changes in certain subjects and it constituted the first proof of naturally occurring bone fluorosis in this region of Africa.

The present paper has been produced to give further details of the conduct and other findings of that survey, to discuss the clinical and public health features of fluorosis, and to suggest preventive measures to control this endemic. It also provides a description of the abnormalities found in the teeth, nails, and thyroid gland of 468 children who were not included in the earlier report.

### The Area

The study was made in the Arusha district of northern Tanzania around the base of Mount Meru. Many streams originate on this 14,978-foot-high volcanic mountain and flow down through or near various habitations where the water is used for domestic purposes. In 1955, Walker and Milne<sup>2</sup> reported very wide variations in the fluoride content of some of these domestic water supplies.

A number of these, together with some subsequent estimations, are shown in

Table 1. The estimations included were performed on samples taken from the main sources of drinking water for the villages and schools that were surveyed.

The Arusha district is 1,150 square miles in area and at the 1957 census had a population of 148,733 persons. The district has an average altitude of about 5,000 feet and the mean recorded annual rainfall at Arusha township is 74.80 inches. The inhabitants consist mainly of Warush and Wameru people. The principal items in their diet are plantains or bananas, maize (corn), milk, legumes, millet, meat, and a variety of green leafy vegetables. The main cash crops are coffee, pyrethrum, and seed beans.

### The Survey

The study was designed to ascertain whether a very high intake of fluoride over a long period of time was producing bone changes and to record the presence or absence of other clinical signs related or possibly related to poisoning with fluoride.

For the main study, four places on different sides of Mount Meru were selected because of the very high fluoride content of their water supply. These places were Maji Ya Chai, Oldonyu Sambu, Ngare Nanyuki, and Olmotoni-

**Table 1—Fluoride content of water in areas of survey**

Sources of water for each location	Fluorine content ppm
1. Maji Ya Chai (a) river	18.6
2. Oldonyu Sambu (a) pipeline (b) spring	14.3
	14.4
3. Ngare Nanyuki (a) river (b) tributary near village (c) furrow (d) spring	24.0
	45.5
	24.8
	6.0
4. Olmotoni-Selian (a) Olmotoni river (b) Selian river	5.9
	6.4
5. Arusha Township (a) municipal water supply (b) Temi river (in township) (c) unnamed stream near quarry	2.5
	2.2
	3.0
6. West Meru School Area (a) Magumira river (b) Mbembe river (c) Tengeru river	1.1
	2.7
	2.0

Selian. For the secondary part of the survey, three schools were selected in areas where there was a possibility of preventive measures being taken if clinical findings justified it. These schools were the Arusha Upper Primary School and the Arusha Secondary School, both situated in Arusha township, and the West Meru Upper Primary School near Tengeru.

Notice was given to local government officials that medical examinations would take place at Maji Ya Chai, Oldonyu Sambu, Ngare Nanyuki, and Olmotoni-Selian.

These officials were asked to assemble as many people as possible of all ages who lived near the particular source of water. All persons who attended were examined and the details of findings filled in on a fluorosis survey form

which was designed for this study.<sup>1</sup> The attendance at Oldonyu Sambu was poor and not very representative. At the other three places, the attendance was very satisfactory. At Maji Ya Chai and Ngare Nanyuki, because of the proximity of a lower primary day school, the children attending these schools were also examined. Those persons who were, or were believed to be, over 40 years of age and who had lived for more than ten years in the area were offered free x-ray examination. An appointment was made and free transport provided to the Radiology Department at Arusha Hospital.

At the two schools in Arusha only those children who had lived in Arusha town and consumed the water from the urban supply for more than five years were examined. This was in order to form a picture of the results of prolonged consumption of this water. Over half the children who were examined at Arusha Upper Primary School were of Asian origin. The other subjects in the study were all Africans.

At West Meru School, all the children were examined. This school takes children as boarders from all over the Arusha district. This group of children form a cross-section of the whole area.

A total of 1,243 persons were examined during this survey. The examination consisted of:

1. *Examination of the Teeth*—These were examined usually in direct light. The only instruments used were a spatula, dental probe and mirror, and occasionally a flashlight. The teeth were examined for:

a. dental fluorosis. This was classified as follows: 0—normal, 1—mild, 2—moderate, 3—severe. The presence of markedly worn teeth was also recorded.

b. dental caries. The WHO Report<sup>3</sup> on Standardization of Reporting of Dental Diseases and Conditions (1962) recommends that in surveys of dental caries a record be made of the number

of teeth decayed (D), missing (M), and filled (F). The average number of teeth decayed, missing, or filled is called the DMF rate or index and gives a good indication of caries prevalence in a population. Before beginning the survey, it was clear that many persons had had teeth removed not because of caries, but as a preventive measure against the lockjaw of tetanus. This practice of removing two or sometimes four central incisors was a fairly common tribal custom which is now disappearing. It was not difficult to tell which teeth had been removed for this reason and the count of these was recorded separately and not used in the computation of the DMF index.

*2. Examination of the Nails*—The nails of both hands (but not of the feet) of all subjects were examined in direct light. The degree of mottling and other changes such as pitting was classified as follows: 0—nil, 1—mild, 2—marked. Positive findings were only recorded if present in three or more nails. This was to avoid inclusion of nail changes caused by trauma.

*3. Examination for Goiter*—The thyroid gland of each individual was examined both visually and by palpation. The size of the gland was classified according to the method suggested by Perez, Scrimshaw, and Munoz,<sup>4</sup> which has been accepted by WHO for use in goiter surveys. The method can be summarized as follows:

Group 0—Persons without goiter and persons with a thyroid less than five times enlarged. (We considered each lobe of a normal thyroid gland to be the size of a kidney bean that would just cover the thumb nail of the subject being examined.)

Group 1—Persons with palpable thyroids more than five times enlarged but not easily visible with the head in normal position.

Group 2—Persons with goiters which are easily visible with the head in normal position but which are smaller than Group 3.

Group 3—Persons with large goiters which can be easily recognized at a considerable distance and are grossly disfiguring.

A record was also made as to whether each goiter was diffuse or adenomatous (nodular).

*4. Radiological Examination*—For practical and financial reasons x-rays were taken of only 112, whereas examination of nails, teeth, and thyroid was carried out on all 1,243 persons in the survey. Those offered radiological examinations were not randomly selected, but were chosen because they were believed to be persons at maximum risk. They consisted of older subjects who had lived in any of the four survey villages for more than ten years and can, therefore, be presumed to have ingested excessive quantities of fluoride over long periods of time. In each case, a radiograph was taken of both forearms, the spine, and the skull.

## Results

*1. Dental Fluorosis*—This was seen most commonly as extensive brown mottling of all the teeth. The mottling was sometimes patchy, sometimes linear but more often what could best be described as geographic, like a faded map or an illustration of the indefinite geography of the moon's surface. In some cases typical chalky white patches were seen. These had the appearance and texture of a plaster of Paris cast rather than of the surface of glazed white porcelain which is normal for a healthy tooth. The teeth were often roughened, pitted, or transversely ridged. When fluorotic changes were not present in all the teeth of a subject, they were most commonly seen in the incisors. The dental fluorosis seen in this survey affected both deciduous and permanent teeth.

Table 2 shows the very high prevalence of dental fluorosis. No group had fewer than 80 per cent of persons with dental fluorosis and of the 1,243 subjects examined 95 per cent were affected. The rate at Ngare Nanyuki is probably

**Table 2—Fluorotic mottling of teeth, showing the number and percentage of people affected**

Place	No. examined	No. of persons with fluorotic mottling				Total no. of persons with mottling	% of persons with mottling
		Grade 0	Grade 1	Grade 2	Grade 3		
1. Maji Ya Chai							
(a) nonschool	188	2	8	28	150	186	98.9
(b) school	192	0	2	30	160	192	100.0
2. Oldonyo Sambu	30	5	8	8	9	25	83.3
3. Ngare Nanyuki							
(a) nonschool	111	17	10	10	74	94	84.7
(b) school	133	23	9	13	88	110	82.7
4. Olmotoni-Selian	121	3*	6	4	107	117	97.5
5. Arusha							
(a) Upper Primary School	103	2	14	29	58	101	98.1
(b) Secondary School	60	1	5	18	36	59	98.3
6. West Meru							
Upper Primary School	305	9	12	27	257	296	97.0
Total	1,243	62*	74	167	939	1,180	94.9

\* One edentulous not included.

a reflection of population shift rather than a lower rate for long-term residents of this area. There has, during the last decade, been an influx of people from other places to fill the land left vacant by the departure of several South African Dutch farmers.

The number of persons with markedly worn teeth does not appear to be directly related to the fluoride content of the water consumed. There is a suggestion, however, that the wearing down process starts earlier in places with exceptionally high levels of fluoride in the water. The teeth most commonly affected were the central incisors. In some advanced cases, more than half of the total of the normally exposed portion of the tooth had been worn away. There did not seem to be any great prevalence of teeth that had crumbled or broken. This was judged from the rather subjective observation that a broken tooth would leave an irregular rough area at

the site of fracture, whereas a worn tooth has a smooth surface.

2. *Dental Caries*—The prevalence of dental caries was found to be very low (Table 3). Of the 1,243 persons examined 76.8 per cent had no teeth that were decayed, missing, or filled other than those that had been extracted for tribal reasons. During the examination, the authors formed the opinion that periodontal disease was common and many teeth which have been recorded as missing, especially in older persons, may have been lost as a result of this cause rather than because of caries.

The total number of teeth decayed, missing, or filled (DMF) was 719, giving a DMF index of 0.58.

3. *Nail Changes*—The nail changes were diverse in character. The commonest findings were longitudinal striations often quite deep. Other abnormalities included those of contour such as spoon shaping, converse watch glass curvature,

or flattening, changes of color, such as brownish pigmentation or abnormal speckling, and alteration in surface texture, such as pitting and roughening.

Table 4 shows that nail abnormalities were common among all the different groups examined. Of the 1,243 subjects in the survey, 43.8 per cent were found to have nail changes. There does not seem to be any significant relationship between the prevalence of nail changes and the fluoride content of the water in the various areas.

While examining the nails it was noted that 18 persons had marked clubbing of the fingers of both hands. They were all adults and 15 were over 40 years of age. No pulmonary or cardiac cause for the clubbing was evident in these subjects and none had cyanosis.

4. *Goiter*—Table 5 shows that goiter was a common finding in the persons examined in this survey. In all, 27.4 per cent of subjects had thyroid glands recorded as being more than five times

their normal size. Only 16 (4.7 per cent) of the goiters were adenomatous (nodular). There appears to be no significant link between goiter prevalence and fluoride content of water in the different areas.

5. *Radiological Findings*—As has been mentioned, the persons x-rayed were a selected group who met certain criteria. There is also no means of knowing what motivated each of the 112 out of 143 persons offered x-ray examinations to accept and arrive for his or her appointment, or for the other 31 to refuse or not arrive for this examination.

The reason why a selected group rather than a random sample were chosen for x-ray examination was because one of the fundamental purposes of the survey was to find whether fluorotic bone changes did occur. They had not previously been reported in this part of Africa. A group was taken who were not typical but were considered

**Table 3—Results of examination of teeth, showing number of DMF teeth, the DMF index (or rate), the number of persons with worn teeth and the number of teeth missing for tribal reasons**

Place	No. examined	No. of teeth DMF	DMF Index	No. of persons with markedly worn teeth	No. of teeth missing for tribal reasons
1. Maji Ya Chai (a) nonschool	188	243	1.29	62	124
(b) school	192	22	0.11	7	2
2. Oldonyo Sambu	30	21	0.70	7	15
3. Ngare Nanyuki (a) nonschool	111	50	0.45	33	68
(b) school	133	3	0.02	24	11
4. Olmotoni-Selian	121	281	2.32	50	122
5. Arusha (a) Upper Primary School	103	53	0.51	14	0
(b) Secondary School	60	18	0.30	2	0
6. West Meru Upper Primary School	305	28	0.09	55	18
Total	1,243	719	0.58	254	360

**Table 4—Results of examination of the nails**

Place	No. examined	Degree of mottling			% persons with mottled nails
		0	1	2	
1. Maji Ya Chai					
(a) nonschool	188	102	84	2	45.7
(b) school	192	142	49	1	26.0
2. Oldonyo Sambu	30	17	13	0	43.3
3. Ngare Nanyuki					
(a) nonschool	111	69	41	1	37.8
(b) school	133	98	35	0	26.3
4. Olmotoni-Selian	121	50	71	0	58.7
5. Arusha					
(a) Upper Primary School	103	56	46	1	45.6
(b) Secondary School	60	22	36	2	63.3
6. West Meru Upper Primary School	305	143	159	3	53.1
Total	1,243	699	534	10	43.8

most likely to show bone changes because they were the persons in the survey who were believed to be a maximum risk through having for long periods of time consumed water with a high fluoride content.

The results showed that 87 per cent of the 112 persons x-rayed had bone changes believed to be due to fluoride poisoning; 19 per cent showed very marked changes.

The commonest abnormality was an increased bone density particularly noticeable in the vertebrae, radius, and ulna. The increased denseness of the bone often obliterated the normal bony architecture and caused increased thickness of bone simultaneously reducing the size of the medullary cavity. Another frequent finding was the calcification of ligaments and muscle attachments. For example, calcification of the paravertebral ligaments was present in 20 per cent of the cases in this series. The most striking radiological finding was that often seen in the forearms which showed massive calcareous de-

posits along the interosseous margins of both the radius and ulna. Marginal lipping of the vertebral bodies commonest in the lumbar segment was present in 45 per cent and calcification of the triceps insertion in 26 per cent of those x-rayed. The fracture rate did not appear to be affected.

#### Discussion

The survey has, for the first time, shown that fluorotic skeletal changes commonly occur among the older inhabitants of an area of East Africa where the fluoride content of the water is high. Further study is necessary to determine at what age this becomes detectable radiologically, at what level of fluoride intake bone changes do occur and most important of all, what symptoms and disability these changes produce. During the survey, those being x-rayed were asked whether they had body pains. Approximately three quarters of those later found to have radiological evidence of skeletal involvement

did complain of pains mainly in the back, chest, and legs. It was not discovered how serious these were nor how much disability exists.

Table 2 shows that fluorotic mottling of the teeth was present in a very high percentage of persons in all six locations where examinations were made. The fluoride content of the main sources of domestic water in these places is shown in Table 1. It is evident that each of the six areas has at least one source of water containing 2.7 or more ppm of fluoride. The range in the fluoride content of the individual water sources is from 1.1 to 45.5 ppm. This high rate of mottling was to be expected because it has been widely reported in persons drinking water with a fluoride content of more than 1 ppm<sup>5</sup> and had previously been reported from northern Tanzania.<sup>6</sup> It has resulted in very unsightly highly pigmented teeth. The local people are conscious of the problem and eager that something be done about it.

The prevalence of dental caries was very low. However, there was no control investigation and therefore the caries rate among persons of the same ethnic group on a similar diet, but with a low fluoride intake, is unknown. However, in Arusha Upper Primary School where over half the children were of Asian origin the incidence of dental caries, although low, was significantly higher than at other schools participating in the survey. This, we presume, is because the Asian children come from homes whose income is higher and whose diet is different. Undoubtedly, these children, whose parents are mainly shopkeepers and traders, consume more sugar, candy, and manufactured food products than do the African children in this study.

The nail changes found in this survey are difficult to interpret. Abnormalities of the nails have been described as an early sign of fluorosis<sup>7</sup> but they also occur in many other conditions. In

Table 5—Prevalence of goiter

Place	No. examined	Size of thyroid				% persons with goiter	No. adenoma- tous
		0	1	2	3		
1. Maji Ya Chai							
(a) nonschool	188	144	29	14	1	23.4	5
(b) school	192	137	53	2	0	28.6	0
2. Oldonyo Sambu	30	20	8	2	0	33.3	0
3. Ngare Nanyuki							
(a) nonschool	111	85	19	7	0	23.4	4
(b) school	133	117	16	0	0	12.0	0
4. Olmotoni-Selian	121	95	19	7	0	21.5	2
5. Arusha							
(a) Upper Primary School	103	79	13	8	3	23.3	4
(b) Secondary School	60	47	9	4	0	21.7	0
6. West Meru Upper Primary School	305	179	103	23	0	41.3	5
Total	1,243	903	269	67	4	27.4	20

the present survey 43.8 per cent of those examined had nail abnormalities and yet 95 per cent had fluorotic mottling of the teeth. A control group examined in Dar-es-Salaam on the coast of Tanzania where the fluoride content of drinking water is 0.2 ppm showed 9 per cent with nail changes. It is difficult to explain why nail changes are seen in some persons and not in others when both are consuming similar quantities of fluoride and both have other stigmata of fluoride poisoning. We believe that there is not adequate scientific evidence to show that a high fluoride intake causes nail abnormalities.

The clubbing of the fingers in 18 adults was an interesting finding. In all cases the nails were curved over the edge closely following the contour of the club. Clubbing, a clinical sign which has fascinated several generations of physicians, is a feature of many diseases including pulmonary tuberculosis, bronchiectasis, empyema, lung abscess, congenital heart disease, bronchiogenic carcinoma, and subacute bacterial endocarditis. In most of these conditions there is chronic arterial anoxia, but the actual mechanism of club formation remains unproved. Mauer<sup>8</sup> suggests that it occurs where there are present in the extremities low oxygen tensions in tissues which are warm but in which the blood flow is greater than normal. We have hypothesized elsewhere<sup>9</sup> that fluorosis, by causing extensive osteosclerosis of the skeletal thoracic cage and calcification of some supporting tissues, has resulted in sufficient rigidity of the chest wall to impair respiration and oxygenation, thus producing the circumstances required for the development of clubbing of the fingers. This fits in with the fact that clubbing was not seen in children, was less common in those 20 to 40 years of age but was frequently found in those over 40 years of age. We can find no previous reference in the litera-

ture relating fluorosis to finger clubbing.

The survey has revealed a goiter rate of 27.4 per cent. Galletti and Joyet<sup>10</sup> and others have suggested that fluoride inhibits the thyroid iodide concentrating mechanism and that when the total iodide pool is low may impose a critical limitation on hormonal synthesis. Studies in South Africa have incriminated excess fluoride intake as a leading cause of goiter in several endemic areas there.<sup>11</sup> The prevalence of goiter in subjects in the present survey is higher than the 13.8 per cent found in the Rufiji District<sup>12</sup> or the 9.7 per cent found in the Central Region of Tanzania.<sup>13</sup> However, it is considerably lower than in the goiter endemic Ukinga highlands where goiter was found in 75.9 per cent,<sup>14,15</sup> the highest goiter rate so far recorded in Africa. In none of these areas has fluorosis been found. It is, therefore, not at present clear whether fluorine is a factor in the goiter found in the Arusha district.

### Conclusions and Recommendations

The high fluoride content of water in parts of the Arusha district is causing one condition of which the people are conscious and for which they are anxious to find a solution, and a second condition of which they are as yet unaware. The former problem concerns the appearance of their teeth and as such is more a cosmetic than a public health problem. It cannot be considered serious when compared with other medical problems in the area, such as tuberculosis, anemia, parasitic diseases, and malnutrition. The second condition is that the high fluoride intake of the inhabitants of this area is, unknown to them, causing skeletal changes. It is not possible even to guess at what proportion of the "rheumatic" pains, the fibrosis, or the bone and body pains are caused by fluorotic bone changes or abnormal calcareous deposits in different sites.

Among older subjects it is probably considerable, as is suggested by studies in India.<sup>16</sup> Certainly physicians should keep this possibility in mind in individuals complaining of deep pain over a bone or who have chronic limitation of movement at any joint. Skeletal fluorosis is easily diagnosed by x-ray examination, provided the physician or radiologist thinks of the possibility.

The solution to the problem of fluorosis is not easy in an area such as this. Arusha township, with a piped municipal water supply, could conceivably obtain apparatus to defluorinate its water. Also when, as seems likely in the near future, the township needs to expand its present supply of water, the choice of an alternate source should be based at least in part on its content of fluoride.

However, the vast majority of persons at risk in the area draw their water from streams, furrows, or wells near their homes. These people could, during the rainy season, collect rain water for drinking purposes and thus considerably reduce their fluoride intake. The very wide variation in the fluoride content of streams in adjacent valleys means that some households could without much extra effort draw their drinking water from a source which contains less fluoride than that which they currently use. When building new homes, inhabitants could consider locating them near water supplies with the lowest concentration of fluoride. To achieve even modest success from solutions such as these would require a very successful campaign of health education. What, however, is clear is that as piped water starts to be provided to villages and later houses in this area, it should be installed only after the alternate water sources have been analyzed so as to ensure that where practicable the one with the lowest fluoride content is used. It is necessary that coordination exist and that cooperation take place between the local

authorities, the public health officials, the government chemist and the hydrological engineer, who is to install new water supplies in the area.

### Addendum

The results of this survey are produced in no way to refute the overwhelming evidence which exists to prove that an adequate intake of fluoride is extremely important in greatly reducing the incidence of dental caries nor to suggest that fluoridation of water up to a level of about 1.2 parts per million causes any harm to man. The authors are strong advocates of the fluoridation of water supplies which do not naturally contain what is considered adequate quantities of fluoride for the particular community. The levels of fluoride which have caused the changes in the persons examined in this survey are of an order very much higher than those that would be contemplated for use in any program of fluoridation. The osteosclerosis found in subjects in the survey does perhaps add support to the view that, in these lesser amounts, fluoride consumed over many years may be beneficial to older subjects by reducing the incidence of osteoporosis.<sup>17</sup>

### Summary

A survey was undertaken in the Arusha district of Tanzania in areas where the water contains 1.1 to 45.5 parts per million of fluoride. Examinations of the teeth for fluorotic mottling and caries, of the nails for certain abnormalities, and of the thyroid gland for goiter, were made on 1,243 persons. The prevalence of fluorotic mottling of the teeth was high (95 per cent) and of dental caries was low (DMF index=0.58). Nail changes were found in 44 per cent of subjects. Clubbing of the fingers which may possibly be related to skeletal fluorotic changes was discovered in 18 older persons. Twenty-seven per cent of those examined had goiter.

Older subjects believed to be at high risk were offered x-ray examinations. Of the 112 who had radiographs taken, 87 per cent had fluorotic bone changes, many of them very marked.

Possible preventive measures to control this endemic focus of fluorosis are discussed. In Arusha township, the alternatives are a defluorination process for the municipal water supply or the phased transfer to sources of water containing lower levels of fluoride. In rural areas, a program of health education to encourage the drinking of rain water, the drawing of domestic water from places with the lowest available content of fluoride, and in the future the careful selection of sites for drawing piped water supplies are suggested.

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