Introduction

The use of fluoride to reduce the incidence of dental caries has been the subject of public debate in this country for several years. Following strong recommendations by the British Medical Association and British Dental Association, the Minister of Health announced in Parliament on 10th December, 1962, that he was prepared to approve, under Section 28 of the National Health Services Act 1946, schemes submitted to him by local authorities for the fluoridation of water supplies. Pronouncements by many eminent authorities in favour of fluoridation, and counter-statements by more vocal but often less well-informed bodies, have appeared in the Press; any move to bring about fluoridation of drinking-water supplies has invariably provoked a strong public reaction. In spite of all assurances to the contrary, a large section of the public, sometimes influenced by the Pure Drinking Water Association, still believes that fluoridation constitutes a danger to public health and that it is an infringement of the liberty of the individual; by their actions they have continued to forestall efforts to introduce it as a public health measure. A similar situation obtains in America and other countries where the opposition has found it profitable to make allegations of a political nature; for instance, “that it is a diabolical scheme organized by communist agents whose aim it is to reduce the population of the Western world to a point of collapse, poisoned by their own drinking-water.”

It is desirable, therefore, that all medical men and others in positions of responsibility should be familiar with the facts of this situation, so that they may be in a better position to support the case for the fluoridation of drinking-water, which, if generally introduced, would eventually benefit the whole population.

It is at present recommended that where necessary the concentration of fluoride in drinking-water supplies should be raised to a level of from 0.9 to 1.0 p.p.m. (1.0 mg. per litre) by the addition of either a saturated solution of sodium fluoride or finely powdered sodium fluorosilicate. This recommendation was based on the results of investigations during a five-year period in the United Kingdom (H.M.S.O., 1962) and on the report of a Commission composed of medical, chemical and dental experts which went to America in 1952 to investigate and report on the practice of fluoridating water supplies as a means of reducing the incidence of dental caries (H.M.S.O., 1953).

It is proposed in this paper to give a short résumé of the historical background of the fluoridation of water supplies, to discuss the influence and mode of action of fluoride on dental caries and the value of other methods of fluoride therapy.
Historical Background

Fluoridation of Drinking-water

As long ago as 1892 Sir James Crighton-Brown suggested that there was a connection between fluoride intake and decreased liability to dental caries.

During the period 1928-37 workers in many countries, including Ainsworth (1933) in the New Malden district of Essex, showed that endemic fluorosis, as evidenced by mottling of the teeth, occurred in those who had, during childhood, consumed water containing 1.5 p.p.m. or more of fluoride and that the severity of the mottling was in direct relation to the fluoride level.

Following the suggestion of Mackay (1939) that the incidence of caries was less in districts where the teeth were mottled, a number of well-planned surveys were carried out, both here and in America, and these showed that the incidence of dental caries was substantially less in areas where the fluoride level of drinking-water was of the order of 1.0 p.p.m. or more. Weaver (1944) reported that the incidence of carious teeth was 45 per cent less in twelve-year-old children in South Shields, where the water was estimated to contain 1.4 p.p.m., as compared with North Shields, where this was only 0.25 p.p.m. The first experiment to see if similar results could be achieved by adding fluoride to the water supply of a "low fluoride" area was inaugurated in 1945 at Grand Rapids, Michigan, and the scheme was so successful that artificial fluoridation of public water supplies had been established in some parts of America by 1951 (see Fig. 1). The 1955-61 five-year fluoridation trial period carried out at Watford, Anglesey and Kilmarnock, with adjacent areas used as controls, was the subject of a Ministry of Health report (H.M.S.O., 1962) which contained the following conclusions:

(a) Five years of fluoridation at a level of 1.0 p.p.m. in the three study areas had brought about in each area a substantial improvement in the teeth of young children (see Tables 1 and 2).
(b) The results of this trial were in line with American experiences.
(c) No evidence of harm from fluoridation had been discovered despite continuous vigilance.
(d) The addition of fluoride to water supplies, at the specified level, had presented no technical difficulties.

This trial showed a reduced incidence of dental caries in the three- to four-year age group of the order of 40-60 per cent. These were children who had drunk fluoridated water during the whole of their lives and who had also been subject to the effects of fluoridation during the period of fetal development.

When invited to become study areas in this experimental work the local authorities for both Norwich and Darlington declined, and that for Andover, which had originally agreed, refused to continue as such after two years. Since then the antagonism towards water fluoridation in Watford and Kilmarnock has increased, to such an extent that the practice has had to be discontinued.

Topical Application

As an alternative to the ingestion of fluoride, considerable thought has been given to applying it to the tooth surfaces. Up to 1946 promising results were obtained from the topical applications of 2 per cent sodium fluoride on four or five occasions at short intervals. Then Muhler and Van Huyson (1947) reported that stannous fluoride was
Fluoride and Dental Caries

superior as an antisolubility agent on enamel, and Muhler (1959; 1960a) reported that his technique of annual applications of 8-10 per cent produced an additional caries-resistant benefit in respect of children residing in optimal fluoride areas. Dentifrices and chewing-gums containing fluoride have appeared on the market, sometimes accompanied by extravagant claims.

The Question of Possible Health Hazards due to Fluoride

The medical aspects of fluoridation are covered in many reports of studies undertaken mainly in communities which have consumed water containing fluoride for many decades, in some cases in a concentration as high as 8.0 p.p.m. Among recent studies, that of Heasman and Martin (1962) underlines again that in communities where naturally fluoridated water was consumed for long periods no adverse effect was found, and that mottling of the tooth enamel is negligible when fluoride concentrations are below 1.5 p.p.m. (Figure 2).

No serious suggestions have been made that methods of topical application are in any way dangerous to health. Solutions of stannous fluoride of strengths even in excess of 10 per cent are unlikely to cause either serious or lasting discoloration of the teeth if applied topically, neither do they have any action on the gingival tissue unless severe inflammation is already present. In some patients a 10 per cent solution may cause a white film to appear where it comes into contact with the gingiva, but this is apparently harmless and disappears in twenty-four hours (Muhler, J. C., 1957).

The most frequently heard criticisms are that fluoride taken in water in even small amounts over long periods may have a toxic effect on the thyroid gland, kidneys and the hæmopoietic system; that it could cause osteosclerosis or arthritis; and that it might interfere with vitamin or cholesterol metabolism. All these have been disproved conclusively by the most careful investigations. Similarly it has been argued that "artificially" added fluoride will not have the same dental effect as that occurring naturally in water, and it has been stated that fluoride has an adverse effect on the gingival and periodontal tissues resulting in loss of teeth; it has also been conclusively proved that these allegations are without foundation. In the United Kingdom the dental aspects of fluoridation have been discussed by Miss Jean Forrest, Senior Dental Officer to the Ministry of Health, Watford (1963). Dr. J. Longwell in his presidential address to the Society of Water Treatment and Examination (1963) has listed all responsible medical and dental authorities in the United Kingdom who support the fluoridation project. Wide study of the comparative mortality data of areas of high and low water fluoride content has revealed no significant difference in correlation with fluoride content. Berry and Trillwood (1963) reported that sodium fluoride solution of 1.0 mg. per litre (0.1 p.p.m.) depresses the growth of two types of mammalian cell in tissue culture, but that no significant reduction of cell reproductive capacity occurs until 10.0 p.p.m. of fluoride in the culture media is reached; a total disappearance of viable cells at 100.0 p.p.m. is reported. This would suggest that the reduction in growth is probably due to a decreased rate of cell division and not to direct and immediate cell destruction. Berry (1957) has discussed at length the passage of fluoride through the body and has pointed out that there would appear to be adequate protective mechanisms against toxic effects.

Fluorides are ubiquitous in nature: they occur in small amounts in most foodstuffs
Figure 1. Average number of decayed, missing and filled (DMF) permanent teeth per child, after ten years' fluoridation at Grand Rapids as compared to Aurora (naturally fluoridated). (From New Zealand report of inquiry on The Fluoridation of Public Water Supplies, p. 177, 1957. Adapted from Arnold, F.A., J. Tennessee D.A. 35: 126, 1955.)

Figure 2. Gross hypoplasia of the enamel of the deciduous teeth and incisal tips of the permanent 1st upper central incisors; associated with an intake of over 5 p.p.m. fluorine during enamel maturation. (Child aged 7 years; frontal view.)
and in most natural waters. Tinned salmon and sardines may contain as much as 7.0 or 12.0 p.p.m.; butter, cheese, beer, infusions of tea, 1.0 p.p.m.; and most meat and vegetables between 0.2 and 1.0 p.p.m. (Maier, F. J., 1963; McClure, 1949). Longwell (1957) and Maier have both assessed the fluoride intake in diets; the average in a solid food is 0.3 p.p.m., and Maier considers that the variations in dental effects in respect of children are determined mainly by the fluoride concentration of treated water supplies rather than by the food consumed. It has not been considered necessary in this country to adopt the practice of reducing the summer fluoride concentration of water supplies to 0.7 p.p.m. to offset the effect of the increased water consumption, as in America.

Mode of Action of Fluoride in the Prevention of Dental Caries

No precise explanation can yet be given to the mechanism by which fluoride reduces the incidence of dental caries. Hardwick (1963) evaluates the various theories, and concludes that two of these, the solubility theory and the enzymatic hypothesis, could well explain the whole action either singly or in conjunction. Of the others he suggests that some are still insufficiently understood for an accurate assessment of their validity to be made, and that the remainder, if substantiated, still have only a minor or are merely complementary to one of the major theories.

The Solubility Theory

This provides a satisfactory explanation of most of, but not all, the known facts regarding the fluoride-dental caries relationship, and is based on the experimental finding that dental enamel becomes less soluble in acid after treatment with fluoride solutions. It is known that fluorapatites are less soluble than the hydroxyapatites present in dental enamel, and it is believed that on treatment there is an exchange of fluoride for hydroxylions in the enamel which renders it less soluble and therefore less susceptible to decay.

The solubility theory is supported by the fact that fluoride is present in increasing amounts with age in the outer enamel layers, coinciding with the decreasing susceptibility to caries, and that enamel imperfections and early carious lesions have a more rapid uptake of fluoride than sound enamel. But there are still a number of factors which suggest that reduction in solubility is not the only mechanism producing the anti-cariogenic effect. Of these perhaps the more significant are, first, that when teeth which have a high fluoride content are introduced to a cariogenic diet they do not have the degree of protection which might be expected; and, second, there is reported to be an inverse relationship between the oral lactobacillus count and the fluoride content of water supply, which is inconsistent with the solubility theory. These findings suggest that the second major theory which is based on the known enzyme-inhibiting property of fluoride salts may well operate in conjunction with solubility reaction.

The Enzymatic Hypothesis

The enzymatic hypothesis is based on the fact that fluoride has been found in sufficient concentration in plaques on the teeth to inhibit the bacterial activity responsible for the initiation of decay, and present investigations are directed towards determining the percentage of this fluoride actually available.

Whatever its mode of action, it must be accepted that fluoride reduces the incidence
of dental caries or, at least, substantially delays its onset. Although this is particularly evident in children, there are good grounds for believing that the beneficial effect persists into adult life and that an absolute reduction of dental caries is achieved. Mühlemann (1963) has postulated that a fluoride concentration of 1000.0 p.p.m. in the outer layers of enamel is necessary to inhibit caries. This is achieved by most teeth unless prematurely lost, but the actual age at which this occurs will depend on the individual experience of the teeth concerned.

The rate of fluoride uptake will depend on:

(a) *Pre-eruptive experience.* During enamel maturation, fluoride will be incorporated into the apatite lattice, the amount depending on the dietary content. The water concentration is said to be of prime importance during this period because milk contains only 0.2 p.p.m. Recent experimental work shows that a reduction in the number of carious cavities of 66 per cent in children aged three years and 50 per cent in those aged five years may be achieved by drinking water containing 1.0 p.p.m. fluoride when compared with those drinking a low-fluoride water.

(b) *Post-eruptive experience.* Dietary fluoride and topical application. It has been shown that a topical application of stannous fluoride can reduce decay in children’s teeth by 40-50 per cent (Muhler, J. C., 1960b); however, this effect appears to be of limited duration and gradually wears off in a year or two. A proportionally smaller additional benefit is seen in areas where the water supply contains optimum amounts of fluoride. Little reliable evidence is available on the effectiveness of fluoridated tooth pastes, powders and chewing-gums, but extensive trials are now being conducted in this country; the findings will be of great interest, particularly in comparison with American results already published.

**Methods of Administering Fluoride**

*Drinking-water*

Using the slightly soluble sodium salts of hydrofluoric and hydrofluorosilicic acids, there is little technical difficulty in maintaining 1.0 p.p.m. fluoride in piped water supplies at a cost in this country of about 10d. per annum per head of population supplied.

*Food*

The addition of fluoride to milk, salt, flour and other foods, and the sale of pharmaceutical fluoride tablets, is practised to some extent on the Continent and in Scandinavia; the inclusion of bone-meal in the diet as a natural source of fluoride has been recommended in America. These methods have found little favour here because of the obvious difficulty of controlling the intake. Topical application of fluoride solution by dentists is laborious, time-consuming and expensive; the teeth must first be thoroughly cleaned, scaled and dried and kept free from saliva for four minutes during the application of the solution. As the mouth can only be treated one quadrant at a time, the whole procedure takes about half an hour per patient; under present conditions in the United Kingdom this would appear to be a practical procedure for widespread use only if it were carried out by trained auxiliary personnel. Under Service
conditions, topical application would appear to be the only appropriate method; arrangements have been made to carry out a controlled experiment on Army apprentices to ascertain if such treatment would be of sufficient benefit to their age group to justify making it available for all Army boys.

### Conclusion

(a) The fluoridation of drinking-water is highly beneficial from a dental standpoint; in fact, the value of fluoride is such that it should be classed as an essential element of the human diet.

(b) There is no evidence that the addition of fluoride to drinking-water to bring the concentration up to 1.0 p.p.m. involves any hazards to health.

(c) Other methods of utilizing fluoride, though less efficient and more difficult to control or expensive to apply, are valuable either in addition to fluoridated drinking-water or as alternatives where the latter is not available.

(d) In spite of the foregoing it has as yet been impossible to persuade more than a minority of the general public in any country to accept fluoridation of water as a public health measure.

### Table 1. Changes in the Three Study and Three Control Areas Combined

<table>
<thead>
<tr>
<th>Children Aged:</th>
<th>Study Areas</th>
<th>Control Areas</th>
<th>Adjusted(c) Percentage Increase in Study Areas</th>
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<tr>
<td></td>
<td>Percentage of Children free from Caries</td>
<td>Percentage Increase</td>
<td>Percentage of Children free from Caries</td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>1961</td>
<td></td>
</tr>
<tr>
<td>3 years (a)</td>
<td>32.5</td>
<td>60.5</td>
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<tr>
<td>4 years (b)</td>
<td>22.2</td>
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<td>5 years (b)</td>
<td>8.1</td>
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<tr>
<td>6 years (b)</td>
<td>6.2</td>
<td>14.0</td>
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<tr>
<td>7 years (b)</td>
<td>4.0</td>
<td>7.7</td>
<td>93</td>
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</tbody>
</table>

**Notes:**

(a) Full dentition.

(b) Deciduous canines and molars only.

(c) That is, after adjustment for the change in the control areas.

(From *Reports on Public Health and Medical Subjects*, No. 105. H.M.S.O., 1962.)
Table 2. Changes in the Three Study and Three Control Areas Combined
Average Number of Carious Teeth per Child

<table>
<thead>
<tr>
<th>Children Aged:</th>
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<th>Control Areas</th>
<th>Adjusted(c) Percentage Reduction in Study Areas</th>
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<td>Average Number of Carious Teeth per Child (DMF)</td>
<td>Average Number of Carious Teeth per Child (DMF)</td>
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<tr>
<td></td>
<td>Baseline</td>
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<td>Percentage Reduction</td>
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<td>3 years (a)</td>
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<td>7 years (b)</td>
<td>7.06</td>
<td>6.05</td>
<td>14</td>
</tr>
</tbody>
</table>

NOTES: (a) Full dentition.
(b) Deciduous canines and molars only.
(c) That is, after adjustment for the change in the control areas.
DMF = decayed, missing or filled.
(From Reports on Public Health and Medical Subjects, No. 105. H.M.S.O., 1962)

REFERENCES