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The Fluoridation Studies in the United Kingdom and the Results Achieved after Eleven Years

LONDON
HER MAJESTY'S STATIONERY OFFICE
1969

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CORRECTION

Page 14, Fig. 5
5 year old children, Watford and Sutton
For "1964" read "1967

Department of Health and Social Security
June 1969

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PREFACE

This is the second report on the fluoridation of water supplies in the United Kingdom. The first, published in 1962 after five years of fluoridation, showed clearly the extent of the reduction in dental decay in the temporary teeth of those children who had consumed fluoridated water since birth. The present report covers 11 years of fluoridation and therefore shows the full extent of the reduction in decay in the temporary dentition and in the permanent teeth of children up to the age of 11. Benefits are also shown in those aged 11–14 years but since these children had not received fluoridated water since birth the full effect cannot yet be assessed.

The study is one of many which have been carried out in various parts of the world and which, taken together, provide ample corroborative evidence of the benefits derived from fluoridation. Studies in the United States and in Canada now extend over 20 years and show evidence of benefit to children in the earlier years comparable with those here recorded and our experience should remain parallel with theirs. Evidence showing that the effects will continue into adult life has been obtained from studies in areas where the natural water already contains adequate amounts of fluoride, and these show that the beneficial effects persist through at least the greater part of adult life.

Critics have claimed that it is unethical to alter the composition of a natural water even though it merely increases, within the recognized limits of safety, the fluoride, sodium and silicon ions which occur naturally in greater amounts in some waters. The Kilmarnock study is of particular interest. The Burgh Council had agreed to take part in the studies, but after six years of fluoridation reversed its decision, and fluoridation ceased in 1962. Professor Mansbridge's investigation presented as an appendix to this report shows the decline in the amount of dental decay which resulted from fluoridation, and the subsequent rise in the prevalence of decay which followed the cessation of this measure. No such convincing demonstration could have been planned, as of course no-one believing in the safety and efficacy of fluoridation could have contemplated withdrawing it.

Evidence from abroad shows that there are economic advantages in addition to the personal benefits conferred by fluoridation. In New Zealand where three quarters of the population on piped water supplies receive fluoridated water it has already been found possible to reduce the dental nurse staff required, as described by the Director General of Health at the last Commonwealth Medical Conference.

The Fluoridation Research Committee has also been unable to find any harmful effects resulting from the fluoridation of water supplies. Alternative measures are no effective substitute; some might contribute to better dental health but none offers such certainty of general improvement in the teeth of children.

In most of Britain at the present time local Councils have the opportunity of making a simple decision about the amount of dental caries their children shall suffer. Five years ago the City of Birmingham decided that it should be reduced and already children of the age of three show the anticipated benefit. There is no valid reason why all our children should lack the same advantage.

These studies have been guided by the Fluoridation Research Committee for whose persistent efforts I express our thanks. Miss Oswald has arranged the

dental examinations with the willing help of dental staff of local health authorities and of Medical Officers of Health. The main work of preparation of the text has been undertaken by Dr. Martin, the statistical work by Dr. Bransby.

G. E. GODBER,

Chief Medical Officer.

Department of Health and Social Security
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ACKNOWLEDGMENTS

The Departments concerned desire to express their thanks to the Anglesey County Council, the London Borough of Sutton, the Borough of Watford, the Burghs of Ayr and Kilmarnock, and their staffs for their helpful co-operation in making these studies possible. Particular thanks are due to Mr. J. R. Collins, Water Engineer and Manager of the Borough of Watford Water Department, Mr. A. B. Groves, County Water Engineer and Manager of the Anglesey Water Undertaking and Mr. D. M. Miller, Water Engineer and Manager to the Kilmarnock Burgh Council for the enthusiasm and skill with which they undertook the fluoridation of the water supplies of their respective undertakings, to Professor J. N. Mansbridge for the part he has played in the Scottish Study, and to Professor O. Backer Dirks for the information he has provided on the Dutch fluoridation studies. Valuable advice on the technical aspects of fluoridation equipment and the control of fluoride concentration has been given by the engineering and chemical staffs of the Ministry of Housing and Local Government, and the Government Chemist's Laboratory. In particular the valuable services of Dr. J. Longwell, C.B.E., late Deputy Government Chemist and a member of the Mission sent to study fluoridation in the U.S.A. in 1952 must be acknowledged. The Departments also acknowledge their thanks to the Medical Officer of Health of Watford, Dr. W. Alcock (retired 1968), the successive County Medical Officers of Health of Anglesey, Dr. Wynne Griffiths (retired 1961), Dr. T. A. I. Rees (1961–65) and Dr. G. Crompton (appointed 1965) and the Medical Officer of Health of Kilmarnock, Dr. B. Nisbet, O.B.E. (retired 1964), for their enthusiastic work in checking the levels of fluoride in the distribution systems, and for the constant watch which they maintained, in co-operation with the medical practitioners in the area, over the health of their respective communities. The efficient conduct of the dental examinations in the study areas was facilitated by the painstaking work of the dental examiners and their assistants and the ready co-operation of the head teachers and staffs of the schools.

Finally the Departments must express their gratitude to the successive Chairmen and Members (past and present) of the Fluoridation Research Committee for the continued and detailed assessment of the medical and dental evidence and for their work in the compilation of this Report.

Committee on Research into Fluoridation

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INTRODUCTION

Some thirty years ago, studies of children's teeth carried out in areas of the United States where natural drinking waters contained varying amounts of fluoride, indicated broadly that the more fluoride there was in the water the less decay there was in the teeth. These observations were subsequently confirmed in the United Kingdom and elsewhere. Water with a level of one part of fluoride to one million parts of water (1 p.p.m.) has been determined as containing the optimum concentration of fluoride which, in temperate climates, confers on those who have drunk it from birth, a high degree of dental protection while at the same time maintaining a wide margin of safety. Water containing this level is associated with good tooth formation characterized by a strikingly good appearance, an opinion which has been confirmed independently by many dentists. Work in the United Kingdom has shown that in areas supplied with natural waters containing about 1 p.p.m. F., the prevalence of enamel defects is lower than when there are substantially greater amounts of fluoride present, or when there is only a trace. Although the natural fluoride content of drinking waters varies considerably in this country it is only in a few areas that it reaches the optimum of 1 p.p.m. All waters however contain at least a trace of fluoride.

The early observations in the United States soon led to a suggestion that it would be beneficial to adjust the fluoride content of drinking water to about 1 p.p.m. the process now known as fluoridation. The suggestion was adopted, and from 1945 onwards, the fluoride content of drinking water at Grand Rapids, Michigan, at Newburgh, New York, at Brantford, Ontario, and from 1947 at Evanston, Illinois, was raised to 1 p.p.m. F. The results of the dental examination of the children living in these towns have shown this to be highly effective in reducing the prevalence of dental decay. This finding has been confirmed by studies in other parts of the world, including those in the United Kingdom which are the subject of this Report. Moreover, there is a wide margin of safety between the low levels of fluoride which are used in controlled fluoridation, and the much higher concentrations very infrequently found in natural water supplies, and which can be associated with undesirable effects on health.

As the beneficial effects of fluoridation became increasingly apparent many more areas adjusted the fluoride levels in their water supplies. At present fluoridation is known to have been introduced in well over thirty countries. By the end of 1967, six million people in Canada, and nearly 72 million in the United States, were drinking fluoridated water and in the latter country a further 10 million people were living in areas where the natural water contained sufficient fluoride. By 1966, the number of people in Europe receiving fluoridated water had been assessed at over four million, and there were plans to double this figure. In the United Kingdom water undertakings are now fluoridating the drinking water of over two million people.

Before reaching a decision on the merits of fluoridation in this country, the Government sent a Mission, in 1952, to study fluoridation in North America. On the basis of the Mission's Report the Government decided that a series of demonstration studies should be carried out in the United Kingdom.

Study areas were selected to be characteristic of particular types of community and fluoridation commenced in 1955 and 1956. For each, with the

exception of Holyhead, an area with broadly similar characteristics was selected as a control. Thus Anglesey, a county of some 50,000 population with a soft water supply, was divided into two zones; the water of the Gwalchmai zone was fluoridated, while that in the adjacent Bodafon zone was left unfluoridated to serve as a control. Holyhead, the largest town in Anglesey with a population of about 10,000, received a mixed water supply, the fluoridated water from Gwalchmai being diluted with unfluoridated water from a local source. Holyhead was therefore treated separately and has no corresponding control area.

Watford, a mainly residential town of some 75,000 population, situated about fifteen miles from London, was chosen with a somewhat similar town, Sutton, as its control. The water supplies of both are naturally hard, but are softened before distribution. Similarly two Scottish towns Kilmarnock and Ayr, were selected, the latter serving as the control; both are industrial localities, with a population in 1956 of some 43,000 each, and both have soft waters of similar composition.

Dental examinations, known as baseline studies, were carried out to establish the prevalence of dental decay in children in the study and control areas before fluoridation started.

In 1962 a Report, 'The Conduct of the Fluoridation Studies in the United Kingdom and the Results Achieved after Five Years' was published by the Ministry of Health, the Scottish Office and the Ministry of Housing and Local Government. In that Report, as in this present one, dental decay was measured by the number of decayed, missing and filled teeth.

Very substantial improvements in the state of the teeth of the three- and four-year-olds were reported in the study areas, which were not apparent in the control areas, where only a slight change was observed. After allowing for changes in the control areas, dental decay among the three-year-old children in the fluoridation areas was found to have been reduced by about two-thirds and in the four-year-olds by about half. In each of the age groups in the fluoridation areas the number of children with ten or more decayed teeth was reduced by about four-fifths, and the number of children free from decay increased by about the same proportion.

Substantial improvements were also found in the dental health of children who were five years old at the time of the dental examinations, despite the fact that a small proportion of them were born before fluoridation commenced and could not, therefore, be expected to show the same degree of benefit as the younger children. Little benefit could be expected in those children who were six or seven years old when examined in 1961, because the formation of their temporary teeth was already complete before fluoridation began.

The present Report, which deals with the effects of eleven years of fluoridation, shows the improvements found in the temporary teeth of six- and seven-year-old children, and in the permanent teeth of children aged eight, nine and ten who have lived in fluoridated areas since birth. The Report also contains information about dental decay among older children, but in considering these age groups it is important to remember that the full benefits will not be achieved unless a child had consumed fluoridated water from birth. In addition this Report confirms the benefit in three-, four- and five-year-old children.

In Kilmarnock, fluoridation was discontinued on the instructions of the Burgh Council in October 1962. Dental examinations to determine the effects of this withdrawal have since been continued by Professor Mansbridge of

Edinburgh University, and his findings are discussed in the Appendix to this Report.

The evidence now available from the study areas makes it possible to compare the results over a wider range of age groups, with those of fluoridation in other parts of the world, and with the effects which have been reported from natural fluoride waters.

STUDIES AND ENQUIRIES ON THE SAFETY OF FLUORIDATION

Following a conference of experts convened by the Medical Research Council in 1956 a Research Committee was established by the Ministry of Health in consultation with the Medical Research Council. The Committee immediately commenced a review of the evidence then available on the safety of fluoridation, and drew up a programme of further studies where it was felt that additional research was needed. The findings on the safety of fluoridation were summarized in Appendix 8 of the 1962 Report. Two investigations made at the request of the Committee and mentioned in the 1962 Report were subsequently published. One, a study by Heasman and Martin (1962) of the comparative mortality rates in areas having high and low fluoride drinking waters, showed that the overall mortality was the same in both types of area, and that differences which were found in the case of certain diseases were unlikely to be associated with fluorides. The results supported those of similar investigations in the United States and Russia. The second paper (Griffith, 1963) described a study of anaemia in pregnancy and indicated that fluoridation in Anglesey had no effect on the prevalence of this condition.

Additional investigations made on behalf of the Research Committee included a study which showed that there was no effect on the size of the thyroid gland in school girls with a raised fluoride intake (Berry and Whittles, 1963). As an extension of a survey of rheumatism already being undertaken in the town of Leigh in Lancashire, where the drinking water had a low fluoride content, Ansell and Lawrence (1966) undertook a comparative study of the incidence of rheumatism in Leigh and in the study area of Watford. They found no increase in the prevalence of rheumatoid arthritis, osteo-arthritis, spondylitis, gout, or disc degeneration in Watford, and demonstrated that rheumatoid complaints as a whole, and incapacity from rheumatism, were significantly less in Watford than in Leigh.

Suggestions are sometimes made that insufficient attention is paid to the presence of fluorides in the atmosphere, where they are derived partly from the burning of coal, and partly from industrial emissions. The deposition of fluorides on herbage in the vicinity of some factories is sometimes so heavy that they cause fluorosis in farm animals (Burns and Allcroft, 1964). In man the principal risk, if any, would be from the inhalation of gaseous fluoride, or of fluoride particles suspended in the air, and measurements of atmospheric fluorides in London and elsewhere, under differing weather conditions, and in the vicinity of known industrial fluoride emissions, have shown that in Great Britain the amounts inhaled are so small as to be of no importance in comparison with the amounts of fluoride normally present in the diet (Martin, to be published). Other investigations have shown that man's fluoride intake from vegetables grown in contaminated areas, or from the meat and milk of cows in these areas is insignificant. The prolonged boiling of bones from cattle bred in

contaminated areas has shown that there would be no hazard in the making of soups and stews (Allcroft, 1956). The Research Committee has found no evidence of any other source of fluoride intake in the diet or environment which, added to the fluoride content of the water supply, would create a hazard.

The influence of fluorides on the skeletal system has been the subject of much research and evidence is now emerging of a possible beneficial effect on the prevalence of osteoporosis in the elderly. Leone and his colleagues (1954) found that in Bartlett, Texas, a town with 8 p.p.m. F. in its water supply, 10–15 per cent of the population had a slightly increased density of the bone and thickening of the trabeculae, which they considered might have a beneficial effect in minimizing the osteoporotic effects of old age. An extension of the study to Framlingham, a town with only a minute trace of fluoride in its water supply, revealed an unusually high incidence of osteoporosis (Leone *et al.* 1960). Subsequently Bernstein and his colleagues (1966) comparing areas with 4·0–5·8 p.p.m. F. in their drinking waters, with those of only 0·1–0·3, found a significantly higher prevalence of reduced bone density of the lumbar spine and of collapsed vertebrae in elderly females in the low fluoride areas, and in both sexes the prevalence of backache was higher. A surprising finding was that calcification of the aorta was more frequent in men living in the low fluoride area. The positive nature of these findings suggest that in Britain with water fluoridated at 1 p.p.m. and with the added intake from tea there may also be some degree of benefit. This possibility is borne out by the findings of Ansell and Lawrence (1966) mentioned above who noted a decreased incidence of osteoporosis in women, though not in men, in Watford as compared with Leigh, though the authors hesitated, at that early stage to attribute this to the effect of fluoridation.

Dental fluorosis is a subject which has frequently given rise to misconceptions, since the term 'mottled enamel' has been used to describe a wide variety of deviations from the normal appearance of the enamel. While it may reasonably be used in connection with the yellow, brown or black markings which occur with the severer grades of fluorosis associated with grossly excessive fluoride intakes, it is also used for faint white flecks or striations. These are found in a small proportion of people living in areas with 1 p.p.m. F. in the drinking water, and are so slight as usually to be undetectable except to a trained observer. The flecks are very similar to the idiopathic enamel opacities not due to fluoride, and only an expert would distinguish the two conditions. In an investigation of British natural fluoride areas, Forrest (1956) found that the prevalence of idiopathic enamel opacities was highest in the low fluoride areas, and that the total prevalence of enamel opacities was higher in areas with 0·1 to 0·2 p.p.m. F. in the water than in an area with approximately 1·0 p.p.m. With fluoride concentrations above this level there was a direct relationship between the total prevalence of the enamel opacities and the fluoride content of the water. Subsequently Forrest and James (1965) carried out a study in Anglesey in which the dental examiners were unaware which of the children came from the fluoridated or the control areas. Of a total of 91 children in the fluoridated area, 33 (36 per cent), were found to exhibit enamel opacities; in 22 these were of the idiopathic type, and of the remaining 11, 8 were classified as having 'questionable fluorosis', and 3 'very mild fluorosis'. In the control area, of 130 children, 61 (47 per cent) had enamel opacities. All of these were idiopathic, but 11 resembled fluorosis, and using the same classification as in the fluoridation area, 3 of these were classified as 'questionable', 5 as 'very mild', 1 as 'mild' and 2 as

'moderate'. The work of Forrest and James in Anglesey therefore confirms the earlier work of Forrest (1956) indicating that the prevalence of enamel opacities is at its lowest in areas with approximately 1 p.p.m. F. in their water supplies and is valuable confirmation that mottling due to fluorosis does not present a particular problem in fluoridated areas.

In October 1965, a summary of the more important evidence demonstrating the safety of fluoridation was issued in a Symposium on Fluoridation published by the *British Dental Journal* (Martin, 1965) and more detailed information has since been published in two American monographs, *Fluorine Chemistry* Volume IV (Hodge and Smith, 1965) and *The Pharmacology of Fluorides* (Smith, 1966). Further evidence will be summarized in a Technical Monograph on *Fluorides and Human Health* to be published shortly by the World Health Organization.

Evidence on the safety of fluoridation, its scientific, administrative and ethical aspects, has been examined by a number of government commissions and legal tribunals in different parts of the world. Thus in 1957, a Commission of Enquiry sat in New Zealand under the Chairmanship of W. F. Stilwell a, judge of the Arbitration Court. After examining in detail the views and statements of many organizations and individuals including many opposed to the measure, the Commission reported in favour of fluoridation (New Zealand, 1957). In Ontario a Committee under the Chairmanship of the Hon. K. G. Morden, a Justice of the Ontario Court of Appeal, reported on the fluoridation of municipal water supplies (Ontario Government, 1961). After an examination of much scientific detail the Committee concluded, as regards safety, that it was physiologically impossible for any person to consume such quantities of water containing approximately 1 p.p.m. of fluoride as would produce any harmful effects attributable to the fluoride content of the water. Similarly, in South Africa a special committee appointed by the Committee for Research reported in favour of fluoridation (Staz, 1962). More recently in that country a Commission of Enquiry appointed by the Government under the Chairmanship of Mr. W. J. McKenzie, former Attorney-General of the Transvaal, also reported in favour of the safety of fluoridation (Republic of South Africa, 1966). In the Republic of Ireland, in a lengthy case heard in 1963 before Mr. Justice Kenny in the High Court, scientific evidence both for and against fluoridation was examined. The Judge held that the amount of fluoride ingested at a concentration of 1 p.p.m. together with the amount in food, in drink, in the air, and in drugs (so far as we knew it), did not involve any risk to health, and concluded that the fluoridation of the public water supplies was not a violation of constitutional rights. His judgement was subsequently upheld in the Supreme Court of the Republic of Ireland.

In the United Kingdom, careful consideration continued to be given to all reports which might have a bearing on the safety of fluoridation, and specific investigations are carried out wherever necessary. During the eleven years covered by this Report only two cases have been reported from the study areas where a medical practitioner suspected that symptoms in a patient might have been associated with fluoridation. In one of these cases suspicion was dispelled as a result of 'double blind' tests in which the patient was given a series of drinking waters, the fluoride content of which varied from a mere trace to 1·0 p.p.m., and the levels of which were unknown either to her or to the doctor conducting the investigation. This technique was not applicable in the case of

the second patient, whose symptoms were of a more chronic nature. By agreement with the patient's practitioner, her condition was investigated by an independent consultant physician, who was unable to find any symptoms attributable to fluoridation.

The absence of adverse symptoms attributable to fluoridation is borne out by observations from elsewhere. In Birmingham however, where the water has been fluoridated since 1964, a case of soreness of the mouth was investigated by Professor Fremlin in association with the patient's own doctor. (Fremlin *et al.*, 1967.) After trials with the fluoridated soft Birmingham water, with Birmingham water from which the fluoride had been removed, with unfluoridated hard Bromsgrove water, and with Bromsgrove water with 1 p.p.m. F. added, it was stated that while the trials could not be conclusive, it was clear that fluoride was not the main cause of the soreness; the results with Bromsgrove water were identical with or without fluoride. The investigation concluded that the results were more suggestive of a possible real difference, independent of fluoride content, between the effects of the Birmingham soft water and the Bromsgrove hard water. These suspicions were later confirmed by an improvement in the patient's condition stated to have been brought about by the administration of extra calcium. At that time Professor Fremlin amplified his earlier opinion by stating that there was no evidence at all that fluoride was responsible for the patient's symptoms. (Fremlin, 1967.)

Allegations are made from time to time that people have been made ill by consuming fluoridated water. This is not surprising in view of the many alarming but ill founded statements in both the antifluoridation publications and the correspondence columns of newspapers, claiming that fluoridated water is capable of producing a wide range of symptoms. As a result people suffering from real, or at times imaginary, symptoms may be firmly convinced they are being made ill by consuming fluoridated water. Where these cases have been brought to the notice of the Department of Health and Social Security it has been found that either the patient has not sought medical advice, or has refused to accept it. In a number of cases it has been shown that the patient never consumed fluoridated water.

The position remains that after eleven years of fluoridation in this country and a much longer experience in North America there is no evidence of harmful effects from the fluoridation of water supplies at the recommended concentrations.

TECHNIQUES OF FLUORIDATION OF WATER

In Watford the method of fluoridation described in the 1962 Report remained unchanged until 1967. At the Watford Fields Pumping Station the water was lime-softened and fluoridation carried out by means of a sodium fluoride saturator. At the Grove Pumping Station the water was softened by base exchange and sodium silico-fluoride added by means of a volumetric solid feeder, fitted with an automatic control to adjust the rate of chemical feed in accordance with the varying amount of water being pumped.

In November 1967, however, the method of fluoridation at Watford Fields was changed to the use of hydrofluosilicic acid in order to obtain experience of a method which would be suitable in situations where fluoridation would otherwise be more costly. Analyses of the fluoride content of the samples subsequently taken have shown that this is a satisfactory method of fluoridation.

In Anglesey, the water supply from the Cefni works was divided into two parts, one supplying the Gwalchmai and Holyhead areas, and the other supplying the Bodafon area. The former has been fluoridated since November, 1955, but because of the need to supplement the Cefni supply with water from unfluoridated local sources, there has been some dilution of the fluoride content in Holyhead and in several small parts of the Gwalchmai study area. In August 1964, new fluoridation plant was installed at Cefni and from that time the supply from the works to the Bodafon zone has also been fluoridated. In July 1967, at the end of the study period, fluoridation was started at a new works at Llyn Alaw and the local source which diluted the fluoride content in Holyhead was taken out of service. Fluoridation is carried out by means of a volumetric solid feeder using sodium silicofluoride.

Supplies of hydrofluosilicic acid at a favourable price are now becoming available in Great Britain and it is probable that fluoridation using this agent will be the method of preference for many installations. The equipment used for this agent at the larger pumping stations is of a standard type readily available. Tests are now being carried out on new automatic equipment designed to use hydrofluosilicic acid at small stations and this should be useful with sources where it has not hitherto been practicable to add fluoride to the supply.

In the dilutions used in the fluoridation of water, sodium fluoride, sodium silicofluoride, and hydrofluosilicic acid separate into their constituent fluoride sodium and silicate ions. Sodium and silicon are normally present in water supplies in quantities greater than are added during fluoridation, and the fluoride and other ions are identical in all respects with those found naturally in water supplies.

Control over the level of fluoride

Water undertakings practising fluoridation aim at maintaining a level of between 0·9 and 1·1 p.p.m. F. These limits are set because experience has shown that modern fluoridation equipment is capable of maintaining this level, and the number of occasions on which the concentration exceeds 1·1 should be very few. From the health aspect it must be emphasized that these levels have a wide margin of safety, and that raised concentrations would have to be maintained for a considerable length of time for ill effects to be noted. Thus, for instance, while 1·5 p.p.m. continued over a lengthy period might produce signs of fluorosis in the teeth of a very small proportion of children, a concentration of over 8 p.p.m. over a period of many years would be required before any effects on general health might be expected. In the natural fluoride areas of this country levels of up to 6·0 p.p.m. have in fact been tolerated in the past.

The fluoridation equipment in use in the United Kingdom is so designed that a concentration much above the optimum level could not be delivered and the precautions taken by water undertakings and health authorities which are described below, are such that continuing dosage above the level will not occur.

At the fluoridation stations in the study areas daily records are kept of the amount of fluoride used and the daily volume of water pumped, and from this information the concentration of fluoride in the water is calculated. As a second check daily samples of water are taken by the waterworks staff, both from the plant tap and from points in the distribution system, and the concentration of fluoride is determined by a simple colorimetric test. As a further check the

Medical Officers of Health arrange for samples to be drawn from the distribution system and send them for analysis at the Laboratory of the Government Chemist. There is thus a triple check on the concentrations achieved and detailed reports of the results are submitted for examination by the Ministry of Housing and Local Government, and the Department of Health and Social Security. As a further means of control, at one of the Watford pumping stations an automatic monitoring device which makes a continuous record of the fluoride concentration of the treated water has been under test, and has been found to be both accurate and reliable.

The results of the daily tests carried out by the waterworks staffs are shown in Table 1. Apart from short periods when fluoridation was suspended owing to the necessity for plant maintenance, fluoride levels of, or slightly below, 1 p.p.m. F. were satisfactorily maintained in Watford and Anglesey. The supplementation of the Cefni supply by water from unfluoridated local sources referred to on page 7, has resulted in low individual samples in Anglesey and an average fluoride content of 0·7 p.p.m. in Holyhead.

Concentrations higher than 1·1 p.p.m. (from 1·2 to 2·5 p.p.m.) were found by the Government Chemist on ten occasions out of 283, nine of them in samples of water from Anglesey. Local analyses, on samples of water obtained on the same days gave no levels above 1·1 p.p.m., and calculations based on the amounts of fluoride used and the amounts of water pumped confirmed the levels found on local analysis. It seems therefore that the higher figures reported by the Government Chemist were not representative of the levels prevailing in the distribution system. The reasons could not be established; a possible explanation is that the water samples sent to the Government Laboratory had, in these isolated instances, become contaminated, perhaps due to the use of contaminated bottles.

DESCRIPTION OF STUDIES

The general plan of the demonstration studies which is described in the 1962 Report has been followed as consistently as practicable. Only children who had lived continuously in the study or control area from birth participated in the studies. Paragraph 2 of Appendix 5 in the 1962 Report described how the preschool children were selected for examination. In Anglesey all eligible school children of the appropriate ages have been examined, and in Watford and Sutton representative cross-sections of children attending school were selected. Table 2 shows the number of children examined.

The only major changes in the studies occurred in October 1962, when the Kilmarnock Burgh Council decided to discontinue fluoridation there, and in August 1964, when fluoridation was introduced in the Bodafon zone of Anglesey, after the County Council had decided that children in that part of their area should also receive the benefits of fluoridation. Although this was the control area for the Gwalchmai zone, the Research Committee felt that studies in Bodafon up to 1967 could still be of interest, even though its value as a control would be limited.

During the first five years of fluoridation, dental examinations were carried out annually from 1955–56 to 1961. They were then discontinued for a period and were resumed in Watford and Sutton in the autumn of 1964, and in Anglesey in the spring of 1965. Thereafter they have been conducted annually in all areas.

The same dentist has examined children in Watford, Sutton, and Holyhead throughout the studies; for the 1964 examinations this dentist was joined by two others in Watford and Sutton. In the Gwalchmai and Bodafon zones of Anglesey one dentist has carried out all the examinations throughout the period.

In this Report, as in the previous one, the main criterion used for the measurement of dental decay (caries) is the average number of decayed, missing and filled teeth per child. The changes in this index over the period of the studies give some indication of the changes in the amount of dental treatment needed. Further criteria used in the studies are the proportions of children free from dental decay, and the proportions with ten or more decayed teeth. At ages three and four the figures were based on the full temporary dentition. Owing to the natural shedding of certain teeth that takes place after those years the figures for the five-, six- and seven-year-olds are related to the temporary canines and molars only.

DENTAL FINDINGS

The detailed results from the studies will be found in Tables 3–10 and Figures 1–8. In considering these it is necessary to bear in mind that in Holyhead, the fluoride concentration averaged only 0·7 p.p.m. over the period of the studies; that Holyhead is a separate study area without a control; and that water in the Bodafon control area has itself been fluoridated since August 1964. Thus the dental benefits in Holyhead are probably a little less than would be expected had the level been 1 p.p.m., and a comparison between Gwalchmai and Bodafon to some extent understates the effects of fluoridation in the former area, while in the latter, fluoridation has not been in progress long enough to show what it can achieve. Some degree of variation in the prevalence of decay has been found to occur in the control areas and this is discussed on page 20.

Permanent teeth, 8–10-year-old children (Figures 1 and 2)

In assessing these results it should be appreciated that by the age of ten years only half the permanent teeth have erupted, some of them very recently. To show the benefits of fluoridation on the full dentition all the teeth must have erupted and have been exposed for a sufficient length of time for decay to be recognized.

Taking the eight-, nine-, and ten-year-olds together, over the period of the study the number of decayed permanent teeth in Watford fell by one half, while in the control area of Sutton there was a fall of only one-fifth. In the Gwalchmai study area there was a reduction of about one-eighth, compared with an increase of one-eighth in its control area (Bodafon). In Holyhead the number of decayed teeth was nearly halved.

In the three fluoridation study areas taken as a whole the proportion of children free from dental decay has more than doubled, in contrast with the two control areas which had only a slight improvement.

FIGURE I.

AVERAGE NUMBERS OF DECAYED, MISSING AND FILLED TEETH PER CHILD.

Permanent Teeth.

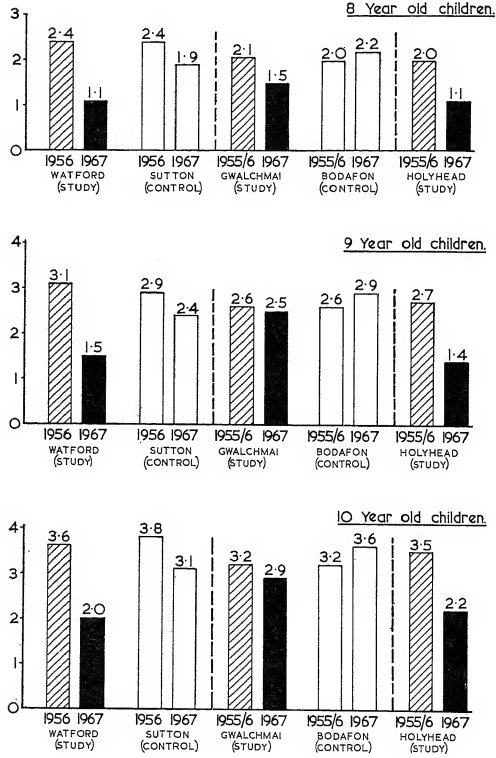
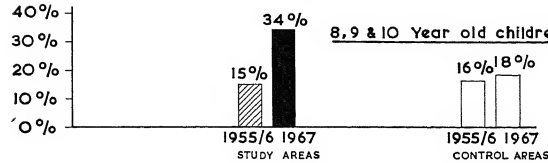


FIGURE 2.
PROPORTION OF CHILDREN FREE FROM DENTAL DECAY
Permanent Teeth.



Permanent teeth, 11–14-year-old children (Figures 3 and 4)

At the time the examinations took place, children in this age group had not had the experience of fluoridation from birth, and consequently the results do not demonstrate the maximum potential benefit which can be expected when fluoridation has been in operation long enough. Nevertheless Figures 3 and 4 indicate a considerable interim improvement in dental health.

Temporary teeth (Figures 5–8)

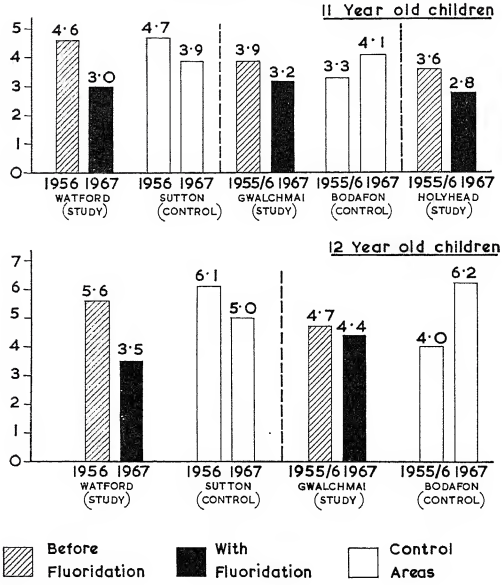
The report provides an opportunity to demonstrate the results of fluoridation on the temporary teeth of children aged from three to seven, who had drunk fluoridated water since birth.

For the 3–4-year-old age group in the three study areas with fluoridated water supply the average number of decayed teeth fell by as much as two-thirds compared with a reduction of only one-fifth in the two control areas, and the corresponding reductions for the 5–7-year-old age group were one half in the study areas and only one-fifth in the control areas.

Over the whole age range three to seven years inclusive, the reductions in the study areas were about two-thirds in Watford, and about one half in both Gwalchmai and Holyhead, and in the control areas a third in Sutton and one-tenth in Bodafon.

Fluoridation also led to an increase in the proportion of children free from decay. In the three- and four-year-old children, the proportion in the study areas doubled while in the control areas it rose by about one quarter, and in the five- to seven-year-old children, the proportion in the study areas showed a fourfold increase, while in the control areas it doubled. Therefore, in the age range

FIGURE 3.
AVERAGE NUMBERS OF DECAYED MISSING AND FILLED TEETH PER CHILD
Permanent Teeth.



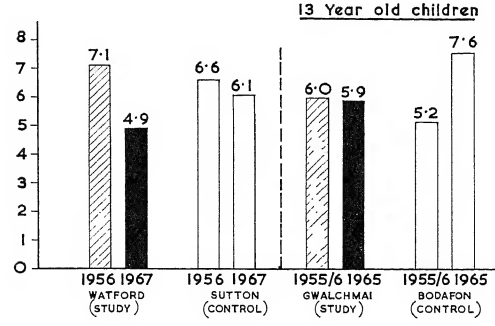
three to seven inclusive, the increase in the proportion free from decay in the study areas was four times greater than that in the control areas.

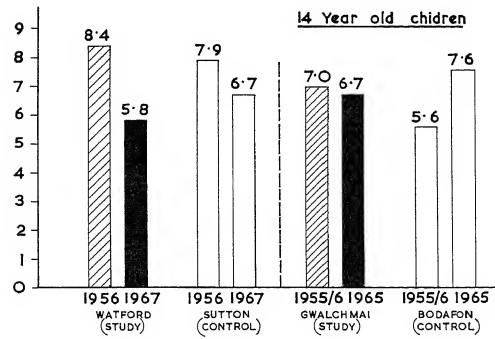
The proportion of children aged three to seven inclusive, with ten or more decayed teeth, fell by four-fifths in the study areas. In the control areas it fell by somewhat over a third.

Kilmarnock

Although fluoridation in Kilmarnock ceased in October 1962, studies of the dental health of children in that town and in Ayr, its control, were continued by Professor J. N. Mansbridge of Edinburgh University. His report in the Appendix is of particular interest for it shows how the amount of decay in Kilmarnock is now climbing back to its pre-fluoridation level.

FIGURE 4.
AVERAGE NUMBERS OF DECAYED MISSING AND FILLED TEETH PER CHILD
Permanent Teeth.





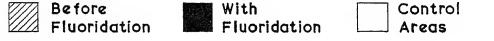


FIGURE 5
AVERAGE NUMBERS OF DECAYED MISSING AND FILLED TEETH PER CHILD

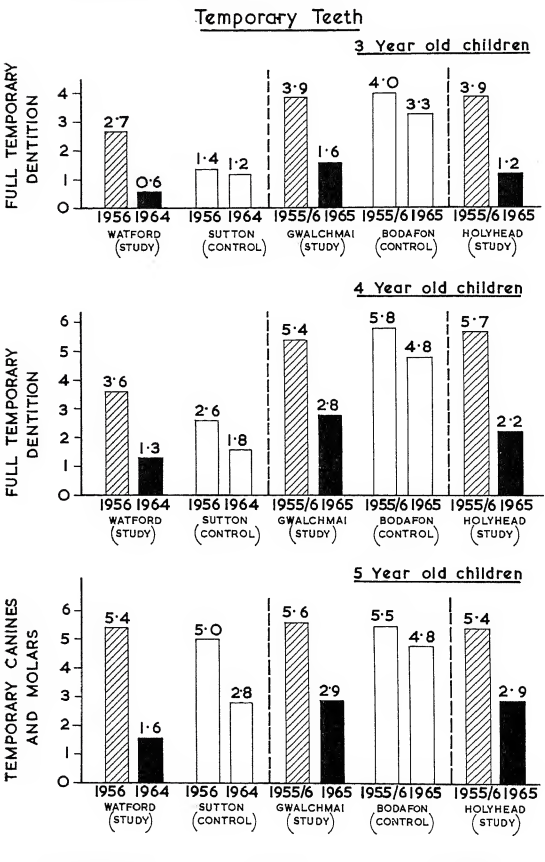


FIGURE 6.

AVERAGE NUMBERS OF DECAYED MISSING AND FILLED TEETH PER CHILD

Temporary Teeth.

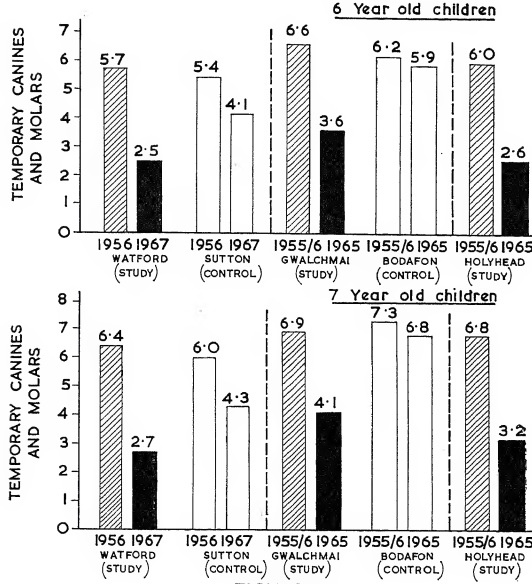


FIGURE 7.

PROPORTION OF CHILDREN FREE FROM DENTAL DECAY

Temporary Teeth

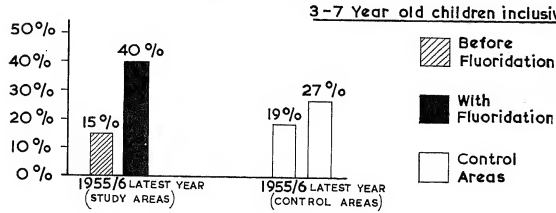
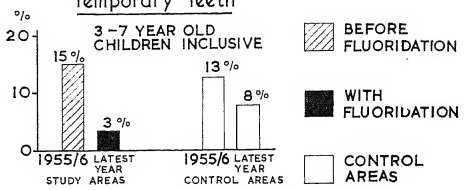


FIGURE 8

PROPORTIONS OF CHILDREN WITH TEN OR MORE DECAYED TEETH



STUDIES IN OTHER COUNTRIES

Some studies of the effects of fluoridation in other countries have been going on long enough to show the effects on older children. This is not yet possible in Britain, where fluoridation in the study areas began in 1955/56, so that only the younger children have consumed fluoridated water all their lives. Figures 9–11 bring together some of the results obtained in other countries. In a Canadian study in Ontario, the prevalence of dental decay in Brantford with a water supply fluoridated at 1 p.p.m., was compared with Stratford where the water had naturally occurring fluoride, and Sarnia where the fluoride content was negligible. The results showed that the benefits of added and naturally occurring fluorides were similar (Brown and Poplove, 1965). It will be seen that in two areas with adequate fluoride in the water, the amount of dental decay in children aged 16 and 17 is less than half that in the control area, and whereas with fluoride about one in eight of such children were completely free from dental decay, the proportion was less than 1 in 200 in the area with unfluoridated water. Other studies showing beneficial results have been conducted in Holland and Sweden (Dirks, 1968; Forrest, 1967).

Dental benefit in adults aged 18–59 has been demonstrated in a study in which Aurora, Illinois with 1·2 p.p.m. of naturally occurring fluoride, was compared with Rockford with 0·1 p.p.m. Substantial benefit was demonstrated throughout the age range (Englander and Wallace, 1962).

When children aged four to eight years inclusive in Kingston, New York, a town without a fluoridated water supply, first attended for dental care, they were found to need nearly 60 per cent more treatment time than children of the same age group in fluoridated Newburgh, and they subsequently needed 80 per cent more treatment time to deal with later dental decay (Ast *et al.*, 1967). In New Zealand, it is reported that, while in areas with non-fluoridated water a school dental nurse can supervise 450 to 500 children, in areas where the water has been fluoridated for some years, she can now easily look after at least 700 children, keeping them in a high state of dental fitness. Examples of school dental nurses looking after 800 to 900 children are becoming more common (New Zealand Government, 1968). In Evanston, Illinois, the estimated savings

to parents in dental bills was 35–40 per cent for children aged six, seven and eight, and 50 per cent for children aged twelve, thirteen and fourteen (American Dental Association, 1965).

It has never been claimed that fluoridation will completely eliminate dental decay, but the results of the various studies show that (a) the reduction in the amount of decay is very substantial; (b) the effect benefits older children and adults, as well as younger children; and (c) fluoridation makes it much easier for the dental service to provide an adequate level of treatment for the amount of decay that still remains.

FIGURE 9

FLUORIDATION ABROAD

AVERAGE NUMBERS OF DECAYED MISSING AND FILLED TEETH PER CHILD

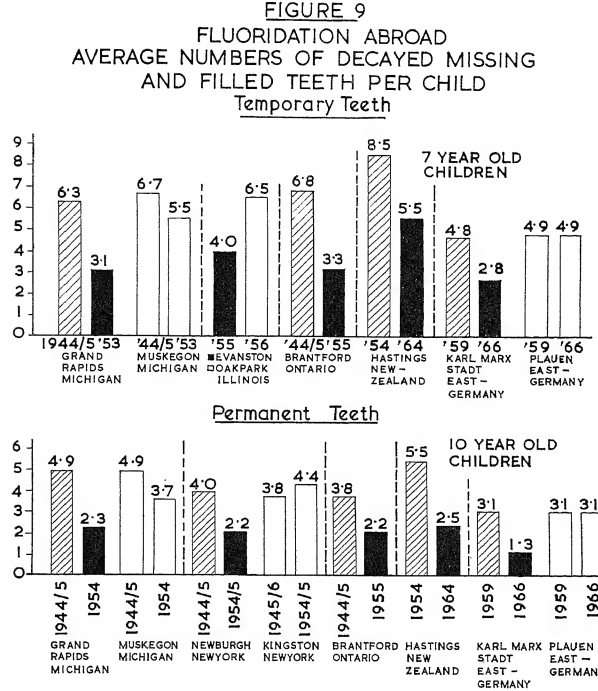


Figure 9. Information in this figure is derived as follows:
Brantford—Hutton *et al.* (1956); Evanston and Oak Park—Blayney *et al.* (1967); Grand Rapids and Michigan—Arnold *et al.* (1956); Hastings—Ludwig (1965); Karl Marx Stadt and Plauen—Kunzel (1960); Newburgh and Kingston–Ast *et al.* (1962).

FIGURE 10

FLUORIDATION ABROAD

AVERAGE NUMBERS OF DECAYED MISSING AND FILLED TEETH PER CHILD

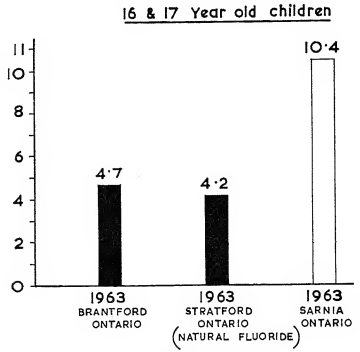
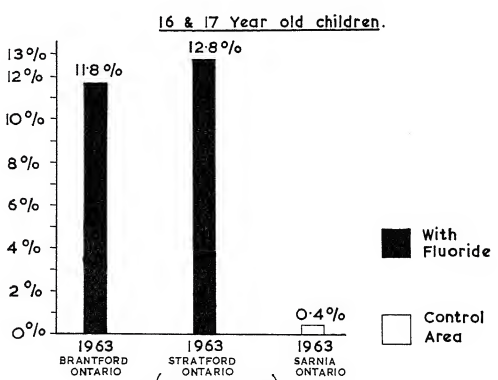


FIGURE 11

FLUORIDATION ABROAD

PROPORTIONS OF CHILDREN FREE FROM DENTAL DECAY.



Figures 10 and 11. Information in these figures is derived from Browne *et al.* (1965).

DISCUSSION

There are considerable differences in the prevalence of dental decay in various parts of the United Kingdom. These are not recognized as widely as they might be and have on occasion given rise to misinterpretation of the results of the fluoridation studies. The differences are more readily appreciated when data from the three control areas, Sutton, Bodafon and Ayr are examined as in Table 11. Some of their geographical and economic characteristics and those of their related study areas have been described on pages 1 and 2. For both temporary and permanent teeth it is seen, that the three control areas are not comparable with each other. The control and study areas were paired because they had similar characteristics, each pair was situated in the same region, and each was as close to its partner as was practicable. It is obvious from an examination of the tables that comparisons of the prevalence of decay should only be made between a study and its corresponding control area. Thus for example, Gwalchmai and Bodafon may be compared, but not Gwalchmai and Sutton.

It is apparent also that during the period of the fluoridation studies the prevalence of decay has altered in the control areas. In some age groups the amount of decay has increased, in others it has decreased. The effects of fluoridation in any study area are judged by comparing the amount of decay in a particular age group with the base-line, i.e. with the amount of decay which existed before the study commenced. The change thus observed has to be considered in relation to any change which has occurred during the same period in the relevant control area.

In the 1962 Report on the studies, the improvement in any age group in a study area was adjusted mathematically to take account of the change in the control area, on the assumption that the same amount of change would have taken place in the study area had there been no fluoridation. Such adjusted figures have not been calculated in this Report as it is felt that they may give an unjustifiable impression of precision. The assumption that had there been no fluoridation, a change would have taken place in a study area of the same order as that in the control area, though not certain, is reasonable. The probability of common influences producing similar effects in each area is greater when the study and control area are adjacent as in Anglesey, than in for example, Sutton and Watford which are some distance apart. Since adjusted figures are not given in this Report it is always necessary when examining figures from a study area to take into account at the same time, the corresponding figures from the control area, in order to obtain an indication of the amount of change which might have taken place had there been no fluoridation.

The 1962 Report, based on five years of fluoridation, dealt mainly with children under the age of six. The further results now available extend information about the effects of fluoridation since birth to children up to age eleven and also show the effects on older children who have drunk fluoridated water for only a part of their lives.

The results of the dental examinations in the study areas over the past eleven years demonstrate the very considerable benefits which fluoridation confers. In the temporary teeth of children aged three to seven inclusive, the amount of decay fell by about a half, more than twice as many children were free from decay, and the number of children with ten or more decayed teeth fell by four-fifths. In the permanent teeth of children aged eight, nine and ten, the reduction

in the amount of decay has been about a third, and again there was a substantial increase in the proportion with no dental decay.

This was in marked contrast to the changes in the control areas. Watford and Sutton are two prosperous urban areas situated some twelve to fifteen miles from the centre of London. In the control area of Sutton, the amount of decay in both the temporary and permanent teeth of children has declined since the base-line study, and it is reasonable to assume that a similar improvement might have taken place in Watford had that area not been fluoridated. The actual improvement in Watford was, however, much greater than this.

In Anglesey, the study and control areas of Gwalchmai and Bodafon are adjacent and of the same rural character. Table 10 shows how, in the permanent teeth of Bodafon children aged eight, nine, ten and eleven, the amount of decay rose during the period of the studies (in contrast to the other control area, Sutton). The underlying factor or factors causing this are unknown, but it can reasonably be assumed that they also affected the adjacent area of Gwalchmai, and would have caused an increase in dental decay in that area had fluoridation not started there in 1955. It is also reasonable to assume that the amount of decay in Gwalchmai would, but for fluoridation, have been greater than the 1967 figures for Bodafon suggest, since Bodafon has itself been fluoridated since August 1964, and, as Table 10 shows, the rise in the amount of decay in that area was checked after fluoridation commenced. In fact, as compared with its base line there has been a reduction in the amount of decay in Gwalchmai at each age studied, and, in the temporary teeth, this has been greater than that in Bodafon.

The social conditions in Holyhead, which is partly urban in character, differ from those in the remainder of Anglesey, and as there is no comparable control area, it was treated as a separate study area. It is important to note that Holyhead received a mixed water supply with an average fluoride level of only 0·7 p.p.m. F. Despite this the reduction in decay in both the temporary and permanent teeth was considerable and shows clearly that in areas where, because of the complexity of the water distribution system, it is not immediately possible to obtain a supply fluoridated at the optimum level of 1 p.p.m. F. a lower fluoride concentration may nevertheless have important beneficial effects.

To the positive improvements resulting from fluoridation of the water supply in Watford and Anglesey must be added the dramatic picture which has emerged in Kilmarnock. In Professor Mansbridge's report in the Appendix it is seen how children's teeth in Kilmarnock benefitted as a result of the six and a half years of fluoridation, and how subsequent to its cessation the prevalence of decay is now rising towards the levels which had existed prior to fluoridation. The effect on the temporary dentition will of course disappear with the shedding of the teeth. Fluoridation did not last long enough for any child to receive the maximum benefit to its permanent dentition, yet some children—those aged 9–14 in 1968 (*see* Table A4) showed considerable improvement, and this small group of children will, judging from experience in natural fluoride areas, carry some degree of benefit into adult life.

A final assessment of the effects of fluoridation on older children will only be possible when the studies have been in progress longer, but the results so far obtained for children aged eleven to fourteen are encouraging. For information on the effects of fluoridation on children in the older age groups it is necessary to consult reports from the United States and Canada where fluorida-

tion has now been practised for over twenty years in Grand Rapids, Newburgh and Brantford. These give a clear indication of the beneficial effects which are to be expected.

Information indicating that the effects will continue into adult life may be obtained from studies in the natural fluoride areas. Weaver (1944) was the first in this country to show benefit in adults. He investigated the dental condition of 100 mothers attending maternity and child welfare centres in each of two towns—South Shields with 1·4 p.p.m. and North Shields with less than 0·25 p.p.m. F. and found that the younger mothers in South Shields had the advantage of about five years in delay of onset of dental decay, but that among the older women there was little difference in the number of defective teeth. Forrest, Parfitt and Bransby (1951) seeking further information in this country carried out investigations of over 500 adults in three high and three low fluoride areas, and found a delay of ten years in the onset of decay. This study like Weaver's was limited to mothers attending ante-natal and infant welfare centres and few of the mothers were aged over 40. Later in the same year in the United States, Russell and Elvove (1951) published a study showing substantial benefit in both men and women to the age of 45 in an area with 2·5 p.p.m. F. in its water supplies. The results of these investigations were discussed in detail in the Report of the United Kingdom Mission (Ministry of Health *et al.*, 1953).

The results of the yet more extensive American survey by Englander and Wallace (1962) mentioned on page 16 showed substantial benefits throughout the age range 18 to 59, and the amount of benefit found in the 50–59 year age group is a clear indication that the protective effects of fluorides persist through at least the greater part of adult life.

Too much importance should not be attached to the study of individual areas in isolation for the strength of the case for fluoridation of water supplies lies not in the results for any single place or any single country, but in the consistency of results from different parts of the world. The findings published in this Report add to the already substantial volume of evidence of the effectiveness of this important public health measure.

CONCLUSIONS

This Report confirms the main findings of 1962, namely that fluoridation produces a substantial reduction in the amount of dental decay in the temporary teeth and shows that in those age groups in which it can be expected to have affected the resistance of permanent teeth to dental decay, fluoridation of water supplies is also having a beneficial effect.

The findings have been given in terms of numbers of decayed, missing and filled teeth, numbers of children free from dental decay, and numbers of children with ten or more decayed teeth, because these are arithmetical results by which comparisons can be made. The results are in line with those which have previously been obtained in similar studies in other parts of the world (*see* Figures 9–11). It must be remembered that fluoride has a continual preventive effect and that it not only reduces the amount but also reduces the rate of dental decay. Furthermore, dentists who have worked in those areas where the water supply is fluoridated are firmly of the opinion that the improved structure of

teeth calcified under the influence of fluoridation results in a strikingly good appearance; the cosmetic effect should not be overlooked.

This Report describes the full effects of fluoridation in children up to the age of 11, and gives an indication of some of the benefits which will be conferred on those of 11–14 years. Evidence from abroad where fluoridation has been practised in the United States and Canada for upwards of twenty years demonstrates the continuing benefits through the first two decades of life, and studies in the natural fluoride areas show the beneficial effects which may be anticipated through at least the greater part of adult life.

The reduction in the number of decayed permanent teeth of ten-year-old children which has occurred at Watford since the water supply was fluoridated represents, over the whole country, a potential reduction of the need to fill over a million permanent teeth in children up to that age each year. Likewise the reduction in the number of decayed temporary teeth at age seven represents nationally an annual potential saving of the need to fill over two and a half million temporary teeth in very young children, who, even in the most favourable circumstances, are not the easiest patients to treat.

Apart from demonstrating the beneficial effects of fluoridation the Report has confirmed its complete safety. During the eleven years under review, medical practitioners reported only two patients with symptoms which they felt might have been associated with fluoridation. Careful investigation in both instances failed to attribute the symptoms to the drinking of fluoridated water.

The Research Committee concludes that the fluoridation of water supplies at the level of 1 p.p.m. F. is a highly effective way of reducing dental decay and is completely safe.

TABLE 1

Concentrations of fluoride ion in samples of water taken from the distribution systems

A. Average concentrations of the fluoride ion

	Period	Number of samples	Average p.p.m.F
Anglesey			
Gwalchmai[a]	June 1961 to	5,355	0·96
Holyhead	July 1967	213	0·71
Watford			
The Grove	June 1961 to	3,172	0·97
Watford Fields ...	December 1967	3,177	1·00

B. Frequency distribution of the fluoride ion

Parts per million F

	0·6 and under	0·7	0·8	0·9	1·0	1·1[b]
Anglesey						
Gwalchmai[a] ...	93	186	490	1,101	2,299	1,186
Holyhead	67	53	54	34	5	—
Watford						
The Grove	17	27	57	910	1,835	326
Watford Fields ...	7	7	24	164	2,555	420

(a) Includes Bodafon after that area was fluoridated from August 1964.
(b) There were no samples with a concentration of more than 1·1 p.p.m.F.

TABLE 2

Numbers of children examined in the study and control areas in the baseline years and the latest years.

Age	ANGLESEY						WATFORD/SUTTON			
	Bodafon zone (control)		Gwalchmai zone (study)		Holyhead (study)		Sutton (control)		Watford (study)	
	Baseline 1955/56	(a) Latest year	Baseline 1955/56	(a) Latest year	Baseline 1955/56	(a) Latest year	Baseline 1956	(a) Latest year	Baseline 1956	(a) Latest year
3	146	105	161	101	149	70	44	144	43	133
4	210	122	227	149	186	118	47	162	66	131
5	256	138	307	170	249	114	110	119	148	111
6	331	133	336	185	267	125	127	107	182	130
7	346	130	366	139	274	127	121	133	192	172
8	351	125	320	156	287	127	148	79	199	95
9	325	134	293	138	260	122	166	95	227	135
10	308	133	255	134	247	107	160	80	134	115
11	270	42	217	59	61	67	126	122	145	200
12	265	108	186	108	(b)	(b)	51	99	111	134
13	274	105	178	93	(b)	(b)	52	127	91	132
14	243	96	158	93	(b)	(b)	36	108	70	90

(a) The latest years were as follows: *Anglesey* 1967 for ages 8, 9, 10 and 11: 1965 for the remainder.
Watford/Sutton 1964 for ages 3 and 4: 1967 for the remainder.

(b) No examinations.

TABLE 3

WATFORD (study) SUTTON (control)

Average numbers of decayed, missing and filled teeth per child

		Average per child		Percentage reduction %
		Baseline (1956)	Latest[a] year	
Full temporary dentition				
Age 3	Watford	2·7	0·6	77
	Sutton	1·4	1·2	12
Age 4	Watford	3·6	1·3	63
	Sutton	2·6	1·8	30
Temporary canines and molars only				
Age 5	Watford	5·4	1·6	70
	Sutton	5·0	2·8	44
Age 6	Watford	5·7	2·5	55
	Sutton	5·4	4·1	25
Age 7	Watford	6·4	2·7	58
	Sutton	6·0	4·3	29
Ages 3–7	Watford	4·8	1·8	63
	Sutton	4·1	2·8	30
Permanent dentition				
Age 8	Watford	2·4	1·1	55
	Sutton	2·4	1·9	23
Age 9	Watford	3·1	1·5	53
	Sutton	2·9	2·4	16
Age 10	Watford	3·6	2·0	45
	Sutton	3·8	3·1	20
Ages 8–10	Watford	3·0	1·5	50
	Sutton	3·0	2·5	19
Age 11	Watford	4·6	3·0	36
	Sutton	4·7	3·9	17
Age 12	Watford	5·6	3·5	37
	Sutton	6·1	5·0	18
Age 13	Watford	7·1	4·9	31
	Sutton	6·6	6·1	7
Age 14	Watford	8·4	5·8	31
	Sutton	7·9	6·7	15
Ages 11–14	Watford	6·4	4·3	33
	Sutton	6·3	5·5	14

(a) 1964 for ages 3 and 4, 1967 for older children.

TABLE 4

WATFORD (study), SUTTON (control)

Percentages of children (a) free from dental decay; (b) with 10 or more decayed teeth

		Percentage of children free from dental decay		Percentage of children with 10 or more decayed teeth	
		Baseline % (1956)	Latest[a] year %	Baseline % (1956)[b]	Latest[a] year %
Full temporary dentition					
Age 3	Watford	37	72	9	Nil
	Sutton	61	67	5	1
Age 4	Watford	35	64	9	1
	Sutton	34	55	4	4
Temporary canines and molars only					
Age 5	Watford	8	46	10	Nil
	Sutton	14	35	10	4
Age 6	Watford	9	36	12	1
	Sutton	10	17	11	1
Age 7	Watford	7	32	14	3
	Sutton	6	18	12	5
Ages 3–7	Watford	19	50	11	1
	Sutton	25	38	8	3
Permanent dentition					
Age 8	Watford	20	53		Nil
	Sutton	22	37		Nil
Age 9	Watford	11	42		Nil
	Sutton	12	21		Nil
Age 10	Watford	10	31		Nil
	Sutton	9	12		Nil
Ages 8–10	Watford	14	42		Nil
	Sutton	14	23		Nil
Age 11	Watford	8	17		Nil
	Sutton	2	10		3
Age 12	Watford	3	15		4
	Sutton	Nil	4		7
Age 13	Watford	3	7		6
	Sutton	4	6		19
Age 14	Watford	Nil	4		11
	Sutton	6	5		23
Ages 11–14	Watford	4	11		5
	Sutton	3	6		13

(a) 1964 for ages 3 and 4, 1967 for older children.
(b) The numbers of children over 7 years old with 10 or more decayed teeth were not recorded in 1956.

TABLE 5

GWALCHMAI (study), BODAFON (control), HOLYHEAD (study)
Average numbers of decayed, missing and filled teeth per child

		Average per child		Percentage reduction or increase(+) %
		Baseline (1955/56)	Latest year[a]	
Full temporary dentition				
Age 3	Gwalchmai	3·9	1·6	58
	Bodafon	4·0	3·3	17
	Holyhead	3·9	1·2	70
Age 4	Gwalchmai	5·4	2·8	49
	Bodafon	5·8	4·8	17
	Holyhead	5·7	2·2	62
Temporary canines and molars only				
Age 5	Gwalchmai	5·6	2·9	49
	Bodafon	5·5	4·8	12
	Holyhead	5·4	2·9	47
Age 6	Gwalchmai	6·6	3·6	47
	Bodafon	6·2	5·9	6
	Holyhead	6·0	2·6	57
Age 7	Gwalchmai	6·9	4·1	41
	Bodafon	7·3	6·8	6
	Holyhead	6·8	3·2	53
Ages 3–7	Gwalchmai	5·7	3·0	48
	Bodafon	5·8	5·1	11
	Holyhead	5·6	2·4	57
Permanent dentition				
Age 8	Gwalchmai	2·1	1·5	26
	Bodafon	2·0	2·2	+11
	Holyhead	2·0	1·1	46
Age 9	Gwalchmai	2·6	2·5	3
	Bodafon	2·6	2·9	+10
	Holyhead	2·7	1·4	47
Age 10	Gwalchmai	3·2	2·9	9
	Bodafon	3·2	3·6	+12
	Holyhead	3·5	2·2	36
Ages 8–10	Gwalchmai	2·6	2·3	12
	Bodafon	2·6	2·9	+11
	Holyhead	2·7	1·6	42
Age 11	Gwalchmai	3·9	3·2	18
	Bodafon	3·3	4·1	+27
	Holyhead	3·6	2·8	21
Age 12	Gwalchmai	4·7	4·4	6
	Bodafon	4·0	6·2	+56
Age 13	Gwalchmai	6·0	5·9	2
	Bodafon	5·2	7·6	+47
Age 14	Gwalchmai	7·0	6·7	3
	Bodafon	5·6	7·6	+36
Ages 11–14	Gwalchmai	5·4	5·0	6
	Bodafon	4·5	6·4	+42

(a) 1967 for ages 8–11 inclusive, 1965 for the remainder.

TABLE 6

GWALCHMAI (study), BODAFON (control), HOLYHEAD (study)
Percentages of children (a) free from dental decay; (b) with 10 or more decayed teeth

		Percentage of children free from dental decay		Percentage of children with 10 or more decayed teeth	
		Baseline (1955/56) %	Latest Year[a] %	Baseline (1955/56)[b] %	Latest year[a] %
Full temporary dentition					
Age 3	Gwalchmai ...	29	55	13	3
	Bodafon	27	20	11	6
	Holyhead ...	28	63	13	1
Age 4	Gwalchmai ...	19	38	24	6
	Bodafon	15	22	19	15
	Holyhead ...	19	48	21	4
Temporary canines and molars only					
Age 5	Gwalchmai ...	10	31	13	3
	Bodafon	7	14	10	10
	Holyhead ...	10	32	11	2
Age 6	Gwalchmai ...	4	21	19	4
	Bodafon	6	11	17	17
	Holyhead ...	6	31	13	2
Age 7	Gwalchmai ...	3	16	22	7
	Bodafon	4	4	25	15
	Holyhead ...	2	24	20	1
Ages 3–7	Gwalchmai ...	13	32	18	5
	Bodafon	12	14	16	13
	Holyhead ...	13	40	16	2
Permanent dentition					
Age 8	Gwalchmai ...	23	32		Nil
	Bodafon	25	21		Nil
	Holyhead ...	24	49		Nil
Age 9	Gwalchmai ...	15	20		Nil
	Bodafon	15	11		Nil
	Holyhead ...	11	41		Nil
Age 10	Gwalchmai ...	13	14		Nil
	Bodafon	8	6		1
	Holyhead ...	12	23		Nil
Ages 8–10	Gwalchmai ...	17	22		Nil
	Bodafon	16	13		Nil
	Holyhead ...	16	38		Nil
Age 11	Gwalchmai ...	12	5		Nil
	Bodafon	13	Nil		2
	Holyhead ...	7	18		1
Age 12	Gwalchmai ...	8	9		7
	Bodafon	10	2		15
Age 13	Gwalchmai ...	4	Nil		10
	Bodafon	5	1		26
Age 14	Gwalchmai ...	5	3		17
	Bodafon	6	1		27
Ages 11–14	Gwalchmai ...	7	4		9
	Bodafon	9	1		18

(a) 1967 for ages 8–11 inclusive, 1965 for the remainder.
(b) The numbers of children over 7 years old with 10 or more decayed teeth were not recorded in 1955/56.

TABLE 7

Study Areas Combined and Control Areas Combined

Average numbers of decayed, missing and filled teeth per child

		Average per child		Percentage reduction or increase(+) %
		Baseline	Latest year	
Full temporary dentition				
Age 3	Study areas	3·5	1·1	67
	Control areas	2·7	2·3	16
Age 4	Study areas	4·9	2·1	57
	Control areas	4·2	3·3	21
Temporary canines and molars only				
Age 5	Study areas	5·5	2·4	55
	Control areas	5·2	3·8	27
Age 6	Study areas	6·1	2·9	53
	Control areas	5·8	5·0	14
Age 7	Study areas	6·7	3·4	50
	Control areas	6·6	5·6	16
Ages 3–7	Study areas	5·3	2·4	55
	Control areas	4·9	4·0	19
Permanent dentition				
Age 8	Study areas	2·1	1·2	43
	Control areas	2·2	2·0	8
Age 9	Study areas	2·8	1·8	36
	Control areas	2·8	2·7	3
Age 10	Study areas	3·4	2·4	31
	Control areas	3·5	3·3	5
Ages 8–10	Study areas	2·8	1·8	36
	Control areas	2·8	2·7	5
Age 11	Study areas	4·0	3·0	26
	Control areas	4·0	4·0	+ 1
Age 12	Study areas	5·1	4·0	23
	Control areas	5·0	5·6	+11
Age 13	Study areas	6·6	5·4	18
	Control areas	5·9	6·9	+17
Age 14	Study areas	7·7	6·3	19
	Control areas	6·8	7·2	+ 7
Ages 11–14	Study areas	5·9	4·7	21
	Control areas	5·4	5·9	+ 9

TABLE 8

Study Areas Combined and Control Areas Combined

Percentages of children free from dental decay

		Baseline %	Latest Year %	Increase or decrease (—) in Percentages %
Full temporary dentition				
Age 3	Study areas	31	63	103
	Control areas	44	44	Nil
Age 4	Study areas	24	50	108
	Control areas	25	39	56
Temporary canines and molars only				
Age 5	Study areas	9	36	300
	Control areas	11	25	127
Age 6	Study areas	6	29	383
	Control areas	8	14	75
Age 7	Study areas	4	24	500
	Control areas	5	11	120
Ages 3–7	Study areas	15	40	167
	Control areas	19	27	42
Permanent dentition				
Age 8	Study areas	22	45	105
	Control areas	24	29	21
Age 9	Study areas	12	34	183
	Control areas	14	16	14
Age 10	Study areas	12	23	92
	Control areas	9	9	Nil
Ages 8–10	Study areas	15	34	127
	Control areas	16	18	13
Age 11	Study areas	9	13	44
	Control areas	8	5	−37
Age 12	Study areas	6	12	100
	Control areas	5	3	−40
Age 13	Study areas	4	4	Nil
	Control areas	5	4	−20
Age 14	Study areas	3	4	33
	Control areas	6	3	−50
Ages 11–14	Study areas	6	8	33
	Control areas	6	4	−33

TABLE 9

Study Areas Combined and Control Areas Combined

Percentages of children with 10 or more decayed teeth

		Baseline (a) %	Latest Year %	Reduction in Percentages %
Full temporary dentition				
Age 3	Study areas	12	1	92
	Control areas	8	4	50
Age 4	Study areas	18	4	78
	Control areas	12	10	17
Temporary canines and molars only				
Age 5	Study areas	11	2	82
	Control areas	10	7	30
Age 6	Study areas	15	2	87
	Control areas	14	9	36
Age 7	Study areas	19	4	79
	Control areas	19	10	47
Ages 3–7	Study areas	15	3	80
	Control areas	13	8	38
Permanent dentition				
Age 8	Study areas		Nil	
	Control areas		Nil	
Age 9	Study areas		Nil	
	Control areas		Nil	
Age 10	Study areas		Nil	
	Control areas		1	
Ages 8–10	Study areas		Nil	
	Control areas		Nil	
Age 11	Study areas		Nil	
	Control areas		3	
Age 12	Study areas		6	
	Control areas		11	
Age 13	Study areas		8	
	Control areas		23	
Age 14	Study areas		14	
	Control areas		25	
Ages 11–14	Study areas		7	
	Control areas		15	

(a) The numbers of children over 7 years old with 10 or more decayed teeth were not recorded for the baseline years.

TABLE 10

GWALCHMAI (study) BODAFON (control)

Average numbers of decayed, missing and filled teeth per child: ages 8, 9, 10 and 11.

1955/56–1967

		Average per child				
		1955/56	1961	1965	1966	1967
Age 8	Gwalchmai	2·1	1·8	2·0	1·8	1·5
	Bodafon	2·0	2·1	2·9	2·2	2·2
Age 9	Gwalchmai	2·6	2·6	2·6	2·4	2·5
	Bodafon	2·6	3·3	3·5	2·9	2·9
Age 10	Gwalchmai	3·2	2·8	3·2	2·6	2·9
	Bodafon	3·2	3·9	4·0	3·8	3·6
Age 11	Gwalchmai	3·9	4·1	4·0	3·3	3·2
	Bodafon	3·3	4·6	5·4	4·0	4·1

TABLE 11

Comparisons of the average number of carious teeth per child in the Control areas, in England, Wales and Scotland

Temporary Teeth

	Age 3	*Age 4*	*Age 5*	*Age 6*	*Age 7*
Baseline					
Sutton	1·4	2·6	5·0	5·4	6·0
Bodafon	4·0	5·8	5·5	6·2	7·3
Ayr	5·2	7·2	6·5	7·3	8·0
Latest Year					
Sutton	1·2	1·8	2·8	4·1	4·3
Bodafon	3·3	4·8	4·8	5·9	6·8
Ayr	3·2	7·0	6·0	7·2	7·5

Permanent Teeth

	Age 8	*Age 9*	*Age 10*	*Age 11*	*Age 12*	*Age 13*	*Age 14*
Baseline							
Sutton	2·4	2·9	3·8	4·7	6·1	6·6	7·9
Bodafon	2·0	2·6	3·2	3·3	4·0	5·2	5·6
Ayr		3·7	4·5	5·4	7·3	8·4	8·7
Latest Year							
Sutton	1·9	2·4	3·1	3·9	5·0	6·1	6·7
Bodafon	2·2	2·9	3·6	4·1	6·2	7·6	7·6
Ayr		4·2	5·3	6·5	9·1	10·2	12·4

APPENDIX

The Kilmarnock Studies

by

Professor J. N. Mansbridge, University of Edinburgh

Fluoridation of the Kilmarnock water supply began in April 1956, and continued until October 1962 when the Kilmarnock Town Council decided to end fluoridation. Throughout this period, representative samples of children in the age range 3–14 years were examined annually in Kilmarnock together with comparable samples of children in Ayr. Following the cessation of fluoridation of the water supply at Kilmarnock in 1962, the annual examinations were continued by the same two dental examiners who were responsible for the examinations in the period 1956 to 1962. In the Kilmarnock Study it is therefore possible to assess the effects of six and a half years of fluoridation on children's teeth and to determine the subsequent effects of reverting to an unfluoridated water supply.

Results

Temporary Teeth

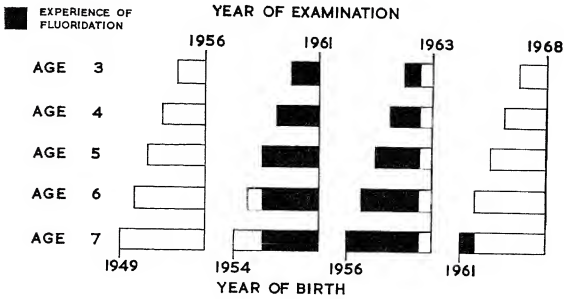
To be fully effective, fluoride should be absorbed continuously during the whole period of tooth formation and calcification and preferably longer. The temporary teeth begin to form before birth and their calcification is completed by one year of age. As the Kilmarnock water supply was fluoridated for only six and a half years, i.e. from April 1956 to October 1962, it is not possible to demonstrate the full effects of fluoridation in *all* the age groups in any *one* year. The extent to which fluoridation was experienced by Kilmarnock children aged 3–7 years in 1956, 1961, 1963 and 1968 is as follows:

(a) 1956: None of the Kilmarnock children had any experience of fluoridation.
(b) 1961: After five years of fluoridation in Kilmarnock the teeth of children up to 5 years of age had had the full effects of fluoridation and the older children had not experienced the full effect.
(c) 1963: All children up to the age of 7 years had experienced fluoridation from birth until 1962, when fluoridation ceased.
(d) 1968: Only the 6- and 7-year-old children had experienced some fluoridation of short duration.

The situation is illustrated in Figure A1, from which it is apparent that one could expect the greatest effect of fluoridation to be seen in *all* these age groups at the 1963 examinations. By that time all children had received the full benefits of fluoridation during the period of tooth development, i.e. first year of life, and longer. (The children examined in 1961 had drunk fluoridated water for five years but not for the whole period of tooth development, as the 6- and 7-year-old children had completed the dental development of their temporary teeth *before* the water supply was fluoridated. Similarly, it is also apparent that the effects resulting from the cessation of fluoridation should be found in all these age groups in 1968. These are the effects which were in fact found, as is shown in Figure A2. The data from which this figure is derived are presented in Table A1.

FIGURE A1

EXPERIENCE OF FLUORIDATION, CHILDREN AGED 3-7YRS EXAMINED IN KILMARNOCK IN 1956, 1961, 1963 AND 1968.

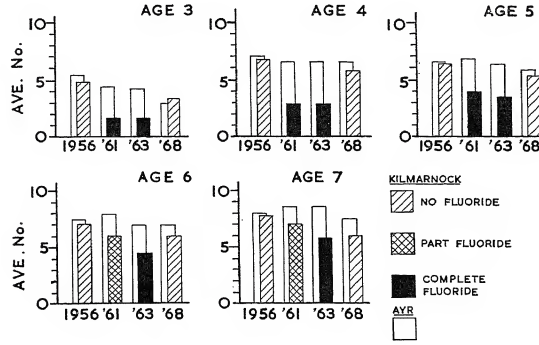


From Figure A2 it may be seen that the benefits shown in the 3-, 4- and 5-year-olds in 1961, continued in 1963. By 1963 however, 6- and 7-year-old children had also received the benefit of fluoridation during the period of tooth development, and showed a substantial reduction in the number of decayed teeth per child compared to the earlier years. In 1968 the prevalence of tooth decay in Kilmarnock children at all ages from 3–7 years had increased; and for the 3-, 4- and 5-year-old children closely approximating the level of decay found in the control area, Ayr.

The proportion of children with ten or more decayed teeth shows a similar pattern over the period 1956 to 1968. For those aged 3, 4, 5 and 6 years, the lowest proportion occurred in 1963, and increased substantially by 1968, in those denied the benefits of fluoridated water. In 7-year-old children, the greatest reduction occurred in 1968. These findings are illustrated in Figure A3 and the data are presented in Table A2.

FIGURE A 2

AVERAGE NUMBER OF DECAYED TEMPORARY TEETH PER CHILD FOR CHILDREN AGED 3-7 YEARS IN 1956, 1961, 1963 AND 1968 IN KILMARNOCK AND AYR.



Fluoridation for six and a half years, resulted in an *increase* in the proportion of children free from dental decay, in the age groups 3 to 7 years by 1963. However, by 1968, as a result of the cessation of fluoridation at Kilmarnock, the proportion of children free from decay approximated to the pre-fluoridation level of 1956, and to that of the control children in Ayr. These changes are illustrated in Figure A4 and are presented in Table A3.

Thus it can be seen that in Kilmarnock, fluoridation commencing in 1956, resulted in a substantial reduction in decay in the temporary teeth of children up to the age of 7 years. The cessation of fluoridation in 1962 has now resulted in a *rise* in the prevalence of decay almost to the level found prior to fluoridation.

Permanent Teeth

As previously stated, fluoride should be absorbed continuously during the whole period of tooth formation and calcification to be fully effective. The permanent teeth develop over a period extending from birth to 12 years of age. This pattern of development is illustrated in Figure A5.

Fluoridation at Kilmarnock continued for only six and a half years and therefore it is not possible to demonstrate the *full* effects of fluoride on the permanent dentition. However, from what is known of the pattern of tooth development, it was clear that fluoridation for six and a half years could be expected to exert *some* influence on the permanent teeth of those children who, when examined in 1968, were aged 9–14 years. That period of their lives during which the water supply of Kilmarnock was fluoridated is shown in Figure A6.

FIGURE A 3

PERCENTAGE OF CHILDREN AGED 3-7 YEARS WITH TEN OR MORE DECAYED TEETH IN KILMARNOCK AND AYR IN 1956, 1961, 1963 AND 1968.

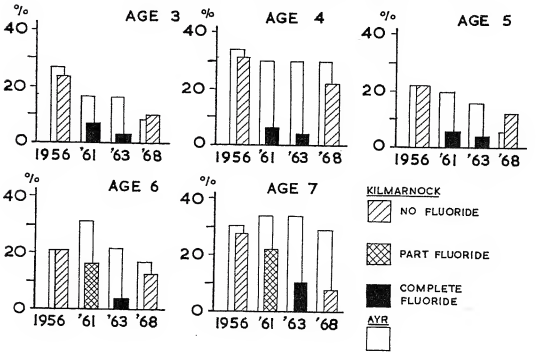


FIGURE A 4

PERCENTAGE OF CHILDREN AGED 3-7 YEARS FREE FROM DENTAL DECAY IN KILMARNOCK AND AYR IN 1956, 1961, 1963 AND 1968.

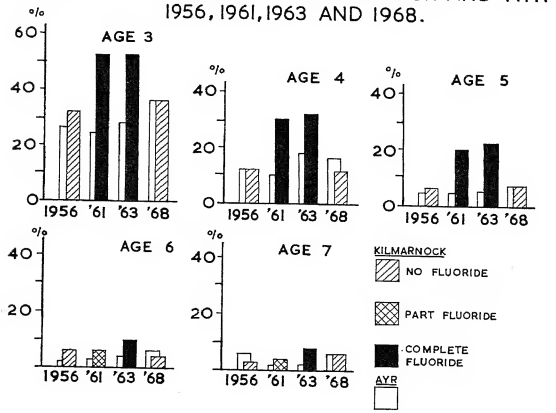


FIGURE A 5
THE PATTERN OF DENTAL DEVELOPMENT
Permanent Teeth

Diagram illustrating the ages at which each crown is being laid down and at which each tooth erupts.

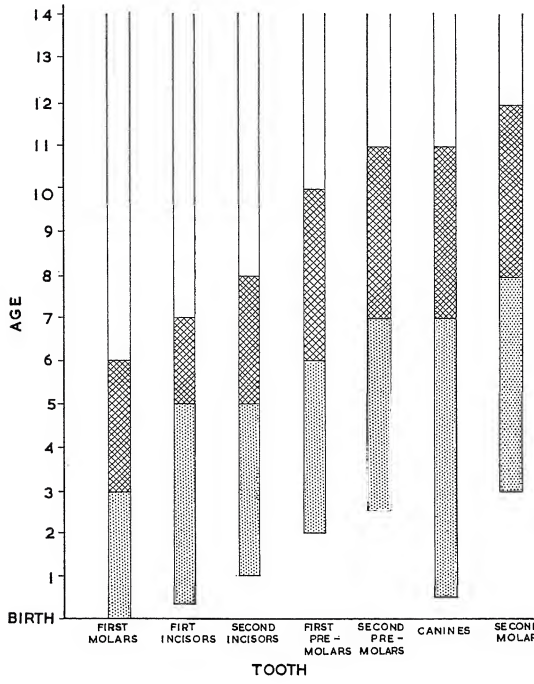
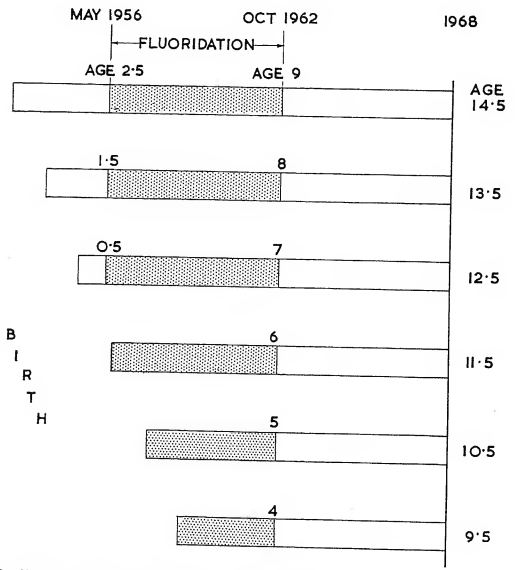


FIGURE A 6

CHILDREN AGED 9-14 YRS. IN 1968 SHOWING THAT PERIOD OF THEIR LIVES DURING WHICH THE WATER SUPPLY IN KILMARNOCK WAS FLUORIDATED



The findings of dental examinations in children 9–14 years in Kilmarnock and Ayr in 1956 and 1968, are illustrated in Figures A7 and A8, and are also presented in Table A4. They show that, in 1956, before fluoridation began at Kilmarnock, the average number of decayed teeth per child was of much the same order in both the Kilmarnock and Ayr children. By 1968, however, the Kilmarnock children, after only six and a half years fluoridation or less at some time in their lives have substantially less decayed teeth than their counterparts in Ayr, the control town.

Over the period 1956–1968, in the Ayr children, the average number of decayed teeth per child increased in all the age groups (9–14 years), whereas in Kilmarnock, the average number of decayed teeth per child has either remained much the same or else decreased.

A similar pattern can be seen in the proportion of children with ten or more decayed teeth. In Ayr an increase has occurred in all age groups between 1956 and 1968, whilst in Kilmarnock there has been a decrease in all but the 14-year-olds.

The numbers of children free from decay of the permanent teeth in both Ayr and Kilmarnock are so few, that no illustration is given. However, the proportion of those free from decay are presented in Table A5.

The dental findings for permanent teeth have therefore shown that fluoridation, even although operative for only part of the total period of tooth development, exerted a considerable influence in inhibiting decay.

FIGURE A 7

KILMARNOCK AND AYR 9 - 14 YEAR OLD CHILDREN - 1956 AND 1968

AVERAGE NUMBER OF DECAYED TEETH PER CHILD

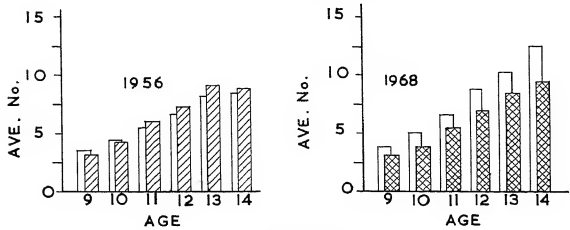


FIGURE A 8

KILMARNOCK AND AYR 9-14 YEAR OLD CHILDREN - 1956 AND 1968

PERCENTAGE OF CHILDREN WITH 10 OR MORE DECAYED TEETH

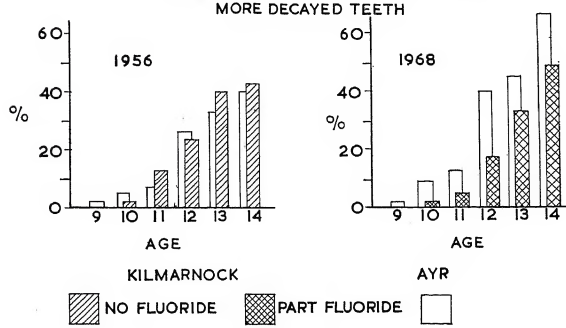


TABLE A1

TEMPORARY TEETH

RESULTS OF DENTAL EXAMINATIONS IN 1956, 1961, 1963 AND 1968

Age Group	Area	Average number of decayed teeth per child (dmf)				*Percentage reduction		
		Baseline	1961	1963	1968	1961	1963	1968
3[1]	Ayr (Control)	5·20	4·45	4·30	3·23	14	17	38
	Kilmarnock (Study)	4·87	1·88	1·79	3·67	61	63	25
4[1]	Ayr (Control)	7·16	6·86	6·85	6·96	4	5	3
	Kilmarnock (Study)	7·12	2·97	2·99	6·08	58	58	15
5[2]	Ayr (Control)	6·52	6·89	6·61	5·98	− 6	− 1	8
	Kilmarnock (Study)	6·44	3·99	3·64	5·81	38	43	10
6[2]	Ayr (Control)	7·29	8·11	7·33	7·21	−11	− 1	1
	Kilmarnock (Study)	7·19	6·05	4·70	6·28	16	35	13
7[2]	Ayr (Control)	7·96	8·45	8·48	7·53	− 6	− 7	5
	Kilmarnock (Study)	7·85	7·09	5·58	6·05	10	29	23

* N.B. a minus percentage reduction is in effect a percentage *increase*.
[1] Full deciduous dentition.
[2] Deciduous canines and molars only.

RESULTS OF DENTAL EXAMINATIONS IN 1956, 1961, 1963 AND 1968

TABLE A2

Age Group	Area	Percentage of children with 10 or more decayed teeth			
		1956	1961	1963	1968
3[1]	Ayr (Control)	27	17	17	9
	Kilmarnock (Study) ...	23	4	2	13
4[1]	Ayr (Control)	34	30	31	31
	Kilmarnock (Study) ...	31	5	4	22
5[2]	Ayr (Control)	21	19	15	5
	Kilmarnock (Study) ...	21	5	3	10
6[2]	Ayr (Control)	21	31	22	19
	Kilmarnock (Study) ...	21	16	3	15
7[2]	Ayr (Control)	30	35	35	29
	Kilmarnock (Study) ...	29	23	10	8

TABLE A3

Age Group	Area	Percentage of children free from dental decay			
		1956	1961	1963	1968
3[1]	Ayr (Control	25	22	29	37
	Kilmarnock (Study) ...	31	51	51	37
4[1]	Ayr (Control)	13	11	17	15
	Kilmarnock (Study) ...	12	30	31	12
5[2]	Ayr (Control)	4	4	5	7
	Kilmarnock (Study) ...	6	20	22	7
6[2]	Ayr (Control)	1	2	3	4
	Kilmarnock (Study) ...	6	6	10	3
7[2]	Ayr (Control)	3	1	1	4
	Kilmarnock (Study) ...	2	2	6	4

[1] Full deciduous dentition.
[2] Deciduous canines and molars only.

TABLE A4

PERMANENT TEETH

RESULTS OF DENTAL EXAMINATIONS OF CHILDREN AGED 9–14 YEARS IN KILMARNOCK AND AYR IN 1956 AND 1968

Age Group	Area	Average number of decayed teeth per child (D.M.F.)		Latest year as percentage of baseline	Percentage of children with 10 or more decayed teeth		Latest year as percentage of baseline
		1956	1968		196	198	
9	Ayr (Control)	3·7	4·2	114	1	1	100
	Kilmarnock (Study Area)	3·4	3·7	109	—	—	—
10	Ayr (Control)	4·5	5·3	118	3	9	300
	Kilmarnock (Study Area)	4·4	4·1	93	1	2	50
11	Ayr (Control)	5·4	6·5	120	7	13	186
	Kilmarnock (Study Area)	5·8	4·9	84	13	4	31
12	Ayr (Control)	7·3	9·1	125	27	39	144
	Kilmarnock (Study Area)	7·4	6·6	89	25	17	68
13	Ayr (Control)	8·4	10·2	121	34	48	141
	Kilmarnock (Study Area)	9·1	8·4	92	41	34	83
14	Ayr (Control)	8·7	12·4	143	41	67	163
	Kilmarnock (Study Area)	9·0	9·6	107	42	49	117

TABLE A5

Permanent Teeth

Percentage of Children Free from Dental Decay In 1956 and 1968

Age Group	Area	Percentage of children free from dental decay	
		1956	1968
9	Ayr (Control)	7	2
	Kilmarnock (Study Area)	4	4
10	Ayr (Control)	6	2
	Kilmarnock (Study Area)	7	2
11	Ayr (Control)	3	Nil
	Kilmarnock (Study Area)	2	1
12	Ayr (Control)	5	Nil
	Kilmarnock (Study Area)	2	Nil
13	Ayr (Control)	2	Nil
	Kilmarnock (Study Area)	2	1
14	Ayr (Control)	Nil	Nil
	Kilmarnock (Study Area)	Nil	Nil

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