Arch. oral Biol. Vol. 5, pp.284–300, 1961. Pergamon Press Ltd. Printed in Gt. Britain.

THE RESULTS OF 6½ YEARS OF ARTIFICIAL FLUORIDATION OF DRINKING WATER IN THE NETHERLANDS

THE TIEL—CULEMBORG EXPERIMENT

O. BACKER DIRKS, B. HOUWINK and G. W. KWANT

Organization for Health Research T.N.O., Laboratory of Microbiology, University of Utrecht, Netherlands

Abstract—In order to assess the effect of water fluoridation on dental caries under Dutch living conditions (food, water consumption, etc.) the drinking water of Tiel was fluoridated since 1953 at 1·1 mg/l. The nearby city of Culemborg served as control (±0·1 mg natural fluoride per litre of water). The principal study groups contained each second year the 11–15 year old children from both cities. Approximal caries was estimated from radiographs only, caries of occlusal and free smooth surfaces in a clinical examination. Both methods were standardized as far as possible. The results after 6½ years of water fluoridation show an important caries inhibiting effect on caries of approximal and free smooth surfaces. The inhibition of occlusal cavities is (at the present time) far less marked. The favourable effect of this water fluoridation is in many respects similar to the results of American studies after the same interval.

INTRODUCTION

THE WELL-KNOWN investigations on artificial water fluoridation in America which started in 1945 (Grand Rapids, Newburgh, Brantford) and 1946 (Evanston) demonstrated the importance of this measure in the prevention of dental caries (ARNOLD *et al.*, 1956; AST *et al.*, 1956; HILL, BLANEY and WOLF, 1957; BROWN, MCLAREN and POPHOVE, 1960). The numerous studies of the last three decades on the effect of fluorides strongly point to the fact that water fluoridation does not endanger the health of the consumer (ORGANISATION MONDIALE DE LA SANTÉ, 1958; HEALTH COUNCIL, 1960; MUHLER and HINE, 1960).

Notwithstanding these studies, the Organization for Health Research T.N.O. in 1951 considered that they were an insufficient basis for fluoridation of the drinking water in the Netherlands. The differences both in dietary habits—which strongly influence caries activity—and in the consumption of drinking water—which determines the fluoride-uptake—made it impossible to apply with confidence the results of the American studies to the Netherlands.

For these reasons it was decided to carry out a study in the Netherlands.

A sociological investigation of a large number of municipalities was carried out in order to find the most suitable pair of cities.

Attention was given to population structure, site, size (above 15,000 inhabitants), migration and water composition, and two cities were selected which were as equal as

possible in these and other respects. Tiel and Culemborg, situated between the rivers Rhine and Maas at a distance of 10 miles from each other, were chosen for the study.

In March 1953 the drinking water in Tiel was fluoridated at a level of 1·1 mg/l. Culemborg with a fluoride concentration of 0·10 mg/l was to serve as control.

METHODS OF CARIES EXAMINATION

Generally four main types of dental caries lesions are distinguished, i.e. lesions of fissures and pits, of the approximal surfaces, of the free smooth surfaces (buccal and lingual surfaces) and of the cervices of the teeth.

This differentiation is more than a purely anatomical and clinical classification. The intra-patient correlation of these types of caries is generally poor (BARR, DIODATI and STEPHENS, 1957) and lends weight to the supposition that the systemic and dietary factors leading to the initiation of caries are not the same for these four types of lesions. Moreover, it is known that these different types of caries are not influenced to an equal extent by fluorides.

The grouping together for statistical purposes of these different caries forms may result in a distorted picture and in the loss of valuable information. It was therefore decided to evaluate the various forms separately.

As approximal caries is the most important one from the therapeutic point of view, our attention was directed in the first place to the evaluation of this type.

Caries of the approximal surfaces

For approximal caries the clinical examination using mirror and explorer was completely abandoned, because of its poor accuracy which makes it almost impossible to standardize diagnosis (GREEN and WEISENSTEIN, 1960; BACKER DIRKS and VAN AMERONGEN, 1953). Furthermore with this method it is impossible to exclude variation in the standard, either during an examination or between yearly examinations and, what is even worse, there is no way of determining the extent of this change in standard.

Approximal caries was exclusively diagnosed from radiographs as described elsewhere (BACKER DIRKS, VAN AMERONGEN and WINKLER, 1951; BACKER DIRKS and KWANT, 1954). All radiographs were made with an apparatus which ensures the correct position of the film in the mouth and of the X-ray beam on the film, so as to ensure reproducible radiographs. All exposures were made at a constant primary voltage and the development of the films was also standardized. The caries examination required two bitewing-radiographs for the posterior teeth and three for the upper anteriors. In general, no radiographs were made of the lower anterior teeth. The exceptional skewness of the frequency distribution of the approximal lesions of the lower anterior teeth makes these data of questionable value. For this reason the lower anterior teeth were only examined in some age groups.

Since all radiographs were made in duplicate to ensure reliability, ten pictures were required. Owing to the standardization of the technique the preparation of the ten radiographs took less than 5 min.

The caries diagnosis made from the radiographs was standardized as far as possible. Four observers (two dentists and two technicians) took part in the evaluation of the radiographs. These observers were given special training in reading radiographs for which carefully checked series of previous films were used as a standard. To avoid and check a possible shift in standard of examination, the observers were regularly required to evaluate a standard set of films between their normal work, i.e. generally after evaluating the radiographs of forty-five patients or less.

Each radiograph was examined independently by one dentist and one technician, and the average score of the two estimations was used in all calculations. After the examination of the radiographs of fifteen subjects the combination of the two observers was changed. The analysis of the results of the four examiners proved the consistency of their examinations. Each examiner evaluated the same number of radiographs from Tiel and from Culemborg without knowledge of the origin of the films.

The approximal carious lesions were classified with regard to the degree of penetration in the direction of the pulp. As the assessment was made from a radiograph it represents the projection and not the actual extent in depth of the lesion. In the case of a lesion extending over a large area or in rotated teeth this will sometimes have resulted in an inaccurate assessment.

Caries I indicates a carious lesion which is limited to the enamel. Caries stages II, III and IV indicate respectively a lesion which has penetrated the dentine, which extends from the enamel–dentine junction halfway to the pulp, or which has reached the pulp. Category V indicates a filling (including crowns, etc.). In general, the caries is indicated as caries I–V, i.e. all lesions and fillings, or as caries II–V, by which is meant those lesions which have already penetrated the dentine. The latter are the lesions which should have been filled, if they are not yet treated. Each surface was separately scored so that all calculations could be carried out per surface and per child.

Since all radiographs were evaluated twice, the number of deviating estimations can be counted and used as a measure for the error of observation. The standard deviation of the evaluation of the percentage of carious surfaces in a group of $\pm$ 100 children is approximately 0·5 per cent, or about one tenth of the standard deviation originating from the scattering of the sample.

The great advantage of the method employed was also that it made a blind evaluation possible: the radiographs made in Tiel and Culemborg were put into unlabelled envelopes, and examined at random.

Pit and fissure caries and caries of the free smooth surfaces

During the clinical inspection of the mouth the teeth present, enamel hypoplasia and hypocalcifications and dental fluorosis, the type of occlusion, the condition of the mucous membranes, the state of oral hygiene, etc., were recorded. After this inspection, selected age classes were examined for pit and fissure caries and for buccal smooth surface lesions.

The method of examination of the pits and fissures has already been published (BACKER DIRKS, KWANT and KLAASSEN, 1957). The examination was restricted to

molars and premolars. The palatine pits of the incisors were not evaluated. In the upper molars two fissures were estimated separately (mesio-occlusal and disto-occluso-palatine) while in the lower molars the occlusal fissure and the buccal pit were diagnosed separately. In the premolars the fissures were diagnosed as one unit.

The fissures were cleaned with a new sharp explorer (Maillefer No. 6) and dried with compressed air. The diagnosis was made with the aid of a small mouthlight of high intensity. Incident and transmitted light were used. Caries was estimated in four different grades (I, II, III, IV) but these grades cannot be compared with those for the approximal caries because of the differences in the methods used. Caries I signifies a minute black line at the bottom of the fissure; in caries II there is in addition a white zone along the margins of the fissure (dark in transmitted light); caries III denotes the smallest perceptible break in the continuity of the enamel (cavity) with or without undermined margins. Caries IV is a large cavity more than 3 mm wide. Caries grade III is from a practical point of view comparable to approximal caries II lesions in that both need treatment.

The standardization of a clinical examination is far more difficult than that of a radiographic examination in which the material remains available for checking purposes. By defining the caries stages as exactly as possible and by having always at hand a set of extracted molars showing examples of each diagnosis, an attempt was made to keep the assessment as constant as possible. Because each child was always examined by two dentists and the examinations were alternated weekly between Tiel and Culemborg, it is fairly certain that the examinations in Tiel were made in the same way as those in Culemborg. For all calculations the mean result of the two dentists were used. To what extent the diagnostic criteria were consistent from year to year is unfortunately impossible to determine. The measures described above were used to provide as many safeguards as possible.

For the groups examined, each composed of 100 children, the standard deviation of the estimation was approximately 0·5 per cent.

The examination of the free smooth surfaces was also made after careful cleaning and drying of these surfaces. When necessary an initial cleaning was made with cotton wool or with a tooth brush; in the final cleaning the surface was scraped with the side of the explorer. The examination—likewise by two dentists independently—was restricted to the buccal and labial surfaces. Two stages of caries were distinguished i.e. "caries white" (c.w.) if the surface showed a white chalky opaque lesion and "carious cavity" (c.c.) if there was a break in the continuity of the enamel perceptible with an explorer.

The time spent on the clinical examination depended upon the number of teeth present in the mouth. The mean examination time spent by each dentist for the groups of 7 years of age was 4·5 min and for the groups of 15 years of age 9·5 min. All the examinations were carried out at the schools. Portable equipment was used.

STUDY GROUPS

The primary purpose of this study pertained to the effect of water fluoridation on approximal caries. This determined the selection of the study groups.

If the water fluoridation is to have practical significance, it must be shown not only that it results in an important percentual reduction of the caries prevalence but also that this reduction, if expressed in numbers of lesions, is of significant practical value. The age group of 11 is the first to show sufficient approximal caries to make this possible. Because of this, the basic material of the investigation was formed by groups of children of 11–15 years old in which the approximal caries was evaluated.

In order to investigate the effect of fluoridation on the other types of caries, a clinical examination was made of some selected age groups.

On the basis of the available data concerning the frequency distribution of caries in the children and the resulting standard deviations of the sample, the standard deviation of the observation and the expected size of the caries preventive effect of the fluoridation, the necessary size of each age class was calculated at 100 children.

Each of the age groups examined contained an equal number of girls and boys, chosen at random from the schools except that allowance was made for the kind of school. From each kind of school (public school, Roman Catholic, Protestant, etc.)

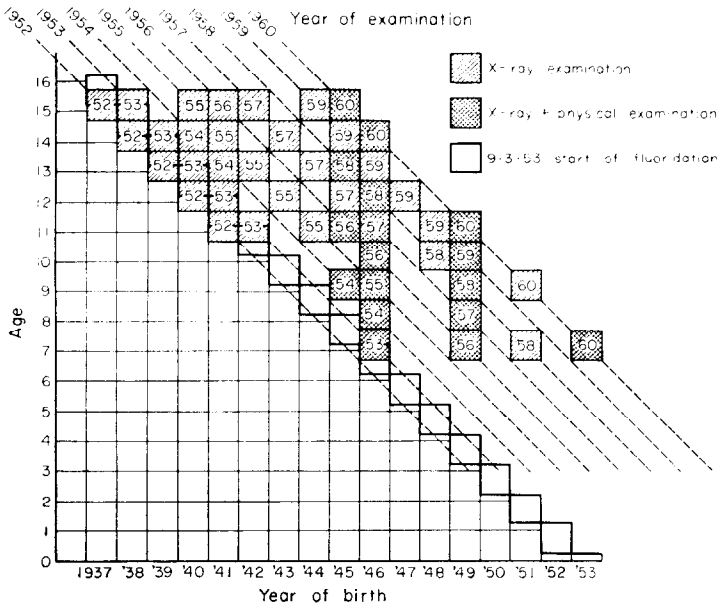

FIG. 1. Age classes studied in the yearly investigations.

a sample was taken in proportion to the number of children attending the school. Only children who had been born in Tiel or Culemborg, and had lived there ever since (except for holidays) and had used the piped water supply, were included in the study.

Fig. 1 gives a survey of the age groups examined with the methods described. As the examination was made always in the last 3 months of the year, and the children grouped by their year of birth, the mean age of the children was $10\frac{3}{4}$, $11\frac{3}{4}$, $12\frac{3}{4}$, etc.

Those groups will be called the 11, 12, 13, etc. year age class. The mean age of the children at the beginning of fluoridation can also be read from Fig. 1.

RESULTS

Approximal caries

First of all the comparability of the children in Tiel and Culemborg as to caries prevalence must be established. In Fig. 2 and Table 1 the average number of approximal lesions per child in 1952 is presented for the group of 11–15 year old children.

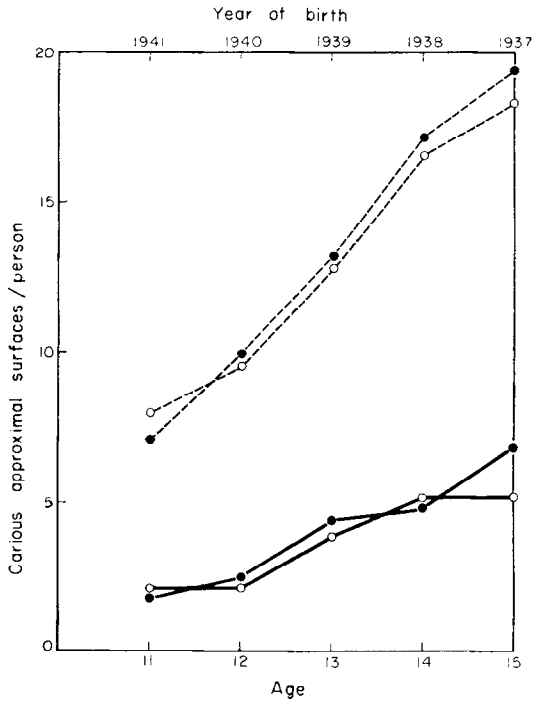

FIG. 2. Average number of carious approximal surfaces per child (broken lines) and the average number of approximal surfaces with caries of the dentine (solid lines), 1952 investigation. ● Culemborg; ○ Tiel.

TABLE 1. AVERAGE NUMBER OF CARIOUS APPROXIMAL SURFACES PER CHILD (I–V) AND AVERAGE NUMBER OF APPROXIMAL SURFACES WITH CARIES OF THE DENTINE PER CHILD (II–V), 1952 INVESTIGATION
None of the differences are significant at the $P=0{\cdot}01$ level

Age	11		12		13		14		15	
Caries grade	I–V	II–V	I–V	II–V	I–V	II–V	I–V	II–V	I–V	II–V
Culemborg	7·1	1·9	9·9	2·4	13·2	4·5	17·2	5·0	19·5	6·5
Tiel	8·2	2·1	9·7	2·4	12·9	3·9	16·7	5·4	18·3	5·3

The graph clearly shows that there were no significant differences between Tiel and Culemborg present at the beginning of the water fluoridation. The minor differences appear to derive from the random composition of the groups. The distributions of the caries lesions over the various tooth surfaces also did not show a significant difference between the two towns. Fig. 3 illustrates this distribution for one age group.

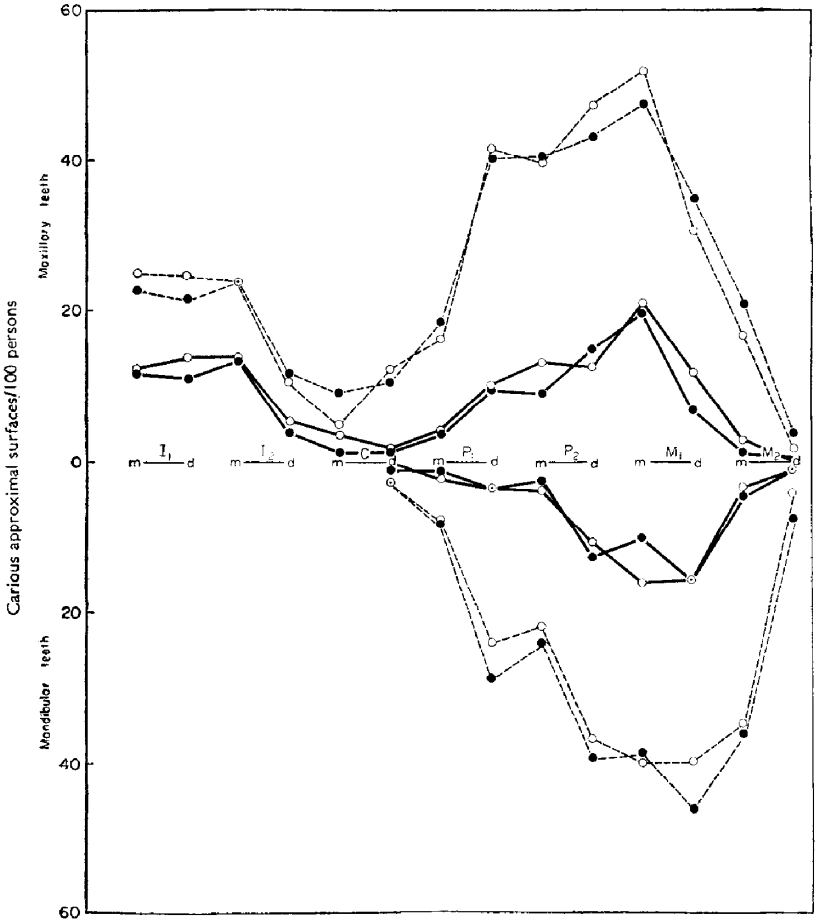

FIG. 3. Number of carious approximal surfaces (broken lines) and of surfaces with caries of the dentine (solid lines) per 100 children of 13 years of age. For each surface the mean number of carious lesions is given for the corresponding surfaces of the right and left mouth half. 1952 investigation. I=incisor; C=canine; P=premolar; M=molar; m=mesial surface; d=distal surface; ●=Culemborg; ○=Tiel.

The effect of fluoridation can be evaluated in various ways:

(a) Comparison of the caries prevalence in Tiel and Culemborg in the same age groups before and after fluoridation (horizontally in Fig. 1);

(b) Comparison of the caries prevalence in Tiel and Culemborg in the same year (diagonally in Fig. 1);
(c) Comparison of the caries increment in Tiel and Culemborg, in the same children (vertically in Fig. 1).

Numbers of approximal carious lesions in Tiel and Culemborg of the age groups 11–15 *years*

In 1952 and 1953 and every second year thereafter the entire group of 11–15 year old children was examined (see Fig. 1).

In Table 2 and Fig. 4 the average number of approximal lesions (I–V) and the average number of dentinal lesions (II–V) are given for the various investigation years. These averages are obtained from the averages of the component age groups.

TABLE 2. THE AVERAGE NUMBER OF APPROXIMAL LESIONS FOR THE AGE GROUPS OF 11 UP TO AND INCLUDING 15 YEARS; 1952 INVESTIGATION UP TO AND INCLUDING 1959 INVESTIGATION

Investigation year	1952		1953		1955		1957		1959	
Caries grade	I–V*	II–V†	I–V	II–V	I–V	II–V	I–V	II–V	I–V	II–V
Culemborg	13·4	4·1	12·2	3·6	13·8	4·2	13·5	5·0	13·8	4·8
Tiel	13·1	3·8	12·2	3·7	12·7	4·1	10·7	3·5	10·8	3·1
Percentage difference	—	—	—	—	—	—	21	30	22	35

* I–V = all approximal lesions. † II–V only approximal dentinal lesions.

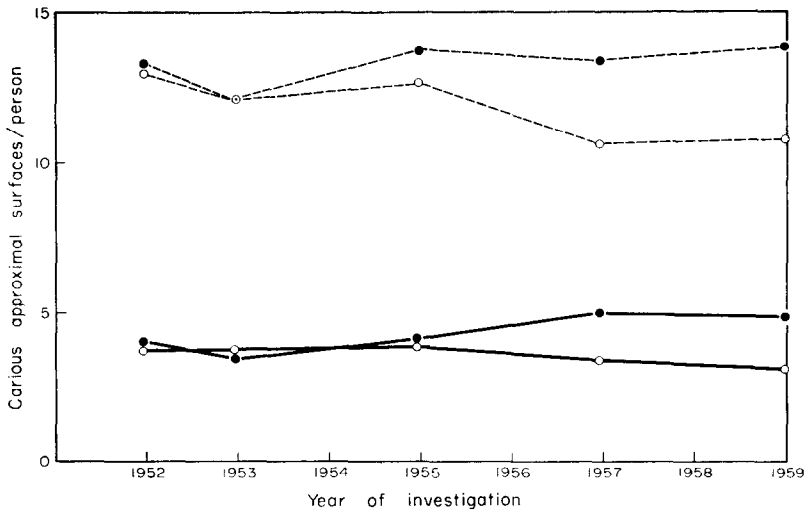

FIG. 4. Average number of carious approximal surfaces (broken lines) and of surfaces with caries of the dentine (solid lines). 11–15 years age group. ● Culemborg; ○ Tiel.

The average of each component age group is always the average number of lesions of the boys' and girls' mean number of lesions.

For the study years of 1952 and 1953 there is no difference between Tiel and Culemborg, in 1955 there is a limited difference and in 1957 and 1959 a clear-cut difference which favours Tiel.

In 1953 the values for the total number of lesions for both Tiel and Culemborg were strikingly low. In analysing the 1953 results it appears that this low average is due to the low caries numbers of the 14 and 15 year old children. It turned out that the radiographs of these age classes were slightly underdeveloped, with the result that especially many of the slightest carious lesions (minute enamel caries) were not diagnosed. These radiographs were developed in the very cold month of February 1954, by a temporary assistant, who did not check adequately the temperature of the development bath. As a consequence the average of 1953 cannot be compared with the averages of the other years. The values for Tiel and Culemborg are, however, mutually comparable since the radiographs were mixed before development. The susceptibility of this method is clearly demonstrated and emphasizes the need for a rigorous standardization of all the methods used in the investigation.

In Culemborg, except for the figure of 1953, the total number of lesions (I–V) is very constant. For Tiel however the numbers for the year 1957 and 1959 are about 20 per cent lower than the numbers for Culemborg and also lower than the numbers for Tiel in 1952.

By contrast the number of dentinal lesions (II–V) in Culemborg shows an important increase while on the other hand Tiel shows a decrease in dentinal lesions of the same magnitude.

The constant increase in caries prevalence is a common observation in Holland as well as in other countries. It seems therefore more logical to compare the caries numbers in the same year of investigation. The basis of the study is the comparability of the two towns. There is no reason to suppose that Tiel (unlike Culemborg) would not have shown, without fluoridation, an increased caries prevalence. The simultaneous development and the blind examination reduces to a minimum the chance for differences in quality of the radiographs and in caries criteria between Tiel and Culemborg within the same year of investigation.

The comparison of averages of such relatively broad age groups (11–15 years) are in general hardly permissible as the oldest age class will have too dominant an effect on the averages. Especially for Tiel this average gives a distorted picture as the youngest age groups (11–12 years) which show the greatest caries reduction hardly affect the mean value of the whole group, whereas a relatively small caries reduction in the oldest age group has an important effect on the mean value.

Number of approximal lesions in Tiel and Culemborg in the same investigation year

In Fig. 2 it has been shown already that there were no significant differences in caries prevalence in Tiel and Culemborg at the beginning of the fluoridation. In 1955 almost all caries figures were somewhat lower in Tiel than in Culemborg. After 4½ years of fluoridation (1957) a distinct difference in the number of carious lesions was found; practically all differences were significant at the 1 per cent level.

The caries figures for 1959 ($6\frac{1}{2}$ years after the beginning of fluoridation) are shown in Table 3 and Fig. 5. The small vertical lines in this figure are twice the standard deviation of each average, put one time above and one time below the average.

With the exception of the caries grades I–V of the 14 year old group and of the caries grades II–V of the 15 year old group, all P values for the differences are smaller than 1 per cent.

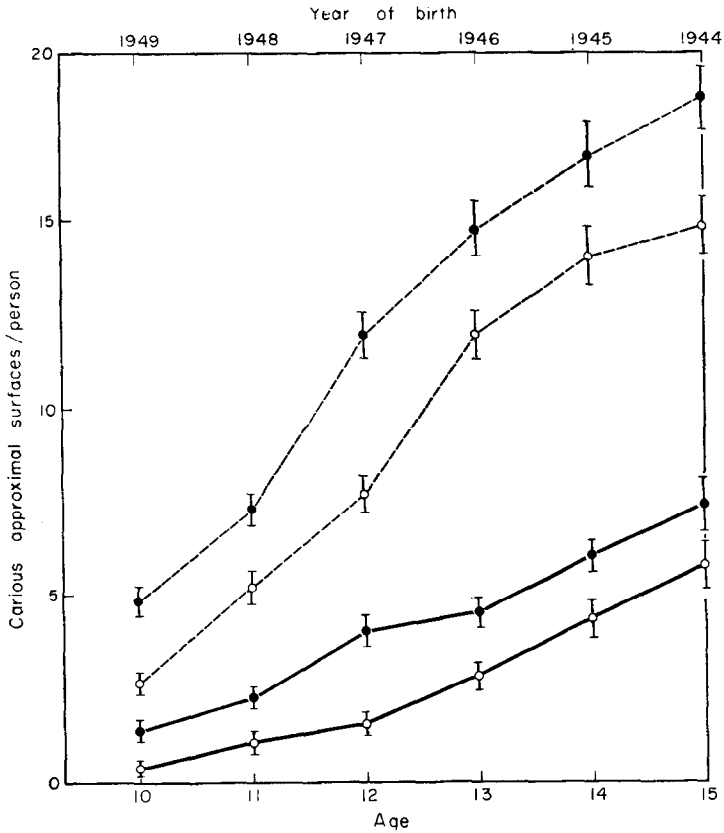

FIG. 5. Average number of carious approximal surfaces per child (broken lines) and the average number of approximal surfaces with caries of the dentine (solid lines), 1959 investigation. The small vertical lines give the standard deviation of the mean (σ_m) above and below the observed averages. ● Culemborg; ○ Tiel.

It can be observed that the differences—when expressed as percentages less caries—are larger in the younger age groups and smaller in the older age classes. This is well in accord with the hypothesis that the water fluoridation is the cause of these differences. The younger the age of the children at the start of fluoridation, the more important the effect should be.

TABLE 3. AVERAGE NUMBER OF CARIOUS APPROXIMAL SURFACES PER CHILD (I–V) AND AVERAGE NUMBER OF APPROXIMAL SURFACES WITH INVOLVEMENT OF THE DENTINE PER CHILD (II–V), 1959 INVESTIGATION

The averages are rounded off at one decimal fraction, the percentages at whole numbers. C.R. (critical ratio) = number of times the difference between Culemborg and Tiel is larger than the standard error of the difference

Age	10		11		12		13		14		15	
Year of birth	1949		1948		1947		1946		1945		1944	
Age at start of fluoridation	3¾		4¾		5¾		6¾		7¾		8¾	
Caries grade	I–V	II–V	I–V	II–V	I–V	II–V	I–V	II–V	I–V	II–V	I–V	II–V
Culemborg (<0·1 mg F/l)	4·9	1·5	7·3	2·3	11·9	4·0	14·7	4·5	16·7	6·0	18·2	7·4
Tiel (1·1 mg F/l)	2·7	0·5	5·3	1·1	7·7	1·6	12·0	2·8	14·0	4·3	14·8	5·8
% less caries lesions	45	67	27	50	35	60	18	38	16	28	19	22
C.R. of the difference	6·84	5·10	3·29	3·86	5·04	6·59	2·77	3·75	2·42*	2·52	3·22	2·01*

* Differences not significant at the $P=0{\cdot}01$ level.

In a binominal frequency distribution the average with its standard deviation is a good description of the observed values. However, if the frequency distribution is very skew, like the frequency distribution of the carious lesions in the children, the

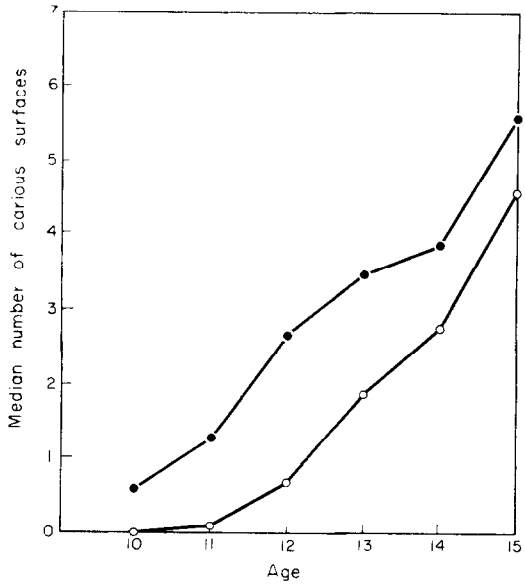

FIG. 6. Median number of approximal surfaces with lesions of the dentine per child, 1959 investigation. ● Culemborg; ○ Tiel.

TABLE 4. MEDIAN NUMBER OF SURFACES WITH DENTINAL LESIONS PER CHILD

Age	10	11	12	13	14	15
Culemborg	0·6	1·3	2·7	3·5	3·9	5·6
Tiel	0·0	0·1	0·7	1·9	2·8	4·6

average is less appropriate to describe the caries prevalence. In order to give a better insight into the caries prevalence Fig. 6 and Table 4 show the median values of the caries degrees II–V (dentinal lesions) for the same groups. The differences in the median values, especially for the younger age groups, are larger than the differences in the mean values.

Caries increment in Tiel as compared to Culemborg

As a number of the groups studied already had caries at the beginning of fluoridation, caries increment will give a better picture of the fluoride effect than caries prevalence (=lifetime caries experience).

In Table 5 are presented the number of approximal dentinal lesions at various ages for the four groups of children born in 1944, 1945, 1946 and 1949. As these caries numbers are calculated only for those children who took part in the subsequent examinations, the figures differ from those of Table 3. All differences in caries increment are larger than the differences in caries prevalence (Table 3).

TABLE 5. APPROXIMAL CARIOUS LESIONS WITH INVOLVEMENT OF THE DENTINE AT DIFFERENT AGES
Average number per child

Age at examination	Year of birth 1944		1945		1946		1949	
	C	T	C	T	C	T	C	T
7							0·0	0·1
8							0·5	0·1
9			0·6	0·9	0·7	0·5	0·9	0·3
10							1·5	0·5
11	2·1	2·4	2·3	1·8	2·5	1·6		
12			4·1	2·8				
13	4·9	4·5	5·4	3·6	4·6	2·8		
14			6·2	4·4				
15	7·5	6·0						
Total caries increment	5·4	3·6	5·6	3·5	3·9	2·3	1·5	0·5
% difference	33		37		41		67	

C=Culemborg; T=Tiel.

For the same children the number of approximal lesions and the number of dentinal lesions are shown graphically in Fig. 7 for the various years of investigation. For Culemborg the curves of the various groups are close to each other. The slope of the curves, i.e. the caries increment, is very similar: all groups from Culemborg belong to the same population ("universe"). For Tiel this is apparently not true and proves the dissimilarity of the four groups. The slope of the curves decreases for each year later the children are born. Each group had a different age at the beginning of fluoridation, and is therefore not protected in the same way.

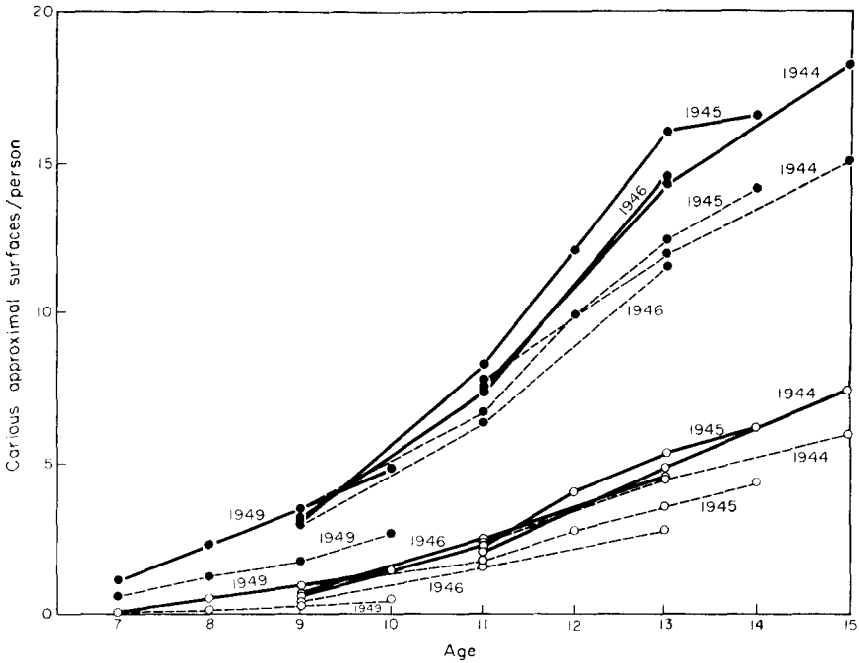

FIG. 7. Mean number of approximal carious surfaces per child at different ages. Longitudinal study of groups of children from Culemborg (solid lines) and from Tiel (broken lines). Year of birth respectively 1949, 1946, 1945 and 1944. ● all carious surfaces; ○ surfaces with caries of dentine.

For all age periods the slope of the curves pertaining to Tiel is less steep than those of Culemborg.

The increment in approximal lesions of the dentine over a 4 year period was for the oldest age group born in 1944 and with a mean age of $8\frac{3}{4}$ years at the beginning of fluoridation 33 per cent smaller in Tiel than in Culemborg.

Pit and fissure caries

In the 1959 investigation only the children of 10 years old (born in 1949) were examined for fissure caries. Therefore the caries figures of the three age groups studied in the 1958 investigation will be shown. In this year the children born in 1945, 1946 and 1949 (9, 12 and 13 years of age) were examined clinically (see Fig. 1).

Whereas caries grade III is clinically comparable to caries grade II of the approximal lesions and caries grade II resembles caries grade I of the approximal lesions, caries figures will be presented in two categories: caries grades III, IV and fillings (denoted as caries III–V) and caries grades II, III, IV and fillings (caries II–V). (In the calculation for pit and fissure caries grade I is evaluated as sound). Extractions are calculated as caries grade IV, except orthodontic extractions of premolars.

In Table 6 and Fig. 8 the data of the various age classes are shown.

TABLE 6. AVERAGE NUMBER OF PIT AND FISSURE LESIONS PER CHILD, 1958 INVESTIGATION

Age	9		12		13	
Year of birth	1949		1946		1945	
Caries grade	II–V	III–V*	II–V	III–V	II–V	III–V
Culemborg	6·6	5·7	12·3	10·0	14·2	11·4
Tiel	5·4	4·1	10·0	7·8	13·0	9·6
% less carious lesions	18	28	18	22	8	16
C.R. of the difference	4·6	5·7	4·3	4·6	2·2†	3·5

Extractions are calculated as caries grade IV.
* III–V = carious cavities only.
† Difference not significant at the $P = 0{\cdot}01$ level.

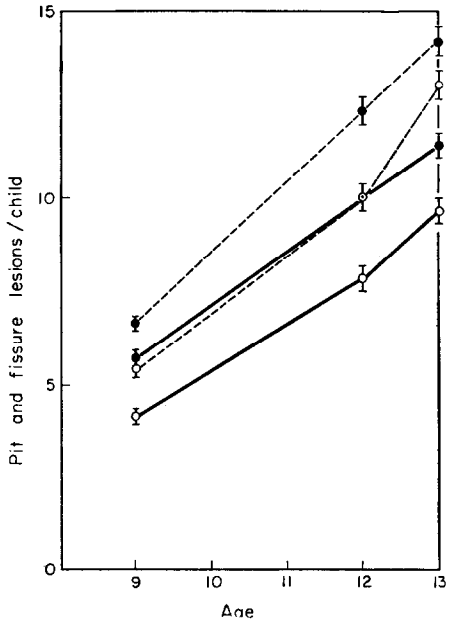

FIG. 8. Average number of pit and fissure lesions per child (broken lines) and average number of pits and fissures with cavitation (solid lines). The small vertical lines give the standard deviation (σ_m) above and below the observed averages. ● Culemborg; ○ Tiel.

The percentage differences in carious lesions of the fissures is much smaller than the differences in lesions of the approximal surfaces. Even in the youngest children, who were $3\frac{1}{4}$–$4\frac{1}{4}$ years old at the beginning of fluoridation, the reduction in the number of carious cavities is only 28 per cent. For the approximal surfaces a caries reduction of 67 per cent was calculated (compare Table 3). Either pits and fissures are affected less by fluoride than approximal surfaces or fluoride must be present in a much earlier phase of tooth development, than for approximal surfaces, to have a comparable caries-preventive effect (BACKER DIRKS, HOUWINK and KWANT, 1961).

Caries of the free smooth surfaces

The carious lesions of the free smooth surfaces were diagnosed during the clinical examination. For the same reason as mentioned in respect of lesions of fissures the results of the 1958 investigation will be shown.

TABLE 7. NUMBER OF CARIOUS LESIONS OF THE SMOOTH BUCCAL AND LABIAL SURFACES PER 100 CHILDREN

Age	9		12		13	
Year of birth	1949		1946		1945	
Caries grade	c.w.*	c.c†	c.w.	c.c.	c.w.	c.c.
Culemborg	175	45	383	86	472	96
Tiel	98	14	269	25	310	43
% less carious lesions	44	69	29	71	34	55

* c.w.=white chalky lesions, without macroscopic loss of substance.
† c.c.=carious lesions with cavitation.

In Table 7 the numbers of buccal or labial lesions of smooth surfaces are presented for three age groups from Culemborg and Tiel. The differences between Tiel and Culemborg in the number of cavities (c.c.) are particularly large in comparison with the approximal surfaces and the occlusal surfaces. Even those surfaces which had already erupted at the beginning of fluoridation (first molars and incisors of the 1945 age class) did show an important caries reduction (40 per cent).

DISCUSSION

The differences in the methods of examination and in the definition of the caries criteria make it difficult to compare the results of this study with the results of fluoridation in the U.S.A. With this in mind it may be concluded that water fluoridation in the Netherlands has a favourable caries inhibiting effect which is fairly comparable to the results of the American studies after the same period. The Dutch governmental committee on "Dental caries and fluorides" recommended, upon the basis of these studies, water fluoridation in the Netherlands (HEALTH COUNCIL, 1960).

The data shown give the effect of fluoridation after $6\frac{1}{2}$ years in children of 10–15 years of age. As the mean age of these children was $3\frac{3}{4}$–$8\frac{3}{4}$ years at the start of fluorida-

tion the great majority of the teeth studied was already calcified or even erupted at this time. In view of the results of the American studies it may be concluded that the caries inhibiting effect of water fluoridation will become still larger when children born in later years are included in the study.

The observation that the fluoride effect is largest for lesions on free smooth surfaces, slightly less for approximal surfaces and smallest for occlusal (pits and fissures) caries is of definite importance. From the theoretical point of view this suggests that the accessibility of the various surfaces to fluoride ions both pre- and posteruptively, is a decisive factor in the fluoride effect (see also BACKER DIRKS *et al.*, 1961). Before eruption the mesial, distal and buccal surfaces will be accessible to the fluoride-containing tissue fluids. However, for the deep occlusal fissures the accessibility will be far less. When after eruption the mesial and distal surfaces become contact surfaces the situation is no longer favourable for the adsorption of fluoride ions from saliva. The diffusion route through plaque material will be much longer in the molar region than in the anterior region (WINKLER and BACKER DIRKS, 1958). The smooth buccal surface remains a freely accessible surface. If this supposition is right, the occlusal fissure will accumulate much less fluoride in the outer enamel than the other surfaces (ISAAC *et al.*, 1958).

This difference in effect is also of practical importance. The fact that the caries site which gives little difficulty in dental treatment is the least influenced by fluoride is a fortunate coincidence.

It is obvious from Tables 3, 6 and 7, that the percentual reduction of caries due to fluoridation is more marked for dentinal lesions only, than for all lesions. This shows that fluoride also inhibits the increase in size of small enamel lesions. It is possible that a rehardening of the initial lesion is promoted by the presence of fluoride, as suggested by the experiments of KOULOURIDES, CURTO and PIGMAN (1961), or that a selective absorption of fluoride ions takes place in the initial enamel lesion.

The differences in caries inhibition, if assessed from the mean caries numbers or from the median caries numbers, lead to the conclusion that the children with the highest caries susceptibility are least protected by fluorides (Figs. 5 and 6).

Acknowledgements—We wish to express our sincere gratitude to Professor Dr. K. C. WINKLER for his advice and help during the study. The execution of important tasks, for example the examination of radiographs, by Misses L. BAUER, J. BROUWER and J. VAN WACHEM and Mr. C. M. VELTEMA is acknowledged with great appreciation.

REFERENCES

ARNOLD, F. A., DEAN, H. T., JAY, P. and KNUTSON, Y. W. 1956. Effect of fluoridated public water supplies on dental caries prevalence. *Publ. Hlth Rep., Wash.* **71**, 652–658.

AST, D. B., SMITH, D. J., WACHS, B. and KANTWELL, K. T. 1956. Newburgh–Kingston caries fluorine study—XIV. Combined clinical and roentgenographic dental findings after ten years of fluoride experience. *J. Amer. dent. Ass.* **52**, 314–325.

BACKER DIRKS, O., VAN AMERONGEN, J. and WINKLER, K. C. 1951. A reproducible method for caries evaluation. *J. dent. Res.* **30**, 346–359.

BACKER DIRKS, O. and VAN AMERONGEN, J. 1953. Cariesonderzoek—II. Klinische experimenten. *Tijdschr. Tandheelk.* **60**, 782–794.

BACKER DIRKS, O. and KWANT, G. W. 1954. A reproducible method for caries evaluation—IV. *Tijdschr. Tandheelk.* **61**, 891–904.

BACKER DIRKS, O., KWANT, G. W. and KLAASSEN, C. B. 1957. A reproducible method for caries evalution—V. Pit and fissure caries of molars and premolars. *Tijdschr. Tandheelk.* **64**, 77–85.

BACKER DIRKS, O., HOUWINK, B. and KWANT, G. W. 1961. Some special features of the caries preventive effect of water-fluoridation. ORCA Proceedings 1960. *Arch. oral Biol.* **4**, 187–192.

BARR, J. H., DIODATI, R. R. and STEPHENS, R. G. 1957. Incidence of caries at different locations on the teeth. *J. dent. Res.* **36**, 536–545.

BROWN, H. K., MCLAREN, H. R. and POPHOVE, M. 1960. The Brantford–Sarnia–Stratford fluoridation caries study—1959 report. *J. Canad. dent. Ass.* **26**, 131–142.

GREEN, G. E. and WEISENSTEIN, P. R. 1960. Symposium on Caries Diagnosis and Experimental Caries, Columbus, Ohio, September 1959.

HEALTH COUNCIL. 1960. *Report of the Committee on Dental Caries Prevention and Fluorides.* The Health Council, Netherlands. (Dutch text).

HILL, I. N., BLANEY, J. R. and WOLF, W. 1957. The Evanston dental caries study—XV. The caries experience rates of two groups of Evanston children after exposure to fluoridated water. *J. dent. Res.* **36**, 208–219.

ISAAC, S., BRUDEVOLD, F., SMITH, F. A. and GARDNER, D. E. 1958. The relation of fluoride in the drinking water to the distribution of fluoride in enamel. *J. dent. Res.* **37**, 318–325.

KOULOURIDES, T., CURTO, H. and PIGMAN, W. 1961. Rehardening of softened enamel surfaces of human teeth by solutions of calcium phosphates. *Nature, Lond.* **189**, 226–227.

MUHLER, J. C. and HINE, M. K. 1960. Fluorine and dental health. *The Pharmacology and Toxicology of Fluorine.* Staples Press, London.

ORGANISATION MONDIALE DE LA SANTÉ. 1958. Série de rapports techniques No. 146. Comité d'experts de la fluoruration de l'eau, premier rapport, Genève.

WINKLER, K. C. and BACKER DIRKS, O. 1958. The mechanism of the dental plaque. *Int. dent. J.* **8**, 561–585.