THE CARIES-INHIBITING EFFECT OF SODIUM, FERRIC AND ZIRCONIUM FLUORIDES

A COMPARATIVE STUDY ON SCHOOL CHILDREN, USING SUPERVISED BRUSHING AS THE MODE OF APPLICATION

by

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In an earlier study of the effect of supervised brushing of the teeth with a one per cent solution of sodium fluoride, carried out on school children, a 25—30 per cent reduction in caries increment was recorded (*Berggren & Welander,* 1960).

To examine the effect of a similar application of sodium and other fluorides when the annual number of applications is varied, a study on some 1300 children at 10 Stockholm elementary schools was carried out over a period of two years between 1958 and 1961. The additional compounds were ferric and zirconium fluorides. Pilot experiments indicate that these compounds are effective inhibitors of caries (*Mühlemann, Schmid & Köning,* 1957; *Torell, Mörch & Hals,* 1959; *Torell, Hals & Mörch,* 1960), but in full-scale clinical studies no significant reduction has been reported (*Henrikson, Oldén & Torell,* 1958; *Rosenkrantz & Torell,* 1959).

Among the reasons why the brushing method of application was preferred to mouth rinses is that with the latter there would seem from earlier reports to be some difficulties in assessing the caries-inhibiting effect; moreover the procedure is time-consuming, it being necessary to repeat it twice a month. A major advantage of supervised brushing is the repeated instruction in

efficient brushing given incidentally — of major importance also for the prevention of periodontal disease.

MATERIAL AND METHODS

General remarks

In view of the wide discrepancies in caries registration performed by different examiners it is necessary that the participating dentists should examine both test and control groups throughout the period of the study. Accordingly, 10 schools were chosen where these requirements could be met. It was planned to test the caries-inhibiting effect of three fluoride solutions at two and five brushings per year; six test groups and one control group were therefore chosen from each school. Because the study was to take two years, during which the material should be kept as far as possible intact with a minimum loss through change of school, the children were taken from the fourth classes (10 years of age). The distribution of the material according to schools, treatment groups, etc., is shown in Table 1.

Table 1

Distribution of the subjects according to school, fluoride used, and number of applications per year

Treatment groups / School		I *Sodium fluoride* 5 appl. ($5F_{Na}$)	II *fluoride* 2 appl. ($2F_{Na}$)	III *Zirconium fluoride* 5 appl. ($5F_{Zr}$)	IV *fluoride* 2 appl. ($2F_{Zr}$)	V *Ferric fluoride* 5 appl. ($5F_{Fe}$)	VI *fluoride* 2 appl. ($2F_{Fe}$)	VII *Control*	*Total*
Adolf Fredrik	(AF)	28	27	27	27	24	27	46	206
Alvik	(A)	13	14	14	12	10	13	25	101
Blackeberg	(B)	12	11	15	12	13	14	51	128
Hässelby	(Hy)	14	13	16	13	15	11	31	113
Högalid	(Hd)	19	14	20	14	15	18	17	117
Kungsholms	(K)	23	25	24	18	23	25	22	160
Loviselund	(L)	17	16	13	13	15	13	31	118
Riksby	(R)	13	14	12	14	13	13	31	110
Södra Ängby	(S)	11	13	9	12	13	11	16	85
Vällingby	(V)	27	27	26	27	26	25	29	187
	Total	177	174	176	162	167	170	299	1,325

Technical procedures

The following fluoride solutions were used,

(1) Sodium fluoride solution 0.5 per cent.

(2) Zirconium fluoride solution, prepared from the following:

Zirconium oxychloride, $ZrOCl_2.8H_2O$	6.4 g
Sodium fluoride, NaF	2.5 g
Distilled water to make	1000 ml.

The pH was adjusted to 2.2—2.5 by adding drops of concentrated hydrochloric acid.

(3) Ferric fluoride solution, prepared from the following:

Ferric chloride, $FeCl_3.6H_2O$	13.5 g
Sodium fluoride, NaF	8.0 g
Distilled water to make	1000 ml.

The pH was adjusted to 2.0—2.2 by adding drops of concentrated hydrochloric acid.

About 25 ml of fluoride solution was made up in a parchment beaker. The tooth brushes were dipped in the solution, and the teeth were brushed for three minutes by the children, under supervision, according to a scheme.

Experience of this method has shown that there is no risk of the children swallowing the solution. In any case the solutions were too weak to have any toxic side effects.

The dentist and his assistant were each able to supervise two or three children at one time.

Registration

The caries registration was performed at each school by the same dentist throughout the period of the study, and the findings were recorded on a special card. Only one half of the dentition was examined in accordance with *Welander*'s (1960) rotation principle for partial caries registration. The accuracy of the registration was increased by including a radiographic examination of the teeth. Since the discrepancies between the interpretations of the radiographs by different dentists are also fairly large (*Berggren & Welander,* 1960), the radiographs were assessed by two dentists well trained in the field. Only in cases in which both examiners were in agreement were their registrations of "radio-

graphic caries" inserted on the card. At the beginning and end of the period of the study it was noted whether the permanent teeth were fully erupted and whether the various tooth surfaces were intact, decayed or filled.

The registration was restricted to the permanent teeth that were fully erupted at the beginning of the study. The criterion of full eruption was that the tooth should make contact with its antagonists or, if these were missing, it should have erupted to the occlusal plane. The "population under risk" thus consisted of permanent teeth and surfaces that had been assessed as intact at the first examination. In view of the familiar possibility of reversal of diagnosis in the case of repeated caries registration the following rules were followed: Fillings and cavities that had been noted at the first examination but not at the last one were excluded from the "population under risk". The surfaces that were recorded as decayed at the first but not at the last examination were included in the "'population under risk" as intact on both occasions.

STATISTICAL ANALYSIS AND RESULTS

The object of the analysis of the results was to study the six experimental groups and the untreated control group. The percentage of newly decayed teeth of the total number of permanent teeth that were fully erupted at the beginning of the two-year period was calculated.

From Table 2 it is seen that the fluoride groups displayed a lower percentage of newly decayed teeth than did the control group, except for the 2 F_{Zr} group, for which there was no difference as regards the whole dentition. The $5F_{Fe}$ group showed the most favourable development and had only 28 per cent of newly decayed upper teeth during the period of the experiment. The caries reduction for the whole dentition was 29 per cent for the $5F_{Na}$ group, 17 per cent for the $5F_{Zr}$ group and 33 per cent for the $5F_{Fe}$ group. For the $2F_{Na}$, $2F_{Zr}$ and $2F_{Fe}$ groups the values were 17, 0, and 8 per cent, respectively. A comparison between the two groups having brushed five times and twice annually with the

Table 2

Percentage of permanent teeth decaying during the two-year period in the test and control groups

School	I $5F_{Na}$			II $2F_{Na}$			III $5F_{Zr}$			IV $2F_{Zr}$			V $5F_{Fe}$			VI $2F_{Fe}$			VII Control		
	q_u	q_l	q_t	q_u	q_l	q_t	q_u	q_l	q_t	q_u	q_l	q_t	q_u	q_l	q_t	q_u	q_l	q_t	q_u	q_l	q_t
AF	30	8	16	32	10	19	21	8	13	39	13	23	30	4	13	21	5	11	30	15	21
A	43	0	18	36	4	19	38	7	22	37	0	18	40	0	18	25	15	19	46	19	29
B	29	13	17	38	13	23	39	10	22	44	23	30	25	14	18	48	11	25	46	11	25
Hy	42	5	23	33	6	17	46	20	32	36	14	22	31	9	18	30	9	17	45	12	25
Hd	13	14	13	52	5	25	29	16	20	56	0	18	17	3	9	59	14	32	37	4	17
K	28	12	19	36	11	21	36	10	21	40	17	28	35	12	21	46	10	27	58	25	28
L	18	6	11	32	7	17	27	15	20	48	3	22	24	7	14	36	3	17	47	5	24
R	38	36	19	47	19	27	29	10	18	35	22	27	42	6	22	63	12	33	50	5	25
S	23	0	8	5	14	11	13	0	6	29	10	18	6	0	3	22	4	12	22	5	13
V	34	6	17	63	1	22	38	12	23	44	12	25	27	3	13	43	10	24	46	10	25
Total	30	7	17	38	9	20	33	11	20	41	12	24	28	7	16	40	9	22	43	11	24
Reduction in caries				I—VII = 29 %			III—VII = 17 %						V—VII = 33 %								

q_u = upper jaw

q_l = lower jaw

q_t = whole dentition

Table 3A

Differences between the test and control groups with respect to the percentage of permanent teeth decayed during the two-year period

School	Control-5F$_{Na}$			Control-5F$_{Zr}$			Control-5F$_{Fe}$		
	q_u	q_l	q_t	q_u	q_l	q_t	q_u	q_l	q_t
AF	0	5	4	9	5	7	0	9	7
A	2	19	11	7	12	7	5	19	11
B	20	— 1	10	10	2	5	24	—2	9
Hy	3	7	2	—1	— 8	—7	14	3	7
Hd	24	—10	4	8	—12	—3	20	1	8
K	16	— 5	3	8	— 3	1	9	—5	1
L	28	— 1	12	19	—10	3	22	—2	9
R	13	—31	8	22	— 5	9	9	—1	5
S	3	6	7	13	6	9	20	6	12
V	12	4	8	8	— 2	2	19	7	12
All pupils	12	3	7	9	— 1	4	14	3	8
Average for the 10 schools	12.1	— 0.7	6.9	10.3	— 1.5	3.3	14.2	3.5	8.1
Variance $S^2 = \frac{1}{10}\left(x^2 - 10x^{-2}\right)$	89	157	11	38	53	24.8	59	45	10
Standard error $\frac{S}{\sqrt{10-1}}$	3.14	4.18	1.11	2.04	2.43	1.66	2.55	2.23	1.07
t	3.8	—	6.2	5.0	—	2.0	5.5	—	7.5

Table 3B

Differences between the various fluoride groups with respect to the percentage of permanent teeth decayed during the two-year period

School	$\frac{I+II}{2} - \frac{III+IV}{2}$			$\frac{I+II}{2} - \frac{V+VI}{2}$			$\frac{III+IV}{2} - \frac{V+VI}{2}$		
	q_u	q_l	q_t	q_u	q_l	q_t	q_u	q_l	q_t
AF	1.0	— 1.5	—0.5	5.5	4.5	5.5	— 4.5	—6.0	—6.0
A	2.0	— 1.5	—1.5	7.0	—5.5	0	— 5.0	4.0	—1.5
B	— 8.0	— 3.5	—6.0	— 3.0	0.5	—1.5	— 5.0	—4.0	—4.5
Hy	— 3.5	—11.5	—7.0	7.0	—3.5	2.5	—10.5	—8.0	—9.5
Hd	—10.0	1.5	0	— 5.5	1.0	—1.5	— 4.5	0.5	1.5
K	— 6.0	— 2.0	—4.5	— 8.5	0.5	—4.0	2.5	—2.5	—0.5
L	—12.5	— 2.5	—7.0	— 5.0	1.5	—1.5	— 7.5	—4.0	—5.5
R	10.5	11.5	0.5	—10.0	18.5	—4.5	20.5	—7.0	5.0
S	— 7.0	2.0	—2.5	0	5.0	2.0	— 7.0	—3.0	—4.5
V	7.5	— 8.5	—4.5	13.5	—3.0	1.0	— 6.0	—5.5	—5.5
All pupils	— 3.0	— 3.5	—3.5	0	0	—0.5	— 3.0	—3.5	—3.0
Average for the 10 schools	— 2.6	— 1.6	—3.3	0.1	1.95	—0.2	— 2.7	—3.55	—3.1
Variance									
$S^2 = \frac{1}{10}\left(x^2 - 10x^{-2}\right)$	52.1	34.5	7.5	54.7	40.5	8.4	69.6	11.7	16.1
Standard error	2.41	1.96	0.91	2.46	2.12	0.97	2.78	1.14	1.34
t			—3.6						—2.3

same fluorine compounds revealed a consistently greater reduction in caries of the upper teeth in the former group, while hardly any difference was observable for the lower teeth.

Thus, five annual brushings had a marked effect *irrespective of which fluorine compound was used.*

In the 2F groups there was only a small difference between the test and the control groups. A more detailed analysis with respect to a caries-inhibiting effect of the fluorine compounds was performed. The results of this analysis are shown in Table 3 A.

The differences between the percentages for the control group and the respective 5F groups were highly significant for sodium and ferric fluorides; and almost significant for zirconium fluoride. For the upper teeth significant differences from the control group were obtained for all these groups whereas for the lower dentition no clear-cut results were found.

To find which of the fluorine compounds displayed the strongest caries-inhibiting effect the corresponding 5F and 2F groups were combined in pairs, *viz.*, I and II, III and IV, V and VI. The differences between the means of the combined three groups for the various schools with respect to the percentages of teeth decaying during the period of the experiment were calculated separately for the upper and lower dentitions, and for the total of both dentitions (Table 3 B).

The difference between the two combined F_{Na} groups and the combined F_{Zr} groups was significant to the advantage of the F_{Na} groups. The differences between the F_{Fe} groups and F_{Zr} groups were also significant, but not those between the F_{Na} and F_{Fe} groups.

A similar analysis was performed with the surface instead of the tooth as the unit. Since the "population under risk" is greater when teeth decayed on some surfaces at the beginning of the experiment later can present new decayed surfaces, an analysis with the surface as the unit provides a more accurate result.

To examine the possibility of a sex difference an analysis was performed for girls and boys separately (Table 4 A).

The differences between the control group and the $5F_{Na}$ and $5F_{Fe}$ groups were significant. Comparison between the sexes shows that the reduction in caries was greater for the girls. The reduc-

Table 4A

Differences between the F_{Na} and F_{Fe} groups with respect to the percentage of surfaces of the upper teeth decayed during the two-year period; according to sex

School	Control-5F_{Na}			Control-5F_{Fe}		
	q_M	q_F	q_{M+F}	q_M	q_F	q_{M+F}
AF	1	0	2	—9	5	0
A	6	9	8	7	2	3
B	6	17	9	10	11	9
Hy	—1	4	1	2	10	6
Hd	5	31	11	10	33	14
K	0	—	1	—1	—	0
L	6	15	10	11	5	7
R	12	2	7	12	3	9
S	—1	3	1	6	3	5
V	—1	—1	2	4	5	5
Number of schools	10	9	10	10	9	10
Average	3.3	8.9	5.2	5.2	7.9	5.8
Variance	17	97	16	48	94	17
Standard error	1.38	3.49	1.31	2.31	3.33	1.36
t	2.39	2.55	3.97	2.25	2.36	4.26
Reduction in caries	22 %	40 %	30 %	35 %	36 %	33 %

M = boys

F = girls

tion was practically the same for groups $5F_{Na}$ and $5F_{Fe}$ as when the tooth was the unit (*cf.* Table 2, bottom row).

A special analysis of the effect of the fluorides on the proximal surfaces was performed (Table 4 B).

There were significant differences between the control group on the one hand and the F_{Na} and F_{Fe} groups on the other with respect to newly decayed proximal surfaces of the upper teeth. If the material is divided according to sex, significant differences are obtained for girls but only almost significant for boys.

For the occlusal and buccal surfaces the effect of brushing could not be reliably examined since the "population under risk" was fairly small. Nevertheless, in group $5F_{Fe}$ some reduction in decay on the occlusal surfaces was evident.

Table 4B

Differences between the F_{Na} and F_{Fe} groups with respect to the percentage of proximal surfaces of the upper teeth decayed during the two-year period; according to sex

School	Control-5F_{Na}			Control-5F_{Fe}		
	q_M	q_F	q_{M+F}	q_M	q_F	q_{M+F}
AF	2	—1	3	—12	6	0
A	2	15	9	10	13	11
B	7	26	12	17	15	13
Hy	—2	2	0	— 1	13	7
Hd	9	30	12	15	32	16
K	—2	—	0	— 2	—	—2
L	5	27	15	14	5	8
R	10	3	7	12	7	10
S	—2	5	2	11	8	10
V	—3	—4	0	0	7	5
Number of schools	10	9	10	10	9	10
Average	2,6	11,4	6,0	6,4	11,8	7,8
Variance	22	156	30	81	62	28
Standard error	1,55	4,42	1,81	3,01	2,79	1,76
t	1,68	2,59	3,31	2,12	4,22	4,43
Reduction in caries	14 %	39 %	26 %	34 %	41 %	34 %

In a study of the reduction in caries on the various surfaces of the lower teeth in analogy with the analysis reported in Tables 4A and 4B, no appreciable effect was found.

The absence of any effect of fluorine on the lower teeth in this study may be due to dilution by the saliva, for it is known that very weak fluoride solutions do not produce any inhibition of caries with intermittent treatment (*Brockman*, 1962). Another and, it would seem, a more likely explanation is that the lower incisors, which in the age group in question constituted the greater part of the permanent teeth, have a much smaller tendency to develop caries. In other words the lower teeth have a considerably smaller "population under risk" and consequently do not give a clear-cut result in the studies.

Acknowledgement

The authors are indebted to *Gunnar Eklund,* Ph.D., the Statistical Institute of the University of Uppsala, who has carried out a substantial part of the statistical analysis,

to Dr. *Karin Widerström,* Principal School Dental Officer, and the dental officers at the various schools for valuable and interested co-operation,

and to Drs. *Gudrun Persson* and *Maj Wickman* for their interpretation of the roentgenograms.

SUMMARY

With the object of examining the caries-inhibiting effect of sodium, zirconium and ferric fluorides, a follow-up study was performed over two years on some 1300 school children aged 10 years at the outset. The fluoride solutions were applied by supervised brushing twice and five times annually.

It was found that five annual applications resulted in a marked reduction irrespective of the type of fluoride solution used. Highly significant differences were obtained between the control group and the sodium and ferric fluoride groups brushed five times annually ($5F_{Na}$ and $5F_{Fe}$ groups); almost significant for the corresponding zirconium group ($5F_{Zr}$). The reduction in caries for the $5F_{Na}$ and $5F_{Fe}$ groups was about 30 per cent and for the $5F_{Zr}$ group 17 per cent. The difference between the $5F_{Na}$ and $5F_{Fe}$ groups on one side and the $5F_{Zr}$ group on the other side reached the level of significance.

In the groups of children brushed twice annually there was only a small difference between the test groups and the control group.

The reduction was greater for the girls than for the boys.

RÉSUMÉ

EFFET INHIBITEUR DE FLUORURE DE SODIUM, DU FLUORURE FERRIQUE ET DU FLUORURE DE ZIRCONIUM SUR LA CARIE

Dans le but d'examiner l'effet inhibiteur du fluorure de sodium, du fluorure de zirconium et du fluorure ferrique sur la carie, une étude poursuivie sur deux ans a été effectuée sur quelque 1300

écoliers âgés au départ de 10 ans. Les solutions de fluorures ont été appliquées sous forme de brossages surveillés faits deux fois et cinq fois par an.

Il ressort de cette étude que les applications faites cinq fois par an ont donné une réduction marquée de la carie, indépendamment du type de la solution de fluorure utilisée. Des valeurs significatives ont été obtenues dans tous les groupes en ce qui concerne les dents supérieures, mais pas en ce qui concerne les dents inférieures. Une analyse de l'effet des fluorures calculé en utilisant la face dentaire comme unité a révélé des différences significatives entre le groupe témoin et les groupes $5F_{Na}$ et $5F_{Fe}$.

La réduction était plus grande chez les filles que chez les garçons.

ZUSAMMENFASSUNG

DIE KARIESHEMMENDE WIRKUNG VON NATRIUM-, EISEN-, UND ZIRKONIUMFLUORIDEN

EINE VERGLEICHENDE UNTERSUCHUNG AN SCHULKINDERN DIE UNTER AUFSICHT ZÄHNEPUTZEN MIT FLUORIDLÖSUNGEN DURCHFÜHRTEN

Um den karieshemmenden Effekt von Natrium-, Eisen- und Zirkoniumfluorid zu studieren, wurden etwa 1300 Schulkinder, die zu Anfang des Versuches 10 Jahre alt waren, einer fortlaufenden 2-jährigen Nachuntersuchung unterzogen. Die lokale Applikation geschah durch unter Aufsicht durchgeführtes Zähnebürsten zwei bezw. fünf Mal im Jahre.

Die Untersuchung ergab, dass ein fünfmal wiederholtes Bürsten einen merkbaren Effekt hatte — ungeachtet welche der Fluoridlösungen zur Anwendung kam. Markant signifikante Unterschiede wurden notiert zwischen der Kontrollgruppe und den Natrium- und Eisenfluoridgruppen, die fünfmal jährlich gebürstet hatten ($5F_{Na}$- und $5F_{Fe}$-Gruppen); beinahe signifikant für die entsprechende Zirkoniumgruppe ($5F_{Zr}$). Die Kariesreduktion für die $5F_{Na}$- und $5F_{Fe}$-Gruppen erreichte etwa 30 % und für die $5F_{Zr}$-Gruppe 17 %. Der Unterschied zwischen den $5F_{Na}$- und $5F_{Fe}$-Gruppen einerseits und der $5F_{Zr}$-Gruppe anderseits erreichte Signifikanzniveau.

Bei den Gruppen von Kindern, die zweimal jährlich gebürstet

hatten, lag nur ein unbedeutender Unterschied zwischen den Test- und Kontrollgruppen vor.

Die Kariesreduktion war grösser für die Mädchen als für die Knaben.

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