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ABRASION AND SOLUTION OF TEETH

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ABSTRACT

Minute changes in the surfaces of teeth are detected by observing the injury to calibrated indentation marks made in these surfaces by a diamond hardness indenter.

Abrasive and chemical injuries are disclosed by observing or photographing a series of these marks, so placed that each small area is definitely identifiable.

Objectionable abrasives in dentifrices are readily detected by brushing a tooth surface on which indentations have been placed.

The indentations also give an indication of the hardness of the tooth and enable the investigator to select areas of known hardness for experimental tests.

Some data are presented to show the initial effects of chemical solutions and bacterial actions, which may play important roles in the development of dental caries.

Eleven figures and two tables correlate the experimental work.

CONTENTS

I. INTRODUCTION

Evaluations of experimental data on abrasion or solution by dentifrice or by the causes responsible for dental caries are usually accompanied by difficulties and uncertainties. These arise from such unknown factors as:

(a) How hard was the tooth tested?

(b) How much of the effect was on enamel, and how much was on other constituents of the tooth?

(c) Did the tooth absorb or lose water during the test or weighings?

(d) Is the abrasiveness of a dentifrice, rubbed or brushed against a metallic or vitreous surface, comparable to its abrasiveness when brushed against a tooth?

The Bureau was called upon during the year 1942 to make an investigation of certain brands of dentifrice for an agency of the United States Government. During the investigation it was necessary to devise a method that would make it possible to follow more precisely and more intelligently the changes taking place during the use of a dentifrice. In other words, it was necessary to find whether a change in weight of a brushed tooth resulted from: a loss or a gain in water content, changes in composition, abrasion, solubility of tooth structures, or some combination of these possible causes.

It seemed sound, experimentally, to employ one of the marking or scratching methods used to determine the wear of bearing surfaces to secure visual evidence of the progress of injury to teeth. Any instrument capable of placing, repeatedly, small marks of known dimensions in enamel or dentin surfaces may be used, provided losses of surface layers or changes in surface structures are revealed by proportionate changes in these marks.

The Knoop pyramidal-diamond indenter,[1] when pressed into flat surfaces, under a constant load, produces indentations of definite depth, width, and length (see fig. 1). It served well in this research. These depressions in the surface are clearly outlined and easily photographed.

Surfaces of enamel or dentin so marked and photographed may then be exposed to the action of an abrasive, a chemical, or a dentifrice and again photographed, after the exposure (see fig. 2). The changes will be evident when the photographs are compared. From such comparisons it is possible to establish on a single tooth the damage to enamel or dentin developed during the experimental procedure. This is a definite advantage not inherent in many other methods employed for studying these problems.

II. EXPERIMENTAL DATA

The following experimental data and figures were obtained, using this method to investigate the attack by the materials indicated on the enamel and dentinal surfaces of teeth.

The linear magnifications of the figures shown in this report are, for figures 1, 4, and 5, B, equal to ×135, and for the remainder, equal to ×45 when printed to a width of 2⅜ inches. Where the surface contains dentin, the dentin is on the lower-right area of the figure.

1. ABRASION OR SOLUTION PRODUCED BY DENTIFRICES

The problem was to determine whether the observed weight losses of teeth brushed with the two dentifrices in question resulted from abrasion or solution of the tooth structure.

The brushing tests were made on the enamel and dentin surfaces of crown sections of teeth cut off above the pulpal chamber. They were held against a rotating bristle wheel with a load just below that necessary to stall the wheel. The teeth were interchanged, so that in most instances each tooth was tested with the three dentifrices. Data for these tests are reported in table 1. (An approximate evaluation of the brushing effect of the rotating brush in terms of hand-brushing gives 3 minutes of the rotating brush equal to 1 year of normal or average hand-brushing.) Definite injury was produced by hand-brushing, using both dentifrices (*A* and *B*), as shown in figures 4 and 5.

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[1] Frederick Knoop, Chauncey G. Peters, and Walter B. Emerson, *A sensitive pyramidal-diamond tool for indentation measurements,* J. Research NBS **23**, 39 (1939) RP1220.

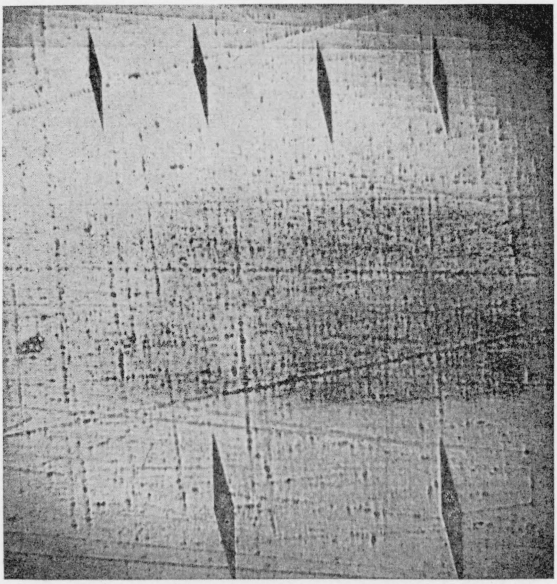

FIGURE 1.—*Dental enamel surface polished and indented.*

In figures 1, 4, and 5, the longer indentations are the result of heavier loads.

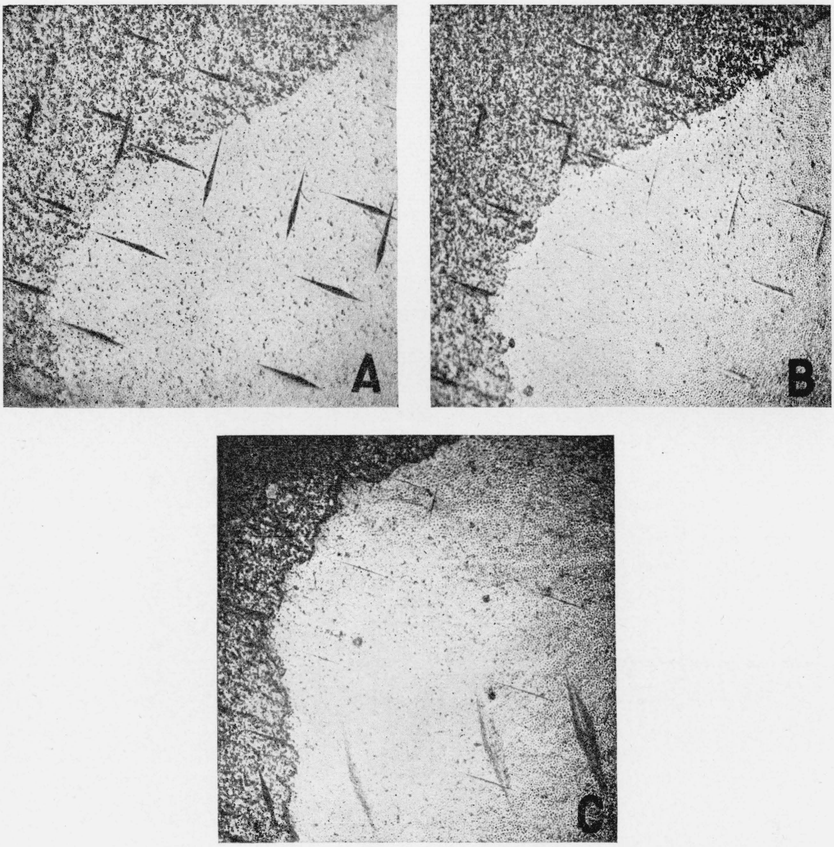

FIGURE 2.—*Enamel-dentin surface polished and indented.*

A, original surfaces; *B*, same surface after 5 days' exposure to a water solution of powder *A*; *C*, same surface after 4 months' exposure to the water solution of powder *A*. The diamond hardness indenter was again applied to the surface (at the end of the 4 months) with the same load as that used on *A*. The solvent and softening actions are evident.

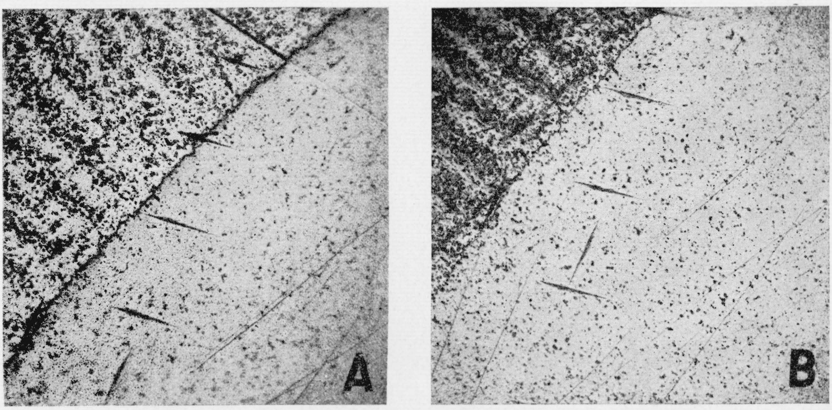

FIGURE 3.—*Enamel-dentin surfaces polished and indented.*

A, original surfaces; *B*, same surfaces after 5 days' exposure to a water solution of powder *B*. No solvent action on the dentin is evident.

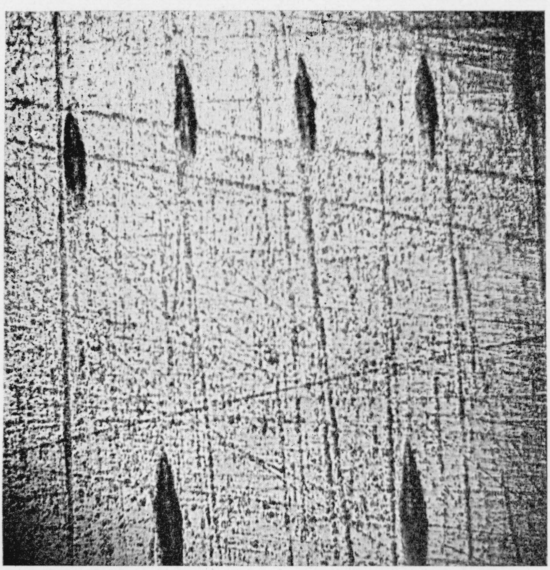

FIGURE 4.—*Dental enamel surface polished, indented and brushed 25 minutes by hand with a waterpaste of powder A.*

Note the difference between an apparent solvent action here and the abrasive action so evident in figure 5.

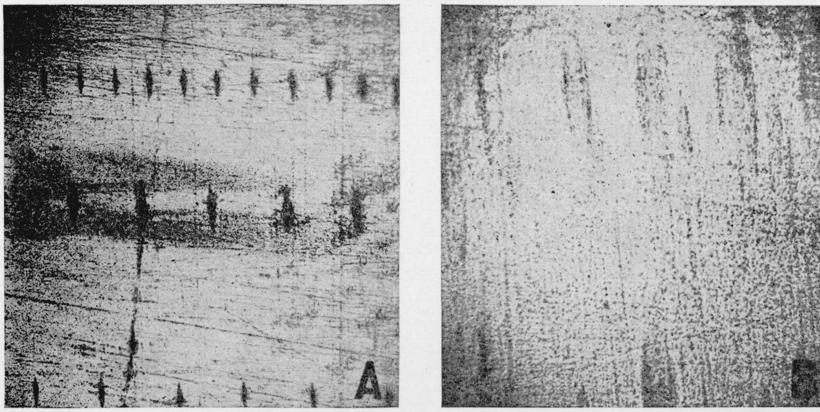

FIGURE 5.—*Dental enamel surfaces polished and indented.*

A, same area as figure 1, brushed 25 minutes with powder *B*; *B*, same area as figure 4, brushed 25 minutes with powder *B* after 25 minutes of brushing with powder *A*.

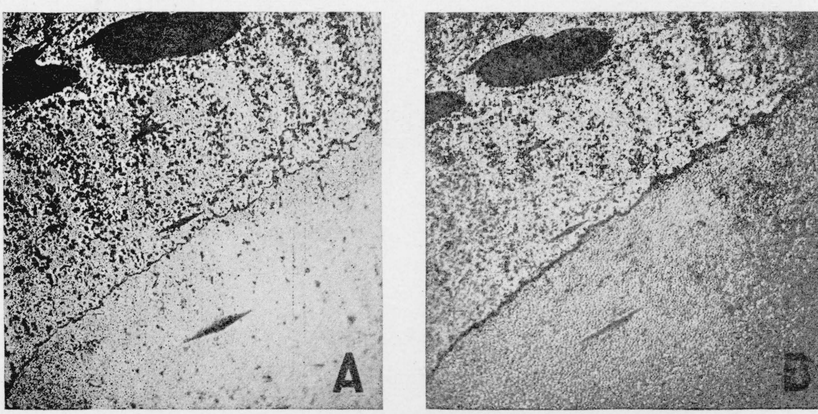

FIGURE 6.—*Enamel-dentin surfaces polished and indented.*

A, original surfaces; *B*, same surfaces after 4 days in a 20-percent solution of granulated sugar in water. (The darker ovals are folds where the contour of the enamel runs below the plane of polish.)

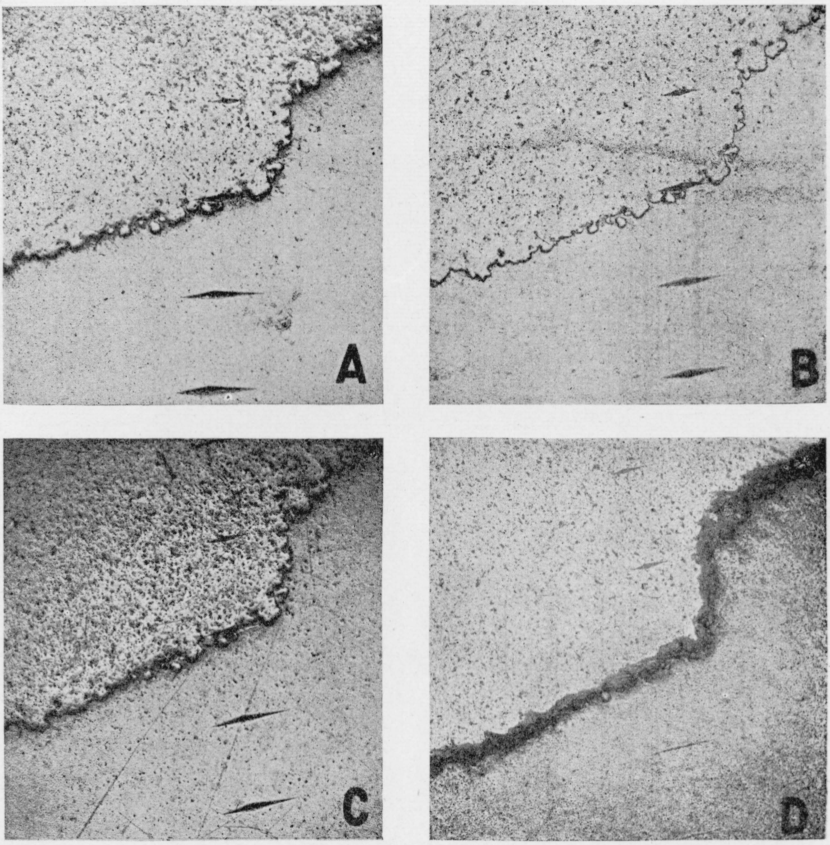

FIGURE 7.—*Enamel-dentin surfaces polished and indented.*

A, original surfaces; *B*, same surfaces after 5 days in water solution—sugar and calcium hydroxide (20 g of sugar and 5 g of $Ca(OH)_2$ per 100 ml of water); *C*, same surface after 6 days in a sterile 20-percent sugar solution; *D*, after 6 days in a 20-percent sugar solution, to which had been added 20 g of $CaSO_4$ and 2 ml of saliva for each 100 ml of solution.

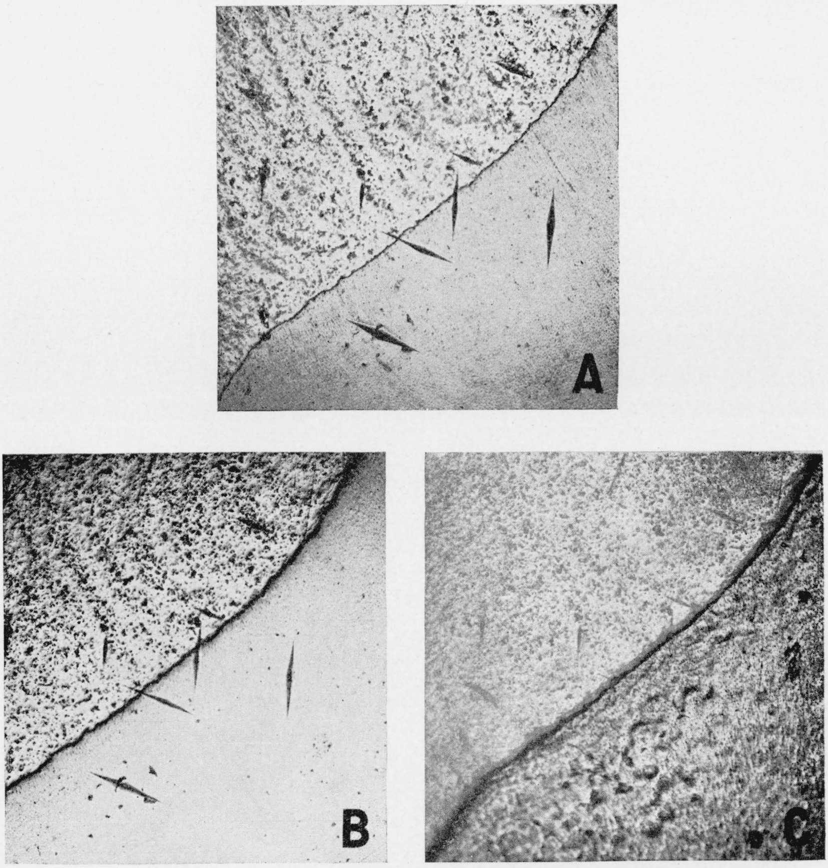

FIGURE 8.—*Enamel-denlin surfaces polished and indented.*

A, original surfaces; *B*, after 5 days in a crude molasses (pH 4.3); *C*, after 5 days in a solution containing 20 g of granulated sugar and 2 g of sodium alginate per 100 ml of water (pH 4.3).

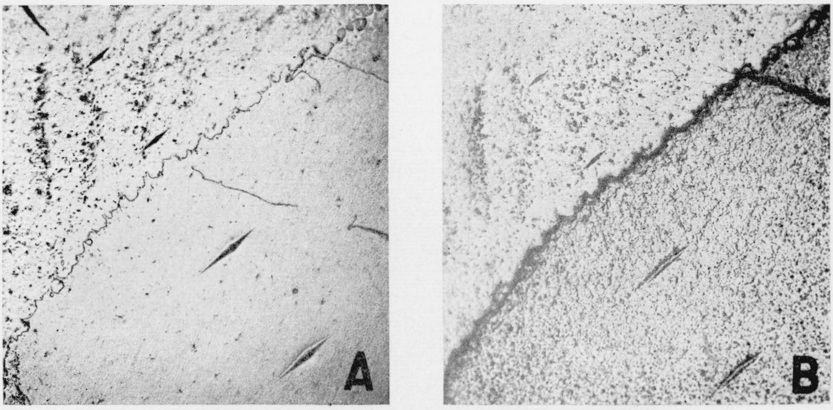

FIGURE 9.—*Enamel-dentin surfaces polished and indented.*

A, newly polished surfaces; *B*, same surfaces after 5 days in a "raw" sugar solution (pH 4.0).

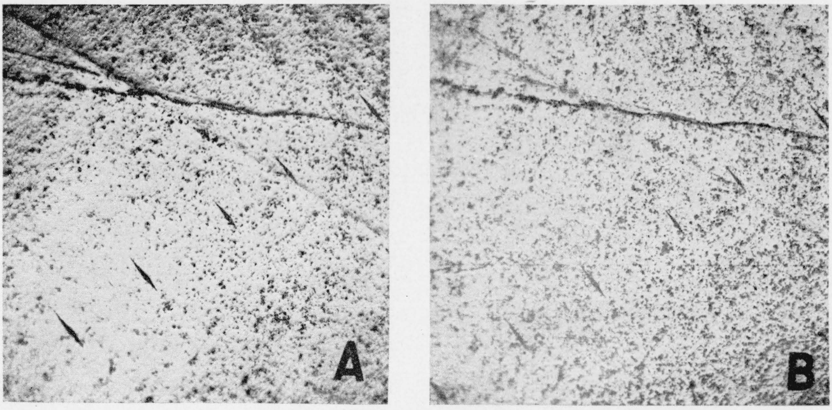

FIGURE 10.—*Dental enamel polished and indented.*

A, white spot in enamel surrounded by clearer enamel; *B*, the same area after 5 days in a "raw" sugar solution.

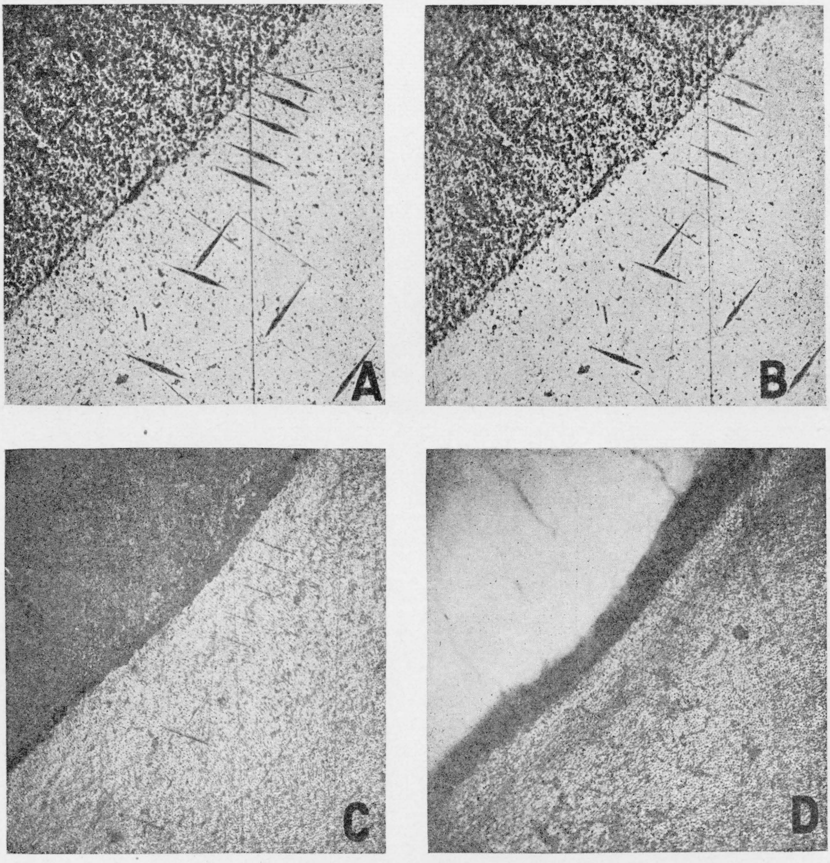

FIGURE 11.—*Enamel-dentin surfaces polished and indented.*

A, polished surfaces; *B*, after 9 days in a water mixture containing a base exchange material; *C*, after 24 hours in a diluted hydrofluoric acid solution; *D*, after 9 days in a sugar solution containing mouth bacteria.

TABLE 1.—*Losses of enamel and dentin during brushing*

[Wheel brush, ⅝-inch, driven at 1,750 rpm]

Brushing agent	Loss in weight [a]
Dental enamel (duration of tests 25 min)	
	mg
Powder *A*	1.1
Powder *B*	1.3
Paste *C*	1.0
Powder *A* plus 25% of FF carborundum	15.6
Water	0.0
Dentin (duration of tests 3 min, average)	
Powder *A*	22.6
Powder *B*	34.6
Paste *C*	7.0
Water	[b] +0.2

[a] Average for 2 or more tests.
[b] Apparent gain only. Accuracy of weighings is thought to be ±0.2 mg.

The principal solid ingredient of powder *A* is said to be sodium metaphosphate, plus a minor percentage of tricalcium phosphate. It is known to be soft, and is claimed to be insoluble. In fact the powder showed no abrasive scratches when rubbed against glass and is said to show little abrasion when rubbed against metal. The loss of enamel during brushing with a ⅝-inch dental wheel driven at 1,750 revolutions per minute and constantly bathed in a water-powder mixture was approximately the same as the loss produced by powder *B*, known to contain abrasives. These losses of enamel are small and perhaps are of minor dental significance (see table 1). The loss of dentin for soft powder *A* is, however, three times as much as the loss for paste *C*, a dentifrice which complies with a Federal specification.[2]

The question naturally arises: How can a slightly abrasive dentifrice do so much damage to the dentin of a tooth? A suspicion that solvent action was occurring arose when the surface injury shown in figure 4 was examined. This surface did not reveal typical abrasive injury. The injury produced when powder *B* was brushed by hand, precisely as powder *A* was brushed, against another surface of enamel showed typical abrasive injury (see fig. 5, A.) The surface, in figure 5, B, near the identations appeared to have been scooped out and pushed away. The surface brushed with powder *A* did not show this uniform removal of enamel over the entire brushed area. There appeared to be local pitting, or honeycombing, of the surface and the general outline of the indentation was better preserved, although there were typical edge and angle losses on the indentation, which are characteristic of chemical attack. This was confirmed in the following tests.

Plane surfaces were cut on teeth selected for the maximum of apparent soundness. The cutting to plane surfaces was done progressively on flat disks, using finer and finer carborundum powder as the cutting agent. The final polish was produced on a velvet-coated

[2] Federal Specification for Dentifrice; Tooth paste, FFF-D-191a.

disk, using wet magnesium oxide as the polishing agent. Marks were placed on both the enamel and dentin surfaces with the indenter, and the teeth were immersed in a mixture of water and the dentifrice to be tested.

The chemical attack on the exposed dentin shown in figure 2, B, developed from the wet dentifrice powder *A* applied to the tooth for 5 days without any brushing. The test was repeated on other teeth with the same result. After 4 months, the hardness indenter was again pressed into the surface of the tooth shown in figure 2, A, (see fig. 2, C) with the same load as that used for the specimen in figure 2, *A*. The dentin had been softened, as is evident from the greater penetration of the diamond indenter. The original normal hardness of about 50 (Knoop number) dropped to about 20 for the surface of the dentin. Figure 3, B, shows no such effect when a tooth is similarly treated with another wet dentifrice, powder *B*. Hardness tests on the surface shown in figures 3, A, and 3, B, were repeated at the end of 5 months' exposure to powder *B*. No such attack as that disclosed in figure 2, B, or 2, C, was evident. The fine scratches left in polishing the tooth were still visible after the 5 months' exposure. Dentifrice powder *A* mixed with water chemically attacks tooth surfaces.

Further confirmation of chemical attack was obtained in the following experiments. Small sections, such as cusps, were cut from teeth and were conditioned by storage in water for a number of days. They were then washed in alcohol and ether for quick drying and weighed on a magnetically damped balance. After the weighing, they were stored for 20 days in solutions of dentifrices *A*, *B*, and *C*. Powder *A* caused losses in weight of 0.2 percent and established the solvent action by the dentifrice. See table 2. This is not surprising, as sodium metaphosphate is a chemical frequently recommended to produce decalcification, when such action is desired in industry. Dentifrice *A* yielded 0.3 percent soluble phosphate rather consistently, even after 15 leachings. Figure 2 confirms the damage indicated in table 2. Perhaps the greatest injury to be anticipated from dentifrices containing such decalcifying ingredients would come from the particles of powder lodged between the teeth or under the gums, where they may be expected to continue their action during 24 hours of each day, unless they are completely dissolved before the next application of dentifrice.

TABLE 2.—*Solvent action of two tooth powders*

[Sections of teeth immersed in diluted dentifrice]

Initial weight of tooth crown	Weight after 20 days	Loss in weight
Powder *A* in water (saturated solution)		
mg	*mg*	*mg*
605.3	604.3	1.0
510.2	509.0	1.2
841.8	840.0	1.8
228.0	227.3	0.7
Powder *B* in water (saturated solution)		
677.2	677.1	0.1
381.9	382.0	[a].1
285.2	285.2	.0
Distilled water		
436.3	436.1	0.2
146.9	147.0	[a].1

[a] On these specimens there was an apparent gain. Since the accuracy of the weighings is thought to be ±0.2 mg, a gain in weight is not established.

2. ATTACK BY OTHER CHEMICALS AND BY BACTERIA

This method of investigation has also been used in a preliminary study of the effects of materials other than commercial dentifrices, such as sugar solutions, fluorides, alginate (a recent component in some dentifrices), and similar chemicals, in the hope that data of value in researches on dental caries might be obtained. It has not been possible to complete these studies. The following figures and comments are recorded, with little attempt therefore to evaluate their significance.

Figures 6 to 11, inclusive, show the effect of exposing tooth enamel and dentin to sugar solutions under various conditions. One of the theories of dental caries is based on the idea that refined sugars, when acted upon by various oral organisms, produce organic acids that attack tooth surfaces. If this process is confined in an isolated and protected area, carious lesions are said to result from such acid attack.

Figure 6 shows: A, the freshly polished surfaces of enamel and dentin; and B, the same surfaces after 4 days in a 20-percent solution of granulated sugar. No attempt was made to sterilize the sugar solution or to prevent bacterial action. Definite attack of the tooth surfaces is evident from the lack of sharp and definite edges of the indentation marks in figure 6,B. The darker ovals in the enamel are folds where the contour of the enamel runs below the plane of polish.

Figure 7 shows: A, the polished surface of enamel and dentin treated in sequence; B, 5 days in a water mixture containing 20 g of granulated sugar and 5 g of calcium hydroxide, $Ca(OH)_2$, for each 100 ml of water (the pH of this solution was 12.3); C, the same surface after 6 days in a sterile water solution containing 20 g of granulated sugar for each 100 ml of water (the pH of this solution was 6.7), and D, after 6 days in a water mixture containing 20 g of granulated sugar, 20 g of calcium sulfate, and 2 ml of fresh saliva for each 100 ml of water (the pH of this solution after 6 days was 3.3). No attack was observed in the sugar solution rendered alkaline by the calcium hydroxide, nor was there any attack by the sterile sugar solution in which bacterial action was prevented. Severe attack did occur, however, when bacterial action was permitted in the sugar solution containing the calcium sulfate. (In this and the following experiments in which bacterial action is discussed, actual bacteria counts were not made. Bacterial action was assumed to have occurred when gas bubbles could be observed escaping from the solution and when the solutions became progressively more acid.)

Figure 8 shows: A, newly polished surfaces of enamel and dentin; B, after 5 days in a crude, not sterilized, molasses (pH 4.3); and C, after 5 days in a water solution containing 20 g of granulated sugar and 2 g of sodium alginate for each 100 ml of water. The pH of this solution at the time the tooth was immersed was 4.3. It is of interest to note that no attack of the tooth surfaces occurred in the crude molasses, and that the same surfaces were severely attacked by the refined sugar solution.

Figure 9 shows: A, newly polished surfaces of enamel and dentin, and B, after 5 days in a water solution containing 20 g of raw sugar for each 100 ml of water. (The pH of this solution was 4.0.) Severe attack occurred. It should be pointed out that although the raw sugar is a crude product, some refining has been done, and it is not as crude as the molasses used in the previous experiment.

Figure 10 shows: A, a white spot in the enamel surrounded by clearer enamel, and B, the same surface after 5 days in a water solution containing 20 g of raw sugar for each 100 ml of water. The white area was definitely softer than the surrounding clear enamel as is indicated by the longer marks in the white area. The actual Knoop hardness numbers were around 250 (kg/mm^2) for the white area, and numbers up to 350 were obtained for the clear enamel. Such soft white areas are considered by some dentists to be more susceptible to attack, and are the areas where carious lesions are most likely to occur, provided the white spot extends to the surface of the tooth.

Figure 11 shows: A, newly polished surfaces of enamel and dentin; and B, after 9 days in a mixture containing 100 g of a base exchange material (1R4 sold by Resinous Products Chemical Co., Philadelphia, Pa.) to each 100 ml of water; C, after 24 hours in diluted solution of hydrofluoric acid (approximately 1 part per million); and D, after 9 days in a water solution containing 20 g of granulated sugar and 2 ml of fresh saliva for each 100 ml of water. It is evident that the hydrofluoric acid solution was too concentrated. The fluoride treatment, however, afforded no protection to the tooth against further attack by the sugar saliva solution, as shown in figure 11,D, in which the enamel is severely corroded.

Sections of the teeth stored in sugar solutions for several months (minimum about 2 months), in which bacterial action was not prevented showed severe attack on the enamel and much less attack on the dentin. Actually, the enamel could be pushed away as a sort of paste-like coating, leaving the dentin sacrcely attacked at all below the orinigal surface. The same general type of attack is illustrated by the enamel in figure 11,D, after storage for 9 days in a sugar solution.

III. SUMMARY

A method of research more searching in its application and permitting more definite visualization of injury to teeth than hitherto used is described.

The injury to enamel from a dentifrice containing harsh abrasives is definitely evident after 25 minutes of brushing with a toothbrush using a technique similar to that employed daily by millions.

The injury to enamel and dentin from a dentifrice containing a decalcifying ingredient is shown.

A few surfaces of enamel and dentin have been photographed before and after exposure to conditious thought to initiate or to foster dental caries.

This method of investigation offers exceptional opportunities for studying minute areas of teeth, enamel-dentin, and tooth-restoration margins with a definiteness not hitherto available. It should be of unusual value in laboratory studies of dental caries, where it will be possible to detect in a few days changes in tooth structures that might require weeks or months by other methods.

WASHINGTON, August 2, 1943.