The sensitivity of dentin

Changes in relation to conditions at exposed tubule apertures

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The sensitivity of experimentally exposed dentin, where the conditions at the outer tubule apertures were changed by various treatments, was studied in 40 contralateral pairs of teeth by intra-pair comparison. The results showed: (1) Dentin areas exposed by fracture were more sensitive than wet-ground dentin surfaces to application of dry, absorbent paper, scraping with a probe and a short blast of air. (2) Ground dentin surfaces treated for 2 minutes with 50% citric acid were more sensitive to the above mentioned stimuli and to application of a hyperosmotic solution (4-M $CaCl_2$) than were untreated ground surfaces. (3) The sensitivity of ground dentin surfaces was markedly reduced by dehydration by a jet of air for 1 minute. The sensitivity rose after rehydration of the dehydrated surfaces by rubbing with water or gentle wet grinding. It is concluded that mechanical and dehydrating pain-producing stimuli are more readily transmitted from a dentin surface when the exposed tubule apertures are wide open, and the tubule contents are thereby easily accessible. This is the case in fractured and acid-treated surfaces, while following grinding and dehydration the apertures are blocked, and this results in a less sensitive surface.

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From clinical experience it is well known that unprotected dentin, exposed by the effect of acid, grinding or abrasion *e.g.* »sensitive tooth necks», as well as prepared surfaces with less well fitting temporary fillings, are often hypersensitive. Experimental investigations (*Anderson, Curven & Howard*, 1958) have also shown that cavities become hypersensitive after having been filled for a few days with guttapercha; a material with poor adaption thereby giving a »leaky filling». *Anderson, Matthews & Shelton* (1967) observed that such cavities were more sensitive to osmotic stimulation than the dentin in a newly prepared cavity in the same tooth. They did not study the teeth histologically, but concluded that this increased sensitivity was due to local changes either »in the dentin stimulated or in the immediately subjacent pulp tissue».

On intra-pair comparison, *Johnson & Brännström* (1971) found that the pain reaction to a cold stimulus applied to amalgam fillings was more intense in

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teeth where a local inflammatory reaction beneath the cavity had been induced before the amalgam was placed. The dentin in such a cavity was also more sensitive to scraping with a probe and a short blast of air. A lowering of the threshold of pain owing to local inflammation of the pulp was therefore assumed to be one reason for the increased sensitivity.

In an investigation using the method of replication of experimentally exposed dentin surfaces *Brännström* (1962) found that surfaces exposed for one week were more sensitive to scraping with a probe and the taking of replicas than newly prepared surfaces. In replicas made a few days after exposure of the dentin, the areas around the apertures of the dentinal tubules were prominent, while the surface of newly ground dentin was more even. In that investigation as well as in later study (*Brännström*, 1965), using replication and electron microscopy, rounded structures, 3—8 μm in diameter with solid material in some of the tubule apertures were observed, and it was assumed that this made the contents of the tubules more easily affected by mechanical disturbances and thereby contributed to the hypersensitivity observed.

Inflammation and tissue changes were noticed in the corresponding area of the pulp beneath the exposed dentin. It was suggested that this also contributed to the hypersensitivity.

From several experiments *in vivo* and *in vitro* there is strong evidence of a hydrodynamic transmission of pain-producing stimuli to nerves in the pulp or in the pulpal part of the dentinal tubules (*Brännström & Åström*, 1972). It has been demonstrated that small, rapid, outward movements of the tubule contents due to forces of capillary attraction occur due to cold and due to removal of fluid by various means from exposed tubule apertures. Therefore, it seems reasonable to assume that not only a local inflammation in the pulp but also conditions at the outer tubule apertures might be of importance for the sensitivity of exposed dentin.

Scanning electron microscopic investigations have shown that the tubules on a dentin surface exposed by fracture are wide open, while a ground surface is covered with a layer of grinding debris, which more or less occludes the tubule apertures. Such investigations also revealed that acid treatment not only removes the debris layer but also opens and widens the apertures (*Brännström & Johnson*, 1974). The effect of acid has a clinical relevance, as both caries and acid food and drinks may contribute to similar changes of an exposed dentinal surface, for instance on the tooth neck.

The purpose of the present study was to investigate whether the sensitivity of the dentin is affected by subjecting the surface to various kinds of treatment, which alter in different ways the structure of the tubular apertures.

One series of experiments in the present study was made to find an answer to the following question:

Is there any difference in sensitivity between (1) dentin exposed by fracture and by grinding and (2) between a ground surface and such a surface after treatment with acid?

In previous investigations it has been proved that applying a hyperosmotic solution of $CaCl_2$ to ground dentin evokes pain (*Anderson & Ronning*, 1962; *Anderson et al.*, 1967a.; *Anderson & Matthews*, 1967c.), and also produces an outward movement of the fluid in the tubules (*Lindén & Brännström*, 1967; *Anderson, Matthews & Goretta*, 1967b.). It has been suggested by *Anderson* (1962, 1967 a., b., c.) that this might be due to osmotic phenomena. Experiments were therefore made to find out if the layer of grinding debris covering the tubular apertures acts as some kind of »semipermeable membrane», and if thus the pain reaction is more intense when a hyperosmotic solution is applied to ground dentin than to dentin with open tubules.

In a previous study it was noted that newly prepared cavities, subjected to a jet of air for 5 minutes, were insensitive to scraping with a probe and a short blast of air, and that this insensitivity persisted for at least 20 minutes (*Brännström*, 1960). Histologically it was noted that the main part of the odontoblast layer was aspirated into the dentinal tubules due to the rapid outward fluid flow produced by the evaporation from the dentin during air-drying. The last series of experiments was therefore designed to answer the following question: Is the insensitivity after such dehydration due to changes in the pulpal part of the tubules i.e. aspiration of odontoblasts into the tubules, or due to changes on the exposed dentinal surface?

MATERIAL AND METHODS

The material consisted of 80 premolars — 40 contralateral pairs — to be extracted for orthodontic reasons in patients aged 12 to 20 years. The teeth were clinically intact or, in a few cases, had small occlusal fillings. Clinical examination revealed no signs of abrasion of any of the cusps.

The dentin on the buccal cusp of all the teeth in the 40 pairs was exposed and treated in different ways, after which an intra-pair comparison was made of the reaction of the exposed dentin surfaces to different pain-producing stimuli. The material was divided into 3 groups according to the treatment given the surface.

Group I. Fractured surface — ground surface

In 8 pairs of teeth the dentin was exposed by fracture in one randomly selected tooth of each pair. The cusp was undermined by cutting a groove into the dentin with a diamond disc under a water coolant, and then fractured with forceps. A dentin surface of roughly equal size on the contralateral tooth was then exposed by grinding with a diamond wheel at low speed, 3000 r.p.m. under water cooling.

The sensitivity of the exposed dentin was tested after the teeth had been isolated with rubber dam, with the aid of (1) dry, absorbent paper applied with gentle pressure, (2) scraping with a probe, and (3) a short blast of air. Care was taken to keep the surfaces moist all the time. Before the sensibility test the patient was asked to note if the test to come caused any pain, and if so, whether there was any difference in the intensity of pain between the two teeth of the pair. Each stimulus was applied first to one tooth and then to the other of the pair, after which the patient was requested to describe what he had felt and to indicate which side — if any — was more sensitive. No attempt was made to grade the intensity of the pain except that a note was made if the patient reported that the pain was strikingly intense or very mild. The intra-pair comparison was made three times for each stimulus, which was applied alternately to each surface of the pair.

Group II. Acid-treated surface — ground surface

The dentin of both teeth in 21 pairs was exposed by grinding with a diamond wheel at low speed, 3000 r.p.m. under a constant stream of water.

A. In 13 of these pairs of teeth, the dentin sufrace in each pair which felt less sensitive or, if no difference was noted, one of the surfaces, decided by lot, was acid-treated by rubbing the dentin for 2 minutes with a cotton pellet soaked in 50% citric acid, after which the surface was rinsed with water. The exposed dentin surface on the contralateral tooth was similarly rubbed for 2 minutes with a pellet soaked in water. The exposed dentin of 5 of these pairs was examined for sensitivity in the same way as in Group I, and in 8 pairs the intra-pair comparison was made for reaction to application of a hyperosmotic solution (4-M $CaCl_2$). A drop of the test solution at room temperature was placed on both the exposed dentin surfaces, care being taken not to irritate the dentin mechanically. Any difference in pain was noted, the $CaCl_2$-solution rinsed off and the test repeated once, but this time the surfaces of the pair were tested in reverse order.

B. To find out whether the changes in sensitivity were in any way related to the effect of acid on the pulp and the contents of the dentinal tubules — the pain threshold is influenced by changes in the Ca^{2+} -ion concentration in tissue fluid (*Brink*, 1954) and such changes may occur because of the effect of citric acid — the exposed dentin areas of the remaining 8 pairs of teeth were treated in the following way. Both dentin surfaces in each pair were rubbed with 50% citric acid for 2 minutes and afterwards rinsed with water. The surface that felt more sensitive or, if no difference was noticed, one of the surfaces selected at random, was again ground with a diamond wheel under water cooling. Sensibility test was then performed as in Group I.

Group III. Dehydrated surface — rehydrated surface

In 11 pairs, the dentin of both teeth in the pair was exposed by grinding in the same way as described above and tested for sensitivity as in Group I. Both dentin surfaces in the pair were then subjected to a jet of air for 1 minute, and the sensibility test was again performed. The surface which was less sensitive after this dehydration or, if no difference was noted, one of the surfaces selected at random, was rehydrated in the following way.

1. The surface was rubbed for 1 minute with a cotton pellet soaked in water, and intra-pair comparison of the sensitivity was made as before.

2. The dentin surface thus rehydrated was then gently reground with a diamond wheel under a constant stream of water and again examined for sensitivity by comparison with the dehydrated and then untreated dentin surface of the contralateral tooth.

All teeth were extracted immediately after the last test and one pair of teeth from each group was fixed in formalin. The exposed dentin surfaces were covered with a gold film about 200 A thick by evaporation *in vacuo* and photographhde in a scanning electron microscope.

RESULTS

Group I. Fractured surface — ground surface

In all 8 pairs of teeth in which a fractured surface was compared with a ground surface, the dentin exposed by fracture was more sensitive to the mechanical and dehydrating stimuli used (Table I). The intra-pair difference was statistically significant (sign test, $p<0.05$).

Table I. *Pain reaction in exposed dentinal surfaces after various treatments*

	Number of pairs	Surface treatment	Number of surfaces with stronger pain reaction at intra-pair comparison				Significance (Sign test)
			Absorbent paper	Probing	Air-blast	4-M $CaCl_2$	
Group I.	8	fractured	7*	7*	8	—	$p<0.05$
		ground	0	0	0	—	
		a.					
Group II.	21	acid-treated	5	4*	5	—	$p<0.01$
		ground	0	0	0	—	
A.	13 (8 tested only with 4-M $CaCl_2$)	acid-treated				7	
		ground				1	
B.	8	acid-treated	4*	7*	8	—	—
		acid-treated-reground	0	0	0	—	
		b.					
Group III.	11	** dehydrated	0	1	0	—	
		rehydrated	1*	8*	6*	—	
		** dehydrated	0	0	0	—	$p<0.01$
		reground	2*	10*	8*	—	

a. ground surface treated with 50% citric acid for 2 minutes;
b. ground surface subjected to a jet of air for 1 minute;
* in remaining pairs no difference or no reaction;
** subsequent tests on same pair of teeth were carried out in this group.

Application of dry, absorbent paper produced pain in the fractured surfaces in 7 of 8 teeth, while the pain reaction of the ground surfaces was weak or absent. Scraping with a probe and a short blast of air produced pain in all 16 exposed dentin areas.

Group II. Acid-treated surface — ground surface

A. In all 5 pairs of teeth where a ground, acid-treated surface was compared with a ground surface treated with water, the pain reaction produced by all three types of stimuli was clearly stronger in the acid-treated dentin surface (Table I).

Application of dry, absorbent paper caused pain in all of the 5 acid-treated — severe pain in 2 cases — and in 3 of the 5 untreated surfaces. Scraping with a probe and a short blast of air produced a painful reaction in all 10 surfaces.

In 7 of the 8 pairs of teeth where the sensibility test was performed with 4-M $CaCl_2$, the reaction was stronger in the acid-treated surface on both applications. In 1 pair the untreated surface was more sensitive (Table I). Application of the test solution caused pain in all 16 surfaces. No »aftereffect» was noted after the $CaCl_2$-solution had been rinsed off.

B. In all 8 pairs of teeth, where a comparison was made between two acid-treated surfaces, one of which had been reground after the acid treatment, the surface not reground was more sensitive to the three stimuli used (Table I). Scraping with a probe and a short blast of air evoked pain in all 16 surfaces. In 3 of the 8 pairs of teeth both dentin surfaces were insensitive to application of dry absorbent paper, in 4 pairs the paper test evoked pain only in the surface not reground and in 1 pair both surfaces were sensitive to this stimulus.

The intra-pair difference in Group II was statistically significant (sign test, $p<0.01$).

Group III. Dehydrated surface — rehydrated surface

After application of a jet of air for 1 minute to the exposed dentin areas of both teeth in 11 pairs the sensitivity of all 22 surfaces to all three types of stimuli was markedly reduced. No pain could be evoked in any of the surfaces by application of dry, absorbent paper, and the pain reaction to scraping with a probe and a short blast of air was very mild or absent.

1. Rehydration by rubbing one dentin surface of the pair with water resulted in increased sensitivity of the rehydrated surface in 9 of the 11 pairs. In 2 pairs there was no difference (Table I).

2. After gentle regrinding of the rehydrated surface the difference on intra-pair comparison was more marked. In all 11 pairs the reground surface was more sensitive than the dehydrated and then untreated surface, (Table I). The intra-pair difference after regrinding was statistically significant (sign test $p<0.01$).

Fig. 1. Dentin surface exposed by fracture. Tubule apertures are open. Scanning electron microscope photograph × 1200.

At the last performed sensibility test the reground surface was sensitive to dry, absorbent paper in 2 pairs, to a short blast of air in 10 pairs and to scraping with a probe in all 1 pairs, while the surface that had been dehydrated and then kept dry was insensitive to all stimuli in 4 pairs and in the remaining 7 pairs only a weak pain reaction could be evoked by probing and/or a short blast of air.

Photographs taken in the scanning electron microscope of the exposed dentin in one pair of teeth from each group confirmed the above-mentioned earlier observations of conditions on fractured, ground and acid-treated surfaces (Figs. 1—3). No difference could be noted between the appearance of a wetground

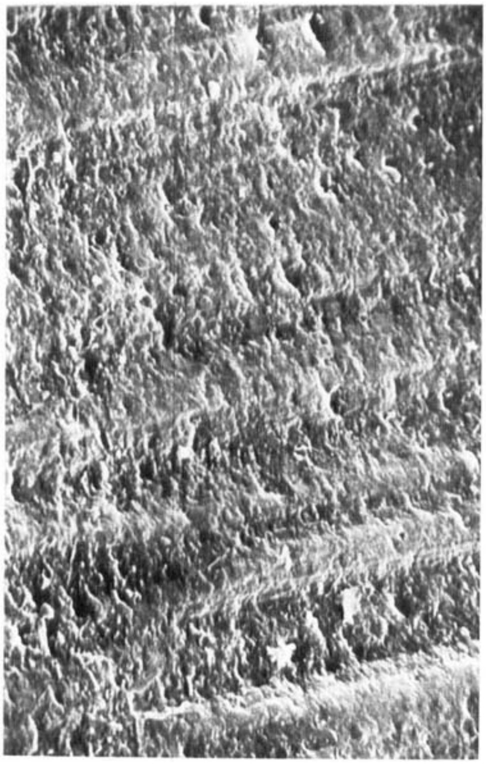

Fig. 2. Ground dentin surface covered with a layer of grinding debris. Most tubule apertures are occluded. Scanning electron microscope photograph × 1200.

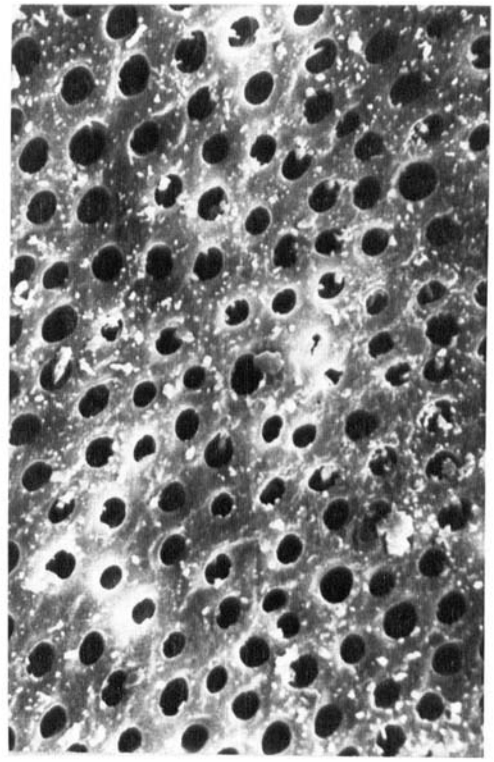

Fig. 3. Dentin surface exposed by grinding and treated with 50% citric acid for 2 minutes. Tubule apertures are opened and widened. Peritubular dentin is dissolved. Scanning electron microscope photograph × 1200.

dentin surface and a similar surface after dehydration by blasting with air for 1 minute.

DISCUSSION

As the investigation was carried out on pairs of teeth from young individuals, and as the teeth were practically clinically intact, the state of the pulp was presumably equal in the two teeth of each pair. Any minor differences in dentin and pulp were randomly distributed between the two teeth after exposure of the dentin and before the various surface treatments were applied.

Fracture alone does not produce any changes in the pulp beneath the fractured dentinal tubules (*Johnson, Olgart & Brännström*, 1973). If any cellular or vascular changes occurred as a consequence of grinding, they must have been minimal, because careful grinding with a diamond under a constant stream of water has been shown not to produce any notable injury to the pulp (*Brännström*, 1960). This is supported also by the observation that the fractured surface was in all cases more sensitive than the ground surface. The observed differences in sensitivity within the pairs of teeth in all groups were therefore presumably not influenced by a lowering of the pain threshold due to changes in the pulp following grinding or fracture.

The results show that the sensitivity of exposed dentin depends to some extent on conditions at the outer apertures of the exposed dentinal tubules. The significantly lower sensitivity of ground dentin compared to that of dentin exposed by fracture or treated with acid appears to depend on the fact that while the tubular apertures on a ground surface are plugged with grinding debris, they are wide open on a fractured or acid-treated surface, and the tubule contents are thereby more readily accessible to mechanical and dehydrating stimuli. This is probable particularly for the acid-treated surface in which the tubule apertures are also widened (Fig. 3), so that the total fluid surface is increased.

The results also showed that the increase in sensitivity after acid-treatment was not due to changes in the tubule contents or in the pulp, since the acid-treated dentin areas were more sensitive in all intra-pair comparisons, irrespective of whether only one of the surfaces of the pair was treated with acid or whether both surfaces were primarily acid-treated and one of them then reground.

Scanning electron microscopic studies of the dentinal tubules and the extent of the odontoblast processes have displayed that the dentinal tubules are mainly filled with fluid (*Brännström & Garberoglio*, 1972). Analysis has shown that this fluid is of extracellular composition and consists mainly of water and salts and a minor amount of proteins and carbohydrates (*Haldi, Wynn & Culpepper*, 1961; *Paunio & Näntö*, 1965; *Coffey, Ingram & Björndal*, 1970; *Haljamäe & Röckert*, 1970). *Coffey et al.* (1970) found that the contents of the tubules were »extremely adhesive and coagulated readily upon exposure to air». The reduction in sensitivity of ground dentin, found in the present investigation after dehydration by application of a jet of air, may be due to a solidification of the plugs of grinding debris in the apertures of the dentinal tubules owing to a cohesion of solid material from the contents of the tubules, since only water evaporates during blasting with air. This explanation is also supported by experiments in which it has been shown that the dentin can be desensitised by prolonged exposure to a stream of air (*Brännström*, 1960) and that desiccation of a cavity reduces the outward fluid flow in the dentinal tubules produced by dehydrating, pain-producing agents (*Polhagen & Brännström*, 1971).

In the present experiment the sensitivity of the dehydrated dentin again increased after rehydration by rubbing with water, presumably owing to dissolution or mechanical removal of part of the plugs from the apertures (*Brännström & Johnson*, 1974). This treatment exposed the contents of the tubules to mechanical irritation and subsequent removal of fluid. Gentle regrinding, under a constant stream of water, of the thus rehydrated surface resulted in a further increase in sensitivity.

The reduction in sensitivity of ground dentin after exposure to a stream of air was obviously not due to changes in or injury to the pulp since the sensitivity returned after rehydration and regrinding of the dehydrated dentin. Earlier investigations have shown that airblasting of ground dentin for periods between 20 sec. and 5 min. results in aspiration of odontoblasts and a marked reduction of the odontoblast layer (*Brännström*, 1960; *Brännström*, 1968). The initially decreased sensitivity of dentin surfaces dehydrated in this way nevertheless recovered, which suggests that an intact odontoblast layer at the pulpal wall is not a necessary condition for the sensitivity of dentin. Neither did the aspirated cells in the dentinal tubules obstruct transmission of pain-producing stimuli. These observations are in accordance with the findings by *Brännström & Åström* (1964) hat dentin surfaces subjected to a stream of air for 1 minute and then left unprotected for a week were sensitive to mechanical irritation, though histological examination showed a marked reduction of the odontoblast layer or necrobiotic changes in the corresponding area of the pulp. It was concluded that the odontoblasts do not play any significant role in the transmission of pain-producing stimuli from exposed dentin.

The relationship between dentin sensitivity and osmosis has been discussed in earlier investigations (*Anderson et al.*, 1967a, 1967b, 1967c). This has probably been based on the assumption that the odontoblast processes fill the entire dentinal tubule, and that the cell membrane acts as a semipermeable membrane. However, in recent scanning electron microscopic studies odontoblast processes have been observed only in the pulpal fourth of the tubules, which further out are filled with fluid (*Brännström & Garberoglio*, 1972), and as pointed out, dentinal pain can be evoked even in the absence of odontoblasts (*Brännström & Åström*, 1964). In the present experiment acid-treated dentin proved more sensitive than ground dentin to a hyperosmotic solution, which suggests that plugs of grinding debris in the tubule apertures do not constitute an »semipermeable membrane», which may be of importance in this connection. It has been suggested that the effect of hyperosmotic solutions in the form of an outward fluid flow in dentinal tubules is related to the water activity of the solutions rather than to purely osmotic phenomena (*Lindén & Brännström*, 1967). This assumption was also supported by observations of *Horiuchi & Matthews* (1973), who noticed that »the fluid movement caused by solutions of different substances could not always be predicted on the basis of their osmotic pressure alone». It therefore seems probable that the osmotic properties of a solution are of minor importance to its painproducing effect. This appears rather to be related to the ability of the solution to remove fluid from the apertures of the dentinal tubules and thereby produce a rapid outward fluid flow by mobilization of capillary forces in the dentinal tubules. This assumption was supported by the results in the present experiment, since the pain evoked by application of 4-M $CaCl_2$ to exposed dentin was more intense when the tubules were open after treatment with acid than when the tubular apertures were occluded by grinding debris.

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