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Wear of dentine in vitro by toothpaste abrasives and detergents alone and combined

C. Moore and M. Addy

Division of Restorative Dentistry, Dental School, Bristol, UK

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Abstract

Aim: To measure in vitro the abrasion of dentine by toothpaste detergents and abrasives alone and combined.

Materials and Methods: Detergents used were tego betain, sodium lauryl sulphate (SLS), adinol and pluronic diluted to 1%w/v. Abrasives were three artificial silicas, tixosil 73 and 123 and Zeodent 113, and calcium carbonate used at 2.5% w/v. Flat human dentine specimens were brushed with aqueous detergent solutions or abrasive slurries, detergent abrasive slurries and water for 20,000 brush strokes. Dentine loss was measured by non-contacting profilometry at 10,000 and 20,000 strokes. Silica particle size distribution was measured by laser deflection.

Results: Loss of dentine occurred with all detergents, abrasives and detergent abrasion combinations, but was not linear with number of brush strokes. Water appeared to remove the smear layer only, but all detergents exceeded the predicted smear layer thickness. The silica abrasives differed in abrasion properties despite similar particle size distribution. Different detergents modulated the abrasives actions in mainly positive or mainly negative directions.

Conclusions: Detergents appear able to attack the dentine surface to produce wear. Abrasives vary considerably in wear produced under similar conditions. Detergents modulate the effect of abrasives in a way that may reflect the rheological properties of the mixture.

Key words: abrasion; abrasives; dentine; detergents; tooth brushing; toothpastes; tooth wear

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Frandsen in his 1986 review concluded that tooth brushing with toothpaste was the most common oral hygiene habit practiced by people in developed countries. Many benefits of regular and efficient tooth cleaning have been cited over the decades and derived from the mechanical actions of the brush and the mechanical/chemical properties of tooth paste (for reviews see Forward 1991, Cummins 1997, Forward et al. 1997). Arguably, the most important benefits of toothpaste relate to dental, gingival and periodontal health, although interest in their use for the control of supragingival calculus (Davies et al. 1997) and, more particularly, extrinsic dental stain (Sharif et al. 2000, Joiner et al. 2002) has grown. Many products today are multi-functional by virtue of a range of agents formulated into toothpaste. Common to most toothpaste is the presence of a detergent, often sodium lauryl sulphate (SLS), and an abrasive system of variable composition (Davis 1978). Toothpaste detergents have a variety of functions including, almost by definition, the removal of organic material on the tooth surfaces. Additionally, SLS has antimicrobial effects, which extend over several hours in the mouth, and a moderate plaque inhibitory action (Jenkins et al. 1991a, b). Abrasives appear to be essential for the control of extrinsic dental stain: brushing with water or non-abrasive toothpaste being associated with the development of tooth staining (Davis 1978, Forward 1991, Dawson et al. 1998).

With any mechanical/chemical cleaning system, however, there exists potential for harm to the recipient surface. In the mouth, damage to hard and soft tissues from tooth brushing with toothpaste may arise from abrasion and/or erosion (for reviews see Hunter et al. 2002, Addy & Hunter 2003). Little scientific data exist for the effects of oral hygiene practices on the gingivae, and the possible role of tooth brushing in gingival recession is derived from case reports of abusive use or extrapolations from epidemiological studies (for reviews see Watson 1984, Smith 1997, Addy & Hunter 2003).

Most interest, and in some countries concern, has been shown in tooth wear caused by tooth cleaning. Most toothpaste, however, is above a pH that might cause erosion to either enamel or dentine; few contain abrasives that can abrade enamel, and toothbrushes alone have little, if any, effects on dental hard tissues (for a review see Addy & Hunter 2003). These factors have resulted in the major interest focusing on the abrasivity of toothpaste to dentine and clinically on the so-called, and probably incorrectly termed, cervical abrasion lesion (Addy & Hunter 2003). The International Standards Organisation (ISO) and the British Standards Institute (BSI) have published rather similar standards concerned with safety aspects of toothpaste, the former being under review at this time. Outside toxicity, major aspects of these standards relate to dentine abrasivity and limits are set relative to standard abrasives: relative dentine abrasivity (RDA) value. Recent reviews have tended to conclude that toothpastes, falling within the RDA limits and in normal use, cannot alone cause clinically significant wear to dentine in a lifetimes use (Hunter et al. 2002, Addy & Hunter 2003). Interestingly, the vast majority of toothpaste wear studies, most in vitro with a few in situ, are concerned with the complete product (Stookey & Muhler 1968, Council of Dental Therapeutics 1970, Addy et al. 2002, Hooper et al. 2003). There are few studies on the interaction of the abrasive system with other ingredients, notably detergents (Harte & Manly 1975, 1976, Redmalm 1986). Also, there are limited data to demonstrate that SLS can remove, very rapidly, the smear layer from dentine (West et al. 1998, for a review see Adams et al. 1992). The aim of this study in vitro was to measure wear of dentine produced by brush applied abrasives and detergents alone or combined.

Materials and Methods

Preparation of dentine samples

The method of sample preparation used the basic principles of the methods employed in previous published studies, in vitro and in situ, of wear of enamel and dentine (West et al. 1998b, Hunter et. al 2000 Vanuspong et al. 2002): a summary will be presented here. Flat dentine specimens were prepared from human third molar teeth extracted from individuals of either gender, aged between 18 and 35 years. After removing any soft tissue remnants the teeth were sterilized in 20,000 ppm hypochlorite for 24 h and stored in isotonic saline until required. The teeth were decoronated with a diamond bur in a high-speed hand piece and depending on the configuration the root portion(s) cut vertically into two or four pieces: each section having one face of surface dentine. The sections were placed into moulds measuring 25 × 25 × 3 mm and embedded in epoxy resin (Stycast 1266, Hitek Electronic Material Ltd., Scunthorpe, UK) for 24 h until fully hardened. Specimens were then polished (Kent 3 Automatic Lapping and Polishing Unit, Kemet International Ltd., Maidstone, UK) up to 1200 grit to expose a window of dentine.

Profilometry

Specimens were firstly baselined by placing each into the right-angled guide on the *X*- and *Y*-axis computer-controlled traversing sample stage of a white light non-contacting profilometer (Proscan 2000, Scantron Industrial Products Ltd., Taunton, UK) and the window of dentine aligned into the centre of the field. The size of the zone to be scanned was keyed in as $X = 2$ mm and $Y = 2$ mm.The *Z*-range of the scanner was then set at $150 \pm 1\ \mu$m. All co-ordinates of the specimen position and scan start were stored to permit exact repositioning of specimens on the scan table. After scanning, the mean profile was calculated and specimens only accepted if this profile was $<0.3\ \mu$m. Specimens were then taped with PTFE tape to expose a window of dentine approximately 1 mm wide (*Y*-axis). After application of the treatment regimens taping was removed and specimens scanned using the same co-ordinates and therefore scan area as at baseline. Images were then cropped so that average measurements of wear were taken from the two previously taped edges of the exposed window (approximately 1 mm across (*Y*-axis) and exactly 1 mm long (*X*-axis)). The software then calculates the mean peak height (lesion depth) over the 1 mm length, using approximately one thousand individual readings across the *Y*-axis.

Study materials

A total of four abrasives and four detergents, which may be or are used in toothpaste products, were chosen, namely the following:

Abrasives (Supplier: GlaxoSmithKline, Weybridge, Surrey, UK)

1 Tixosil 123 (silica).
2 US Grade Calcium Carbonate TPO1.
3 Tixosil 73 (silica).
4 Zeodent (silica).

To determine whether particle size influenced abrasion by the same type of abrasive, the particle size percent distribution by number and volume of the three silica abrasives was measured by a laser deflection particle size instrument (Mastersize, Malvern Instruments Ltd., Malvern, UK).

Detergents (Supplier: GlaxoSmithKline, Weybridge, Surrey, UK)

1 Tego Betain CKD (zwitteronic).
2 SLS 0303VA (anionic).
3 Adinol CT95 (anionic).
4 Pluronic F108 (non-ionic).

Aqueous slurries of abrasives were made to represent a concentration found in toothpastes, namely 2.5%. Aqueous dilutions of detergents were made to represent available levels found in toothpastes, namely 1%. Combinations of each detergent with each abrasive were calculated to give final slurries of 2.5% abrasive and 1% detergent.

Abrasion method

Groups of six dentine specimens were placed into the countersunk slots of the slurry tray of an electric motor driven reciprocal action tooth-brushing machine. The machine brushing head held two flat trim toothbrush heads (Oral B 35, Oral B, London, UK) under a 200 g load. A 75 ml aliquot of the abrasive slurry, detergent solution or combined abrasive detergent slurry under test was placed into the tray of the brushing machine. Specimens were brushed for 10,000 strokes (83 min.) with solutions/slurries agitated manually every 10 min. and replaced after 5000 strokes. Specimens were taken out of the machine, their taping removed and then rinsed under copious quantities of tap water and allowed to bench dry. Dentine loss was then measured on the profilometer described above. Specimens were then re-taped and returned to the brushing machine and a further cycle of 10,000 strokes was performed with the test solution. Further profilometry readings were taken at this 20,000 stroke point. Tooth brush heads were replaced after each 10,000 strokes. A water control was also performed.

Results

The particle size distribution by number and volume for the three silicas are shown in Table 1. The distribution by number has been stated at as near 95% as possible. Using this range the percent by volume is then stated. The distribution by number and volume of the larger particle size range is then quoted. By number most of the particles accounting for 95% of the total are similar for all three silicas 2–10 μm in diameter. The particle size range for above 10 μm diameter is very similar for Tixosil 73 and 123 with a slightly smaller range for Zeodent. The percentage by number and volume accounted for by the larger particles is, however, very similar for the three silicas.

The mean and standard deviation of peak height for dentine loss with the four detergents and water at 10,000 and 20,000 strokes are shown in Table 2. For all detergents there was increased dentine loss at 20,000 strokes compared with 10,000 strokes. Dentine loss was not proportional to the number of strokes. Water produced just greater than 1 μm depth of dentine loss with little difference between the depth at 10,000 and 20,000 strokes. In mean terms, at both 10,000 and 20,000 strokes, the order of least to greatest depth of dentine loss was Tego Betain, Pluronic, SLS and Adinol. Analysis of variance at 10,000 strokes revealed the differences between detergents were significant ($p<0.001$), but not at 20,000 strokes ($p>0.05$).

The mean and standard deviations of peak height for dentine loss with the four abrasives at 10,000 and 20,000 strokes are shown in Table 2. Again, the dentine loss was not proportional to the number of strokes. Mean differences between abrasives were considerable and the order of effect from least to greatest at both 10,000 and 20,000 strokes was $CaCO_3$, Tixosil 123, Tixosil 73 and Zeodent. Analysis of variance over abrasives was highly significant ($p<0.001$). With the exception of $CaCO_3$, at 20,000 strokes the mean abrasive dentine losses were greater than the mean detergent losses.

The means and standard deviations of the peak height for dentine loss with the 4×4 detergent/abrasive combinations at 10,000 and 20,000 strokes are shown in Table 3. The means varied at the extreme from 2.96 to 25.57 μm at 10,000 strokes and from 3.29 to 39.92 μm at 20,000 strokes. The same combination accounted for the least and greatest effects at both stroke points, namely Tego Betain/$CaCO_3$ and Adinol/Zeodent, respectively. For all combinations, more dentine loss was apparent at 20,000 strokes than at 10,000 strokes, but, again, dentine loss was not proportional to strokes with less additional loss after the second 10,000 strokes than after the first 10,000 strokes. An observational appraisal of the data at 10,000 and 20,000 strokes revealed that the detergents modulated the abrasivity of the abrasives in both a positive and a negative direction and to variable magnitudes. Thus, Adinol increased dentine loss with all four abrasives and, with the exception of $CaCO_3$, by two to more than four times the loss produced by the same abrasives in water. SLS similarly increased the dentine loss created by the abrasives and by two to nearly three times. Tego Betain increased the abrasion of Tixosil 123, had little effect on $CaCO_3$ and reduced abrasion by Tixosil 73 and Zeodent 113. Pluronic increased abrasion by $CaCO_3$ but decreased abrasion by the other three abrasives.

Analysis of variance to determine if the abrasion values differed with the combination of the four detergents with the same abrasive revealed highly significant differences for Tixosil 123 and Tixosil 73 at both 10,000 and 20,000 strokes but no significant differences for $CaCO_3$ or Zeodent 113. Analysis of variance to determine whether abrasion values differed with the combination of the four abrasives with the same detergent revealed mostly significant differences at 10,000 and 20,000 strokes (p ranged from <0.001 to <0.05); the exceptions were borderline significance for SLS at 20,000 strokes ($p=0.06$) and Tego Betain at 10,000 strokes ($p=0.06$).

Table 1. Particle size percentage distribution by number and volume for Tixosil 73 and 123 and Zeodent 113

	Particle Size Range μm	Percentage by number of range	Percentage by volume of range
Tixosil 73	2.2–10.2	95.0	34.8
	11.6–84.0	5.0	65.2
Tixosil 123	2.2–10.3	95.1	40.4
	12.4–83.9	4.9	59.6
Zeodent 113	2.4–9.5	95.3	36.9
	11.6–46.0	4.7	63.1

Table 2. Mean (standard deviation) erosion/abrasion of dentine by detergents and abrasives after 10,000 and 20,000 brush strokes measured in microns ($n=6$)

Detergent	10,000 strokes	20,000 strokes
Tego Betain	0.57(0.13)	2.47(0.34)
SLS	2.00(0.18)	2.98(0.38)
Adinol	2.06(0.45)	3.92(0.96)
Pluronic	0.89(0.11)	2.79(1.78)
Abrasive		
Tixosil 123	5.47(1.55)	7.77(1.35)
$CaCO_3$	2.69(0.61)	3.40(0.57)
Tixosil 73	9.18(2.32)	20.95(2.60)
Zeodent 113	13.28(7.83)	17.80(3.58)
Water	1.04(0.12)	1.17(0.14)

Table 3. Mean (standard deviation) erosion/abrasion of dentine by combinations of detergents and abrasives after 10,000 and 20,000 brush stokes in microns

Combination	10,000 strokes	20,000 strokes
Tego Betain/ Tixosil 123	6.28(4.44)*	10.40(4.89)*
$CaCO_3$	2.96(1.33)‡	3.29(1.48)‡
Tixosil 73	7.57(2.85)†	10.13(3.36)†
Zeodent 113	9.04(4.44)†	11.78(3.92)†
SLS/Tixosil 123	14.42(6.84)*	17.49(10.57)*
$CaCO_3$	4.81(2.92)*	7.59(4.68)*
Tixosil	12.04(5.94)*	18.33(7.84)*
Zeodent 113	19.45(11.80)*	22.89(12.21)*
Adinol/ Tixosil 123	22.17(7.18)*	32.03(9.87)*
$CaCO_3$	3.89(1.55)*	5.38(2.50)*
Tixosil 73	22.26(9.81)*	39.51(15.59)*
Zeodent	25.57(10.42)*	39.92(13.16)*
Pluronic/ Tixosil 123	4.13(1.97)†	5.74(1.67)†
$CaCO_3$	6.04(4.03)*	6.72(3.72)*
Tixosil 73	10.95(3.04)†	15.27(5.14)†
Zeodent 113	11.59(8.27)†	15.95(8.77)†

*Detergent increases abrasion
†Detergent decreases abrasion
‡Little or no effect of detergent on abrasion when compared to equivalent abrasive date in Table 1

Discussion

A variety of methods and materials have been used to study and measure dental abrasion by toothpastes and their ingredients (for reviews see Hunter & West 2000, West & Jandt 2000, Hunter et al. 2002). While the measurement method may not be important, providing it is accurate, the data from the present study suggest the choice of substrate may be of critical importance. Thus, all of the detergents alone resulted in loss of dentine. If another substrate had been used, a common example is acrylic (Sexson & Phillips 1951, Addy et al.1991, for review see Hunter & West 2000), the action of the detergent would have been underestimated in the abrasion process. Previous studies suggested that SLS or the liquid phase of toothpastes only removed the smear layer to expose the underlying tubules (West et al. 1998). The present results indicated that not only was the smear layer removed but also body dentine. The water brushing appeared only to remove the smear layer, which is usually quoted as approximately 1 μm thick (Pashley 1984). Further evidence for this, in the present experiments, was the lack of significant increase in dentine loss with water brushing at 20,000 strokes compared with 10,000 strokes. How the detergents caused dentine loss is not clear. Abrasion can clearly be ruled out as can erosion, because the pH of the detergents was above neutral. A direct chemical attack on the organic material in dentine, mainly collagen, may explain this phenomenon. Interestingly, the two anionic detergents were the most aggressive and it is known that SLS and therefore probably Adinol are rapidly adsorbed onto hydroxyapatite (Barkvoll et al. 1988). There have been several studies on dentine wear with whole toothpaste formulations (Stookey & Muhler 1968, Council on Dental Therapeutics 1970) and a few measuring the influence of diluents, including SLS, on the action of abrasives (Manly et al. 1974, Harte & Manly 1975, 1976, Redmalm 1986). Unfortunately, this appears to be the only study that measured the effects of detergents alone on dentine.

The variable, wear of dentine by the abrasives alone, or more accurately in aqueous slurry, was expected and has been studied previously (Harte & Manly 1975, 1976, Redmalm 1986). Several factors have been cited to explain different wear levels produced by different abrasives. Probably of importance must be hardness of particles. Most toothpaste abrasives have reduced hardness relative to enamel, which explains the almost complete lack of toothpaste abrasion of this tissue (for a review see Hunter & West 2000): the exception is paste containing non-hydrated alumina. The low abrasion caused by the $CaCO_3$ used in the present study probably reflects the softness of this material relative to the other abrasives and dentine. Other chalks are available for use in toothpastes, which are much harder than the present material.

Particle size and shape are also stated to influence abrasion particularly when comparing abrasives made of the same compound, as here, namely silicon dioxide (artificial silica) (Davis 1978). Although one study (Redmalm 1986), which cited the importance of particle size, elicited data for abrasion by different silicas, that was not consistently related to particle size. In the present study, although not planned a priori, the particle size distribution of the silicas was very similar. In the event, therefore, the variable of particle size for the silicas was fortuitously negated. The data suggest that, at least for these silicas, other chemical or physical properties of the abrasives influenced the abrasion in an aqueous environment. Few studies have similarly compared only abrasives. Harte & Manly (1976) compared variables including brush, abrasive, temperature, diluent and concentration; however, it is difficult to compare findings with the present study because of the peculiar brushing system used by these authors (Harte & Manly, 1976), which used brushes with all but one tuft removed. Indeed, this method produced completely contradictory data for the relevance of filament stiffness to paste abrasion. Thus, two studies using whole brushes demonstrated that soft brushes caused more abrasion than hard brushes and for which there is an obvious explanation in respect of the improved carriage of the paste over the substrate with soft brushes (Phaneuf et al. 1962, Dyer et al. 2000). The Harte & Manly (1976) study reported that hard brushes are more abrasive with paste than soft brushes. These authors, again using highly modified brushes, also reported differences in abrasion dependent on the abrasive used and on its concentration (Harte & Manly 1975, 1976). The reasons for the differences between abrasives were not discussed.

Perhaps of greater interest than the effects of different abrasives in this study was the influence of different toothpaste detergents on the abrasiveness of the abrasives. The two anionic detergents SLS and Adinol increased abrasion by the abrasives whereas Pluronic and Tego Betain reduced abrasion for three out of four abrasives. There have been few studies, which determined the effect of detergents, usually SLS, on abrasivity (Redmalm 1986). Unfortunately, these studies used plastic substrates and not dentine, which may account for the difference in effect noted here. Thus, most data indicated that SLS decreased abrasivity for most, but not all, abrasives tested. An explanation for this has been the formation of stable foams reducing the amount of abrasive in contact with the surface at any one time. Other explanations of the possible variable effects of detergents on abrasives are as follows: increased particle separation increasing abrasion; clumping of particles decreasing abrasion; particle lubrication or surface coating reducing abrasion and, as discussed earlier, an actual chemical detergent attack on dentine to increase tissue loss.

It is clearly apparent that not only is the abrasive relevant to wear of dentine but also the detergent both interacting to produce variable amounts of wear dependent on which combination is used. Other work has also clearly shown that the dilution of the abrasive in the diluent effects abrasion by different abrasives (Manly et al. 1974, Harte & Manly 1976). This was not tested here as an attempt was made to mimic concentration of both abrasive and detergents in common use. The picture clearly will become even more complex when other constituents of toothpaste are considered, notably thickeners *or humectants*. One study showed that these agents did influence the abrasion by abrasives, although detergents were not employed (Harte & Manly 1976). Clearly, there is a need for further research on how various ingredients might influence abrasivity although there will be a limit to how far this work can go given the vast number of combinations that could be compared and contrasted. The aim should be to assess the likely major variables such as abrasives, detergents and thickeners.

In conclusion, different abrasives, detergents alone and in combination produced different abrasion to dentine. When combined it would appear that the rheological properties of the final mixture combined with the chemical action of the detergent determine the net loss of dentine. The chemical action of detergents suggests that the assessment of toothpaste abrasivity should always use dentine and not a substitute substrate.

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Address:
Martin Addy
Division of Restorative Dentistry
Dental School
Lower Maudlin Street
Bristol BS1 2LY UK.
E-mail: Martin.Addy@bristol.ac.uk

Clinical Relevance

The benefits of toothpaste to oral health are well known, but they have the potential to cause harm through tooth wear. An International Standard Organisation standard for toothpastes is in place but under review. Abrasivity of toothpastes to dentine is a key feature of the standard to avoid excessive tooth tissue loss in normal toothpaste usage. It is apparent that much is still to be learnt and/or published into the public domain concerning optimisation of tooth cleaning by toothpaste while minimising wear. More data on the interplay of individual ingredients are required rather than merely publishing relative RDAV for finished products. This study clearly shows that individual abrasives and detergents interact quite differently to produce varying degrees of dentine wear.