The Measurement of Enamel Wear of Two Toothpastes

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Purpose: The aim of this study was to compare the enamel abrasivity of a whitening toothpaste with a standard silica toothpaste.

Materials and Methods: Polished human enamel blocks (4 x 4 mm) were indented with a Knoop diamond. The enamel blocks were attached to the posterior buccal surfaces of full dentures and worn by adult volunteers for 24 hours per day. The blocks were brushed *ex vivo* for 30 seconds, twice per day with the randomly assigned toothpaste (n = 10 per treatment). The products used were either a whitening toothpaste containing Perlite or a standard silica toothpaste. After four, eight and twelve weeks, one block per subject was removed and the geometry of each Knoop indent was re-measured. From the baseline and post-treatment values of indent length, the amount of enamel wear was calculated from the change in the indent depth.

Results: The mean enamel wear (sd) for the whitening toothpaste and the standard silica toothpaste after four weeks was 0.20 (0.11) and 0.14 (0.10); after 8 weeks was 0.44 (0.33) and 0.18 (0.17), and after 12 weeks was 0.60 (0.72) and 0.67 (0.77) microns respectively. After four, eight and twelve weeks, the difference in enamel wear between the two toothpastes was not of statistical significance ($p > 0.05$, 2 sample t-test) at any time point.

Conclusions: The whitening toothpaste did not give a statistically significantly greater level of enamel wear as compared to a standard silica toothpaste over a 4-, 8- and 12-weeks period.

Key words: tooth wear, tooth whitening, abrasion, toothpaste

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Esthetic dentistry and tooth whitening continues to be an expanding area of interest that has been fuelled by patients' demand for both healthy and cosmetically attractive smiles (Joiner, 2004). Indeed, for the majority of people the appearance of the teeth is very important and any discoloration or stain that may form on them will affect their esthetic qualities. The color of the teeth is influenced by a combination of their intrinsic color and the presence of discolorations or extrinsic stains which may form in the acquired pellicle (Watts and Addy, 2001; Joiner, 2004). The challenge to enhance the cosmetic appearance of teeth has led to the launch of a multitude of improved toothpastes, in-office or home-prescribed professional bleaching kits and mass market technologies for tooth-whitening (Haywood, 2000; Gerlach, 2000; Slezak et al, 2002; Joiner et al, 2002; Collins et al, 2004).

The major component of a toothpaste which controls extrinsic stain is the abrasive, and these are typically insoluble materials such as silica, calcium carbonate, calcium phosphates, aluminum oxide and pumice (Pader, 1996). It is widely accepted in the dental profession that some degree of abrasivity must be tolerated in a toothpaste if satisfactory cleaning is to be achieved (Forward, 1991; Stookey et al, 1982). However, the abrasive nature of a given

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product must be determined to ensure that during use the oral hard tissues are not compromised. To this end, the abrasivity of toothpastes is the subject of international standards (ISO 11609, 1995) and can be measured by a range of *in vitro* methods. The most widely used method is the Relative Dentine Abrasivity (RDA) method as described by Hefferen (1976) which evaluates the ability of a slurry of toothpaste to remove radioactive dentine during a brushing protocol relative to a standard abrasive. Similarly, the Relative Enamel Abrasivity (REA) method uses radioactive enamel. However, it is difficult to extrapolate the *in vitro* RDA and REA values into clinical meaning, particularly since tooth wear is multifactorial and the inability to apply sufficiently sensitive measurements for determining tooth wear *in vivo.* Approaches based on *in situ* methods, on the other hand, have been developed and used to measure a range of erosion and abrasion phenomena (West et al, 1998; Addy et al, 2002).

A new whitening toothpaste (White System[1]) has been developed that contains Perlite and has been demonstrated to have stain removal and prevention benefits in a clinical trial (Joiner et al, 2002). The objective of the present work was to determine the effect of this new toothpaste on enamel wear over a 12-weeks period using an *in situ* model with *ex vivo* brushing.

MATERIALS AND METHODS

Preparation of Inserts

The roots of human extracted incisors and molars were removed by using a diamond abrasion wheel. The lingual part of the tooth was then flattened to approximately 3 mm thick using the high abrasive disc (Tycet Ltd, Hemel Hempstead, Herts, UK), turned over and the facial surface polished with the abrasive disc to flatten the surface. The polished sections were cut on a diamond wire cutter (Two Well Model 3242 Wire Cutter, Ebner, Le Locle, Switzerland) into approximately 3 x 3 x 2.5 mm blocks and labeled individually with a number.

The blocks were then polished successively with 9 micron polishing powder and 3, 1 and 0.25 micron diamond polishes (Kemet International Ltd, Maidstone, UK) and indented three times with a Knoop diamond using a Micromet 2100 Microhardness Tester (Buehler, Lake Bluff, IL, USA) and a 50 g weight. The blocks were finally sterilized by gamma irradiation prior to the *in situ* phase.

Study Protocol

The study was monadic in design. Twenty subjects with full dentures and in good health were recruited onto the study. Informed consent was obtained and the protocol reviewed by the Unilever Research Port Sunlight Ethics Committee. Enamel blocks were placed in individual recesses created in the buccal surfaces of the denture. The subjects were randomly assigned to either the White System toothpaste (pH 8.2) or the commercial standard silica toothpaste (pH 7.0) (10 subjects per toothpaste). The panelists were asked to remove their dentures for cleaning twice per day with the assigned toothpaste and toothbrush (Lever Faberge, Milan, Italy; filament diameter = 0.18 mm; filament length = 10 mm). The toothpaste was used undiluted and subjects brushed their own enamel blocks for 30 seconds. However, for the first 24 hours, the blocks were avoided altogether in order to allow pellicle to form. Subjects were instructed to wear their dentures continually for 24 hours and not use any other toothpaste, mouthwash, dental floss or denture cleaner for the duration of the study. At each of the follow-up visits at 4, 8 and 12 weeks, one of the enamel blocks was removed for wear analysis. The recess in the denture was repaired. The RDA and REA values were determined using standard methods (Hefferren, 1976) at Indiana University School of Dentistry.

Statistical Design

The measured amount of enamel wear and a clinically relevant threshold level of enamel wear was compared statistically and this comparison was the primary outcome of the study. The clinically relevant threshold level of enamel wear was calculated as follows. Enamel wear during a lifetime of less than 100 microns can be considered clinically irrelevant (Hooper et al, 2003) since enamel is typically 130 microns in thickness near the cervical enamel border (Gaspersic, 1995) and is considerably thicker over much of the tooth surface. Assuming a life-

1 Marketed as Signal/Mentadent/Pepsodent/Aim White System, Lever Faberge, Milan, Italy

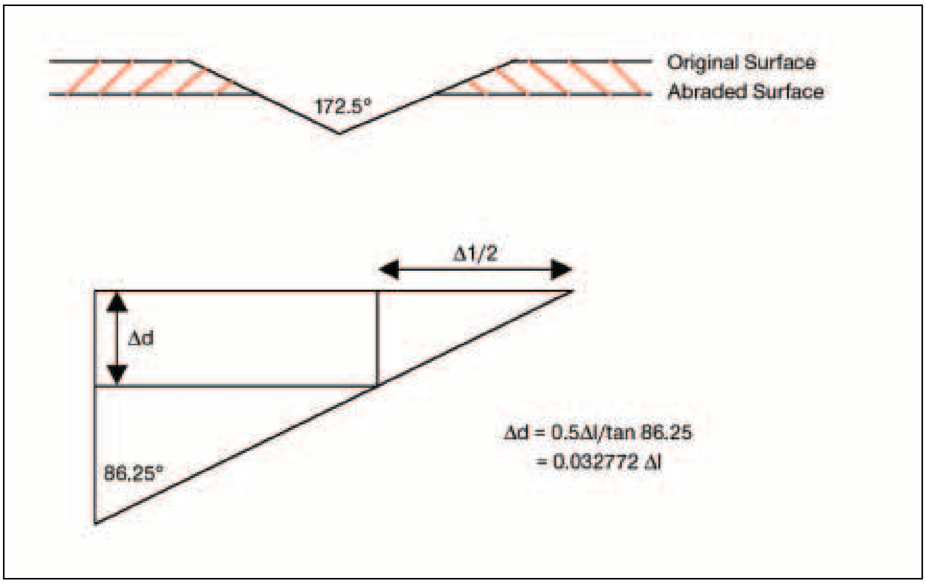

Fig 1 Geometry of Knoop indent before and after wear.

time is 100 years, the average tooth brushing time is typically 50 s (Duke and Forward, 1982) and a typical tooth surface *in vivo* is brushed on average 5 s, twice per day. For 100 microns of wear in 100 years of brushing, the rate of wear can be calculated to be 2.74 x 10^{-4} microns/sec of brushing. Now, the specimens were brushed for 4 weeks, twice per day for 30 s, which equals 1680 s of brushing time. Therefore, the clinically relevant threshold for 4 weeks is (2.74 x 10^{-4}) (1680) = 0.46 microns. Thus if the level of wear after 4 weeks is significantly below 0.46 microns, then the lifetime's wear will be less than 100 microns and can be considered clinically irrelevant. Likewise, the threshold levels are 0.92 microns at 8 weeks and 1.38 microns at 12 weeks.

The wear after 12 weeks is the best measure of the rate of wear since these specimens have had the longest abrasion time. Measurements at 4 weeks and 8 weeks help to establish the uniformity of the wear. A one-sample t-test is used to test the hypothesis that the population mean wear at the end of the 12 week period is 1.38 microns, and similarly at the end of the 4 week and 8 week periods. This is done separately for each product, and then differences between products can be tested using a two-sample t-test. The tests at the three time periods are not independent, but emphasis lies with the 12 week period. Since the data tend not to be normally distributed, the tests are better carried out on the log data.

A test of the uniformity of the wear can be carried out using a one-sample t-test (wear at 4 weeks + wear at 12 weeks – 2 x wear at 8 weeks) for each product. Acceptance of the null hypothesis of zero mean indicates that the wear is uniform over the 12-weeks period.

Another approach is to use a generalized linear model with a gamma distribution and the identity link function, but with zero intercept. The mean wear is modeled as β x time, where β is the rate of wear. For the wear to be below the threshold level, β has to be less than 0.12 (i.e. 0.12 microns per week). The model can incorporate separate β's for the two products, whereupon a test of equal rates of wear can be carried out.

Wear Measurement

The lengths of the Knoop indents were measured before the *in situ* phase of the study using the micro hardness machine. After removal from the denture, the indent lengths were remeasured with the microhardness machine. The change in indent depth (Δd) was calculated from the change in indent length (Δl) using (see Fig 1):

$$\Delta d = 0.032772\ \Delta l$$

The mean amount of enamel abrasion was thus given by the average change in indent depth (Δd).

Table 1 RDA and REA Values (n = 8)

Toothpaste	RDA (sd)	REA (sd)
White System	120 (20)	7.68 (0.54)
Standard Silica	80 (10)	3.86 (0.42)

RESULTS

The mean RDA and REA values for both toothpastes are shown in Table 1. The mean enamel wear, standard deviation and sample size for the data at all time points is shown in Table 2. The same is given for log (enamel wear), the log transformation being used to make the data closer to normality. Hypothesis tests of mean enamel wear of 0.46 for 4 weeks, 0.92 for 8 weeks and 1.38 for 12 weeks, all show significantly less than the clinically relevant threshold. These results also hold for the log data, where p-values are likely to be more accurate due to the log data being closer to normality.

The means (standard deviations) for (wear at 4 weeks + wear at 12 weeks – 2 x wear at 8 weeks) were White System: – 0.13(0.59); Standard Silica: 0.40(0.86). For each product the hypothesis of zero mean was not rejected (White System: $p = 0.538$; Standard Silica: $p = 0.227$), indicating uniform wear over the twelve week period.

The generalized linear model approach gave similar conclusions. The estimate (standard error) of the rate of wear for each product was White System: 0.05 (0.009); Standard Silica: 0.04 (0.008). These are well below the threshold level of 0.12 microns per week, and hypotheses of wear rate being equal to 0.12 are rejected ($p < 0.001$ in both cases). The hypothesis of equal wear rates is not rejected ($p = 0.238$). Overall, at all time points both toothpastes can be considered safe towards enamel.

The statistical comparison of both products shows no differences between them (Table 3).

DISCUSSION

In situ models are important in dental research and have been utilized in a number of areas for investigating the processes that occur in the oral cavity. For examples, *in situ* models have successfully been used for measuring enamel de- and remineralization processes (Manning and Edgar, 1992; ten Cate, 1994); measuring extrinsic stain formation (Joiner et al, 1995); investigating pellicle formation (Hannig, 2002); and measuring a range of erosion and abrasion processes (West et al, 1998; Addy et al, 2002). The advantages of *in situ* models are that they allow the substrate, often tooth enamel specimens, to be exposed to the effects of saliva, bacteria, etc., whilst maintaining the sensitivity of laboratory analysis techniques.

The clinical measurement of the wear of natural dentition is problematic, for a number of reasons. Tooth wear *in vivo* is multifactorial in origin and currently there is no evidence to show which are the dominant factors (Hunter et al, 2002). Wear is a slow process, and one is hampered by problems related to volunteer compliance and sensitivity of measurement (Saxton and Cowell, 1981). In contrast, applying the *in situ* model approach, coupled with a sensitive laboratory measurement technique, enables small levels of enamel or dentine wear to be accurately determined in a relatively short period of time. Indeed, a number of *in situ* studies have reported the ability to measure sub micron levels of tooth wear (Jaeggi and Lussi, 1999; Hooper et al, 2003) using techniques such as indent depth change and profilometry.

The indentation of the enamel surface with a Knoop diamond produces an indent of known geometry that does not change with time (Herkstroter et al, 1989), thus giving a stable reference point. As the original enamel surface is abraded the Knoop indent length will shorten (Fig 1). Since the Knoop indent is much longer than its depth, relatively small changes in indent depth can be accurately determined by measuring small changes in indent length. In the current study, sub micron levels of wear were also measured confirming the sensitivity of measuring Knoop indent depth changes (Jaeggi and Lussi, 1999).

Subject compliance during the current study appears to be good since for both toothpastes the rate of wear was uniform during the 12 weeks study period.

The level of enamel wear after 4 weeks measured in the current study is comparable to previously reported values of 0.088 and 0.137 microns for a standard silica toothpaste and the White System toothpaste respectively, after 4 weeks, using

Table 2 Mean enamel wear and statistical comparison to enamel wear threshold

	Mean(sd)(n) of enamel wear (microns)		
	4 weeks	8 weeks	12 weeks
White System	0.20 (0.11) (9)	0.44 (0.33) (10)	0.60 (0.72) (10)
Test val.	0.46	0.92	1.38
p-value	p = 0.0001	p = 0.0012	p = 0.0077
Standard Silica	0.14 (0.10) (9)	0.18 (0.17) (9)	0.67 (0.77) (8)
Test val.	0.46	0.92	1.38
p-value	p < 0.0001	p < 0.0001	p = 0.0354
	Mean(sd)(n) of log (enamel wear)		
	4 weeks	8 weeks	12 weeks
White System	– 0.78 (0.31) (9)	– 0.66 (0.71) (10)	– 0.43 (0.45) (10)
Test val.	– 0.337	– 0.036	0.14
p-value	p = 0.0026	p = 0.0216	p = 0.0028
Standard Silica	– 1.00 (0.46) (9)	– 0.98 (0.65) (9)	– 0.59 (0.84) (8)
Test val.	– 0.337	– 0.036	0.14
p-value	p = 0.0027	p = 0.0024	p = 0.0432

an identical protocol and products (Joiner et al, 2002). Thus the current protocol and subsequent laboratory measurements are highly reproducible in terms of enamel wear.

Jaeggi and Lussi (1999) measured the extent of abrasive wear to erosively softened human enamel after subsequently being worn *in situ* for up to one hour followed by a 30 s brushing with a toothpaste of RDA = 77 and REA = 4.5. The levels of enamel wear were found to be between 0.19 and 0.26 microns. These values are higher than for the standard silica toothpaste in the current study (that has similar RDA/REA values) over a significantly shorter total brushing time and thus indicates the profound effect that an erosive challenge can have on tooth wear. Indeed, Hooper et al (2003) have shown that the brushing of enamel specimens with a toothpaste following an erosive challenge of orange juice gave significantly more wear than brushing after exposure to mineral water. In addition, Hooper et al (2003) report an enamel wear value for a silica toothpaste with similar RDA and REA values to the standard silica toothpaste in the current study of 0.561 microns after 20 mins total brushing time over 5 days (4 x 1 min/day). This is considerably higher than the value obtained in the current study after the equivalent of 28 mins total brushing time (over 4 weeks). The reasons for the lower level of wear in the current study are unknown, but it is speculated that the Hooper et al (2003) study utilizes a more vigorous brushing regime per day. This would potentially remove and/or reduce the protective qualities of any acquired pellicle that has formed on the enamel (Hannig, 2002), leading to enhanced abrasive effects. Indeed, the presence of the acquired pellicle on enamel is considered an important factor in abrasion studies (Joiner et al, 2004).

Table 3 Product comparisons

	4 weeks	8 weeks	12 weeks
Raw data	ns (p = 0.433)	ns (p = 0.061)	ns (p = 0.547)
Log data	ns (p = 0.372)	ns (p = 0.350)	ns (p = 0.349)

The levels of enamel wear for both toothpastes in the current study was found to be below the clinically relevant threshold values at all time points. The differences between the mean enamel wear value and the clinically relevant theshold value was of high statistical significance (Table 2). This indicates that the abrasion of enamel by these toothpastes will not be clinically relevant over a subject's lifetime.

In conclusion, the current methodology has successfully been utilized to study enamel wear due to brushing with toothpaste over a 12-weeks period. It was found that a tooth whitening toothpaste containing Perlite did not give a statistically significantly greater level of enamel wear as compared to a standard silica toothpaste over the 12-weeks period.

REFERENCES

1. Addy M, Hughes J, Pickles MJ, Joiner A, Huntington E. Development of a method *in situ* to study toothpaste abrasion of dentine. J Clin Periodontol 2002;29:896-900.
2. Collins LZ, Maggio B, Liebman J, Blanck M, Lefort S, Waterfield P, et al. Clinical evaluation of a novel whitening gel, containing 6% hydrogen peroxide and a standard fluoride toothpaste. J Dent 2004;32:13-17.
3. Duke SA, Forward GC. The conditions occurring *in vivo* when brushing with toothpastes. Brit Dent J 1982;152:52-54.
4. Forward GC. Role of toothpastes in the cleaning of teeth. Int Dent J 1991;41:164-170.
5. Gaspersic D. Micromorphometric analysis of cervical enamel structure of human upper third molars. Arch Oral Biol 1995; 40:453-457.
6. Gerlach RW. Shifting paradigms in whitening: introduction of a novel system for vital tooth bleaching. Compend of Contin Educ Dent 2000;21:S4-S9.
7. Hannig M. The protective nature of the salivary pellicle. Int Dent J 2002;52:417-423.
8. Haywood VB. Current status of nightguard vital bleaching. Compend Cont Educ Dent 2000;21:S10-S17.
9. Hefferen JJ. A laboratory method for assessment of dentifrice abrasivity. J Am Dent Assoc 1976;55:563-573.
10. Herkstroter FM, Witjes M, Ruben J, Arends J. Time dependency of microhardness indentations in human and bovine dentin compared with human enamel. Caries Res 1989;23: 342-344.
11. Hooper S, West NX, Pickles MJ, Joiner A, Newcombe RG, Addy M. Investigation of erosion and abrasion on enamel and dentine: a model *in situ* using toothpastes of different abrasivity. J Clin Periodontol 2003;30:802-808.
12. Hunter ML, Addy M, Pickles MJ, Joiner A. The role of toothpastes and toothbrushes in the etiology of tooth wear. Int Dent J 2002;52:399-405.
13. ISO. ISO 11609. Dentistry-toothpastes-requirements, test methods and marking. Geneva: International Organization for Standardization 1995;1-10.
14. Jaeggi T, Lussi A. Toothbrush abrasion of erosively altered enamel after intraoral exposure to saliva: An *in situ* study. Caries Res 1999;33:455-461.
15. Joiner A. Tooth color: A review of the literature. J Dent 2004; 32:3-12.
16. Joiner A, Jones NM, Raven SJ. Investigation of factors influencing stain formation utilizing an *in situ* model. Adv Dent Res 1995;9:471-476.
17. Joiner A, Pickles MJ, Matheson JR, Weader E, Noblet L, Huntington E. Whitening toothpastes: Effects on tooth stain and enamel. Int Dent J 2002;52:424-430.
18. Joiner A, Pickles MJ, Tanner C, Weader E, Doyle P. An *in situ* model to study the toothpaste abrasion of enamel. J Clin Periodontol 2004;31:434-438.
19. Manning RH, Edgar WM. Intra-oral models for studying de- and remineralization in man: Methodology and measurement. J Dent Res 1992;71:895-900.
20. Pader M. Dental products. In: Williams DF, Schmitt WH (eds). Chemistry and Technology of the Cosmetics and Toiletries Industry. 2nd Edition. London: Blackie Academic and Professional 1996;225-271.
21. Saxton CA, Cowell CR. Clinical investigation of the effects of dentifrices on dentin wear at the cemento-enamel junction. J Am Dent Assoc 1981;102:38-43.
22. Slezak B, Santarpia P, Xu T, Monsul-Barnes V, Heu RT, Stranick M, et al. Safety profile of a new liquid whitening gel. Compend Contin Educ Dent 2002;23:S4-S11.
23. Stookey GA, Burkhard TA, Schemehorn BR. In vitro removal of stain with dentifrices. J Dent Res 1982;61:1236-1239.
24. Ten Cate JM. *In situ* models, physico-chemical aspects. Adv Dent Res 1994;8:125-133.
25. Watts A, Addy M. Tooth discoloration and staining: a review of the literature. Brit Dent J 2001;190:309-316.
26. West NX, Maxwell A, Hughes JA, Parker DM, Newcombe RG, Addy M. A method to measure clinical erosion: the effect of orange juice consumption on erosion of enamel. J Dent 1998;26:329-335.