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The use of a profilometer for both quantitative and qualitative measurements of toothpaste abrasivity

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Liljeborg A, Tellefsen G, Johannsen G. The use of a profilometer for both quantitative and qualitative measurements of toothpaste abrasivity.

Abstract: *Aim:* To evaluate the abrasivity of different toothpastes both quantitatively and qualitatively with a profilometer technique and to correlate these findings to the radioactive dentin abrasivity (RDA) value. *Materials and methods:* Acrylic plates were exposed to brushing in a brushing machine with 11 different toothpastes. The results were evaluated using a profilometer. A surface roughness value (Ra-value), that is, a qualitative measurement, and also a volume value, that is, a quantitative measurement, were calculated from the profilometer results. These values were then correlated to each other and to the RDA-value. A comparison between RDA, Ra and volume measurements was performed using linear fitting procedure. *Results:* The results showed that the correlation between RDA and Ra measurements was low (R^2 = 0.04) and also that the correlation between RDA and volume measurements was low (R^2 = 0.00002). Correlation between Ra and abraded volume was high (R^2 = 0.87). *Conclusions:* It is important to consider not only the RDA-value when evaluating toothpaste abrasivity. From the profilometer results both a quantitative (volume) and qualitative (roughness) measurement of the abrasivity of a toothpaste can be obtained.

Key words: profilometer; RDA-value; toothpaste abrasivity

Introduction

Many laboratory procedures have over the years been used for the measurement of toothpaste abrasivity (1, 2).

Both quantitative and qualitative techniques have been used. Gravimetric measurements (3, 4) and radio tracer techniques (2,

5) are examples of quantitative techniques where the amount of substance removed is analysed, whereas light reflexion techniques (1, 6, 7) and surface profile measurements (8, 9) have been used as qualitative techniques, to evaluate the appearance of the surface after brushing.

To date the most commonly used and accepted way to describe the abrasivity of a toothpaste is through the use of a radio tracer technique, the radioactive dentin abrasivity (RDA)-value. This is a quantitative technique based on irradiation with neutrons of the tooth substance in the test material which converts phosphorous of the hydroxy apatite of the dentin to its radioactive isotope. After brushing with a toothpaste, the substance abraded from the surface of the specimen is measured with a Geiger counter. The amount of substance removed is calculated and compared with a reference paste (2, 10). The reference paste is usually Calcium pyrophosphate and the abrasivity value is set to 100 and the abrasivity of the test paste is expressed in relation to this value.

The RDA-value gives an estimate of how much of the surface is abraded, that is, a quantitative measurement of surface abrasivity. It does not measure the roughness of the abraded surface. The roughness of the surface is strongly correlated to the discoloration and to the plaque accumulation (11–13).

Wülknitz (5) studied the correlation between the cleaning power of 41 different European toothpastes and the dentin abrasion. The cleaning power was measured with the pellicle cleaning ratio (PCR) method, which was defined as the ratio of the increase in brightness of the tooth mounts brushed with the test paste divided by the increase of the calcium pyrophosphate reference. The dentin abrasivity was measured with the RDA method. The correlation was found to be low and these results were explained by the different influence on dentin and stains by factors such as abrasive type, particle surface and size and also the chemical influence of other toothpaste ingredients.

Barbakow *et al.* (14) showed that chemically different types of abrasives can have different cleaning/abrasivity patterns and also that chemically identical abrasives such as hydrated silica or calcium carbonate can differ distinctively in these matters and can also have different cleaning/abrasivity ratios.

In order to further evaluate the abrasivity of a toothpaste, the quantitative measurement should be completed with a qualitative measurement, for example, by using a profilometer.

Profilometer techniques have been used in earlier studies (9, 15–18). In a study by Davis and Winter (16) a profilometer was used to evaluate the abrasivity of different toothpastes on human enamel. They measured the mean depth of the profiles and presented the results as a percentage of the abrasion of chalk which was set to 100.

As the roughness is not only strongly correlated to bacterial accumulation, but also to the 'luster' of the tooth (19, 20), such measures are important and have a great clinical relevance.

The purpose of this study was using a surface profile measuring technique to calculate both a quantitative (volume) and a qualitative (roughness) measurement of the toothpaste abrasivity. Furthermore, the purpose of this study was to correlate the RDA-value to the Ra-value, (roughness-value, mean arithmetic value), and also to the volume measurement, using standard linear fitting procedure.

Material and methods

The following equipment was used:

Eleven commercially available toothpastes containing the following abrasives:

	Abrasive	Product name	RDA
A	Sodium metaphosphate	Acta Original®	40
B	Sodium metaphosphate	Acta Proactive®	40
C	Silicone dioxide	Colgate 'blå mintgel'®	70
D	Silica	Aquafresh for kids®	50
E	Silica	Sensodyne fresh sensitive®	55
F	Calcium phosphate, Calcium carbonate and Aluminum silicate	Clinomyn for smokers®	130
G	Silicon dioxide	Pepsodent Crystal Fresh®	79
H	Silica	Zendium Classic®	50
J	Silica	Bamse (for children)®	55
K	Silica	Zendium Dentine Sensitive®	30
L	Silica	Theramed Ice Fresh®	50

Acrylic plates

Polymethylmetacrylate (PMMA) type Plexiglas XT (Quinn Plastics NV, Geel, Belgium). Dimensions 115 × 25 × 3mm.

Density 1.18 g m^{-3}, ball hardness HD 10 sec (DIN 53.456) 190 MPa, light transmission (380–720 nm) 92%, reflexion loss 4%. The plate was provided with two drilled holes matching the brads on the holder and the brushing machine.

Brushing machine

Reciprocating movement of 85 mm, 2000 double strokes per hour. Load 2.35N.

The apparatus had six brush sites, and each brush site had a trough for the toothpaste water slurry, in which the test plates were placed. Between each test, new brushes were mounted in the machine and filament dimensions were controlled.

Toothbrushes

The brushes were all of the brand 'TePe vågig®, soft'. They all had a filament material of nylon 6–12, the filament diameter was 0.23 mm and the length was 10–12 mm with a contoured profile. There were four rows with 34 tufts and the number of filaments per tuft was approximately 32 and the trim dimension was 27 mm × 9.5 mm.

The filament ends were top-rounded.

Test procedure

Three plates were mounted in the brushing machine and the toothpaste water slurry was added. The slurry contained 25 mg toothpaste and 50 ml water.

After 1 h the plates were removed and rinsed in lukewarm water and the slurry was refilled (21). The total brushing time was 6 h corresponding to 12 000 double strokes.

This procedure was repeated with the eleven different commercially available toothpastes. The abraided area was covering the full length between the mounting holes (Fig. 1). The plates were then analysed using a surface profilometer (P15, KLA Tencor Corp., San Jose, CA USA) with the following characteristics:

A diamond stylus with a tip-radius of 2 μm is used to scan the surface profile across a sample. The force of the tip and the scan speed were adjusted so the tip closely followed the abraided surface. Two thousand sample points were collected for each profile over a length of 20 mm. In some cases the scan length was extended to 22 mm to cover the entire abraided area. The scan rate was 0.2 mm s^{-1} giving a collection time for each profile of 100 s.

Three profiles were collected for each sample (Fig. 2), one at midpoint between the mounting holes, and two profiles 20 mm above and below the midpoint. Profiles were also collected outside of the abraided area to measure the curvature of

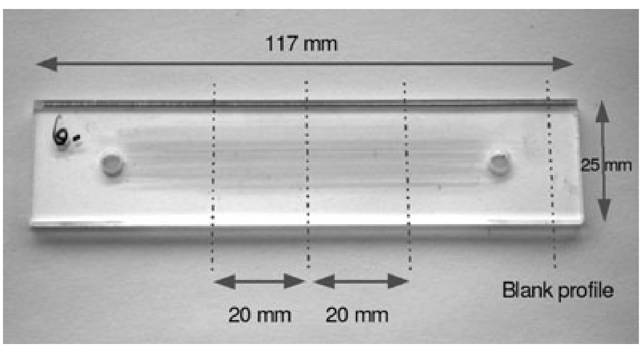

Fig. 1. Plexi sample with indication where the profiles were collected.

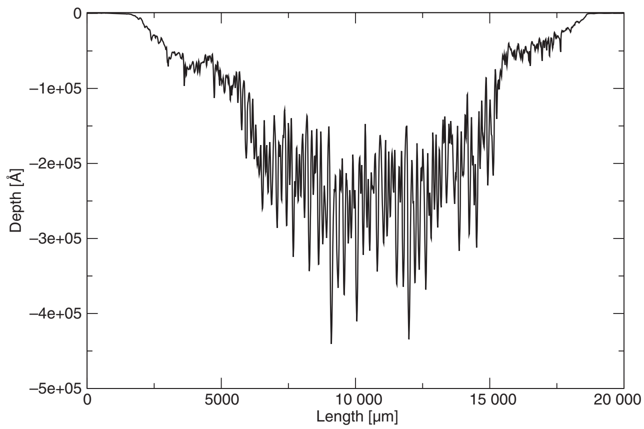

Fig. 2. Typical profile with straight ends.

the clean sample surface. The curvature was considerable and gave significant errors to the volume measure if not compensated for. The curvature across the width of the sample varied along the length of the sample. Therefore the profile across the sample at the non-abraided area could not be used to compensate for curvature with good result. Instead the first and last 100 data points in each profile were used in a numerical fitting procedure (singular value decomposition, third order polynomial fit) to compute a simulated un-abraided profile of the sample at the position of the profile in the abraided area (Fig. 3). This profile was subtracted from the abraided profile to produce a 'straight' profile (Fig. 4).

These straightened profiles were used to compute the volume of removed material between the upper and lower profiles. Also the roughness average (Ra-values) were computed for the centre 20% length in each profile. Ra is defined as the

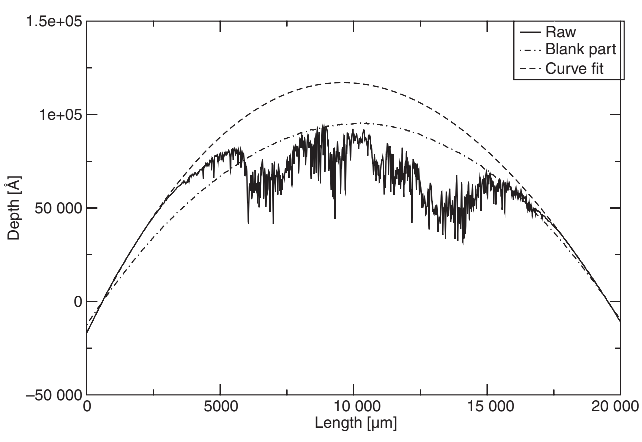

Fig. 3. Typical profile with curved ends is shown in black. Profile on blank area showing curvature (dot-dash), numerically fitted profile shown in dashed line. Note that profile from blank area does not fit very well with profile in abraided area, thus making it less useful to compensate for curvature.

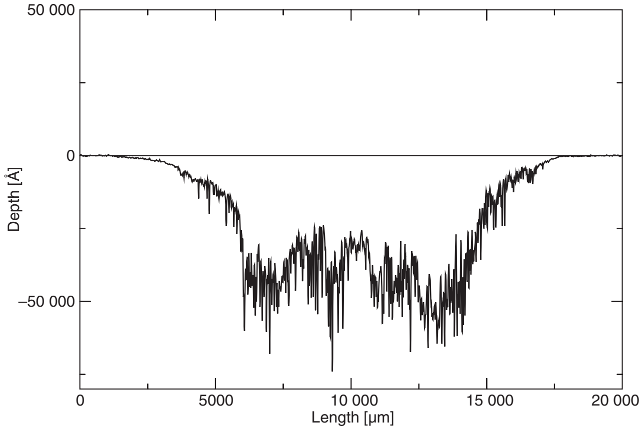

Fig. 4. Straightened profile using the numerically fitted curvature. The zero line is also shown.

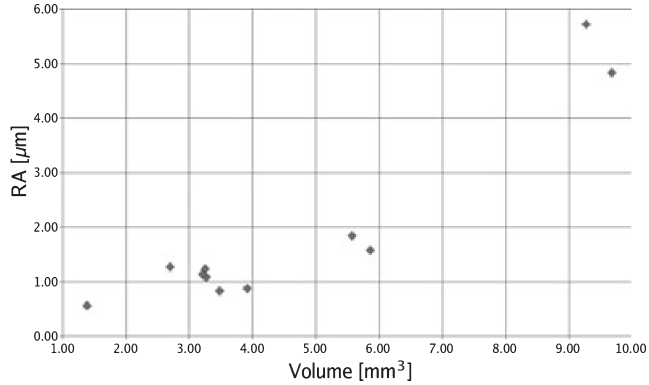

Fig. 5. Roughness average (Ra) for the centre 20% of the profiles versus volume. There is a high correlation between Ra and abraded volume (R^2 = 0.87, P = 0.003%).

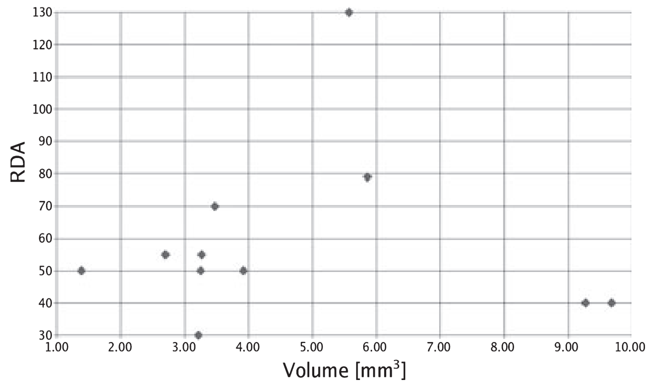

Fig. 6. RDA versus volume. No correlation could be found between RDA value and abraded volume (R^2 = 0.00002).

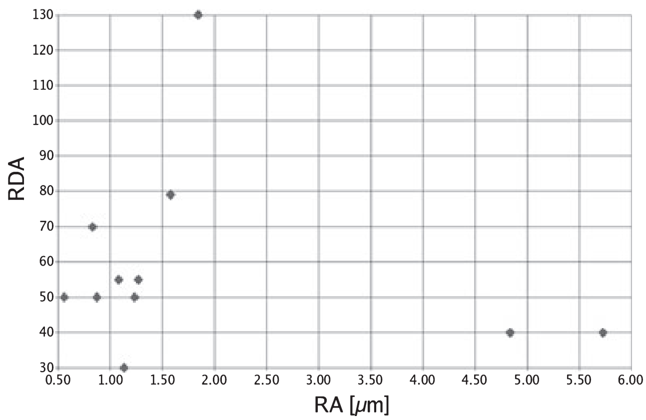

Fig. 7. RDA versus RA. No correlation could be seen between RA and RDA (R^2 = 0.04).

arithmetic average deviation of the absolute values of the roughness profile from the mean line or the centreline.

The volume values and Ra-values were then correlated to each other and also to the RDA-value received from the manufacturer of the toothpaste using standard line fitting procedure.

Results

The results are shown in Table 1 and in Figs 5–7. Three samples of each toothpaste were analysed. In Table 1, the volume and the Ra measurements are presented for each toothpaste along with the SD, and also the RDA-values received from the manufacturers of the toothpastes.

As can be seen in Table 1 and Fig. 7 the correlation between the RDA-value and the Ra-value was very low (R^2 = 0.04), with toothpaste A displaying a low RDA-value (40) and the highest Ra-value (5.73), while toothpaste *F* is showing the highest RDA-value (130) and a Ra-value of 1.84. Toothpaste *K* has the lowest RDA-value (30) and a Ra-value of 1.13.

Figure 6 illustrates the correlation between RDA and volume measurements which also was low (R^2 = 0.00002). The

Table 1. **Results of the toothpaste abrasion measurements**

Toothpaste	Ra (μm)	SD	Volume (mm^3)	SD	RDA
A	5.73	0.61	9.27	0.50	40
B	4.83	1.25	9.68	0.26	40
C	0.83	0.34	3.48	0.30	70
D	0.56	0.12	1.39	0.18	50
E	1.08	0.25	3.27	0.24	55
F	1.84	0.30	5.57	0.32	130
G	1.58	0.33	5.86	0.34	79
H	1.23	0.32	3.25	0.19	50
J	1.27	0.26	2.70	0.83	55
K	1.13	0.39	3.21	0.13	30
L	0.87	0.32	3.92	0.25	50

For each toothpaste is shown the roughness average (Ra) and abraded volume as well as the radioactive dentin abrasivity (RDA) value. SDs for Ra and volume have been calculated.

correlation between Ra and volume measurements is illustrated in Fig. 5, and was found to be good ($R^2 = 0.87$, $P = 0.003\%$), where toothpaste *D* show the lowest Ra-value and the lowest volume measurements. R^2 designates the square of the Pearsons correlation coefficient.

Discussion

It has been widely accepted in the dental profession that some degree of abrasivity is needed in a toothpaste if satisfactory cleaning of the teeth is to be achieved (22, 23). On the contrary, recently, no contributing effect to the mechanical plaque removal by the use of a toothpaste was found (24), however no aspects of stain removal were taken into consideration.

As the staining of the teeth by, for example, coffee, tea, smoking, etc. is strongly correlated to surface roughness, (12, 13) it is important to study not only the quantitative aspect, that is, how much of the surface that has been abraded, but also how the surface texture appears after the brushing, that is, the qualitative aspect.

One of the most interesting findings in the present study is that toothpastes A and B, both containing sodium metaphosphate as abrasive, both display very low RDA-values (40) but still by far show the highest Ra and volume-values. Similar Ra-values were also found in toothpastes with RDA values ranging from 80 to 130.

The RDA-values have been used to measure the abrasivity of dentin. However, to measure the abrasivity of enamel a similar technique has been used where the substrate is enamel (REA-value).

The clinical relevance of both RDA and REA-values has been studied before by Joiner et al. (25). They used an *in vivo* method where a piece of the enamel of an extracted tooth was placed in the denture of the participants. They brushed their dentures twice daily during 28 days. Three different toothpastes were used with different RDA and REA values. Evaluation of the results was made by using a micro-hardness meter and measuring the changes of indent geometries. They found that the RDA-values had little influence on enamel wear since similar REA-values were found in toothpastes where the RDA varied between 85 and 189.

Philpotts *et al.* (26) found a good correlation between median dentin wear and RDA-values when evaluating toothpastes with a range of RDA- and REA-values. The RDA- and REA-values were correlated to the Knoop-indent measuring technique, and Philpotts also found that the highest wear was produced by the toothpaste with the highest REA-value. However, the RDA value was not correlated to the REA value.

Zimmer *et al.* (27) evaluated dentin abrasion *in vitro* following professional tooth cleaning, using a profilometer technique. They compared prophy brushes and prophy cups with four different abrasives each (calcium pyrophosphate, pumice, Hawa cleanic and Nupra course) giving a total of eight different tooth cleaning procedures on dentin specimen. No statistical differences between brushes and cups were found and they also conclude that none of the procedures represented any major risk for dentin loss.

Radioactive dentin abrasivity measurements have also been compared to gravimetric measurements. Barbakow et al. (14) compared RDA values to weight loss and found a poor correlation and concluded that clinicians benefit by having a ranked list of toothpaste abrasion scores but they should critically review the methods employed in arriving at the abrasion scores.

In this study, a good correlation was found between the Ra measurements and the volume measurements ($R^2 = 0.87$, $P = 0.003\%$) but not between the RDA-values and volume measurements.

The combination of detergents and the abrasive in a toothpaste may affect the abrasivity. Moore and Addy (28) stated that if acrylic is used as a substrate it would be influenced by the detergents in the toothpaste. Furthermore, they stated that the net loss of dentin is determined by the rheological properties of the final mixture combined with the chemical action of the detergent.

In this study, acrylic plates with a hardness similar to that of dentin were used. The selected brand of acrylic resin had well-defined physiochemical properties and is equivalent to acrylics used in dental praxis (29). The purpose of the study was to compare the abrasivity of different toothpastes and to correlate these relative results with other methods. There was no intention of making absolute measurements of the abrasivity and therefore we found it satisfactory to use these acrylic plates.

Similar materials have also been used before in several abrasion studies (3, 17–18, 30–31). In order to minimize errors from variations in material properties, such as in dentin and enamel, these materials were not used in this study.

Addy et al. (15) compared the abrasivity of two different toothpastes with RDA values of 85 and 189, respectively, on dentin specimens *in situ*. They found a good correlation between the expected abrasive difference measured by a profilometer and the RDA-value, although the standard deviation exceeded the mean values in some of the measurements.

In this study, the different toothpastes were used on acrylic plates and the results were evaluated after 6 h of brushing, equal to 12 000 double strokes. It is difficult to translate these results into a clinical situation but a reasonable estimate would be about 2 years of brushing twice daily, this is in accordance with estimations made by Sexson and Phillips (30) and Wright (32).

As just one observation was made, after 12 000 double strokes, it is difficult to say anything about the speed of the abrasion process. As new scratches after a while replace old ones, a kind of steady state level should be reached regarding the qualitative aspect of the abrasion process (1).

This study suggests that it is important as a clinician when giving advice on which toothpaste to use, not only to take the RDA value into consideration but also the qualitative aspect of the abrasivity.

Conclusion

The results of this *in vitro* study emphasize the importance of looking at both the quantitative and qualitative aspects of the abrasivity process. Therefore the RDA-value should be complemented with a qualitative measurement when evaluating the abrasivity of a toothpaste. Furthermore, it is shown that by the use of the results in this profilometer study both the quantitative and qualitative aspects of the abrasivity of a toothpaste can be acknowledged.

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