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ORIGINAL ARTICLE

The importance of measuring toothpaste abrasivity in both a quantitative and qualitative way

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Abstract

Objective. To evaluate the relative abrasivity of different toothpastes and polishing pastes both qualitatively and quantitatively. ***Materials and methods.*** Acrylic plates were exposed to brushing in a brushing machine with a toothpaste/water slurry for 1 and 6 h. Twelve different toothpastes were used and also four different polishing pastes. The results were evaluated using a profilometer after 1 and 6 h of brushing (corresponding to 2000 and 12 000 double strokes, respectively). A surface roughness value (Ra-value) and also a volume loss value were calculated from the profilometer measurements. These values were then correlated to each other. An unpaired *t*-test for the difference in the abrasion values between the toothpastes and the abrasion values over time was used. ***Results.*** The polishing paste RDA® 170 yielded higher Ra-values than RDA 250®, both after 1 and 6 h of brushing (1.01 ± 0.22 and 8.99 ± 1.55 compared to 0.63 ± 0.26 and 7.83 ± 5.89, respectively) as well as volume loss values (3.71 ± 0.17 and 20.20 ± 2.41 compared to 2.15 ± 1.41 and 14.79 ± 11.76, respectively), thus poor correlations between the RDA and Ra and Volume loss values were shown. Among the toothpastes, Apotekets® showed the highest Ra value after 1 h of brushing and Pepsodent® whitening after 6 h of brushing. Pepsodent® whitening also showed the highest volume loss values, both after 1 and 6 h of brushing. ***Conclusion.*** This study emphasizes the importance of not only considering the RDA value, but also a roughness value, when describing the abrasivity of a toothpaste. Furthermore, it can be concluded that so called 'whitening' toothpastes do not necessarily have a higher abrasive effect than other toothpastes.

Key Words: *abrasivity, dentifrice, profilometer*

Introduction

Toothpastes and different polishing pastes have during the years been used in order to increase whiteness of the teeth. The wear produced by toothpastes, toothbrushes and polishing pastes is defined as abrasion in contrast to the tooth-to-tooth contact wear which is defined as attrition. The acid-mediated softening of a tooth is defined as erosion [1]. The wear due to abrasion can be reduced by the presence of a pellicle [2], but the wear can also be reduced by adding silicone oil to the toothpaste [3]. It was demonstrated that the addition of silicone oil to a toothpaste decreased the abrasion rate and made the surface of the treated material smoother than after brushing with the original toothpaste. Abrasion and erosion can also be somewhat prevented by high fluoride concentration gel [4]; however, it was concluded that fluoridated toothpaste provided very little protection.

To evaluate toothpaste abrasivity, many different techniques have been used, e.g. the RDA method, weight and volume loss techniques which are quantitative techniques, measuring the amount of abraded material removed [5,6] as well as profilometer and light reflexion techniques, which are qualitative techniques measuring the roughness of the abraded material [7,8].

The purposes have been to evaluate if toothpastes with higher abrasive content cause more damage to the tooth surface and to investigate the relation between abrasivity and cleaning–whitening [9,10].

Abrasion studies have been performed *in vitro* using various specimens of enamel and dentine. Bovine dentine specimens have been shown to act as an

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Table I. Twelve commercially available toothpastes and four polishing pastes containing the following abrasives were used.

Toothpaste	Abrasive	RDA
Acta original	Natriummetafosfat	45–60
Apoliva	Silica	70
Apotekets classic	Silica	71
Colgate Total	Hydrated silicon dioxide	44
Opalescense	Silica	66
Oral B advantage	Hydrated silica	65
Zendium	Hydrated silica	80
Pepsodent white naturals	Silicon dioxide	142
Pepsodent xylitol	Silicon dioxide	50
Clinomyn	Calcium carbonate Silicon dioxide, aluminium silicate	124
Aloe Vera	Hydrated silica low	
Colgate whitening	Hydrated silica	96
RDA 250	Pumice	250
RDA 170	Pumice	170
RDA 120	Hydrated silica	120
RDA 40	Hydrated silica	40

appropriate substitute for human dentine [11]. Acrylic plates with the same hardness as dentine have also been used and been shown to be appropriate for comparative studies of dentifrice abrasivity [12]. *In vivo* investigations have been performed in order to be able to translate the *in vitro* results into a clinical reality [13]. The abrasive component in toothpastes differs, but the most common abrasives used today are derivatives of silica. The abrasivity of a toothpaste depends on the amount of abrasive, particle size, surface structure of the particle and on the chemical influence of other types of ingredients in the product [14].

It is difficult to distinguish the effect of the toothbrush on the abrasivity from that of the toothpaste and it is probably dependent on the interaction between the two [15]. During the years the toothbrush has only been considered to contribute to the abrasivity indirectly through harboring the toothpaste across the surface and in itself only having a negligible effect [5,16].

Since toothpaste manufacturers change the composition of the toothpastes on a regular basis also regarding the abrasive part and since the RDA value is the only measurement of abrasivity that is being tested, it is important to measure also a roughness value of the abraded material. Increased RDA value doesn't necessarily mean an increased roughness, which implies that a toothpaste with a low RDA value still can create a rougher surface than a toothpaste with a higher RDA value [12].

The aim of the present study was, therefore, to evaluate the relative abrasivity *in vitro* of different toothpastes and polishing pastes using the same method for both qualitative and quantitative evaluation.

Materials and methods

Twelve commercially-available toothpastes and four polishing pastes containing the following abrasives are included in the study and presented in Table I. All toothpastes were provided from a Swedish pharmacy. The RDA values were obtained from the manufacturer.

Table II. Ra and volume loss values after 1 and 6 h.

Toothpaste	Ra, μm ± SD (1 h)	Ra, μm ± SD (6 h)	Vol mm^3 (1 h)	Vol mm^3 (6 h)
Opalescence	1.30 ± 0.53	6.67 ± 2.71	3.26 ± 0.89	10.61 ± 6.60
RDA 170	1.01 ± 0.22	8.99 ± 1.55	3.71 ± 0.17	20.20 ± 2.41
RDA 250	0.63 ± 0.26	7.83 ± 5.89	2.15 ± 1.41	14.79 ± 11.76
RDA 120	0.33 ± 0.12	1.70 ± 0.56	0.52 ± 0.40	3.42 ± 1.63
Apotekets	0.33 ± 0.12	1.41 ± 0.33	0.53 ± 0.31	2.16 ± 1.20
Pepsodent W	0.31 ± 0.10	2.37 ± 1.30	1.32 ± 0.25	5.25 ± 3.56
RDA 40	0.27 ± 0.20	0.65 ± 0.34	0.34 ± 0.08	1.42 ± 1.06
Apolivia	0.27 ± 0.09	1.46 ± 0.46	0.53 ± 0.32	2.72 ± 0.90
Colgate W	0.20 ± 0.10	0.97 ± 0.31	0.58 ± 0.32	2.32 ± 0.86
Oral B	0.19 ± 0.06	1.13 ± 0.65	0.45 ± 0.32	2.45 ± 2.17
Colgate Tot	0.19 ± 0.07	0.97 ± 0.56	0.62 ± 0.19	1.82 ± 1.41
Pepsodent Xyl	0.18 ± 0.08	1.44 ± 1.00	0.44 ± 0.31	1.73 ± 0.69
Aloe Vera	0.13 ± 0.09	1.11 ± 0.62	0.34 ± 0.21	1.76 ± 1.27
Clinomyn	0.13 ± 0.08	1.15 ± 0.24	0.35 ± 0.35	1.76 ± 0.76
Acta	0.10 ± 0.03	0.50 ± 0.19	0.29 ± 0.16	1.10 ± 0.25
Zendium	0.08 ± 0.05	0.81 ± 0.54	0.19 ± 0.14	0.99 ± 0.89

Table III. Ra values after 1 h.

	RDA 170	RDA 250	RDA 120	Apotekets	PepsodentW	RDA 40	Apoliva	Colgate W	Oralb Sens	Colgate Tot	Pepsodent Xyl	Aloe Vera	Clinomyn	Acta	Zendium
RDA 170															
RDA 250	**														
RDA 120	***	**													
Apotekets	***	**	NS												
Pepsodent W	***	**	NS	NS											
RDA 40	***	**	NS	NS	NS										
Apoliva	***	**	NS	NS	NS	NS									
Colgate W	***	***	*	*	*	NS	NS								
Oralb Sens	***	***	**	*	**	NS	*	NS							
Colgate Tot	***	***	**	*	**	NS	*	NS	NS						
Pepsodent Xyl	***	***	**	*	**	NS	*	NS	NS	NS					
Aloe Vera	***	***	**	**	**	NS	**	NS	NS	NS	NS				
Clinomyn	***	***	**	**	**	NS	**	NS	NS	NS	NS	NS			
Acta	***	***	***	***	***	*	***	*	***	**	*	NS	NS		
Zendium	***	***	***	***	***	*	***	*	**	*	*	NS	NS	NS	

*$p < 0.01$, **$p < 0.001$, ***$p < 0.0001$.

Table IV. Ra values after 6 h.

	RDA 170	RDA 250	Peps W	RDA 120	Apolivia	Peps X	Apotekets	Clinomyn	Oral B	Aloe Vera	Colgate W	Colgate T	Zendium	RDA 40	Acta
Toothpastes															
RDA 170															
RDA 250	NS														
Peps W	*	*													
RDA 120	***	**	NS												
Apolivia	***	**	NS	NS											
Peps X	***	**	NS	NS	NS										
Apotekets	***	**	*	NS	NS	NS									
Clinomyn	***	**	*	*	NS	NS	NS								
Oral B	***	**	*	NS	NS	NS	NS	NS							
Aloe Vera	***	**	*	NS	NS	NS	NS	NS	NS						
Colgate W	***	**	**	**	*	NS	*	NS	NS	NS					
Colgate T	***	**	**	*	NS	NS	NS	NS	NS	NS	NS				
Zendium	***	**	**	**	*	NS	*	NS	NS	NS	NS	NS			
RDA 40	***	**	**	***	***	*	***	**	NS	NS	*	NS	NS		
Acta	***	**	***	***	***	*	***	***	*	*	**	*	NS	NS	

*$p < 0.01$, **$p > 0.001$, ***$p > 0.0001$.

Table V. Volume loss values after 1 h of brushing (mm^3).

	RDA 170	RDA 250	Peps W	Colgate T	Colgate W	Apolivia	Apotekets	RDA 120	Oral B	Peps Xyl	Clinomyn	RDA 40	Aloe Vera	Acta	Zendium
Toothpastes															
RDA 170															
RDA 250	**														
Peps W	***	NS													
Colgate T	***	**	***												
Colgate W	***	**	***	NS											
Apolivia	***	**	***	NS	NS										
Apotekets	***	**	***	NS	NS	NS									
RDA 120	***	**	***	NS	NS	NS	NS								
Oral B	***	**	***	NS	NS	NS	NS	NS							
Peps Xyl	***	**	***	NS	NS	NS	NS	NS	NS						
Clinomyn	***	**	***	NS	NS	NS	NS	NS	NS	NS					
RDA 40	***	**	***	***	NS	NS	NS	NS	NS	NS	NS				
Aloe Vera	***	**	***	**	NS	NS	NS	NS	NS	NS	NS	NS			
Acta	***	**	***	**	*	NS	NS	NS	NS	NS	NS	NS	NS		
Zendium	***	***	***	***	**	*	**	*	*	*	NS	*	NS	NS	

*$p < 0.01$, **$p < 0.001$, ***$p < 0.0001$.

Table VI. Volume loss values after 6 h brushing (mm^3).

	RDA 170	RDA 250	Peps W	RDA 120	Apolivia	Oral B	ColgateW	Apotekets	Colgate T	Aloe Vera	Clinomyn	Peps X	RDA 40	Acta	Zendium
Toothpastes															
RDA 170															
RDA 250	NS														
Peps W	***	*													
RDA 120	***	*	NS												
Apolivia	***	**	NS	NS											
Oral B	***	**	NS	NS	NS										
Colgate W	***	**	*	NS	NS	NS									
Apotekets	***	**	*	NS	NS	NS	NS								
Colgate T	***	**	*	*	NS	NS	NS	NS							
Aloe Vera	***	**	*	*	NS	NS	NS	NS	NS						
Clinomyn	***	**	*	*	*	NS	NS	NS	NS	NS					
Peps X	***	**	*	*	*	NS	NS	NS	NS	NS	NS				
RDA 40	***	**	**	**	*	NS	NS	NS	NS	NS	NS	NS			
Acta	***	**	**	***	***	NS	***	*	NS	NS	*	*	NS		
Zendium	***	**	**	**	***	NS	**	*	NS	NS	NS	NS	NS	NS	

*$p < 0.01$, **$p < 0.001$, ***$p < 0.0001$.

Acrylic plates with the following specifications were used as substrate: Polymethylmetacrylate (PMMA) type Plexiglas XT. Dimensions 115 × 25 × 3 mm. Density 1.18 g/m^3, ball hardness HD 10 s (DIN 53.456) 190 MPa.

Brushing machine

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

Test procedure

Three plates were mounted in the brushing machine and toothpaste water slurry, containing 25 g of toothpaste mixed with 50 ml of water, was added. Every hour the plates were removed and rinsed in luke-warm water and the slurry was refilled. The total brushing time was 6 h, corresponding to 12 000 double strokes, but the plates were also analyzed after 1 h brushing (2000 double strokes). This procedure was repeated with the 12 different toothpastes and the four polishing pastes.

The plates were then analyzed using a surface profilometer (P15, KLA Tencor Corp., San Jose, CA) For detailed characteristics see Liljeborg et al. [12].

A low-force scanhead equipped with a diamond stylus (tip radius of 2 μm) was used to scan the surface profile across the sample. The force of the tip can be finely controlled between 0.05 mg up to 50 mg, as well as the scanning speed and the sampling interval of the depth values.

The vertical repeatability is 0.03 μm for a range of 30 μm. The maximum vertical range of the profilometer is 130 μm, which was enough for all the samples. Three profiles were collected for each sample, one at mid-point of the plate and two profiles 20 mm above and 20 mm below the mid-point. Roughness average (Ra) values were computed for each profile. Ra is defined as the arithmetic average deviation of the absolute values of the roughness profile from the mean line or the center line. Since all the measurements started and ended outside of the abraded area, it was also possible to compute the volume of removed material.

Statistical methods

The difference in the abrasion values between the toothpastes and also the abrasion values over time were calculated using the statistical package (SPSS 18.0 Statistical Package for the Social Services), using an unpaired *t*-test for calculating equality between means.

Results

The results are shown in Tables II,III,IV,V,VI and illustrated in Figures 1,2,3. The volume loss and the Ra measurements (Table II) are presented after 1 and 6 h along with the standard deviation. In Tables III,IV,V,VI the statistical significance of

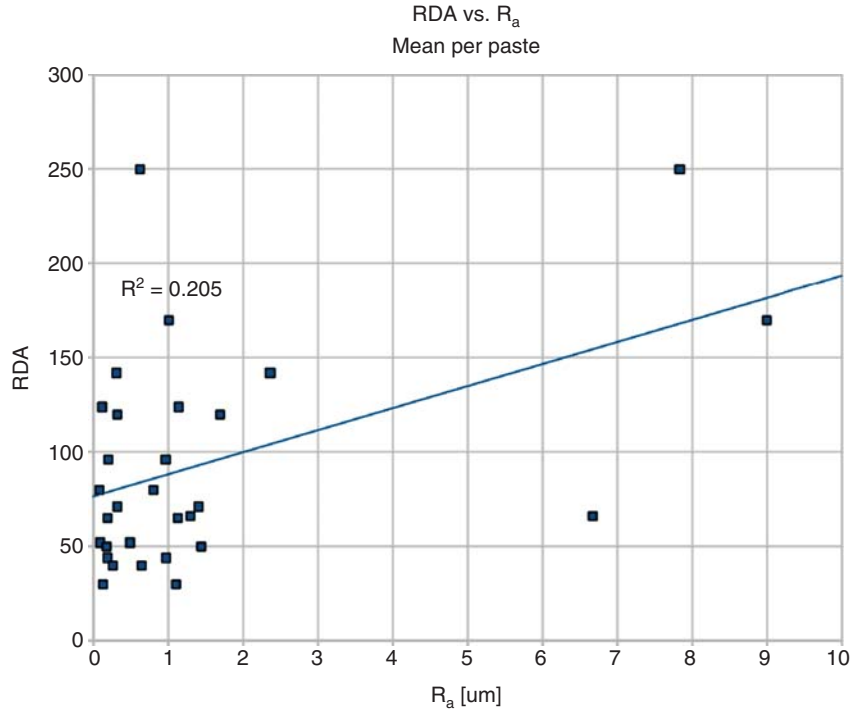

Figure 1. RDA values vs R_a (roughness average) for brushing both at 1 and 6 h. Correlation coefficient is 0.45 (equal the square root of the regression coefficient, R^2, shown in the diagram).

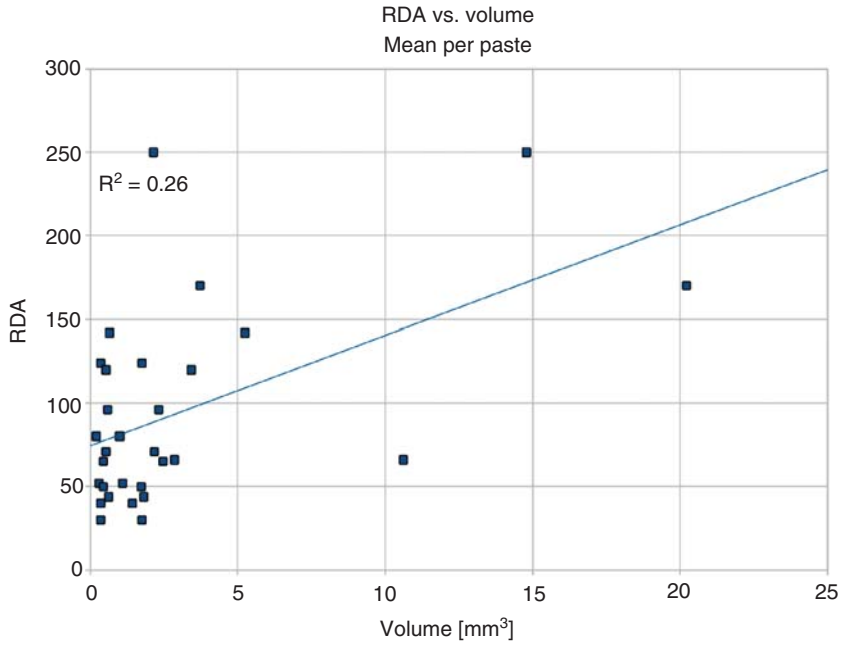

Figure 2. RDA values vs volume for brushing both at 1 and 6 h. Correlation coefficient is 0.51.

the differences between the toothpastes is presented. The highest Ra value and also Volume loss value was shown by the polishing pastes RDA 170® and RDA 250®, respectively, both after 1 and 6 h brushing. The correlation coefficient between RDA and Ra was 0.45 (Figure 1), between RDA and Volume loss 0.51 (Figure 2) and between Ra and Volume loss 0.98 (Figure 3).

Among the toothpastes, the highest Ra values were shown by Apotekets® followed by Pepsodent whitening® after 1 h of brushing and by Pepsodent whitening® followed by Apolivia® after 6 h of brushing. Regarding the volume loss values the highest were created by Pepsodent whitening® followed by Colgate total® after 1 h of brushing and Pepsodent® followed by Apolivia® after 6 h of brushing.

Zendium® followed by Acta ®showed the lowest Volume loss values both after 1 and 6 h and also the lowest Ra values after 1 h brushing, while after 6 h Acta® showed the lowest Ra value followed by RDA 40® and Zendium®.

The values for Opalescence® were excluded from the study due to the reasons given below.

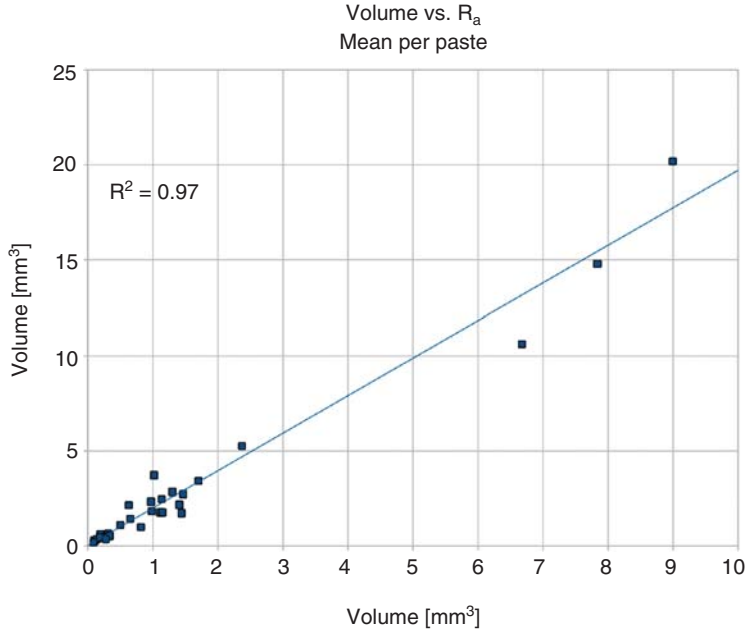

Figure 3. Volume vs R_a (roughness average) for brushing both at 1 and 6 h. Correlation coefficient is 0.98.

Discussion

The present study revealed a poor correlation between the Ra, Volume loss and RDA values, which is clearly shown in Figures 1,2,3, and also when comparing the values for the polishing pastes RDA 170® and RDA 250®. Both after 1 and 6 h of brushing RDA 170® yielded higher Ra and Volume loss values than RDA 250®. This is also in line with the results earlier obtained by Liljeborg et al. [12], which emphasizes the importance of considering both a qualitative (roughness) value and a quantitative (volume loss) value when describing a toothpaste abrasivity.

Another interesting finding in the present study was that the ranking order between the toothpastes was not the same after 1 and 6 h of brushing, indicating that the abrasion was not linear to the number of strokes, Colgate total® was ranked as number 5 regarding volume loss values after 1 h but as number 10 after 6 h brushing. Regarding Ra values, RDA 40® was ranked as number 7 after 1 h but as number 15 after 6 h of brushing. Other investigators have found similar results [17].

When discussing the abrasivity of whitening toothpaste vs conventional toothpaste results are varying. Some studies indicate that a whitening toothpaste does not cause more wear than a conventional toothpaste [18,19], but another study [10] concluded that the highest wear was caused by the whitening toothpastes compared to conventional toothpastes. In the present study no significant differences between the two whitening toothpastes (Pepsodent whitening® and Colgate whitening®) and conventional toothpastes regarding abrasivity were found.

The polishing pastes used in the present study were pastes used in the dental practice. As expected RDA 170® and RDA 250® yielded the highest abrasion values, both regarding the Volume loss and Ra value, after 1 and 6 h. Among the toothpastes, Clinomyn® (RDA = 124) revealed much lower values than the polishing paste RDA 120®, especially concerning the Ra values both after 1 and 6 h. One of the reasons can be that Clinomyn® contains silicon oil which makes the surface of the abraded material smoother and reduces the abrasive effect [3].

Opalescense®, a whitening toothpaste, somewhat influenced the acrylic surface chemically. It contains carbomer and acrylic acid which might have the ability to interact and dissolve acrylic. This must be taken into consideration if and when Opalescense® is being used on other acrylic replacements in the mouth. Therefore, the Ra and Volume loss value for Opalescense® was excluded from this study.

The wear process due to abrasion can also be influenced by erosion. This interaction has been studied by Hooper et al. [20], who used two toothpastes with different RDA values *in vivo*. The test persons wore a removable acrylic appliance holding one piece of polished enamel and one piece of polished dentine during 10 days (8 h per day). Five different treatment regimens were tried with drinking water or orange juice before brushing to influence the surface. Synergetic effects on enamel were directional but not statistically significant. The synergetic effect on dentine could not be measured due to the exceeded measurement range of the profilometer; however, they found that dentine was more susceptible than enamel to erosion and abrasion alone or combined. This was also in line with findings of Voronets and Lussi [21], who compared softened enamel (by citric acid and orange juice) to non-softened enamel after brushing with a toothpaste water slurry. They found that the softened enamel showed an increase in abrasion, which also has been shown by Kielbasa et al. [22]. Also, detergents can modify the abrasivity [17]. They compared brushing with water, detergent slurries and toothpaste detergent slurries and found that brushing with detergents alone also caused loss of dentine. Furthermore, they found that the different silicas used as abrasives differed in abrasion properties, despite similar particle size.

One limitation of the present study was that the brushing was carried out on acrylic plates. The reason for choosing acrylic plates instead of dentin specimen was to get an homogenous surface with the same hardness as dentin that would be equal for all the experiments. Therefore, we only claim the relative comparisons between the toothpastes.

To transform these results into a clinical reality is difficult, but a rough estimate would be that 12 000 double strokes equals 2 years with twice daily brushing [23]. The clinical relevance of these results is obvious, since today the abrasivity of toothpaste is often only based on the RDA value and, since toothpastes with low RDA values are recommended to patients, especially in situations with recession defects, periodontal cases and hypersensitive teeth. Furthermore, the risk for damaging the tooth surface by using whitening toothpastes may be exaggerated. This expresses the need for an *in vivo* investigation to confirm these results.

Conclusion

From the present study it can be concluded that it is important to consider not only the RDA value, but also a roughness value, when describing the abrasivity of toothpastes. Furthermore, this study supports the theory that one toothpaste can cause a higher volume loss value but still create a smoother surface than another toothpaste and that '**w**hitening' toothpastes may very well be used as 'every day' toothpastes.

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