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The role of the toothbrush in the abrasion process

Abstract: *Aim:* To evaluate the relative abrasivity of different toothbrushes both qualitatively and quantitatively. *Materials and Methods:* Acrylic plates were exposed to brushing in a brushing machine with ten different toothbrushes with water alone and with a toothpaste. The results were evaluated using a profilometer after one 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 compared to each other. *Results:* The results showed that brushing with water alone caused less abrasion than when a toothpaste was added. Six-hour brushing with water caused less abrasion than 1 h with a toothpaste. The number of filaments or filament diameter influenced the results in various ways. When brushing with water, the harder toothbrush (Jordan Medium) caused more abrasion (higher Ra-value), but when adding the toothpaste, the softer toothbrush (Jordan soft) caused more abrasion after 12 000 double strokes. *Conclusion:* Besides supporting the fact that a toothpaste is needed to create a significant abrasion, this study also showed that a softer toothbrush can cause as much and in some cases more abrasion than harder ones. When conducting abrasivity studies, it is important to look at both the quantitative and qualitative aspect of abrasivity.

Key words: abrasivity; profilometer; toothbrush

Introduction

Wear of a tooth is comprised of a combination of attrition, erosion and abrasion. Attrition being the tooth to tooth contact wear, erosion is caused by acid-mediated surface softening and abrasion constituting the wear because of toothbrushing with toothpastes (1).

Joiner *et al.* (2) have shown that tooth surface wear caused by abrasion can be reduced by the presence of a pellicle, but wear can also be reduced by adding silicone oil to the toothpaste (3). Abrasion and erosion can be somewhat prevented by high fluoride concentration gel (4); however, it was concluded that fluoridated toothpaste provided very little protection.

Many different techniques have been used to evaluate toothpaste abrasivity. Quantitative techniques, e.g. the RDA method, weight and volume loss techniques (5–7), as well as qualitative techniques, e.g. profilometer and light reflection, have been used (8, 9).

The purpose of these techniques has been to evaluate whether toothpastes with higher abrasive content cause more damage to the tooth surface and also to investigate the relation between abrasivity and cleaning–whitening (10, 11).

Abrasion studies have been performed *in vitro* using various specimens of enamel and dentine. 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, 13).

It is difficult to distinguish between the effect of the toothbrush on the abrasivity from that of the toothpaste, and it is probably dependent on the interaction between them (14). During the years, the toothbrush has only been considered to contribute to tooth surface abrasion indirectly through harbouring the toothpaste across the surface and in itself only having a negligible effect (15, 16).

The hardness of the filaments is regarded to have a certain influence on gingival retraction (17, 18); however, long-term studies are inconclusive, and the prevalence of recession is dependent on the age and characteristics of the population. Nevertheless, toothbrush abrasion may be an integral part in the aetiology of recession (19).

A well-spread opinion is that hard toothbrushes cause more abrasion than soft brushes; however, there are only a few studies to support this (15, 20). There are also studies supporting the opposite, i.e., that soft brushes lead to more abrasion than hard ones (14, 21). This is explained by the fact that soft bristles are able to retain more toothpaste and creating a larger contact surface onto the substrate. However, a larger surface contact should also mean a better cleaning ability. Other researchers claim that the filament hardness of the toothbrush is not a factor that influences abrasivity (22, 23).

The purpose of this study was to evaluate the relative abrasion *in vitro* of 10 different commercially available toothbrushes both qualitatively and quantitatively to find out the role of the toothbrush in the abrasion process.

Materials and methods

Ten commercially available toothbrushes were used:

Toothbrushes	No. of filaments	Filament diameter (mm)	Filament length (mm)
TePe x-mjuk	2856	0.13	11.32
Dentosal (ACO)	2720	0.12	10.62
Jordan soft	2052	0.12	11.20
TePe select, mjuk	1794	0.16	10.88
Pepsodent essential	1748	0.12	10.68
Oral B cross A	1680	0.14	11.10
Jordan Medium	1330	0.14	10.84
Oral B, barn	896	0.14	9.09
Butler gum 431	884	0.19	11.05
TePe vågig, mjuk	816	0.20	11.40

All toothbrushes were manufactured according to the ISO standard 20126:2005, where the toothbrushes are defined and the general requirements and test methods regarding physical inspection, tuft removal force, fatigue resistance and chemical challenge are described. The possible abrasive effect of the toothbrushes on teeth or dental materials is not included or described.

Acrylic plates with the following specifications were used as substrate:

Polymethylmetacrylate (PMMA) type Plexiglas XT. Dimensions $115 \times 25 \times 3$ mm. Density 1.18 g m^{-3}, ball hardness HD 10 s (DIN 53.456) 190 MPa.

Brushing machine:

Reciprocating movement of 85 mm; 1200 double strokes per hour; and load of 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 acrylic plates were mounted in the brushing machine, and the brushing procedure was carried out with water alone on three plates with three brushes of the same brand, and this was then repeated with the same type of brush, but this time with a toothpaste (Clinomyn® – RDA = 130) – water slurry (25 mg toothpaste + 50 ml water) that was added. Every hour the plates were removed and rinsed in lukewarm water, and the slurry was refilled. The total brushing time was 6 h corresponding to 12 000 double strokes, but the plates were also analysed after 1 h brushing (2000 double strokes). This procedure was then repeated for all the ten brushes.

The plates were then analysed using a surface profilometer (P15; KLA Tencor Corp., San Jose, CA, USA) with the following characteristics (for details see Ref. 12):

A diamond stylus with a tip radius of 2 μm was used to scan the surface profile of the sample in a direction perpendicular to the brushing direction. The force of the tip can be controlled, as well as the scanning speed and the sampling interval of the depth values. The profilometer uses a flat glass surface as vertical reference.

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. 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, 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 centre line. Because all the measurements started and ended outside of the abraded area, it was also possible to compute the volume of removed material.

The significance of the difference in the abrasion values between the toothbrushes was calculated using unpaired *t*-test (for calculating equality between means). The *t*-test was also applied on the abrasion values over time. Correlation between Ra and volume measurements and between number of filaments and abrasion values was calculated using Pearson's correlation test (SPSS 13.0, Statistical Package for the Social Sciences; IBM Corp, Somers, NY, USA).

Results

In Tables 1 and 2, the Ra-values [Roughness average (μm)] and the volume loss values (mm^3) obtained from the different toothbrushes used with water alone and with Clinomyn are presented. In Table 1, the Ra-values after 1- and 6-h brushing are presented together with the respective standard deviations. In Table 2, the volume loss values after 1- and 6-h brushing are presented in the same way. The toothbrush that caused the highest Ra-value, i.e. the highest roughness value on the acrylic plates after brushing with water, was Jordan Medium® both after one and 6 h ($P < 0.0001$), and the one causing the least abrasion was TePe select® and Dentosal® after 1 h ($P < 0.001$) and TePe select® and TePe x-soft® after 6 h ($P < 0.001$). After brushing for 1 h with Clinomyn® toothpaste, Butler Gum® showed the highest Ra-value ($P < 0.0001$), i.e. greatest abrasion, and TePe select® and TePe x-soft® the lowest, ($P < 0.001$; Table 3). The 6-h brushing with toothpaste (Clinomyn) also revealed that Butler Gum® caused the highest abrasion ($P < 0.0001$), and Pepsodent the lowest, ($P < 0.0001$; Table 4).

Concerning the quantitative values (volume loss), Jordan Medium again showed the highest values after 1 h with Clinomyn and TePe select the lowest, however, not significant against all the other brushes (Table 5). After 6 h with Clinomyn, Butler Gum revealed the highest volume loss values followed by Jordan Medium, and the lowest 6 h values were shown by TePe select and OB Cross A, however, not significant against all the other brushes (Table 6). The volume loss values caused by abrasion from water alone had such a high uncertainty that ranking was not possible neither for one or 6 h of brushing; therefore, no SD values were relevant.

The correlation of Ra and volume loss values with filament diameter, number of filaments and abrasion values, after 1 and 6 h, are shown in Table 7. Here, it can be seen that after 1 h of brushing, the Ra-values decreased with increased number of filaments ($r = -0.295$), while there is no dependence of the total brushing area. The volume loss values also decreased with increased number of filaments ($r = -0.388$), but there was a weak dependence of filament diameter and a decrease with the total brushing area ($r = -0.446$).

After 6 h, the Ra-values still decreased with increasing number of filaments, but the volume loss values showed a small increase. The Ra-values showed furthermore a small increase with increasing filament diameter ($r = 0.228$), but the volume loss values had no dependence at all. Regarding the total brushing area, the Ra decreased with increasing area ($r = -0.333$), and volume loss showed a small non-significant increase.

Discussion

The present study showed that brushing with water caused very little abrasion on the acrylic plates, and small differences could be found between the brushes, Tables 1 and 2, which is in line with other studies (24), who also claimed that the abrasion that occurred when combining the water with toothpaste was dependent on the shape of the bristle cut and on the toothbrush roughness. However, in our study, the relevance of the toothbrush was more obvious when toothpaste was added, where the abrasion values increased more than ten times, depending on the toothbrush.

In the present study, the filament diameter varied between 0.12 and 0.20, and the number of filaments varied between

Table 1. **Ra (roughness average) values (μm) for toothbrushes using water and Clinomyn**

Water 1 h		±SD	Water 6 h		±SD
Jordan Medium	0.344	0.07	Jordan Medium	0.456	0.079
OB barn	0.140	0.015	OB barn	0.235	0.042
Pepsodent	0.094	0.021	OB cross A	0.184	0.028
Butler Gum	0.086	0.02	Dentosal	0.151	0.021
Jordans soft	0.083	0.015	TePe vågig	0.151	0.015
TePe vågig	0.075	0.015	Pepsodent	0.120	0.015
TePe x-mjuk	0.072	0.015	Butler Gum	0.119	0.032
OB cross A	0.069	0.011	Jordan soft	0.097	0.008
Dentosal	0.05	0.005	TePe select	0.082	0.014
TePe select	0.049	0.013	TePe x-mjuk	0.069	0.013
Clinomyn 1 h			Clinomyn 6 h		
Butler Gum	3.223	0.514	Butler Gum	17.433	0.3197
OB barn	1.409	0.334	Jordans soft	14.542	1.549
Jordan Medium	1.281	0.143	TePe select	11.198	2.554
TePe vågig	1.271	0.086	TePe vågig	9.247	0.761
Jordan soft	1.198	0.078	OB barn	9.091	2.813
OB cross A	1.086	0.124	TePe x-mjuk	8.696	2.168
Dentosal	0.883	0.165	Dentosal	8.340	1.352
Pepsodent	0.747	0.121	Jordan Medium	7.572	0.914
TePe select	0.666	0.124	OB cross A	5.601	0.604
TePe x-mjuk	0.597	0.119	Pepsodent	3.645	0.749

Table 2. **Volume loss values (mm^3) for toothbrushes using water and Clinomyn. Values for brushing with water have a high uncertainty; therefore, SD values are not shown**

Water 1 h			Water 6 h		
Jordan Medium	0.15		Jordan Medium	0.28	
Pepsodent	0.14		OB barn	0.21	
OB barn	0.11		OB Cross A	0.14	
TePe vågig	0.09		Butler	0.13	
Butler	0.07		Dentosal	0.11	
OB Cross A	0.07		TePe vågig	0.09	
TePe x-mjuk	0.05		Jordan soft	0.08	
Jordan soft	0.05		Pepsodent	0.08	
TePe select	0.03		TePe x-mjuk	0.08	
Dentosal	0.02		TePe select	0.03	
Clinomyn 1 h		**±SD**	**Clinomyn 6 h**		**±SD**
Jordan Medium	0.97	0.19	Butler	6.2	2.23
TePe vågig	0.96	0.1	Jordan Medium	5.45	1.14
Butler	0.88	0.2	TePe vågig	5.32	0.34
Jordans soft	0.75	0.14	Dentosal	5.28	1.88
Pepsodent	0.74	0.35	TePe x-mjuk	4.98	4.05
TePe x-mjuk	0.67	0.55	Jordan soft	4.95	2.09
OB barn	0.65	0.06	OB barn	2.91	0.87
Dentosal	0.48	0.24	Pepsodent	2.82	2.48
OB Cross A	0.33	0.18	TePe select	2.68	3.26
TePe select	0.31	0.15	OB Cross A	1.63	0.11

Table 3. **Significance of differences (*P*-values) for Ra-values, 1-h brushing with Clinomyn**

	Butler	OB barn	Jordan Medium	TePe vågig	Jordan soft	OB Cross A	Dentosal	Pepsodent	TePe select	TePe x-mjuk
Butler										
OB barn	***									
Jordan Medium	***	NS								
Tepe vågig	***	NS	NS							
Jordan soft	***	NS	NS	NS						
OB Cross A	***	*	**	**	*					
Dentosal	***	**	***	***	***	**				
Pepsodent	***	***	***	***	***	***	NS			
TePe select	***	***	***	***	***	***	**	NS		
TePe x-mjuk	***	***	***	***	***	***	***	*	NS	

NS, not significant.
*$P < 0.05$, **$P < 0.001$, ***$P < 0.0001$.

Table 4. **Significance of differences (*P*-values) for Ra-values, 6-h brushing with Clinomyn**

	Butler 411	Jordans soft	TePe select	TePe vågig	OB barn	TePe x-mjuk	Dentosal	Jordan Medium	OB Cross A	Pepsodent
Butler 411										
Jordan soft	***									
TePe select	***	*								
TePe vågig	***	***	*							
OB barn	***	***	NS	NS						
TePe x-mjuk	***	***	*	NS	NS					
Dentosal	***	***	**	NS	NS	NS				
Jordan Med	***	***	**	**	NS	NS	NS			
OB Cross A	***	***	***	***	*	**	***	***		
Pepsodent	***	***	***	***	***	***	***	***	***	

NS, not significant.
*$P < 0.05$, **$P < 0.001$, ***$P < 0.0001$.

Table 5. **Significance of differences (*P*-values) for volume loss values, 1-h brushing with Clinomyn**

	Jordan Medium	TePe vågig	Butler	Jordan soft	Pepsodent	TePe x-mjuk	OB barn	Dentosal	OB Cross A	TePe select
Jordan Medium										
TePe vågig	NS									
Butler	NS	NS								
Jordans soft	*	*	NS							
Pepsodent	NS	NS	NS	NS						
TePe x-mjuk	NS	NS	NS	NS	NS					
OB barn	**	***	*	NS	NS	NS				
Dentosal	**	***	*	*	NS	NS	NS			
OB Cross A	***	***	***	***	*	NS	***	NS		
TePe select	***	***	***	***	*	NS	***	NS	NS	

NS, not significant.
*$P < 0.05$, **$P < 0.001$, ***$P < 0.0001$.

Table 6. **Significance of differences (*P*-values) for volume loss values, 6-h brushing with Clinomyn**

	Butler	Jordan Medium	TePe vågig	Dentosal	TePe x-mjuk	Jordan soft	OB barn	Pepsodent	TePe select	OB Cross A
Butler										
Jordan Medium	NS									
TePe vågig	NS	NS								
Dentosal	NS	NS	NS							
TePe x-mjuk	NS	NS	NS	NS						
Jordan soft	NS	NS	NS	NS	NS					
OB barn	**	***	***	**	NS	*				
Pepsodent	*	*	**	*	NS	NS	NS			
TePe select	*	*	*	NS	NS	NS	NS	NS		
OB cross A	***	***	***	***	*	**	**	NS	NS	

NS, not significant.
*$P < 0.05$, **$P < 0.001$, ***$P < 0.0001$.

Table 7. **Correlations between Ra and volume loss with number of brush filaments, filament diameter and brush area. Pearson's correlation test was used**

	Number of filaments	Filament diameter	Brush area*
After 1 h brushing			
Ra	−0.3	0.53	0.06
Volume loss	−0.39	0.22	−0.45
After 6 h brushing			
Ra	−0.33	0.23	−0.33
Volume loss	0.22	0.07	0.16

*Brush area = number of filaments times area of one filament.

816 and 2856. The brushes with the smallest filament diameter contained the highest number of filaments, e.g. TePe x-soft with a diameter of 0.13 contained 2856 filaments while TePe vågig with a filament diameter 0.20 contained 816 filaments. A correlation showing that increased filament diameter caused more abrasion after 1 h of brushing was found and that decreasing Ra and volume loss values were associated with a higher number of filaments. This might be explained by the fact that the more the filaments, the less the diameter of the filament. A more confusing finding was that Ra was not dependent on the total brushing area, i.e. number of filaments × area per filament, but that volume loss value decreased with total brushing area. After 6-h brushing with Clinomyn, the values differ, as an example TePe select with 1794 filaments showed higher abrasivity (Ra-value) than TePe vågig with 816 filaments. Another interesting finding was that Jordan soft with 2052 filaments caused more abrasion (higher Ra-value) than Jordan Medium with 1330 filaments, after 6-h brushing with toothpaste; however, when comparing the volume loss values, the results were the opposite.

The 6-h correlation values revealed that the Ra-value and volume loss value still decreased with increasing number of filaments, and the correlation was weak, however, regarding the volume loss value. Also when looking at the total brushing area, it was evident that the Ra-value decreased with increasing total brushing area, but only a weak correlation to volume loss values was found.

These results neither support nor oppose the theory about soft brushes holding the abrasive medium longer and in larger contact with the substrate thus causing more abrasion (14), but support the fact that one toothbrush–toothpaste combination can cause more volume loss and in the same time less deep scratches, i.e. a smoother surface than another combination. This once again emphasizes the importance of not only measuring a quantitative value, i.e. volume loss of abrasion (12).

The influence of the filament diameter on the abrasion has been investigated earlier (25). Filament diameters of 0.15, 0.20 and 0.25 mm with toothpaste water slurries with different RDA values (20, 50 and 100) were compared. It was found that abrasion of eroded dentine increased with the RDA value of the toothpaste slurry and with decreasing filament diameter of the toothbrush.

In an earlier study (26), toothbrushes with the same filament diameter as in the above-mentioned study (25) were used in a brushing machine on eroded enamel with toothpastes with different radioactive enamel abrasivity (REA) values. The conclusion was that toothbrush abrasion of eroded enamel is mainly influenced by the abrasivity of the toothpaste slurry, but is modified by toothbrush filament stiffness. Somewhat surprisingly it was found that toothpastes with 0.20 mm filament diameter caused higher enamel loss than 0.15 and 0.25.

In the present study, the two brushes with the largest filament diameter (Butler Gum and TePe vågig) showed similar abrasion values, both regarding Ra and volume loss after brushing with water or toothpaste and also among the highest abrasion values after brushing with toothpaste. The abrasive effect of hard, medium and soft bristled toothbrushes together with toothpaste in a brushing machine on enamel and dentine has also been compared (27). Laser interferometry was used to investigate the surface topography, and it was found that neither soft, medium nor hard brushes were able to abrade enamel, but dentine was abraded by medium and hard bristled brushes. It has also been shown that brushes that had a declared equal stiffness of the bristles still differed considerably in that same property (28).

In our study, TePe x-soft (a toothbrush designed to be extra soft and gentle towards the tooth surface) caused similar abrasion (Ra-values) to that of Jordan Medium after 6 h of brushing with toothpaste.

Furthermore, the Ra-values between 1 and 6 h of brushing with Clinomyn showed a large increase (Tables 1 and 2), e.g. TePe x-soft showed similar values after brushing for 1 and 6 h with water, but after 1 h with toothpaste, the values increased almost ten times and after 6 h brushing another ten times. A similar pattern was also shown for TePe select.

To transform these results into a clinical reality is difficult, but a rough estimate of 12 000 double strokes would be equal to 2 years with twice daily brushing (29).

One of the limitations of the present study was that the brushing was carried out on acrylic plates instead of dentin specimen, the reason being to get a homogenous surface that would be equal for all the experiments, and that we only claim the relative differences between the brushes. Because dentin is not a homogenous material, we did not find it suitable for these investigations. However, the acrylic plates had the same hardness as dentin, which means that similar results would have been expected on a dentine specimen. Because enamel is a much harder material, it is reasonable to expect that the abrasion caused by the toothbrushes will be insignificant. Another interesting aspect that was not considered in the present study is the brushing effect on gingiva. Hard brushes may well be more harmful than soft ones in that respect.

The clinical relevance of these results is obvious because today soft toothbrushes are recommended to patients, especially in situations with recession defects, periodontal cases and hypersensitive teeth. There is also a possibility that the risk of using harder toothbrushes might be exaggerated. This expresses the need for an *in vivo* investigation to confirm these results.

Conclusion

The present study showed that the influence of the toothbrush on the abrasivity is negligible when using water as substrate, but when a toothpaste is added, the influence of the toothbrush is of great importance where a softer toothbrush might cause similar or even more abrasion than that of a harder one. Furthermore, one toothbrush–toothpaste combination can cause more volume loss but still create a smoother surface than another that highlights the need for looking at both the quantitative and qualitative aspect when conducting abrasion studies.

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References

1 Barbour ME, Rees GD. The role of erosion, abrasion and attrition in tooth wear. *J Clin Dent* 2006; **17:** 88–93.

2 Joiner A, Schwartz A, Philpotts CJ, Cox TF, Huber K, Hannig M. The protective nature of pellicle towards toothpaste abrasion on enamel and dentine. *J Dent* 2008; **36:** 360–368.

3 Johannsen G. The influence of silicone oil in toothpastes on abrasion in vitro. *Swed Dent J* 1993; **17:** 117–122.

4 Lagerweij MD, Buchalla W, Kohnke S, Becker K, Lennon AM, Attin T. Prevention of erosion and abrasion by a high fluoride concentration gel applied at high frequencies. *Caries Res* 2006; **40:** 148–153.

5 Franz G. Untersuchungen der Kunststoffoberfläche auf mögliche Veränderungen durch das Zähneputzen. *Zahnärztl Mitt* 1974; **64:** 1190–1195.

6 Hefferen JJ. A laboratory method for assessment of dentifrice abrasivity. *J Dent Res* 1976; **55:** 563–573.

7 Hotz PR. Untersuchungen von Abrasivität von Zahnpasten. *Schweiz Mschr Zahnheilk* 1983; **93:** 93–99.

8 Redmalm G, Ryden H. Dentifrice abrasivity. The use of laser beams for comparative studies in vitro of surface changes. *Swed Dent J* 1979; **3:** 91–100.

9 Kielbasa AM, Gillman L, Zantner C, Meyer-Lueckel H, Hellwig E, Schulte-Monting J. Profilometric and microradiographic studies on the effects of toothpaste and acidic gel abrasivity on sound and demineralized bovine dental enamel. *Caries Res* 2005; **39:** 380–386.

10 Vincentini BC, Braga SR, Sobral MA. The measurement in vitro of dentine abrasion by toothpastes. *Int Dent J* 2007; **57:** 314–318.

11 Joiner A, Pickles MJ, Lynch S, Cox TF. The measurement of enamel wear by for toothpastes. *Int Dent J* 2008; **58:** 23–28.

12 Liljeborg A, Tellefsen G, Johannsen G. The use of a profilometer for both quantitative and qualitative measurements of toothpaste abrasivity. *Int J Dent Hyg* 2010; **8:** 237–243.

13 Addy M, Goodfield S. The use of acrylic to compare the abrasivity and stain removal properties of toothpastes. *Clin Mater* 1991; **7:** 219–225.

14 Dyer D, Addy M, Newcombe RG. Studies in vitro of abrasion by different manual toothbrush heads and a standard toothpaste. *J Clin Periodontol* 2000; **27:** 99–103.

15 Harrington JH, Terry I. A automatic and handbrushing abrasion studies. *J Am Dent Assoc* 1964; **68:** 343–350.

16 Absi EG, Addy M, Adams D. Dentine hypersensitivity: uptake of toothpastes onto dentine and effects of brushing, washing and dietary acids. *J Oral Rehabil* 1995; **22:** 175–182.

17 Smith RG. Gingival recession. Reappraisal of an enigmatic condition and a new index for monitoring. *J Clin Periodontol* 1997; **24:** 201–205.

18 Addy M. Measuring success in toothbrushing design-an opinion and debate of the concepts. *Int Dent J* 1998; **48:** 378–385.

19 Litonjua LA, Andreana S, Bush PJ, Cohen RE. Toothbrushing and gingival recession. *Int Dent J* 2003; **53:** 67–72.

20 Skinner EW, Takata GK. Abrasions of the tooth surface by nylon and natural bristle toothbrushes. *J Dent Res* 1951; **30 abstract 163.**

21 Phaneuf EA, Harrington JH, Dale PP, Stklar G. Automatic toothbrush: a new reciprocating action. *J Am Dent Assoc* 1962; **65:** 12–25.

22 Björn H, Lindhe J. Abrasion of dentine by toothbrush and dentifrice. *Odont Revy* 1966; **17:** 17–27.

23 Bergström J, Lavstedt S. An epidemiologic approach to toothbrushing and dental abrasion. *Community Dent Oral Epidemiol* 1979; **7:** 57–64.

24 Remizov SM, Pruzhanskii L. The effect of toothbrushes on human dental enamel and dentin wear. *Stomatologiia* 1990; **4:** 4–6.

25 Wiegand A, Kuhn Sener M, Roos BM, Attin T. Abrasion of eroded dentin caused by toothpaste slurries of different abrasivity and toothbrushes of different filament diameter. *J Dent* 2009; **37:** 480–484.

26 Wiegand A, Schwerzmann M, Sener B *et al.* Impact of toothpaste slurry abrasivity and toothbrush filament stiffness on abrasion of eroded enamel- an in vitro study. *Acta Odontol Scand* 2008; **66:** 231–235.

27 Azevedo AM, Panzeri H, Prado CJ, De-Mello JD, Soares CJ, Fernandes-Neto AJ. Assessment in vitro of brushing on dental surface roughness alteration by laser interferometry. *Braz Oral Res* 2008; **22:** 11–17.

28 Nygaard-Ostby P, Spydevold B, Edvardsen S. Suggestion for a definition, measuring method and classification system of bristle stiffness of toothbrushes. *Scand J Dent Res* 1979; **87:** 159–170.

29 Sexson JC, Phillips RW. Studies on the effect of abrasives on acrylic resins. *J Prosthet Dent* 1951; **1:** 454–471.