



Original Article

Tooth wear and cleaning effect of an abrasive-free dentifrice



Jae-Hyun Ahn ^{a*}, Ji-Hye Kim ^a, Won-Ho Ha ^a, Yong-Duk Park ^b

^a Department of Oral-care, LG Household & Health Care Research Park, Daejeon, South Korea

^b Kyung Hee University, School of Dentistry, Preventive and Social Dentistry, South Korea

Received 13 September 2017; Final revision received 12 October 2017

Available online 28 November 2017

KEYWORDS

abrasion;
tooth wear;
cleaning power;
dentifrice

Abstract *Background/purpose:* To evaluate the degree of wear on human teeth and the cleaning effect of abrasive-free dentifrice. A sodium pyrophosphate and cellulose-containing abrasive-free dentifrice and calcium carbonate-containing control dentifrice were evaluated.

Materials and methods: Dentin and enamel specimens were subjected to 109,500 successive double strokes and 5480 double strokes in pH-cycling condition. A profilometer measured abrasion depth. The cleaning effect of dentifrices on artificial stain was evaluated by cleaning power (modified Stookey method) and by removal of colored stain on artificial tooth.

Results: The experimental results were evaluated using Mann–Whitney *U* test. The abrasion depth in dentin specimens was 13.97–26.73 times smaller with abrasive-free dentifrice than with control dentifrice. The abrasion depth of enamel specimen was $2.17 \pm 0.66 \mu\text{m}$ with control dentifrice. The values for abrasive-free dentifrice were too small to measure. In pH-cycling conditions using dentin specimens, abrasion depth was 14.28–19.00 times smaller with abrasive-free dentifrice than with control dentifrice. The cleaning power and removing effect of colored stain were statistically insignificant between abrasive-free dentifrice and control dentifrice ($P > 0.05$).

Conclusion: The abrasive-free dentifrice was as effective as control dentifrice in its cleaning effect on artificial stain and can significantly reduce tooth wear more than control dentifrice.

© 2018 Taiwan Association of Obstetrics & Gynecology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

* Corresponding author. Department of Oral-care, LG Household & Health Care Research Park, 84 Jang-dong, Yuseong-gu, Daejeon, South Korea. Fax: +82 42 863 2073.

E-mail address: jhahnjhahn@hanmail.net (J.-H. Ahn).

Introduction

The basic function of dentifrices is to remove dental plaque physically on the surface of the teeth. In general, people who have hypersensitive teeth because of gingival recession or marginal tooth wear should be cautious when using a highly abrasive dentifrice, although it has a substantial cleaning effect.¹ On the other hand, because residual plaque causes dental caries by bacteria and chronic gingivitis by plaque calcification process, people who have healthy teeth should be cautious when using a dentifrice that is too low in abrasivity since it is unable to remove dental plaque properly.² The number of patients with tooth hypersensitivity is increasing every year, and primary reason for this is the high abrasivity of dentifrices, based on a study by Moon et al.³ The global standard by the International Standard Organization (ISO) and American Dental Association have announced only upper limit values, compared to standard dentifrice, by using radio trace method or surface profile method. Based on measurement methods, the global standard (ISO 11609) recommends upper limit value of abrasivity 2–2.5 times less for dentin and 2–4 times less for enamel.⁴ The British Standard (BS 5136) represents upper limit of abrasivity value as 2 times less for dentin and 4 times less for enamel, compared to standard dentifrice.⁵ These guidelines indicate that excessive abrasivity of dentifrice can be harmful to the teeth. It is surely ideal to use dentifrice that minimizes abrasivity while maximizing the cleaning effect. Dental plaque can be removed by brushing without using dentifrice, but it is not as effective as using dentifrice, according to study by Dudding et al.⁶ In previous studies focusing on tooth wear, Miller⁷ was the first to investigate the abrasion of tooth powder; afterwards, many studies investigated how to measure the abrasivity of dentifrice. Liljeborg et al.⁸ have recently reported that the surface profile method was useful in obtaining quantitative and qualitative results such as surface roughness on the brushed tooth surface. Franzo et al.⁹ studied the degree of tooth wear by using various concentrations of dentifrice and brushing strokes. Philpotts et al.¹⁰ also compared the degree of tooth wear for different abrasive dentifrices on human teeth. Hooper et al.¹¹ and Kim et al.¹² evaluated the influence of abrasion with an acidic beverage. The higher abrasivity of dentifrice in general represents higher cleaning effect, but it can create different pattern, depending on the composition of dentifrice. With respect to this, we designed dentifrice that can remove dental plaque without causing tooth wear. It would be an ideal dentifrice and become a new paradigm dentifrice in the future market. The objective of the present study was to evaluate the degree of tooth wear on human teeth and cleaning effect of artificial stain by abrasive free dentifrice containing cellulose powder and sodium pyrophosphate.

Materials and methods

Test materials

The experimental dentifrice (i.e., abrasive-free dentifrice) consisted of 3.0% cellulose powder and 3.4% sodium pyrophosphate ($\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$) without conventional

abrasives. The control dentifrice consists of 40.0% calcium carbonate as abrasive (Table 1).

Removing effect of colored stain

The dental model (D51DP-TRM.444; Nissin Dental Products Inc., Kyoto, Japan) was dipped in colored stain solution for 10 s, coated, and dried in constant temperature and humidity chamber (25 °C, 55%) to maintain same coating condition. The colored stain solution (consist of poly vinyl pyrrolidone K-90, Red No. 40, ethyl alcohol and water) was made in accordance with the modified method by Volpenhein et al.¹³ The coated dental model was placed in brushing instrument, which is especially designed to control brushing speed, force, and length. Table 2 presents details of brushing condition. The removing effect of the colored stain was calculated by measuring the removed area of colored stain on the surface of dental model by using a microscope that could automatically analyze and calculate the area (Somotech Co., Seoul, Korea) (Fig. 1).

Cleaning power

Cleaning power was measured by the modified Stookey method (i.e., the Pellicle cleaning ratio [PCR]).¹⁴ Artificially stained bovine enamel specimens were prepared and initial lightness values were measured with a colorimeter (Minolta CR-321; Minolta Camera, Osaka, Japan). They were brushed for 800 double strokes under 250 gF¹⁵ at a rate of 90 double strokes per minute in 2:1 slurry mixtures of artificial saliva solution and each dentifrice. L* (Lightness), a* (degree of redness and greenness) and b* (degree of yellowness and blueness) values after brushing were measured.

The abrasion depth in continuous brushing

The method used in this study was based on the surface profile method (BS 5136)⁵ to quantify the degree of surface

Table 1 Ingredients of experimental and control dentifrice.

Test ingredients	Experimental dentifrice	Control dentifrice
	Cellulose powder 3.0%	Calcium carbonate 40.0%
	Sodium pyrophosphate 3.4%	
Glycerin	30.0%	30.0%
Sodium carboxyl methyl cellulose	2.5%	1.5%
Colloidal silica	3.0%	3.0%
Sodium lauryl sulfate	2.0%	2.0%
Flavor	1.0%	1.0%
Purified water	To 100%	To 100%

Glycerin is humectant. Sodium carboxyl methyl cellulose and Colloidal silica are viscosity controlling agents. And Sodium lauryl sulfate is foaming agent.

Table 2 Conditions of the brushing instrument.

Measurements	Stroke type	
	Back-and-forth	Up-and-down
Angle of brush	90.00	90.00
Stroke length (mm)	20.83	12.70
Brush Speed (mm/s)	147.32	76.20
Force (gram)	300.00	300.00

wear as cross-sectional area of worn dentin and enamel specimens. They were brushed with 2:1 slurry mixture of the artificial saliva solution and each dentifrice underwent 27,375 (Step 1); 54,750 (Step 2); 82,125 (Step 3); and 109,500 double strokes (Step 4) in succession by brushing machine at 250 gF. The abrasion depth was measured by a profilometer (Mitutoyo SV-3000; Mitutoyo, Tokyo, Japan). The depth was calculated (from plots of wear surface) by dividing the full length of the wear surface area into 10 equal parts, summing the length of 9 places (except for both end lengths of the 10 parts), and dividing by 9.

The abrasion depth in the pH-cycling condition

Preparation of specimens and the principle of measuring abrasion depth in pH-cycling condition were the same as in continuous brushing. The procedure of pH-cycling condition was as follows: 1) the dentin and enamel specimens were brushed with 2:1 slurry mixture of artificial saliva solution and each dentifrice for 548 double strokes in succession by using brushing machine at 250 gF; 2) 5 mL of artificial saliva solution was added for every 200 double strokes; 3) the specimens were then treated in artificial saliva solution for 1 h, and then in acid solution (0.1M lactic acid; pH 5.0) for 1 h, and again in artificial saliva solution for 1 h. These processes formed 1 cycling; 10 cyclings (total of 5480

double strokes) were repeated. The abrasion depths were measured for every even cycling.

Statistical analysis

Experimental data were analyzed by the statistical program SPSS 20.0 (IBM Co.; Armonk, NY, USA). Mann–Whitney *U* test was conducted to determine statistical significance between dentifrices at significance level of $\alpha = 0.05$.

Results

Cleaning power

The ΔL^* , Δa^* , Δb^* and ΔE^* values for experimental dentifrice were 47.51 ± 1.80 , -10.24 ± 0.59 , -13.31 ± 1.13 and 50.41 ± 1.51 . The control dentifrice showed 50.27 ± 7.36 , -11.54 ± 2.22 , -9.74 ± 2.11 and 52.60 ± 7.09 . Although the experimental dentifrice showed better effect in Δb^* value, there were no statistical significance in ΔL^* and ΔE^* values calculated from ΔL^* , Δa^* , and Δb^* ($P > 0.05$) (Table 3).

Removing effect of the colored stain

The removed areas of colored stain on the surface of dental model by experimental dentifrice and control dentifrice were $99.20 \pm 2.41 \text{ mm}^2$ and $98.92 \pm 4.32 \text{ mm}^2$, respectively. The experimental dentifrice value was a little higher than that of control dentifrice; however, the difference was not statistically significant ($P > 0.05$) (Table 4).

The abrasion depth in continuous brushing

In dentin specimen, abrasion depth of control dentifrice for Step 1 to Step 3 was $86.67 \pm 20.00 \text{ }\mu\text{m}$ (Step 1),

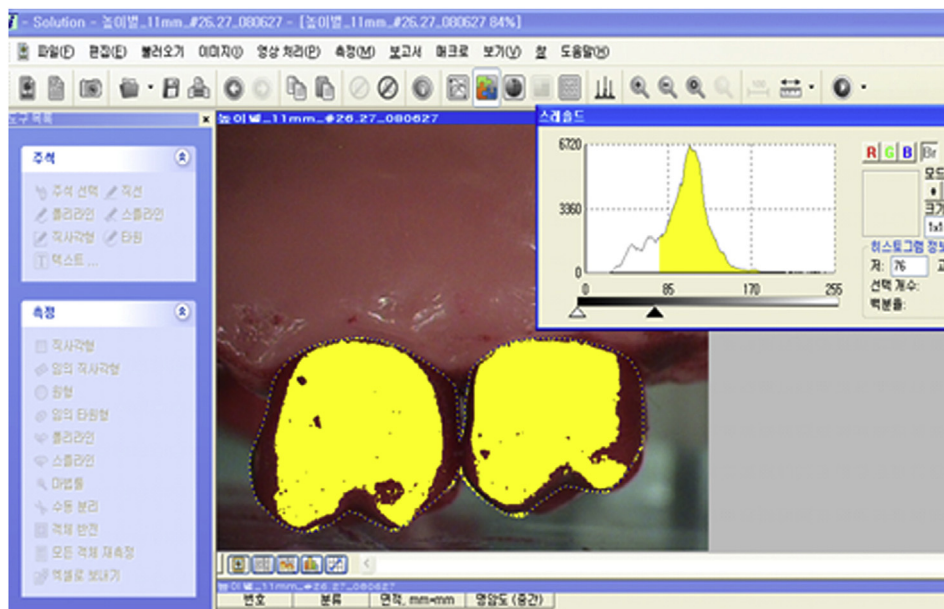


Figure 1 The removing effect of the colored stain was calculated by measuring the removed area of the colored stain on the surface of the dental model by using a microscope that could automatically analyze and calculate the area (upper right graph).

Table 3 Cleaning power (Pellicle cleaning ratio) of the experimental and control dentifrices.

Group	N	ΔL^*	Δa^*	Δb^*	ΔE^*
Control dentifrice	12	50.27 \pm 7.36	-11.54 \pm 2.22	-9.74 \pm 2.11	52.60 \pm 7.09
Experimental dentifrice	12	47.51 \pm 1.80	-10.24 \pm 0.59	-13.31 \pm 1.13	50.41 \pm 1.51
P		P > 0.05	P > 0.05	P < 0.05	P > 0.05

The values are presented by the mean \pm the standard deviation. The P values were calculated by Mann–Whitney *U* test. ΔL^* = change in lightness value. Δa^* = change in degree of redness and greenness. Δb^* = change in degree of yellowness and blueness. ΔE^* = $(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$.

Table 4 The removed area of the colored stain.

Groups	N	The removed area of the colored stain (mm ²)	P
Control dentifrice	8	98.92 \pm 4.32	P > 0.05
Experimental dentifrice	8	99.20 \pm 2.41	

The values are presented as the means \pm the standard deviation. The P value was calculated by Mann–Whitney *U* test.

173.33 \pm 58.95 μ m (Step 2), and 283.33 \pm 108.97 μ m (Step 3); however, it was impossible to measure abrasion depth for Step 4 because excessive wear was beyond measuring range of profilometer. The abrasion depths of experimental dentifrice for Step 1 to Step 4 ranged from 6.20 \pm 0.11 μ m to 15.50 \pm 0.53 μ m (Table 5). In enamel specimens, abrasion depth for control dentifrice was 1.17 \pm 0.25 μ m at Step 1; 1.67 \pm 0.25 μ m at Step 2; 1.87 \pm 0.48 μ m at Step 3; and 2.17 \pm 0.66 μ m at Step 4. The abrasion depths were small but incrementally increased with the number of brushings. However, abrasion depth could not be measured for experimental dentifrice since its values were too small (Table 5).

The abrasion depth in the pH-cycling condition

The abrasion depth for enamel specimens was very small, according to results of abrasion depth in continuous brushing. Because we thought it was difficult to get discriminating data for enamel specimen, only dentin specimen was used in pH-cycling condition. The experimental and control dentifrices were evaluated. Water was another control that was evaluated at the same time. Table 6 shows abrasion depths of 2 dentifrices and water control at every even cycling. Fig. 2 is abrasion area graph after pH-cycling brushing for dentin specimen (10 cyclings).

Discussion

Enamel thickness varies depending on the position of tooth surface. In general, the enamel is the thickest at occlusal surface and thinnest at gum boundary. Enamel tissue disappears at cementum enamel junction (CEJ) and periodontal ligament with the cementum is combined with alveolar bone from tooth root portion. According to a study by Lee et al.,¹⁶ which analyzed enamel thickness, labial enamel thickness above 1.0 mm, 3.0 mm, and 5.0 mm from CEJ in maxillary central incisor was 0.32 \pm 0.01 mm,

Table 5 Abrasion depth after continuous brushing.

Group	Brushing strokes	Abrasion depth (μ m)	
		Dentin	Enamel
Control dentifrice	27,375 (Step 1)	86.67 \pm 20.00	1.17 \pm 0.25
	54,750 (Step 2)	173.33 \pm 58.95	1.67 \pm 0.25
	82,125 (Step 3)	283.33 \pm 108.97	1.87 \pm 0.48
	109,500 (Step 4)	—	2.17 \pm 0.66
Experimental dentifrice	27,375 (Step 1)	6.20 \pm 0.11	<1.0
	54,750 (Step 2)	8.25 \pm 0.27	<1.0
	82,125 (Step 3)	10.60 \pm 0.43	<1.0
	109,500 (Step 4)	15.50 \pm 0.53	<1.0

Table 6 Abrasion depth with pH-cycling (dentin, μ m).

	Accumulated brushing strokes	Control (Water)	Control dentifrice	Experimental dentifrice
Cycling 2	1096	1.13 \pm 0.40	12.40 \pm 2.57	0.78 \pm 0.23
Cycling 4	2192	2.50 \pm 0.53	18.00 \pm 2.14	1.05 \pm 0.05
Cycling 6	3288	2.00 \pm 0.53	25.00 \pm 5.35	1.75 \pm 0.27
Cycling 8	4384	2.05 \pm 0.05	37.70 \pm 13.58	2.10 \pm 1.11
Cycling 10	5480	2.75 \pm 0.80	42.75 \pm 13.42	2.25 \pm 0.27

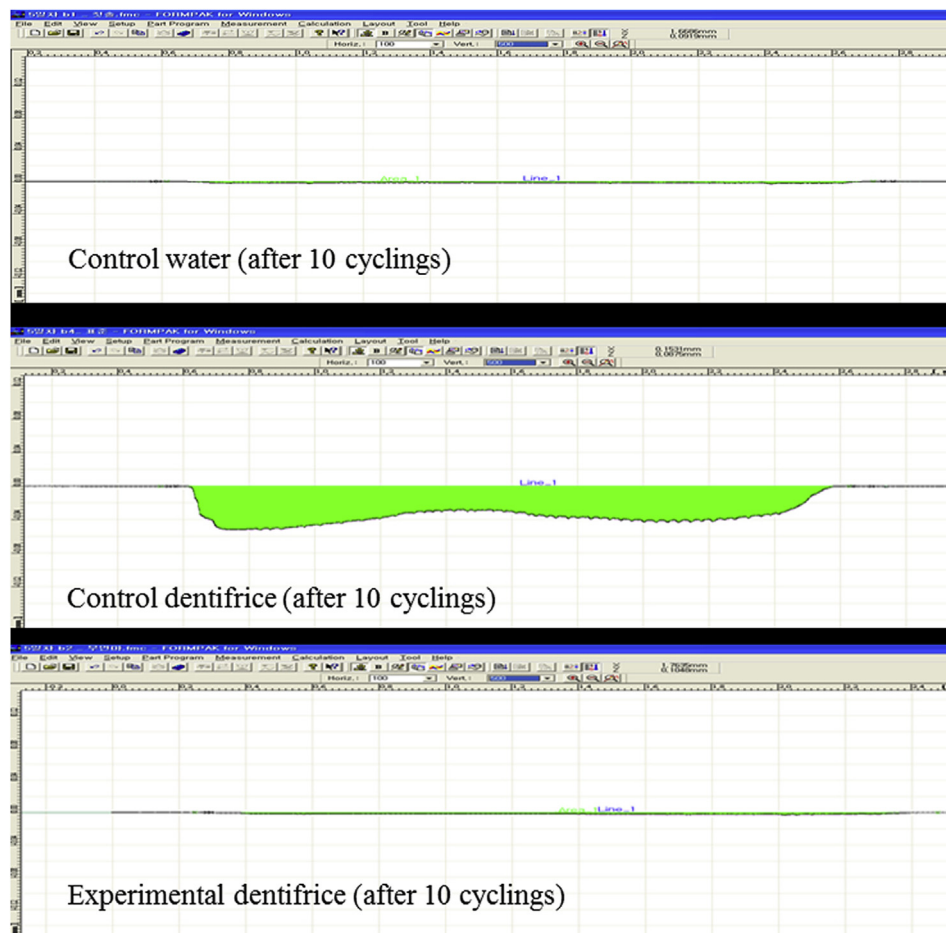


Figure 2 The degree of surface wear as cross-sectional area of the worn dentin after pH-cycling brushing.

0.50 ± 0.02 mm, and 0.70 ± 0.02 mm, respectively. Dentin has many dentin tubules which are kinds of channel transferring outer stimuli. The thickness of dentin is approximately 1.5–3.0 mm. In milk teeth, dentin thickness is one-half that of permanent teeth.¹⁷ Cellulose powder¹⁸ used in this study is made of wood plant which consists of combination of beta-1, 4 polysaccharides. It is water insoluble and is soft material so it can remove dental plaque gently without tooth wear. It is also commercially available at low price. Sodium pyrophosphate¹⁹ is a type of metal-chelating agent that sequesters metallic ions that can cause extrinsic stains. It is widely used as anti-tartar or anti-stain agent in dentifrice industry. Wiilknitz¹ studied the correlation between dentin abrasivity and cleaning power of 41 dentifrices that were commercially available in Europe, and found correlation coefficient (r) of 0.66. This indicated overall positive correlation. However, various aspects were revealed, depending on the composition of dentifrices. Klüppel et al.²⁰ claimed that dentifrice with low abrasivity and high cleaning power could be produced by controlling the composition of dentifrice. In general, enamel is the hardest tissue in human body so that the degree of wear caused by daily brushing with dentifrice is too small to detect. In contrast, calcium carbonate-containing control dentifrice increasingly wears the enamel in proportion to the number of brush strokes. The abrasion depth for

enamel specimen was $2.17 \pm 0.66 \mu\text{m}$ after 109,500 double strokes. But, enamel wear in experimental dentifrice was not detectable. It is generally recommended that the number of brushing strokes at one time is at least 5 double strokes (i.e., 10 strokes) to each surface of the tooth and brushing frequency is 3 times daily. In this sense, brushing by 109,500 double strokes corresponds to approximately the number of brushing strokes for 20 years, when arithmetically calculated. With continuous brushing, abrasion depth of dentin specimens was 13.97–26.73 times smaller with experimental dentifrice than with control dentifrice. The degree of dentin wear was more serious with control dentifrice than with experimental dentifrice. According to a study by Lee et al.,¹⁶ dentin thickness is 1.0–1.5 mm (1000–1500 μm). The abrasion depth on dentin specimens with control dentifrice was $173.33 \pm 58.95 \mu\text{m}$ after 54,750 double strokes, which represents the number of brushings for 10 years. For experimental dentifrice, abrasion depth was $8.25 \pm 0.27 \mu\text{m}$, which was approximately 21 times smaller than that for control dentifrice.

The results of abrasion depth based on brushing strokes were plotted and trend line equation was obtained (Fig. 3). By using 1000–1500 μm as average dentin thickness, the number of brushing strokes as 5 double strokes to each tooth surface, and brushing frequency of 3 times daily, half-wear periods for dentin were calculated as 26.61–40.04

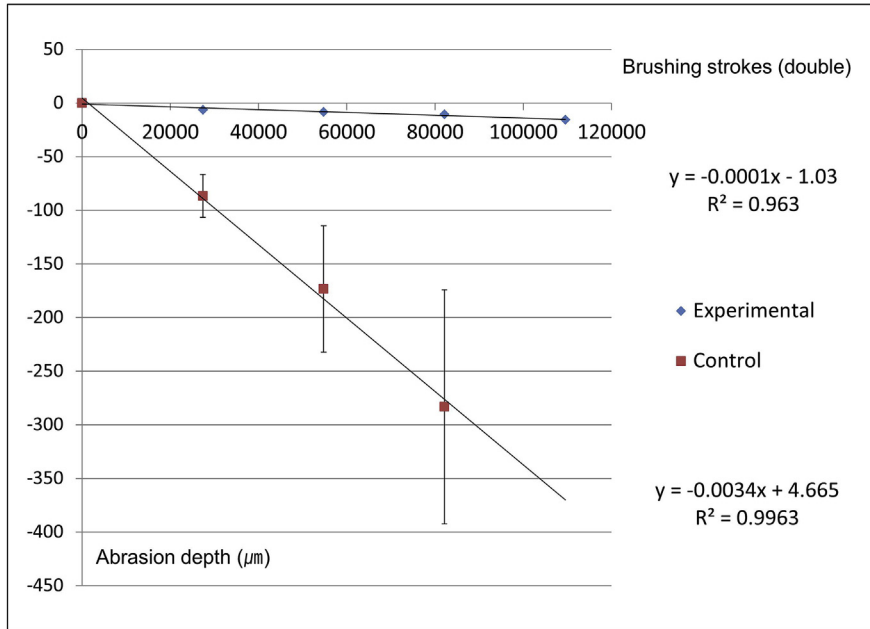


Figure 3 Plot and trend line equation of the abrasion depth according to continuous brushing strokes for dentin specimens.

years for control dentifrice and 915.12–1371.74 years for experimental dentifrice. In pH-cycling conditions, abrasion depth of dentin specimens was 14.28–19.00 times smaller with experimental dentifrice than control dentifrice. The abrasion depth of experimental dentifrice was also smaller than that of water control (i.e., without dentifrice). This indicates experimental dentifrice has no abrasivity. The reason that abrasion depth was smaller with experimental dentifrice than with water control was because of lubrication by water-soluble polymers or viscous humectants such as glycerin. These chemicals could accordingly reduce physical friction from bristles of toothbrush. In addition, as indicated in studies by Bartlett et al.²¹ and Hara et al.,²²

fluoride in dentifrice increases surface hardness of dentin so that it is more resistant to brushing abrasion. The number of brushing strokes at the end of pH-cycling was 5480 double strokes. This corresponds to approximately the number of brushing strokes for 1 year, when calculated arithmetically. The results of abrasion depth, based on brushing strokes, were plotted and trend line equation was obtained (Fig. 4). As in continuous brushing condition, half-wear periods for dentin were calculated for 11.88 years–17.80 years for control dentifrice and 228.18 years–342.23 years for experimental dentifrice. For both dentifrices, the degree of dentine wear was more severe in pH-cycling brushing than in continuous brushing. These

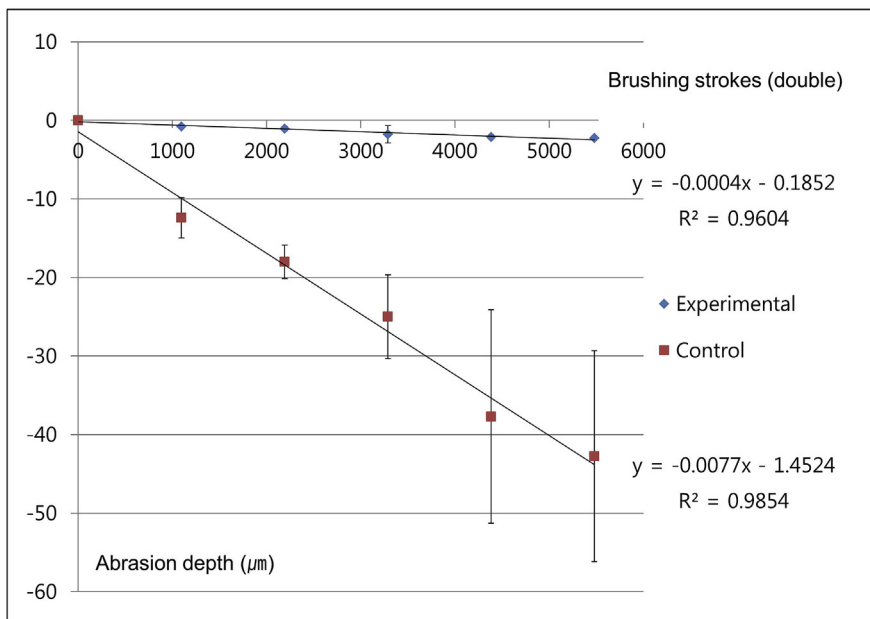


Figure 4 Plot and trend line equation of the abrasion depth according to pH-cycling brushing strokes for dentin specimens.

results could be because acid treatment decreased dentine hardness.

Conclusively, abrasive-free dentifrice was as effective as control dentifrice in its cleaning effect of an artificial stain and significantly reduces tooth wear to a greater degree than control dentifrice. However, limitation of this study was that all results were obtained from the evaluation of laboratory methods and in others to obtain discriminating results. All evaluations were performed in a short time under harsh conditions. Therefore, based on these results, future evaluations are needed for humans (*in situ* or *in vivo*).

Conflict of interest

The authors have no conflicts of interest relevant to this article.

References

1. Wiilknitz P. Cleaning power and abrasivity of European dentifrice. *Adv Dent Res* 1997;11:576–9.
2. Kang SY, Jo JW, Chang YS, et al. An experimental study on cervical abrasion of the tooth surface by toothbrushing with horizontal scrub. *Int J Clin Prev Dent* 2007;3:81–91.
3. Moon HS, Jung SH, Paik DI, Kim JB. A study on the distribution of optimal relative dentifrice abrasivity in Koreans. *J Korean Acad Oral Health* 1997;21:331–40.
4. Test Methods and Marking. ISO 11609 *International Standard Organization Dentistry—Dentifrices—Requirements*. 1995.
5. BS 5136 *British Standard Institution Specification for Dentifrice*. 1981.
6. Dudding NJ, Dahl LO, Muhler JC. Patient reactions to brushing teeth with water, dentifrice, or salt and soda. *J Periodontol* 1960;31:386–92.
7. Miller WD. Experiments and observations on the wasting of tooth tissue variously designated as erosion, abrasion, chemical abrasion, denudation, etc. *Dent Cosm* 1907;2:109–24.
8. Liljeborg A, Tellefsen G, Johannsen G. The use of a profilometer for both quantitative and qualitative measurements of dentifrice abrasivity. *Int J Dent Hyg* 2010;8:237–43.
9. Franzo D, Philpotts CJ, Cox TF, Joiner A. The effect of tooth-paste concentration on enamel and dentine wear in vitro. *J Dent* 2010;38:974–9.
10. Philpotts CJ, Weader E, Joiner A. The measurement in vitro of enamel and dentine wear by dentifrices of different abrasivity. *Int Dent J* 2005;55:183–7.
11. Hooper S, West NX, Pickles MJ, Joiner A, Newcombse RG, Addy M. Investigation of erosion and abrasion on enamel and dentine: a model in situ using dentifrices of different abrasivity. *J Clin Periodontol* 2003;30:802–8.
12. Kim YH, Lee JY, Jeong MK. The erosion of the tooth enamel and the cementum by carbonate beverage. *Int J Clin Prev Dent* 2011;7:1–13.
13. Volpenhein DW, Walsh ME, Dellerman PA, Burkett TA. A new method for in vitro evaluation of the interproximal penetration of manual toothbrushes. *J Clin Dent* 1994;5:27–33.
14. Stookey GK, Burkhard TA, Schemehorn BR. In vitro removal of stain with dentifrices. *J Dent Res* 1982;61:1236–9.
15. Lee KH, Jee YJ, Lee CH, Choi YH, Park JH, Choi HN. Clinical study on tooth brushing forces. *Int J Clin Prev Dent* 2007;3:92–100.
16. Lee KB, Cho YW, Cho JH. A study on enamel thickness of maxillary incisors using X-ray microcomputed tomography. *J Korean Acad Pros* 2010;48:301–7.
17. Ruschel HC, Chevitarese O. A comparative study of dentin thickness of primary human molars. *J Clin Pediatr Dent* 2003;27:227–81.
18. Bayera EA, Chanzy H, Lamén R, Shoham Y. Cellulose, cellulases and cellulosomes. *Curr Opin Struct Biol* 1998;8:548–57.
19. Ma DS, Park DY, Park DI, Moon HS, Kim JB. A clinical study of dentifrice containing pyrophosphate, hydroxyapatite and vitamin-E on the prevention of calculus formation and gingivitis. *J Korean Acad Oral Health* 1998;22:13–8.
20. Klüppel HJ, Plöger W, Förg F, Umbach W. Parameters for assessing the cleaning power of dentifrices. *J Soc Cosmet Chem* 1986;37:211–33.
21. Bartlett DW, Smith BGN, Wilson RF. Comparison of the effect of fluoride and non-fluoride dentifrice on tooth wear in vitro and the influence of enamel fluoride concentration and hardness of enamel. *Br Dent J* 1994;176:346–8.
22. Hara AT, González-Cabezas C, Creeth J, Parmar M, Eckert GJ, Zero DT. Interplay between fluoride and abrasivity of dentifrices on dental erosion-abrasion. *J Dent* 2009;37:781–5.