Necmettin Erbakan Üniversitesi Diş Hekimliği Dergisi
Necmettin Erbakan University Dental Journal (NEUDentJ)
DOI: 10.51122/neudentj.2023.73

Cilt:5 Sayı:3 Yıl:2023 | Araştırma Makalesi / Research Article | E-ISSN: 2687-5535

The Effect of Brushing Force on The Surface Properties and Color Stability of Dental Enamel

Fırçalama Kuvvetinin Diş Minesinin Yüzey Özelliklerine ve Renk Stabilitesine Etkisi

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ABSTRACT

Aim: This study aimed to determine the effects of toothbrushing force on the surface roughness, gloss, and color change of dental enamel.
Material and Methods: This study was carried out on the sound vestibular enamel surfaces of 16 human permanent incisors extracted for periodontal or orthodontic reasons. Teeth were randomly divided into 2 subgroups (n=8, per group) and embedded in acrylic blocks. The vestibular enamel's initial surface roughness, gloss, and color were measured. Three measurements per sample were performed and averaged. Six months of toothbrush simulation with 5,000 circular cycles (with a load of 1.5 and 2.5 N for groups 1 and 2, respectively) (MOD Dental, Turkey) was performed. The same measurements were repeated and the data were analyzed with independent samples and paired sample t-tests ($p<0.05$).
Results: A significant difference was observed between the surface roughness values after the toothbrushing simulation with 1.5 and 2.5 N ($p=0.022$). Surface gloss values decreased significantly when 1.5 and 2.5 N forces were applied ($p=0.001$, $p=0.002$, respectively). Color change (ΔE) for brushing force of 2.5 N (3.48±0.83) was statistically significantly higher than 1.5 N (2.42±0.86), ($p=0.025$).
Conclusion: Results of this study revealed that the surface roughness and color change values increased depending on the applied brushing force whereas gloss values decreased.

Keywords: Dental enamel, Oral hygiene, Surface properties, Toothbrushing, Tooth abrasion

Received: 11.04.2023 **Accepted:** 03.08.2023 **Published:** 27.12.2023

ÖZ

Amaç: Bu çalışmanın amacı, diş fırçalama kuvvetinin diş minesinin yüzey pürüzlülüğü, parlaklığı ve renk değişimi üzerindeki etkilerini incelemektir.
Gereç ve Yöntem: Bu çalışma, periodontal veya ortodontik nedenlerle çekilmiş 16 insan daimî kesici dişinin sağlam vestibüler mine yüzeyleri üzerinde gerçekleştirildi. Dişler rastgele 2 alt gruba ayrıldı (grup başına n=8) ve akrilik bloklara gömüldü. Vestibüler minenin başlangıçtaki yüzey pürüzlülüğü, parlaklığı ve rengi ölçüldü. Numune başına üç ölçüm yapıldı ve ortalaması alındı. 5.000 dairesel döngü (grup 1 ve 2 için sırasıyla 1.5 ve 2.5 N kuvvet ile) (MOD Dental, Türkiye) ile altı aylık diş fırçalama simülasyonu yapıldı. Ardından aynı ölçümler tekrarlandı ve veriler bağımsız örneklem ve eşleştirilmiş örneklem t-testleri ile analiz edildi ($p<0.05$).
Bulgular: 1.5 ve 2.5 N ile diş fırçalama simülasyonu sonrası ölçülen yüzey pürüzlülük değerleri arasında anlamlı derecede fark gözlendi ($p=0,022$). 1.5 ve 2.5 N kuvvet uygulandığında yüzey parlaklık değerleri anlamlı derecede azaldı (sırasıyla $p=0,001$, $p=0,002$). 2,5 N (3,48±0,83) fırçalama kuvveti ile meydana gelen renk değişimi (ΔE), 1,5 N'dan (2,42±0,86) istatistiksel olarak anlamlı derecede yüksekti ($p=0,025$).
Sonuç: Bu çalışmanın sonuçları uygulanan fırçalama kuvvetine bağlı olarak yüzey pürüzlülüğü ve renk değişimi değerlerinin arttığını, parlaklık değerlerinin ise azaldığını göstermiştir.

Anahtar Kelimeler: Diş minesi, Ağız hijyeni, Yüzey özellikleri, Diş fırçalama, Diş aşınması

Geliş: 11.04.2023 **Kabul:** 03.08.2023 **Yayın:** 27.12.2023

Atıf/ Citation: Büyükgöze-Dindar M., Tekbaş-Atay M., The Effect of Brushing Force on The Surface Properties and Color Stability of Dental Enamel, NEU Dent J. 2023;5:167-72.

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INTRODUCTION

Recently, maintenance of the surface properties of dental hard tissues and restorative materials against intra-oral abrasive factors has become an important factor in terms of clinical success, aesthetics, and durability. Intra-oral tribology of dental hard tissues and restorative materials is a very complex phenomenon influenced by various extrinsic and intrinsic factors.[1] Many components contribute to the intra-oral wear of enamel and dentin.[2] Occlusal contacts of the teeth with their antagonists during mastication (attrition), contact of teeth with foreign bodies (abrasion) such as toothbrushing with toothpaste, exogenous acid attacks due to consumption of acidic fruits and beverages or endogenous acid attacks with gastric fluids caused by gastroesophageal reflux disease and vomiting (erosion).[3,4] In addition, abnormal occlusal forces (parafunctional habits and bruxism) can also cause wear of dental hard tissues.[5]

Toothbrushing is the most effective and common self-performed mechanical plaque control method and daily practice is required.[6] However, dental hard tissues and restorative materials can be abraded during brushing.[7] In studies investigating the harmful effects of toothbrushing on the surface properties of dental hard tissues and various restorative materials, it has been stated that brushing force, technique, frequency, duration, and condition of the toothbrush and the abrasiveness of the toothpaste used are important determinants of effective plaque control and wear.[8,9] The surface deterioration caused by toothbrushing can increase plaque retention and patients are hypersensitive to roughness in the mouth. Quirynen et al.[10] revealed that the threshold value for bacterial accumulation on titanium surfaces is 0.2 µm. Jones et al.[11], on the other hand, revealed that patients could detect even 0.3 µm changes with their tongues. Brushing wear on the dental enamel can increase the surface roughness and cause plaque accumulation and thus caries formation, as well as dentin sensitivity due to wear in the long term.[12] It is known that individuals apply different amounts of force while brushing. According to ISO/TR 14569-1:2007, the recommended brushing force during toothbrushing simulations should be between 0.5 - 2.5 N.[13] In the previous studies, a wide range of brushing force values were applied, and there is no standard brushing force value applied in all studies in the literature.[1,14-16] Therefore, this study aims to investigate the effects of various brushing forces on the surface roughness, gloss, and color change of dental enamel.

The hypotheses tested were (1) that the surface gloss and roughness of dental enamel will not be affected by increasing toothbrushing forces and (2) there will be no effect on color stability.

MATERIAL AND METHODS

This study was carried out after the necessary permissions were obtained from the Trakya University Scientific Research Ethics Committee (TÜTF-GOBAEK2022/226) and an informed consent form was obtained from all patients before the extraction of the teeth to be used in the current study. The sample size for this study was conducted according to a previously published study[14] and a total of 16 teeth were decided to be included in the study with an alpha level of 0.05, 95% power, and 2.10 effect size (G∗Power software version: 3.1.9.7). Subsequently, human permanent incisors extracted for periodontal or orthodontic reasons were gathered and disinfected with 0.1% chloramine solution after the removal of calculus and tissue residues. Vestibular enamel surfaces were examined under magnification (X20) with a stereomicroscope and worn, fractured, cracked, and decayed teeth were excluded from the study. The teeth were ultrasonically cleaned for 1 min and the residues that would affect the measurement were detached from the surface. Afterward, the extracted teeth were randomly divided into 2 subgroups (n=8, per group) and embedded in acrylic blocks in such a way that their vestibule faces were exposed.

Before the toothbrushing simulation, the surface roughness was determined with a contact profilometer (Taylor Hobson-Surtronic S128, Leicester, England) with a standard cutoff value of 0.8 mm, tracing length of 5.6 mm, and stylus speed of 0.5 mm/s. Three measurements were made from different locations and the mean surface roughness values (Ra) were recorded (in µm). The surface gloss was then measured at a specular angle of 60° using a precision gloss meter (Nuvo-Curve, Rhopoint, East Sussex, UK) calibrated to the black glass calibration tile with a reference value of 93.3 gloss units. (GU). Three measurements were completed per sample (at 60° light incidence, with the sample rotated 90° each time) and averaged.

All specimens were measured three times with a spectrophotometer for their optical properties as transmission (VITA Easyshade V; VITA Zahnfabrik)

and discoloration rates on a standard white background and all devices were calibrated before each use.

After the initial surface measurements were conducted, a toothbrushing simulation (MOD Dental, Turkey) was applied to a group of samples with a force of 1.5 N at 5,000 circular cycles (r:10 mm), which was corresponding to approximately 6 months of tooth brushing. The rotation frequency was 1 Hz. For this simulation, medium-bristle toothbrushes were divided from the neck and located in the toothbrushing simulator. Colgate Total containing hydrated silica as an abrasive and a relative dentin abrasivity (RDA) of 70 was the toothpaste of choice (Colgate Palmolive, Hamburg, Germany). A ratio of 2 g distilled water to 1 g paste was used according to ISO/TR 14569-1:2007 during this process. To the other group, a toothbrushing simulation with 5,000 circular cycles (r:10 mm), equivalent to 6 months of tooth brushing with 2.5 N force, was applied. Finally, the same roughness, gloss, and color measurements were repeated from the samples, and the obtained values were recorded.

The color change value was calculated as follows (ΔE*ab):

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

(L: lightness, a: green-red (-a=green; +a=red) and b: blue-yellow (-b=blue; +b=yellow).

Statistical Analysis

After the distribution was checked by Shapiro-Wilk tests, data was analyzed with IBM SPSS Statistics for Windows (Version 23, SPSS Inc., Chicago, IL, USA). Since the data was normally distributed, an independent sample t-test for inter-group and paired t-test for within-group comparisons were performed. Descriptive statistics (arithmetic mean and standard deviation) were given and the limit for significance was $p<0.05$.

RESULTS

According to the outcomes of the current study (Table 1), it was determined that the surface roughness values increased as the applied force increased (Figure 1). Even though the surface roughness values of the dental enamel were increased more after the 2.5 N application (Ra: 0.32±0.4), no significant difference was detected between the 1.5 N application (Ra: 0.09±0.1), (p=0.139). After 6 months of tooth brushing simulation, the surface roughness values of the 2.5 N force applied group (Ra: 0.84±0.3) were significantly higher. Besides, a significant difference was observed between the roughness values measured after the toothbrushing simulation with 1.5 and 2.5 N (p=0.022), (Figure 2).

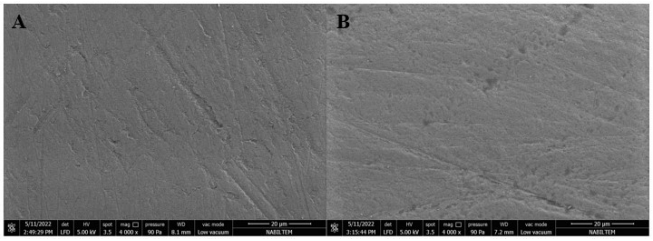

Figure 1. SEM images (x4000) of dental enamel after application of **(A)** 1.5 N and **(B)** 2.5 N during the toothbrushing simulation.

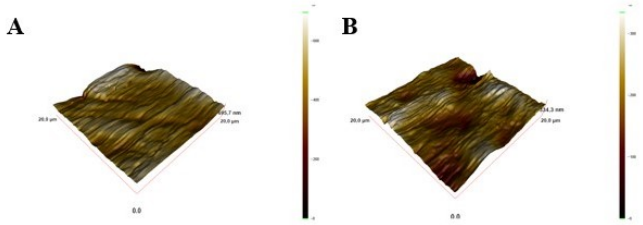

Figure 2. AFM images of dental enamel after application of **(A)** 1.5 N during the toothbrushing simulation and **(B)** 2.5 N. Note the roughened surface after 2.5N brushing force is applied.

Table 1. The surface roughness (Ra) values of the study groups (μm)

Brushing Force	Surface Rougness (Ra)			
	Initial	After	*P*	Difference
1.5 N	0.48 ±0.16	0.52 ±0.15	0.416″	0.09 ±0.11
2.5 N	0.52 ±0.12	0.84 ±0.30	0.051″	0.32 ±0.38
P	0.603′	**0.022*′**		0.139′

′:independent samples t-test, ″:paired sample t-test.*<0.05

Gloss measurements and color changes before and after the toothbrushing simulation were shown in Table 2. Surface gloss values decreased significantly when 1.5 and 2.5 N forces were applied (p=0.001, p=0.002, respectively). Nevertheless, no significant difference was detected among the number of changes in the surface gloss values of both groups (p=0.951).

Table 2. The mean surface gloss (GU) and color change (ΔE) of study groups

Brushing Force	Surface Gloss (GU)				Color Change
	Initial	After	*P*	Difference	(ΔE)
1.5 N	12.28 ±2.56	6.47 ±2.82	**0.001*″**	-5.80 ±2.88	2.42 ±0.86
2.5 N	10.78 ±2.01	5.1 ±3.86	**0.002*″**	-5.70 ±3.45	3.48 ±0.83
P	0.212′	0.420′		0.951′	**0.025*′**

′:independent samples t-test, ″:paired sample t-test.*<0.05

Color change (ΔE) when 2.5 N was applied (3.48±0.83) was statistically significantly higher than when 1.5 N was applied (2.42±0.86), (p=0.025).

DISCUSSION

In the current study, 5000 cycles of toothbrushing simulation, equivalent to 6 months of brushing, were applied to the enamel surface of the extracted human incisors with 1.5 and 2.5 N force. Considering the outcomes of the current study, it was observed that the surface deterioration increased as the brushing force increased. However, when the changes in surface roughness and gloss values were taken into consideration, no statistically significant difference was observed between the groups. Therefore, the first hypothesis was partially rejected.

Toothbrushing with toothpaste causes a three-body wear process in which the toothpaste acts as a third body between the dental hard tissues and the toothbrush, causing both wear on the toothbrush and tooth surfaces.[17] Studies have shown that brushing without toothpaste has no or minor effect on dental enamel and dentin, which is considered clinically insignificant.[18] Nevertheless, toothbrushing with toothpaste causes wear with a correlation to toothpaste's RDA values.[19] Moreover, the characteristics of the toothbrush, particularly the filament arrangement, texture, and density can alter the abrasivity of the toothpaste.[20] Since it was aimed to determine the effects of the brushing force in the current study, the same type of medium hardness toothbrush (all bristles were straight and rounded) was used in all groups (38 bundles and each bundle contains 40 bristles) and Colgate Total with a RDA value of 70 was the toothpaste of choice.

Toothbrushing wear is time-dependent, furthermore, brushes have a recommended lifespan. The American Dental Association advises renewal of the toothbrush every 3-4 months or even earlier if the bristles become frayed since worn and thinned filaments are less effective at removing microbial plaque.[21] However, not all patients comply with this recommendation, and surveys among patients revealed that the average toothbrush replacement period is 2.5 to 6 months.[22] Previous studies have agreed that 10,000 cycles are corresponding to a year of tooth brushing.[23] Since the maximum lifespan of a toothbrush was 6 months, 5000 cycles corresponding to 6 months of tooth brushing were applied in the current study.

Toothbrushing wear is affected by many factors such as brushing frequency, duration, and force. The brushing forces differed from 1.6 to 3.23 N in previous studies for manual toothbrushes and 0.9 to 4 N for power toothbrushes.[1,8,24] However, according to ISO/TS 14569-1, the brushing force should be between 0.5 N and 2.5 N.[13] Therefore, the average (1.5 N) and the maximum (2.5 N) values recommended by ISO/TS 14569-1 were compared in the current study. Addy and Hunter[12] stated that normal toothbrushing habits with toothpaste conforming to the ISO standard will, in lifetime use, cause virtually no wear or clinically insignificant wear to tooth enamel (about 0.5 mm per 50 years). On the other hand, abusive use of toothbrushes with excessive force can result in pathological levels of abrasion.[17] Even though there was no statistically significant difference between the roughness change values, the increase in surface roughness after tooth brushing simulation with 2.5 N was higher than the 1.5 N group. This situation, consistent with the literature, indicates that as the brushing force increases, surface deterioration may occur.

The alterations in the surface gloss caused by toothbrushing have been investigated in previous studies and a decrease has been determined in correlation with brushing frequency, cycles, and the applied force.[25,26] In the current study, surface gloss values were decreased significantly after tooth brushing simulation application in both groups, however, no significant difference was detected between the amount of gloss reduction between groups. A study conducted by O'Neill et al. investigated the gloss retention of dental enamel after toothbrushing simulation with different dentifrices and revealed no significant gloss change after 5000 cycles with Sensodyne Repair and Protect, consistent with the present study.[25] On the

other hand, other dentifrices used in this study caused significant gloss reduction proving the role of dentifrice type on surface alterations. In the same study, it was stated that the surface gloss decreased as the toothbrushing cycles increased. Accordingly, the reason why there was no significant reduction in gloss values in the present study may be due to the number of cycles.

It is known that dental hard tissues are prone to discoloration depending on the toothpaste's RDA value and the characteristic features of brushing.[27] Similarly, the color change value of the 2.5 N applied group was statistically significantly higher than 1.5 N. Moreover, the ΔE of the 2.5 N applied group (ΔE: 3.48±0.83) was above the threshold ΔE:3.3 which is considered clinically acceptable.[28] Consequently, the second hypothesis was rejected.

Within the limitations in the current study, the alterations in the surface properties of dental enamel caused by the brushing force were investigated. However, in vivo wear was much more sophisticated due to additional factors such as erosion and abfraction. The in vitro nature of this study is not suitable for determining the cumulative effect of nutrients, beverages, and parafunctional habits such as bruxism. Another limitation of the study is that the amount of wear can differ depending on the type or brand of toothbrushes and pastes. Therefore, further investigations with various toothbrushes and toothpastes need to be performed.

CONCLUSION

The results of the current study disclosed that the habit of toothbrushing with increasing forces may have a harmful effect on the surface roughness, gloss, and color stability of dental enamel. Therefore, dentists have an important role in guiding their patients about the adequate toothbrushing force for plaque removal as well as the technique and selection of instruments that can be protected from toothbrush abrasion and its' side effects on dental hard tissues.

ETHICAL COMMITTEE APPROVAL

The necessary ethical approval for this study was received from Trakya University Non-Interventional Scientific Research Ethics Committee.(TÜTF-GOBAEK2022/226).

FINANCIAL SUPPORT

The authors declare that this study received no financial support.

CONFLICT OF INTEREST

The authors deny any conflicts of interest related to this study.

AUTHOR CONTRIBUTIONS

Design: MBD, MTA, Data collection and processing: MBD, MTA, Analysis and interpretation: MBD, MTA, Literature review: MBD, Writing: MBD, MTA.

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