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Original Article

Dentistry Section

Comparative Evaluation of Enamel Surface Abrasion Produced by Three Different Types of Toothbrush Bristle Designs: An In-vitro Study

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ABSTRACT

Introduction: The toothbrush is one of the most commonly used mechanical aids for plaque control, capable of removing plaque efficiently. However, improper toothbrushing habits can lead to tissue trauma, such as abrasion or gingival recession. The design of toothbrush bristles is one of the most common etiological factors for abrasion.

Aim: To evaluate and compare the enamel surface abrasion produced by three different toothbrush bristle designs in conjunction with a standard dentifrice.

Materials and Methods: In this in-vitro study conducted in the Department of Periodontics, Bharati Vidyapeeth Dental College and Hospital, Pune, Maharashtra, India, from June 2023 to January 2024, a total of 21 extracted human premolars were collected. After thorough cleaning, the teeth were stored in normal saline. The crown portions of the teeth were mounted on an acrylic resin base and profilometric analysis was performed to record the average enamel surface roughness (Ra) value. The teeth were randomly divided into three groups based on the toothbrush bristle design used for toothbrushing: Group A: Tapered bristle, Group B: End-rounded bristle, Group C: Flat-trim bristle. Toothbrushing was carried out using a customised toothbrushing device and a standard dentifrice twice daily for six weeks. After six weeks, profilometric analysis was conducted again. Descriptive statistics were expressed as means and standard deviations. The comparison of enamel surface abrasion among the three different toothbrush bristle designs was performed using the One-Way Analysis of Variance (ANOVA) test, followed by the post-hoc Bonferroni test for pair-wise comparison. In this test, a p-value less than or equal to 0.05 was considered statistically significant. All analyses were conducted using Statistical Package for the Social Sciences (SPSS) version 25.0.

Results: The results showed significantly greater Ra values for Group C (flat-trim bristle: 0.13±0.06) compared to Group A (tapered bristle: 0.09±0.03) and Group B (end-rounded bristle: 0.04±0.02). Group B exhibited the lowest Ra value, indicating the least enamel surface roughness (p-value: 0.038*).

Conclusion: Within the limitations of the study, stylus profilometer analysis demonstrated that the flat-trim toothbrush bristle design is more prone to causing enamel surface abrasion than the end-rounded and tapered bristle designs. The end-rounded toothbrush bristle design causes minimal enamel surface abrasion and is safer to use as an effective mechanical plaque control aid.

Keywords: Dental plaque, Dentin hypersensitivity, Periodontitis, Tooth wear, Toothbrushing

INTRODUCTION

Plaque biofilm is the complex microbial colony formed on the intraoral tissue surfaces and embedded in the polymeric matrix secreted by the host or bacteria. Although periodontitis is a multifactorial disease, the plaque biofilm is the primary etiological factor of periodontal inflammation. As the disease progresses, the microbial complex shifts from a symbiotic to a dysbiotic stage [1]. To prevent this disease from progressing into the periodontal tissue, plaque control is an essential step. Plaque control can be achieved using chemical or mechanical plaque control aids. Mechanical plaque control aids are simple and efficient ways to disrupt and remove the plaque biofilm and they are widely employed in daily life [2]. Brushing and flossing are the most accepted oral hygiene methods used today [3]. However, improper tooth brushing can lead to hard and soft tissue trauma, such as abrasion and gingival recession.

Abrasion is the most commonly occurring wasting disease. It is defined as the loss of tooth substance due to mechanical wear between the tooth and any exogenous substance (most commonly a toothbrush) [4]. It most commonly affects the cervical area of the canines and premolars. Numerous factors are responsible for abrasion, including the position of the tooth, overzealous tooth brushing, the stiffness of toothbrush bristles (hard), frequency of tooth brushing and tooth brushing technique, among others. Abrasion creates a rough surface, which leads to increased plaque retention, a higher prevalence of caries and dentinal hypersensitivity [5].

With advancements in science and technology, toothbrushes have been modified in terms of bristle stiffness (soft/medium/hard), bristle arrangement (zig-zag/spiral/multi-level) and bristle design (flat-trim/bi-beveled/end-rounded) [6]. Recently, nanoparticle-infused toothbrushes with antibacterial properties have also become available in the market [7]. Modifications in toothbrush bristle design are carried out to improve plaque removal ability in sulcular and interdental regions [8]. Various commercial brands claim better plaque control ability for their different toothbrush bristle designs, but it is also important to evaluate the surface abrasion caused by them [8-10]. Limited studies have assessed the role of toothbrush bristle design on enamel surface abrasion [11-14].

Therefore, the aim of the present study is to conduct an in-vitro assessment and comparison of enamel surface abrasion produced by three different toothbrush bristle designs.

MATERIALS AND METHODS

The present in-vitro study was conducted in the Department of Periodontics, Bharati Vidyapeeth Dental College and Hospital, Pune, Maharashtra, India. The study period lasted from June 2023 to January 2024. After obtaining approval from the Institutional Ethical

Committee (Registration No. EC/NEW/INST/2021/MH/0029), a total of 21 extracted permanent premolars, which were removed for orthodontic purposes or due to mobility, were collected from the Department of Oral and Maxillofacial Surgery.

Inclusion and Exclusion criteria: Permanent premolars with intact crown surfaces, teeth without developmental defects, carious and non carious lesions and cracks were included in the study. All damaged teeth were excluded.

Sample size calculation: To calculate the sample size for the present study, the following was used:

The sample size (n) was derived using the "comparing two means" formula:

$$n=\frac{(\sigma_1^2+\sigma_2^2/\kappa)\,(Z_{1-\alpha/2}+Z_{1-\beta})^2}{\Delta^2}$$

Where:

σ_1=standard deviation of Group 1,

σ_2=standard deviation of Group 2,

Δ=difference in group means (reference: Caporossi LS et al., 2015) [12]:

	Group 1	Group 2	Difference*
Mean	3.06	7.35	-4.29
Standard deviation	0.45	2.7	
Variance	0.2025	7.29	

=ratio=n_2/n_1=1,

$Z_{1-\alpha/2}$=two-sided Z value (e.g., Z=1.96 for a 95% confidence interval),

$Z_{1-\beta}$=power of the study (80% power, critical value of 0.84).

Substituting the values into the above formula:

$$n=\frac{\{(0.45)^2+(2.7)^2\}*(1.96+0.84)^2}{(3.06-7.35)^2}$$

n=7 samples per group.

Considering three groups, a total sample size of 21 samples was derived.

Total sample size=21 samples.

Study Procedure

The collected tooth specimens were cleaned of superficial debris, plaque and calculus. The tissue tags were removed. To prevent dehydration, the teeth were preserved in a 0.9% normal saline solution for two hours. After that, the tooth specimens were sectioned horizontally at the level of the Cementoenamel Junction (CEJ) using a diamond disc to obtain the crown portion, which was then mounted on the acrylic resin base [Table/Fig-1].

[Table/Fig-1]: Tooth specimen cut at CEJ and mounted on acrylic resin base.

The average surface roughness (Ra) value was evaluated for all the specimens using a stylus profilometer Mitutoyo SJ-210 surface roughness testing machine (Baseline Ra value).

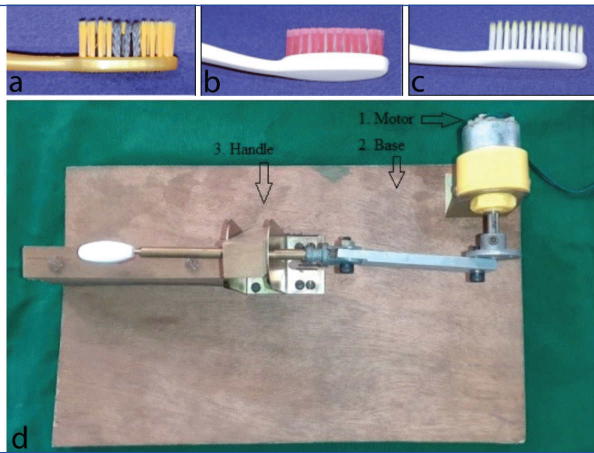
After the evaluation of baseline parameters, the mounted specimens of the crown portion were randomly divided into three groups based on the toothbrush bristle design used for tooth brushing:

Group A: Toothbrush with tapered surface bristles [Table/Fig-2a],

Group B: Toothbrush with end-rounded bristles [Table/Fig-2b],

Group C: Toothbrush with flat trim bristles [Table/Fig-2c].

Brushing was carried out using a customised brushing device to generate an equal amount of brushing force of 2 N in the horizontal direction. This customised brushing device consisted of the following parts [Table/Fig-2d]:



[Table/Fig-2]: Customised toothbrushing device and three types of bristle design- (a) Tapered bristle design, (b) End-rounded bristle design, (c) Flat-trim bristle design, (d) Customised toothbrushing device.

Motor: For unidirectional movement of the toothbrush and to generate an equal amount of force of 2 N.

Base: To support the crown portion mounted on the acrylic base.

Handle: The toothbrush is attached to this handle, allowing it to move to and fro.

Three different toothbrushes with varying bristle designs were selected. The stiffness of the bristles in all three groups was uniform, i.e., soft bristles (diameter-0.006 inches) [9]. Additionally, toothbrushes of the same brand were used in this study. Tooth brushing was carried out using the customised brushing device and a standard dentifrice for two minutes twice daily for six weeks. This brushing device generated an equal amount of force of 2 N and the horizontal scrub brushing technique was used for all three groups. After six weeks, profilometric analysis was conducted using the same profilometer and the results were analysed.

Profilometric analysis was carried out using a contact (stylus) profilometer (Mitutoyo SJ-210 surface roughness testing machine) at Praj Laboratory, Pune. This stylus profilometer is equipped with a diamond tip of 20 μm. The tip moves in three dimensions and measures average surface roughness in Ra units. The results of average surface roughness before brushing and after brushing were analysed and compared. The difference between the preoperative and postoperative Ra units was considered a measure to assess enamel surface abrasion. The treatment protocol is summarised in the flowchart [Table/Fig-3].

STATISTICAL ANALYSIS

The comparison of enamel surface abrasion among the three different toothbrush bristle designs was conducted using the One-way ANOVA test, followed by the post-hoc Bonferroni test for pair-wise comparisons. In this analysis, a p-value less than or equal to 0.05 was considered statistically significant. All analyses were performed using SPSS version 25.0.

21 extracted permanent premolars were collected

↓

Tissue tags were removed and scaling and root planning of all teeth carried out

↓

Teeth were cut at the CEJ

↓

Tooth specimen was mounted on the acrylic resin base

↓

Average surface roughness (Ra) value was recorded at baseline (before brushing)

↓

Teeth were randomly divided into three groups

Group-A: Toothbrush with tapered surface bristles

Group-B: Toothbrush with end-rounded bristles

Group-C: Toothbrush with flat trim bristles.

↓

Brushing was carried out using customized toothbrushing device for 2 min. twice daily for 6 weeks

↓

Average surface roughness (Ra) value was recorded after 6 weeks (after brushing)

↓

Difference of Ra value before and after brushing was evaluated and recorded

[Table/Fig-3]: Flowchart of treatment protocol followed.

RESULTS

The results showed that the average enamel surface roughness (Post-Pre) (Ra) values were higher in Group C (0.13±0.06) than in Group A (0.09±0.03) and Group B (0.04±0.02) [Table/Fig-4]. Intergroup comparison indicated that Group B had the least post-brushing enamel surface roughness values, which were statistically significant [Table/Fig-5].

Groups	Preoperative profilometric analysis (Mean±SD)	Postoperative profilometric analysis (Mean±SD)	Difference (Post- Pre) (Mean±SD)
Group A	0.89±0.42	0.98±0.40	0.09±0.03
Group B	0.57±0.22	0.61±0.22	0.0±0.02
Group C	0.54±0.37	0.67±0.41	0.13±0.06
p-value (One-way ANOVA test)	0.038*		

[Table/Fig-4]: Comparative evaluation of enamel surface abrasion produced by three different toothbrush bristle design.

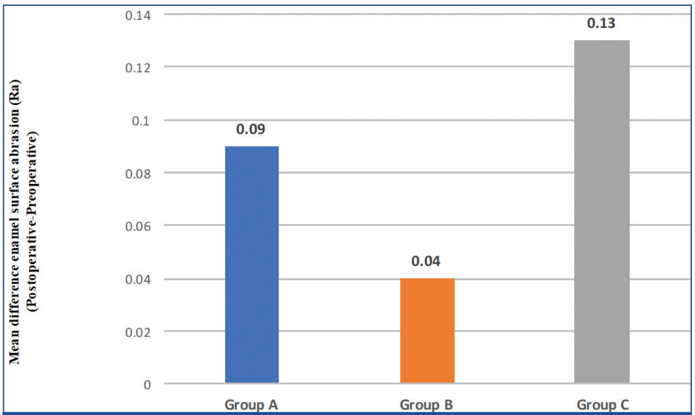
p-value (Bonferroni test)	Group A	Group B	Group C
Group A	-	0.426	0.587
Group B	0.426	-	0.037*
Group C	0.587	0.037*	-

[Table/Fig-5]: Pair-wise comparison of enamel surface abrasion.
*p≤0.05 is statistically significant

A graphical representation of the mean enamel surface abrasion (Ra) produced by the three different toothbrush bristle designs is presented in [Table/Fig-6].

DISCUSSION

Based on epidemiological data, a definite correlation between bacterial plaque biofilm and the occurrence of periodontal disease



[Table/Fig-6]: Comparison of enamel surface abrasion (Ra) produced by three different toothbrush bristle design.

has been confirmed [8,11]. Clinical studies have proven that the removal of bacterial plaque biofilm facilitates a reduction in gingival inflammation [15,16]. Therefore, at home, plaque removal is essential for the prevention of periodontal diseases and for maintaining good oral health. Tooth brushing is one of the most reliable and efficient mechanical plaque control aids. Innovations in science and technology have led to changes in the traditional design of manual toothbrushes to achieve better plaque control. These advancements have been achieved in bristle design, bristle arrangement, modes of action of brushes and the introduction of nanoparticle-infused toothbrushes, among others.

For the selection of an appropriate toothbrush, it is necessary to consider both the benefits (plaque removal) and hazards (tooth abrasion) of a particular brush design. Abrasion is a multifactorial non carious dental lesion that may manifest as mechanical wear of the cervical portion of the tooth surface, forming a V-shaped notch. Among all non carious cervical lesions, abrasion accounts for approximately 23.7% [17]. Several studies have been conducted to evaluate the various factors that contribute to tooth abrasion, such as brushing force, bristle stiffness, dentifrice and brushing technique [11,18-24].

Toothbrush bristle design is one of the most important factors responsible for enamel surface abrasion. Bass recommended an end-rounded filament design to minimise hard tissue trauma while describing the optimal characteristics of toothbrushes [25]. However, Hine M suggested that bristle design has the least significant role in the etiology of abrasion [26]. Therefore, the present in-vitro study was conducted to evaluate and compare the roughness of the enamel surface caused by three different toothbrush bristle designs. The roughness of the enamel surface before and after tooth brushing was assessed using stylus profilometric analysis, while other factors responsible for enamel surface abrasion— such as brushing force, bristle stiffness, dentifrice and brushing technique—were held constant. Wiegand A et al., conducted an observational study stating that approximately 1.6±0.3 N of force is exerted during manual tooth brushing [5]. Therefore, in this study, a customised brushing device was fabricated to generate a unidirectional force of 2 N. This allowed us to nullify the effect of brushing force on enamel surface roughness.

A wide range of techniques has been used to evaluate dental surfaces, such as microradiography, surface profilometry and scanning electron microscopy. Surface profilometry is a well-established technique used in surface science and dental research to evaluate the contour, profile and roughness of an object. This technique is also known as “surfometry.” It can be carried out using either direct (stylus profilometer) or indirect (laser profilometer) methods. In the present study, a stylus profilometer is used since the stylus tip remains in constant contact with the surface being measured, allowing for an exact Ra value. Although the stylus profilometer has certain disadvantages, such as potential damage to the specimen caused by the diamond tip and the possibility of missing finer surface details due to external vibrations of the stylus tip, it remains a valuable tool in this context [18].

The results of the study showed that an end-rounded bristle design causes the least enamel surface roughness compared to flat trim and tapered bristle designs. These results may be explained by the fact that the smooth, end-rounded bristle surface comes into contact with the tooth, while the flat trim and tapered bristle designs have comparatively sharper edges. The results were consistent with those of Caporossi LS et al., in which plaque control efficacy and gingival abrasion were evaluated after brushing with end-rounded and tapered bristle toothbrushes. The study found that the end-rounded toothbrush bristle design had better plaque control efficacy and no significant difference was noted between the abrasion caused by the two different toothbrush bristle designs ($p \geq 0.05$) [12].

A similar study conducted by Kumar S et al., showed contradictory results, stating that the flat bristle design caused the least enamel surface abrasion compared to the zig-zag and bi-beveled toothbrush bristle designs ($p \geq 0.05$) [13]. However, a study conducted by Dabhi MV et al., showed a statistically insignificant difference in enamel roughness due to the flat-ended bristle, zig-zag bristle and powered toothbrush ($p \geq 0.05$) [14].

Abrasion is a multifactorial, non carious cervical lesion and toothbrush bristle design has a small impact on enamel surface abrasion. The present study evaluated commonly marketed bristle designs for their ability to produce enamel surface abrasion. Therefore, the findings of the present study will be helpful in highlighting the adverse effects of specific toothbrush bristle designs.

Limitation(s)

The present study had a few limitations, such as the in-vitro assessment, which can show variable results due to the absence of saliva, which plays an important role in the prevention of tooth wear. Additionally, the simulator can be used to mimic the actual arch form and the study had a small sample size and a short duration.

CONCLUSION(S)

Within the limitations of the study, it is concluded that toothbrush bristle design plays a significant role in the roughness of the enamel surface. The end-rounded bristle design was found to be safer than the flat trim and tapered bristle designs, thereby minimising the risk of tooth abrasion. However, future in-vivo evaluations are required, with a long-term follow-up period, for a detailed conclusion on the role of bristle design in tooth abrasion.

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