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Comparative Evaluation of Enamel Abrasion Caused By Charcoal-Containing and Conventional Toothpaste Using an Oscillatory Toothbrush: An In Vitro Study

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Abstract:
Background: *Maintaining enamel integrity is crucial for long-term oral health. With the growing popularity of whitening products, charcoal-containing toothpastes have emerged as a trending choice due to their purported ability to remove stains and impurities. However, concerns have been raised about their potential to increase enamel abrasion due to their abrasive composition.*
Aim: *The aim of the present in vitro study was to compare the abrasiveness caused by charcoal-containing toothpaste and conventional toothpaste on human enamel using an oscillatory toothbrush under a profilometer.*
Materials and Methods: *Twenty freshly extracted single-rooted human teeth were randomly divided into two groups (n=10). Group A was brushed with Colgate® Charcoal Black Gel Toothpaste, and Group B with Colgate® Total Advanced Health Anti-germ Toothpaste. Brushing was simulated using a powered toothbrush under a standardized 250 g force for 2 minutes twice daily over 60 days. Surface roughness (Ra) was measured using a profilometer before and after the brushing regimen.*
Results: *Both groups exhibited an increase in enamel surface roughness. Group A showed a significantly higher increase in Ra (0.21 ± 0.06 μm) compared to Group B (0.05 ± 0.02 μm) ($p < 0.05$), indicating greater abrasivity of the charcoal-based toothpaste.*
Conclusion: *Charcoal-containing toothpaste resulted in significantly more enamel abrasion than conventional toothpaste. While effective in stain removal, such dentifrices may compromise enamel integrity over time. Further clinical studies are needed to corroborate these findings and assess their implications in real-world oral hygiene practices.*
Keywords: *Charcoal toothpaste, Conventional toothpaste, Enamel abrasion, Toothpaste abrasivity, Oscillatory toothbrush.*

INTRODUCTION

Dental abrasion is an irreversible loss of dental hard tissue. It is a type of tooth surface loss (TSL) that is caused by the sliding or rubbing of abrasive external objects against the tooth surfaces. Several factors are reported to cause such TSL. [1] These factors include the use of an abrasive toothpaste, hard bristles, and a vigorous brushing technique. Toothbrushing with toothpaste is the most common form of oral hygiene practice, [2] avoiding dental plaque and gingival bleeding. [3] It is widely accepted that toothpastes require a certain amount of abrasivity in order to reduce or prevent extrinsic stains from forming since a low or non-abrasive paste is unable to prevent extrinsic stains. However, the abrasivity of the toothpaste needs to be moderated in order to prevent removal of the underlying enamel.[4]

Toothpastes typically include ingredients such as detergents, humectants, water, colorants, fluoride, and thickeners like silica. Silica is considered a high-quality abrasive and is often used in dentifrices to effectively remove dental biofilm and stains. [5-7] Research has shown a strong connection between tooth wear and the cleaning effectiveness of dentifrices. [6] Several studies have evaluated surface roughness in vitro using automatic brushing machines to simulate toothbrushing. [5,8-15] The surface roughness created by brushing with abrasive toothpastes is considered a major concern for oral health. [10,15] Most oral microorganisms can thrive and form colonies on rough surfaces like enamel or cementum. A study examining changes in the surface roughness of tooth enamel found that alterations in enamel texture could promote bacterial growth, biofilm formation, and increase bacterial resistance, ultimately heightening the risk of developing dental caries and dentinal hypersensitivity. [16]

The abrasiveness of toothpaste is determined by the hardness, size, and shape of the abrasive particles it contains. [17] Other factors, such as the brushing technique, pressure applied, hardness of the toothbrush, and the number of strokes, also contribute to tooth abrasion. [16] As mentioned earlier, typical abrasive agents used in toothpaste include silica, phosphates, carbonates, and bicarbonates. Recently, activated charcoal has been added to some toothpastes, which are marketed as charcoal toothpastes, as it may help with tooth whitening through its abrasive properties. Activated charcoal, a key ingredient in certain toothpaste products, is valued for its ability to absorb impurities and help clean the teeth, including the areas between them that are often difficult to reach with regular brushing. This makes charcoal-based toothpaste popular for its potential to effectively remove plaque and surface stains, particularly those caused by food, beverages, or tobacco. [16] However, despite these cleaning benefits, concerns arise from the abrasive nature of charcoal. The shape, composition, and particle size of charcoal can vary, and these characteristics contribute to its abrasive properties. When charcoal is used in toothpaste, its particles can potentially cause abrasion on the surface of tooth enamel. Over time, this abrasion can lead to an increase in the roughness of enamel, making it more prone to further staining and plaque buildup. [4]

Ever since its invention, the toothbrush has been an important tool for maintaining oral health and hygiene. Power-driven toothbrushes have been available since the 1940s and are now commonly used due to their proven effectiveness in reducing dental plaque and gingivitis, especially when compared to manual toothbrushes (MTBs) in both short- and long-term studies. As a result of their cleaning performance and ease of use, power driven toothbrushes are increasingly popular. [16]

Although the abrasion effects of charcoal-based toothpastes have been examined through surface roughness analysis, there is a gap in the literature concerning quantitative studies on the abrasion of human enamel when using oscillatory toothbrushes [18], specifically measured by a profilometer. In the present study, the enamel abrasion associated with brushing with a charcoal-based toothpaste and a conventional toothpaste was evaluated with the help of profilometer.

MATERIALS AND METHOD

The present in vitro study was conducted in the Department of Periodontology at the Himachal Institute of Dental Sciences, Paonta Sahib (H.P.), to evaluate and compare the effect of charcoal-containing and conventional toothpastes on enamel surface roughness following simulated toothbrushing.

Sample Selection

Twenty freshly extracted single-rooted human teeth were collected from patients undergoing extraction for periodontal reasons in the Department of Oral and Maxillofacial Surgery.

a. Inclusion Criteria

The inclusion criteria comprised vital teeth at the time of extraction, sound single-rooted teeth that were extracted due to periodontal disease, and teeth without any prior restorations. Only those teeth that met all of these conditions were selected for the study to ensure uniformity and minimize variables affecting enamel integrity.

b. Exclusion Criteria

The exclusion criteria included teeth with visible carious lesions on the crown, fractured teeth, non-vital teeth or those with periapical infections, and teeth exhibiting developmental malformations.

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Additionally, teeth affected by wasting diseases such as erosion, attrition, or abrasion, as well as those with congenital abnormalities of the cementum or dentin, were excluded from the sample pool. These criteria were established to eliminate factors that could potentially compromise the accuracy of surface roughness evaluation.

Specimen Preparation and Storage

After extraction, the teeth were thoroughly cleaned using ultrasonic scaling and root planing, rinsed with distilled water, and stored in 10% formalin at room temperature. The specimens were then randomly divided into two groups of ten teeth each using the coin flip method. Each tooth was mounted in an acrylic block, exposing the coronal enamel surface, to ensure stability during brushing and accurate profilometric analysis.

Grouping and Brushing Procedure

- **Group A (Charcoal Group):** Teeth were brushed using Colgate® Charcoal Clean Black Gel Toothpaste, containing activated charcoal.
- **Group B (Conventional Group):** Teeth were brushed using Colgate® Total Advanced Health Anti-germ Toothpaste.

Table 1: Product Name and Composition of the Toothpastes Used

GROUP	PRODUCT NAME	COMPOSITION
GROUP A Charcoal-containing toothpaste group	COLGATE® CHARCOAL CLEAN BLACK GEL TOOTHPASTE	Sorbitol, Water, Silica, Sodium Lauryl Sulphate, Flavour, Cocamidopropyl Betaine, Polyethylene Glycol 600, Sodium Carboxymethyl Cellulose, Sodium Saccharin, Sodium Fluoride, Charcoal, Benzyl Alcohol, Eugenol.
GROUP B Conventional toothpaste group	COLGATE® TOTAL ADVANCED HEALTH ANTI-GERM TOOTHPASTE	Glycerin, Silica, Sodium Lauryl Sulphate, Arginine, Flavor, Cocoamidopropyl Betaine, Zinc Oxide, Sodium Carboxymethyl Cellulose, Titanium Dioxide, Poloxamer 407, Zinc Citrate Trihydrate, Tetrasodium Pyrophosphate, Xanthan Gum, Benzyl Alcohol, Phosphoric Acid, Sodium Saccharin, Sodium Fluoride, Titanium Dioxide Coated Mica, Sucralose, CI 74260, CI 47005:1, Eugenol, in aqueous base

Brushing was simulated using an Oral-B™ Revolution AA Battery Electric Toothbrush mounted onto a custom-made wooden brushing machine (Fig.1). A standardized brushing force of 250 g was applied using a force gauge, as showed in Fig.2, with each brushing cycle lasting 2 minutes, twice daily, for 60 days. A pea-sized amount of the assigned toothpaste was applied before each session. Between sessions, the teeth were stored in artificial saliva to mimic oral conditions.

Fig.1: Sample placed in Custom-made Wooden Machine

Fig.2: Standardized brushing force of 250 g applied using a force gauge

Fig.3: Evaluation of Sample under Surface Profilometer

Surface Roughness Evaluation

Surface roughness was assessed using the Mitutoyo™ SJ-400 surface profilometer. Baseline roughness measurements were taken before the initiation of brushing, and final readings were recorded after the 60-day brushing regimen (Fig.3). The profilometer measured roughness parameters such as Ra to evaluate changes in enamel surface roughness caused by the different dentifrices.

OBSERVATIONS AND RESULTS

The primary objective of this study was to compare the abrasiveness of a charcoal-containing toothpaste and a conventional fluoride toothpaste on human enamel, using an oscillating toothbrush and profilometric evaluation.

Group A (charcoal-containing toothpaste) demonstrated a notable increase in enamel surface roughness over the course of the two-month brushing regimen. As shown in *Table 2*, the mean surface roughness (Ra) increased from **0.31 ± 0.19 µm** at baseline to **0.52 ± 0.20 µm** post-treatment, indicating a substantial change in enamel roughness attributable to the charcoal-based formulation.

Table 2: Comparison of Mean Value of Change in Surface Roughness (Ra) Between Initial Values (Before Brushing) and Final Values (After Brushing) of Group A

Group A	N	Min	Max	Mean	SD	Mean difference	t value	P value
Initial values	10	0.14	0.76	0.31	0.19	0.21	10.392	0.000 S
Final values	10	0.26	0.96	0.52	0.20			

Statistical Analysis: Paired t test. S: Statistically significant if P<0.05.

In **Group B** (conventional toothpaste), a comparatively smaller increase in surface roughness was observed. According to *Table 3*, the mean Ra value rose from **0.37 ± 0.21 µm** to **0.42 ± 0.20 µm** following the same brushing protocol. While this change was less pronounced than that seen in Group A, it nonetheless suggests a degree of enamel abrasion associated with long-term use of conventional dentifrice.

Table 3: Comparison of Mean Value of Change in Surface Roughness (Ra) Between Initial Values (Before Brushing) and Final Values (After Brushing) of Group B

Group B	N	Min	Max	Mean	SD	Mean difference	t value	P value
Initial values	10	0.18	0.73	0.37	0.21	0.05	6.029	0.000 S
Final values	10	0.20	0.75	0.42	0.20			

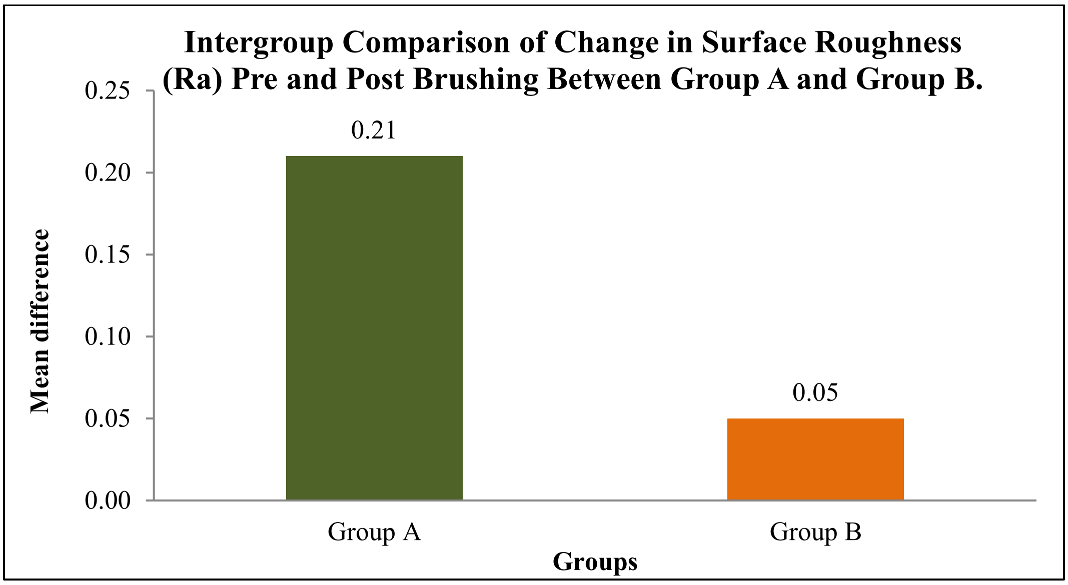
Statistical Analysis: Paired t test. S: Statistically significant if P<0.05.

A comparative analysis of the mean change in surface roughness between both groups is summarized in *Table 4* and *Graph 1*. Group A exhibited a significantly higher mean increase in Ra (**0.21 ± 0.06 µm**) compared to Group B (**0.05 ± 0.02 µm**). These findings indicate that the charcoal-containing toothpaste produced a greater abrasive effect on enamel than the conventional toothpaste, suggesting a higher potential for surface roughness with prolonged use.

Table 4: Intergroup Comparison of Change in Surface Roughness (Ra) Pre and Post Brushing between Group A and Group B

Groups	N	Final values - Initial Values		t value	P value
		Mean	SD		
Group A	10	0.21	0.06	7.636	0.000 S
Group B	10	0.05	0.02		

Statistical Analysis: Independent sample t test. S: Statistically significant if P<0.05.



Graph 1: Bar Representation of Intergroup Comparison of Change in Surface Roughness (Ra) Pre and Post Brushing Between Group A and Group B.

DISCUSSION

Abrasion is a frequently occurring dental issue that results in changes to the enamel surface, leading to increased roughness. This roughened surface facilitates the retention of plaque and encourages bacterial growth, which in turn raises the risk of developing dental caries and dentinal hypersensitivity. [19] Today, a wide array of toothpastes is available on the market, each containing various types of abrasive particles, detergents, and therapeutic agents. Therefore, it is crucial for consumers to be well-informed about the ingredients and functions of each toothpaste to select the most suitable one for their specific needs. An ideal toothpaste should offer effective cleaning and protection while minimizing abrasion to the enamel. [20]

In recent years, charcoal-containing toothpaste has gained significant popularity due to its purported ability to whiten and clean teeth. The characteristics of charcoal particles help remove extrinsic stains, biofilm, and food particles from the enamel surface. Despite the benefits, it is important to examine the potential effects that charcoal toothpaste may have on tooth enamel, especially in comparison to traditional toothpaste.

In the present study, the abrasiveness of a charcoal-based toothpaste (Colgate® Charcoal Black Gel Toothpaste) was compared with a conventional toothpaste (Colgate® Total Advanced Health Anti-germ Toothpaste). A total of twenty freshly extracted single-rooted teeth were collected from patients undergoing extraction for periodontal reasons. Following ultrasonic scaling and root planing, the teeth were rinsed and stored in artificial saliva to simulate intraoral conditions. According to Imfeld (1996) [21], artificial saliva is supersaturated with calcium and phosphate ions, which aid in the remineralization of enamel surfaces.

In this study, a custom-made wooden brushing apparatus was used to ensure a consistent brushing force across all samples, following methods used by Singh TP et al. (2021) [22], Teche et al. (2011) [23], Ganss et al. (2009) [24], and Dabhi et al. (2016) [25]. The oscillatory toothbrush was fixed perpendicularly to the tooth surface, and a pea-sized amount of toothpaste was applied before each session. Both groups used the same soft-bristle oscillatory brush under controlled conditions. A force gauge was attached to maintain uniform pressure of 250 g, as studies like Van der Weijden et al. (2004) [26] highlighted that exceeding 250 g can impact toothbrush performance.

Although soft-bristle brushes are generally preferred for minimizing trauma to gingival tissues, studies by Pertiwi et al. (2017) [16], Kumar et al. (2015) [27], Teche et al. (2011) [23], and Dyer et al. (2000) [28] have highlighted that their flexibility and broader contact area may actually contribute to increased enamel surface loss when used with abrasive toothpaste formulations. The greater flexibility of the bristles allows for more toothpaste retention and increased exposure to abrasive particles, enhancing surface wear. Furthermore, oscillatory toothbrushes have been shown to produce more abrasion than linear ones due to their rotating and oscillating motion, which rapidly moves across the enamel surface and increases the brushing surface area.

After completing the brushing regimen of 2 minutes twice daily for 60 days, as outlined by Singh TP [22], the enamel surface roughness was reassessed using the same profilometer. The results revealed that both types of toothpaste increased enamel surface roughness over time. In Group A (charcoal toothpaste), the mean Ra value increased from 0.31 ± 0.19 μm to 0.52 ± 0.20 μm, while in Group B (conventional toothpaste), it rose from 0.37 ± 0.21 μm to 0.42 ± 0.20 μm. These findings were statistically significant ($p = 0.000$) and demonstrated that while both toothpastes caused enamel abrasion, the charcoal-based formulation led to more pronounced changes.

The increased abrasion observed in the charcoal toothpaste group can be attributed to its composition. Colgate® Charcoal Black Gel Toothpaste contains common abrasives such as silica, as well as activated charcoal particles. Studies by Garza (2019) [29] and Pertiwi et al. (2017) [16] have shown that the shape, size, and structure of charcoal particles, often irregular and star-shaped, can significantly influence surface roughness. Larger and more angular particles tend to cause more surface disruption. Particle size analysis by Pertiwi indicated that charcoal-based toothpaste had larger abrasive particles (7.853 μm) compared to conventional toothpaste (4.625 μm), which likely contributed to the greater increase in Ra values. [16] Similar results were reported by Koc Vural (2021) [17], Greuling et al. (2021) [18], and Sanusi et al. (2019) [30], all of whom found that long-term use of charcoal-containing toothpaste could lead to progressive enamel wear.

In contrast, the conventional toothpaste group, though also containing silica-based abrasives, exhibited significantly less increase in enamel roughness. Silica abrasives can still cause micro-scratches and mineral loss on the enamel surface but to a lesser degree than charcoal. [16] Additionally, abrasive hardness plays a key role in enamel wear. As noted by Patni et al. (2008) [32], charcoal has a Mohs hardness of 2–3, which, despite being softer than enamel (5), can still contribute to significant wear due to particle shape and application technique. Silica, on the other hand, ranges from 5–7 on the Mohs scale, making it closer in hardness to enamel and more capable of producing micro-abrasions, especially under sustained brushing. [16]

The comparative analysis between both groups revealed a highly significant difference in Ra values, with Group A showing greater surface abrasion than Group B ($p = 0.000$). This indicates that charcoal-containing toothpaste exerts a more aggressive mechanical action on enamel, leading to increased surface roughness. This roughened surface not only predisposes the tooth to further wear but also enhances plaque retention and bacterial colonization, as surface roughness values exceeding 0.2 μm have been associated with increased microbial adherence (Kumar et al., 2014). [31] Over time, this can escalate the risk of dental caries, gingival inflammation, dentinal hypersensitivity, and pigmentation.

LIMITATIONS

This study had a few limitations. The teeth used were randomly selected, with unknown dental histories, which may have contributed to variability in initial enamel roughness. Additionally, the in vitro setup did not fully replicate natural oral conditions, such as continuous saliva flow, dietary factors, or bacterial activity. As a result, the findings, while informative, should be interpreted with caution when applying them to real-world scenarios.

CONCLUSION

This study found that both charcoal-based and conventional toothpastes increase enamel surface roughness, but charcoal toothpaste caused significantly greater abrasion. The abrasive nature of larger, irregular charcoal particles contributes to more pronounced enamel wear, which may promote plaque buildup and increase the risk of caries and sensitivity. While charcoal toothpaste may offer whitening benefits, its frequent use should be approached with caution. Consumers should choose toothpastes that clean effectively without compromising enamel integrity, and dental professionals should provide guidance based on individual oral health needs.

LIST OF ABBREVATIONS

1. Surface Roughness (Ra)
2. Tooth Surface Loss (TSL)
3. Manual Toothbrush (MTB)

DECLARATIONS-

1. ETHICAL APPROVAL AND CONSENT TO PARTICIPATE- Not applicable.
2. CONSENT FOR PUBLICATION- Not applicable.
3. AVAILABILITY OF DATA AND MATERIALS- Self.
4. COMPETING INTERESTS- The authors declare that they have no competing interests.
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REFERENCES

1. Warreth A, Abuhijleh E, Almaghribi MA, Mahwal G, Ashawish A. Tooth surface loss: A review of literature. Saudi Dent J. 2020 Feb;32(2):53-60.
2. Löe H, Kleinman DV. Dental Plaque Control Measures and Oral Hygiene Practices. Oxford: IRL Press; 1986; 332p.
3. Bueno MAM, Toledo S, Sallum EA, Nociti Junior FH. Influência da escovação dental orientada na redução do sangramento gengival, em áreas próximas a restaurações metálicas. Rev ABO Nac. 1998; 6: 44-7.
4. Philpotts CJ, Weader E, Joiner A. The measurement in vitro of enamel and dentine wear by toothpastes of different abrasivity. Int Dent J. 2005;55(3 Suppl 1):183-7.
5. Andrade Junior ACC, Andrade MRTC, Machado WAS, Fischer RG. Abrasividade de dentifrícios: Revisão de literatura. Rev Periodontia. 1997; 6: 25 30.
6. Baxter PM, Davis WB, Jackson J. Toothpaste abrasive requirements to control naturally stained pellicle. J Oral Rehabil. 1981; 8: 19-26.
7. Hefferren JJ, Schemehon B, Storek A, Lerck M, Li N. Silica as a reference for laboratory dentifrice assessment methods: multiple collaborative study. J Clin Dent. 2007; 8: 12-6.
8. Stookey G, Muhler J. Laboratory studies concerning the enamel and dentin abrasion properties of common dentifrice polishing agents. J Dent Res. 1968; 47: 524-32.
9. Slop D, Rooij JF, Arends J. Abrasion of enamel. I. An in vitro investigation. Caries Res. 1983; 17: 242-8.
10. Heath J, Wilson J. Abrasion of restorative materials by toothpaste. J Oral Rehabil. 1976; 3: 121-38.
11. Patrão FGD, Sinhoreti MAC, Consani S, Correr Sobrinho L, Milan FM. Avaliação in vitro da rugosidade produzida por escovas dentais e dentifrícios em resina para base de prótese. Rev Fac Odontol Univ Passo Fundo. 1998; 3: 7-14.
12. Correr Sobrinho L, Francisco MU, Consani S, Sinhoreti MAC,Consani RLX. Influência da escovação na rugosidade de superfície de materiais restauradores estéticos. PGR Pós-Grad Rev Fac Odontol São Jose dos Campos. 2001; 4: 47 55.
13. Lara EHG, Panzeri H, Ogasawara MS, Ciampo JOD, Moraes JT. Avaliação laboratorial dos dentifrícios comerciais. Rev ABO Nac. 1996; 4: 176-80.
14. Addy M, Goodfield S, Harrison A. The use of acrylic to compare the abrasivity and stain removal proprieties of toothpastes. Clin Mater. 1991; 7: 219-25.
15. Young Alciara, Saliba Nemre, Consani Simonides, Sinhoreti, Mário. (2008). In vitro evaluation of the abrasiveness of a commercial low-abrasive dentifrice and an experimental dentifrice containing vegetable oil. Brazilian Journal of Oral Sciences (ISSN: 1677-3217) Vol 7 Num 24. 7.
16. Pertiwi U I, Eriwati Y, Irawan B. Surface changes of enamel after brushing with charcoal toothpaste. J Phys Conf Ser. 2017;884:012002.
17. Koc Vural U, Bagdatli Z, Yilmaz AE, Yalçın Çakır F, Altundaşar E, Gurgan S. Effects of charcoal-based whitening toothpastes on human enamel in terms of color, surface roughness, and microhardness: an in vitro study. Clin Oral Investig. 2021 Oct;25(10):5977-5985.
18. Greuling A, Emke JM, Eisenburger M. Abrasion Behaviour of Different Charcoal Toothpastes When Using Electric Toothbrushes. Dent J (Basel). 2021 Aug 20;9(8):97.
19. Karale AM, Waghmare P, Dodwad V, Pharne P, Karale A.(2024).Comparative Evaluation of Enamel Surface Abrasion Produced by Three Different Types of Toothbrush Bristle Designs: An In-vitro Study,J Clin of Diagn Res. 18(12), ZC01-ZC04.
20. Balhaddad AA, Almalki F, Altayyar R, Alzahrani R, Alotaibi S, Al Dehailan L, Ibrahim MS. The interplay between toothbrush stiffness and charcoal-containing dentifrice on the development of enamel topography changes. BMC Oral Health. 2024 Nov 16;24(1):1394.
21. Imfeld T. Prevention of progression of dental erosion by professional and individual prophylactic measures. Eur J Oral Sci 1996;104:215-20.

22. Singh TP, Nirola A, Brar R. A profilometric and scanning electron microscopic analysis of tooth surface abrasion caused by rotary/oscillatory, linear motion, sonic, and ultrasonic toothbrushes: An in vitro study. J Indian Soc Periodontol. 2021 Mar-Apr;25(2):112-119. Epub 2021 Mar 1. Erratum in: J Indian Soc Periodontol. 2021 May-Jun;25(3):270.
23. Teche FV, Paranhos HF, Motta MF, Zaniquelli O, Tirapelli C. Differences in abrasion capacity of four soft toothbrushes. Int J Dent Hyg 2011;9:274-8.
24. Ganss C, Hardt M, Blazek D, Klimek J, Schlueter N. Effects of toothbrushing force on the mineral content and demineralized organic matrix of eroded dentine. Eur J Oral Sci 2009;117:255-60
25. Dabhi MV, Kisan KV, Shah S. Comparative evaluation of three different types of tooth brush on surface abrasion of enamel and nanohybrid composite: An in vitro study. IOSR JDMS 2016; 15:122-7.
26. van der Weijden GA, Timmerman MF, Versteeg PA, Piscaer M, van der Velden U. High and low brushing force in relation to efficacy and gingival abrasion. J Clin Periodontol 2004;31:620-4.
27. Kumar S, Kumar Singh S, Gupta A, Roy S, Sareen M, Khajuria S. A Profilometric Study to Assess the Role of Toothbrush and Toothpaste in Abrasion Process. J Dent (Shiraz). 2015 Sep;16(3 Suppl):267-73.
28. 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.
29. Garza L A 2009 Effect of toothbrushing on surface roughness and shade of extrinsically stained pressable ceramic restorations. Theses Paper 303 (Milwaukee: Marquette University School of Dentistry).
30. Sanusi SH, Zam NZ, Mohamad Z, Noor FM, Lajis A. The efficiency of dentifrice abrasive particles under different tooth-brushing parameter. IJIGS. 2019;81:747–52.
31. Kumar S, Kumari M, Acharya S, Prasad R. Comparison of surface abrasion produced on the enamel surface by a standard dentifrice using three different toothbrush bristle designs: A profilometric in vitro study. J Conserv Dent. 2014 Jul;17(4):369-73.
32. Patni A, Ludlow D, Adams C. Characteristics of ground granular activated carbon for rapid small-scale column tests. J Environ Eng (ASCE). 2008;134(3):216-22.