Original Article

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Dentistry Section

Effects of Brushing Simulation on the Surface Roughness, Microhardness and Colour Stability of Indirect Composite Resin and Polyetheretherketone Polymer: An In-vitro Study

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ABSTRACT

Introduction: Indirect composite and Polyetheretherketone (PEEK) are widely used in restorative dentistry due to their favourable mechanical and aesthetic properties. However, their durability under simulated brushing conditions, which mimic routine oral hygiene practices, remains understudied.

Aim: To evaluate and compare the effects of brushing simulation on the surface roughness, microhardness, and colour stability of indirect composite and PEEK materials.

Materials and Methods: The present in-vitro study was conducted at Saveetha Dental College and Hospitals, Chennai, Tamil Nadu, India in the Department of Prosthodontics, in April 2024. Thirty-six samples each of indirect composite and PEEK were fabricated and polished to a standardised finish. The samples were subjected to brushing simulation for 20,000 cycles with a soft bristled toothbrush under a 2 N load using a toothpaste of standardised abrasivity. Surface roughness was measured using a profilometer, microhardness using a Vickers Hardness Tester, and colour stability (ΔE values) with a spectrophotometer employing the Commission Internationale de l'Eclairage (CIE). Lab* system. Statistical analysis was performed using independent and paired t-tests.

Results: The surface roughness ($p=0.71$) and microhardness ($p<0.001$) of PEEK decreased after brushing simulation. For indirect composite resin, the surface roughness decreased ($p<0.001$) while the microhardness increased ($p<0.001$) after brushing. The difference in colour stability after the brushing simulation was greater in PEEK than in the indirect composite resin group ($p<0.001$).

Conclusion: PEEK was more resistant to surface wear but less colour-stable, while indirect composite resin demonstrated better colour stability and higher post brushing hardness but was more affected in terms of surface roughness.

Keywords: Colourimetry, Dental polymers, Hardness tests, Surface properties, Toothbrushing

INTRODUCTION

Restorative dentistry has witnessed significant advancements with the introduction of innovative materials aimed at enhancing both the functionality and aesthetics of dental prostheses. Among these, indirect composite and PEEK have emerged as prominent materials due to their unique properties [1]. The selection of restorative materials plays a pivotal role in determining the long-term success of dental restorations, as they are constantly exposed to mechanical wear and chemical challenges in the oral cavity. Indirect composites are widely used in restorative procedures for their superior aesthetic qualities, ease of handling, and ability to mimic natural tooth structures [2,3]. However, their performance in high wear areas, such as posterior teeth, can be compromised due to abrasion and colour changes over time. PEEK, on the other hand, is a high-performance polymer that has gained attention in dentistry due to its composition and provides excellent resistance to wear, low surface roughness, and stability against chemical degradation [4]. Compared to indirect composites, PEEK is considered less prone to abrasion and discolouration, making it a preferred choice for high stress restorative applications, especially in posterior regions [5].

One of the most significant factors affecting the longevity of dental restorations is daily tooth brushing. Brushing, while essential for maintaining oral hygiene, subjects restorative materials to repeated mechanical abrasion from toothbrush bristles and toothpaste [6,7]. Over time, this leads to surface degradation, including increased roughness, loss of gloss, and changes in colour. Surface roughness is particularly critical, as increased roughness not only affects aesthetics but also promotes bacterial adhesion, leading to plaque accumulation and potential periodontal issues [8,9]. Similarly, loss of gloss and colour changes compromises the aesthetic appeal of restorations, which is a primary concern for patients. While several studies have evaluated the performance of indirect composites and PEEK independently, direct comparisons between these materials under brushing simulation conditions are limited [2,4,5,10]. Furthermore, their comparative performance under prolonged brushing stress remains inadequately explored. Identifying differences in durability and aesthetics between these two dental prosthetic materials is essential to optimising material choice for long-term success in high functioning and aesthetically demanding restorations. Such comparisons provide valuable insights into their suitability for different clinical applications and help clinicians make informed decisions based on the specific requirements of each case.

This study aims to evaluate the effects of brushing simulation on the surface properties and colour stability of indirect composite and PEEK. By analysing changes in surface roughness, gloss retention, and colour stability after brushing simulation, this study seeks to determine the relative durability and aesthetic performance of these materials and to provide evidence-based recommendations for their clinical use.

MATERIALS AND METHODS

This study was of an in-vitro nature, and samples in each group were equal. It was conducted at Saveetha Dental College and Hospitals in Chennai, Tamil Nadu, India, in the Department of Prosthodontics, in April 2024, within a university framework. Approval from the Institutional Review Board (SRB/SDC/PROSTHO-2205/23/219) was obtained prior to its initiation.

Specimen preparation: Disc-shaped specimens of PEEK and indirect composite were prepared with dimensions of 10 mm in diameter and 2 mm in height, in accordance with ISO 4287:1997 for Geometrical Product Specifications (GPS) [11]. A total of seventy-two specimens for each material were prepared, with the sample size determined using an earlier publication and G*Power 3.1.9.3 for Mac OS X® (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). A power of 0.95 (1-β error probability), an effect size (dz=1.5004), and a significance level of 0.05 (α) were confirmed from prior research [12]. Thirty-six samples were allocated to Group-PE (PEEK polymer, n=36) and Group-IC (indirect composite resin, n=36). An Standard Tessellation Language (STL) file of the specified dimensions was created using computer-aided design.

This file was then nested into a PEEK disc (Upcera®, Shenzhen Upcera Dental Technology Co., Ltd., Guangdong, China). The disc was subsequently milled using the IMES iCore® milling unit (CORiTEC 350i, Eiterfeld, Germany). The indirect composite specimens were fabricated by creating an index of the milled PEEK in clear silicone putty using Ceramage® (Shofu, Kyoto, Japan). Following milling and duplication, the specimens were polished using a series of silicon carbide burs to achieve the final finish (600, 800, 1,000, and 1,200-grit) [13]. Finally, the specimens were polished using a cloth wheel and pumice, with only one surface polished to replicate intraoral conditions. All the specimens were thoroughly washed with distilled water to remove any debris or contaminants and were then used for the study. Each specimen was mounted at the centre of a circular block to ensure stability during testing.

Brushing Simulation

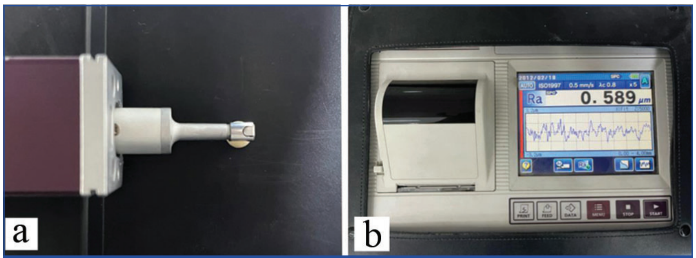
Following the initial surface roughness measurement, the specimens were secured in a brushing simulator (ZM3.8 SD Mechatronik®, SD Mechatronik GmbH, Feldkirchen-Westerham, Germany). Brushing was performed with a soft-bristled toothbrush and fluoridated toothpaste under a consistent pressure of 2 N. Each specimen was subjected to 20,000 cycles of brushing: 10,000 times in the x-axis direction and 10,000 times in the y-axis direction, along with 5,000 times in clockwise and counterclockwise directions, at a rate of 75 strokes per minute. This setup was designed to closely mimic the multidirectional forces encountered during actual manual tooth brushing in the oral cavity, simulating approximately seven years of brushing [14]. A 2 N load closely simulates the average force applied during manual tooth brushing, which typically ranges from 1.5 to 2.5 N, depending on brushing technique and hand pressure. This value ensures that the test reflects realistic intraoral conditions without causing excessive, non-clinical wear on the samples, as shown in [Table/Fig-1].

[Table/Fig-1]: Brushing simulator showing 4 samples tested using soft-bristled toothbrush and fluoridated toothpaste under a consistent pressure of 3 N.

Surface Roughness Measurement

The surface roughness of the prepared specimens was measured prior to brushing using a stylus profilometer (Mitutoyo SJ 310®, Mitutoyo Corporation, Japan) with a 2 µm tip and a 60° angle [15]. The stylus profilometer employs a non destructive, highly sensitive, and reproducible method, making it ideal for assessing how abrasion affects the surface texture of dental materials [16].

The device was manually moved across the surface of each specimen to record baseline roughness values, as shown in [Table/Fig-2]. The surface roughness was then calculated using the following formula [17]:



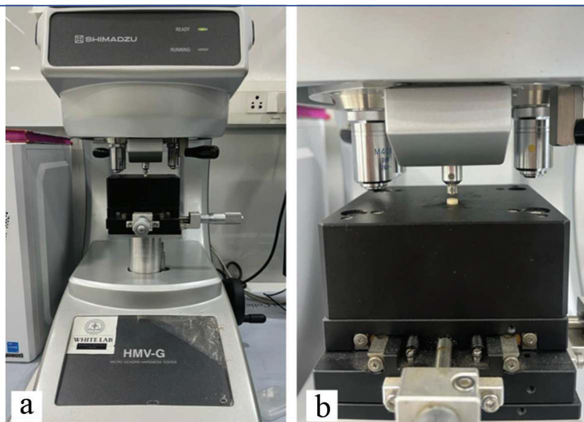
[Table/Fig-2]: Surface roughness measurement using stylus profilometer: a) Stylus touching the profile of the sample prepared; b) Reading obtained with the prepared sample.

Where 'Ra' represents the arithmetical mean roughness (measured in micrometers, µm); 'L' refers to the sampling length (total length of the surface profile measured); and 'y(x)' denotes the absolute deviation of the surface profile from the mean line at any point x. After completing the brushing simulation, the surface roughness of the specimens was re-evaluated using the same stylus profilometer under identical conditions to ensure consistency.

Microhardness Test

Microhardness was measured using Vickers testing both before and after the brushing simulation. In the Vickers microhardness test, the surface of the sample is indented using a pyramidal diamond indenter with a 136° angle between its opposite faces. The test follows standardised protocols (ISO 6507-1, ASTM E384), ensuring reliable, reproducible data, which is critical for validating material performance for clinical applications [18].

The test involves applying a specified load on equally divided samples in each group (n=18 for both before and after brushing simulation) for a set duration, after which the width of the resulting indentation is measured. This width is used to calculate the area of the indentation both before and after the brushing simulation. In this study, the Shimadzu HMV-G 31 DT® Micro Vickers Hardness Tester was utilised, as illustrated in [Table/Fig-3].



[Table/Fig-3]: Microhardness test was performed using vickers hardness tester: a) The HMV-G 31 DT® micro vickers hardness tester; b) The zoomed view of the testing of sample.

A force of 0.3 kgf (2.942 N) was applied, with a holding time of 20 seconds [19]. The Vickers Hardness Number (HV) is calculated using the following formula [20]:

Where 'F' represents the applied load (in Newtons) and 'd' denotes the average of the two diagonals of the indentation.

Colour Stability

The colour stability of each specimen was evaluated using a spectrophotometer (SpectraMagic NX®, RM2002QC, Konica Minolta Corp., Ramsey, Japan). The colour parameters (L*, a*, b*) were assessed according to the standards set by the Commission Internationale de l'Eclairage (CIE). This method is widely accepted due to its accuracy, reproducibility, and ability to simulate human visual perception [21]. The device relies on the CIE Standard 2° observer model for its colour assessments and features an 8-mm aperture.

The measurements were performed on a grey background. All readings were conducted by a single operator in a room with controlled temperature, humidity, and ambient daylight. Calibration of the spectrophotometer occurred before each set of measurements, with three readings taken per specimen and the results averaged. The CIEDE2000 formula was used to calculate the colour differences (ΔE) between materials. The colour differences were calculated both before and after the brushing simulation to assess the impact of the procedure on the specimens.

STATISTICAL ANALYSIS

The data analysis was performed using IBM Statistical Package for Social Sciences (SPSS) Statistics® for Windows, Version 24 (Released 2016; IBM Corp., Armonk, New York). The mean and standard deviation for surface roughness, microhardness, and colour stability were calculated. Given that the sample size exceeded fifty, the Kolmogorov-Smirnov test was employed to assess the normality of the data. Changes in surface roughness, microhardness, and colour stability before and after the brushing simulation were evaluated using a paired sample t-test, while an independent t-test was utilised to compare the PEEK and indirect composite resin groups. The results were presented graphically to provide a clearer representation of the changes in surface roughness for both materials.

RESULTS

The descriptive data for surface roughness, microhardness, and colour stability were recorded and tabulated in [Table/Fig-4]. An independent t-test was employed to compare the surface roughness values between both groups, and no significant difference was observed after brushing (p=0.60, test statistic=0.527). The indirect composite retained significantly higher microhardness than PEEK after brushing, with a highly significant difference (p<0.0001). Additionally, PEEK showed a greater colour change compared to the indirect composite after brushing, and this difference was also highly significant (p<0.0001), as shown in [Table/Fig-5].

Groups	Ra		MHV		CIE (lab values)	
	Before	After	Before	After	Before	After
Group-PE	2.054±0.61	1.746±0.70	24.08±0.34	21.67±0.28	L*-70.00±0.50; a*-2.00±0.30 b*-10.00±0.40	L*-70.50±0.40 a*-2.30±0.20 b*-11.30±0.30
Group-IC	0.825±0.90	1.838±0.78	40.12±0.45	34.28±0.38	L*-70.00±0.60 a*-2.00±0.30 b*-10.00±0.40	L*-70.00±0.40 a*-2.20±0.20 b*-9.30±0.30

[Table/Fig-4]: Descriptive data of surface roughness, microhardness and colour stability, before and after simulated brushing.
[a]Ra, Surface Roughness (μm); MHV, Micro Hardness Value (kgf/mm²); L*: Lightness scale; a*: Red vs green b*: Yellow vs blue; Group-PE, PEEK; Group-IC, Indirect composite resin

The results of the paired sample t-test indicated that for the surface roughness of PEEK, the change from before to after the brushing simulation was not statistically significant (p=0.71). For the indirect composite, the values obtained before and after the brushing simulation were statistically significant (p<0.001). The intragroup comparisons for surface roughness, microhardness, and colour stability has been shown in [Table/Fig-6].

After brushing	Group-PE	Group-IC	Test statistics	SE	N	p-value
Ra	1.746±0.70	1.838±0.78	0.527	0.17	36	0.60
MHV	21.67±0.28	34.28±0.38	0.293	0.08	36	<0.0001[a]
ΔE	1.47±0.21	0.067±0.24	26.40	0.05	36	<0.0001[a]

[Table/Fig-5]: Inter-group comparisons of colour stability, after simulated brushing using Independent t-test.
[a]Statistically significant at p<0.05. Ra, Surface Roughness (μm); MHV: Micro Hardness Value (kgf/mm²); ΔE, Difference in colour stability; Group-PE, PEEK; Group-IC, Indirect composite resin.

Groups	Ra		p-value	MHV		p-value	CIE (Lab)
	Before	After		Before	After		p-value
Group-PE	2.054±0.61	1.746±0.70	0.71	24.08±0.34	21.67±0.28	<0.0001[a]	Δ L*: +0.50; <0.001[a] Δ a*: +0.30; <0.001[a] Δ b*: +1.30; <0.001[a]
Group-IC	0.825±0.90	1.838±0.78	0.001[a]	40.12±0.45	34.28±0.38	<0.0001[a]	Δ L*: 0.00; p=0.998 Δ a*:+0.20; p=0.10 Δ b*:–0.70; p=0.06

[Table/Fig-6]: Intra-group comparisons of microhardness, before and after brushing using paired t-test.
[a]Statistically significant at p<0.05. Ra, Surface Roughness (μm); MHV: Micro Hardness Value (kgf/mm²); MHV: Micro hardness value; Group-PE: PEEK; Group-IC: Indirect composite resin

DISCUSSION

On obtaining the results of the current research, it was observed that PEEK and indirect composite materials demonstrated comparable resistance to changes in surface texture after simulated brushing conditions. Both materials exhibited a reduction in microhardness after brushing; however, the indirect composite resin retained higher hardness levels compared to PEEK. PEEK displayed more pronounced colour changes, while the indirect composite resin remained highly stable after brushing.

PEEK did not demonstrate significant changes in surface roughness when compared before and after brushing, whereas the indirect composite resin showed a significant increase in surface roughness. Both groups exhibited a significant decrease in microhardness from before to after brushing. These findings highlight the distinct behaviours of the two materials under brushing-induced stress.

The results of the present study align with investigations that reported PEEK's moderate mechanical resilience and increased susceptibility to colour changes upon mechanical wear. This behaviour is often attributed to the material's semi-crystalline polymeric structure and lack of fillers, which compromises its colour retention under abrasive conditions [22,23]. In a study by Narde J et al., Polymethyl Methacrylate (PMMA) demonstrated inferior colour stability and increased surface roughness following thermocycling compared to indirect composite materials, suggesting careful consideration in material selection for provisional restorations [2]. The findings from Porojon L et al., stated that water absorption was associated with a decrease in the microhardness of PEEK. Surface characteristics were affected by water immersion and thermocycling; however, perceivable colour changes of the materials were not detected [24]. The indirect composite resin demonstrated increased surface roughness and superior colour stability, in agreement with prior studies that attribute this performance to its high filler load, resin matrix cross-linking, and minimal surface porosity [2,25-27]. The unexpected decrease in surface roughness post brushing in the PEEK group may be due to the levelling effect from prolonged brushing, as suggested by Al Ali M et al., who observed a similar reduction in surface irregularities after extended abrasive cycles [28].

PEEK's resistance to changes in surface roughness suggests its potential for use in areas subjected to mechanical wear, such as frameworks or posterior restorations. Its softer nature may also reduce wear on opposing teeth. However, its susceptibility to colour changes may limit its use in highly visible areas [4]. In contrast, the indirect composite resin, with its superior hardness and excellent colour stability, is well-suited for aesthetic restorations in anterior regions. Clinicians should weigh these material properties against the functional and aesthetic requirements of the specific clinical situation.

Potential bias in this study could stem from variations in the brushing simulation process, including the consistency of brushing pressure and duration. However, the strength of the present research lies in its study design, which mitigated this bias by standardising these parameters across all specimens. Furthermore, brushing was performed with fluoridated toothpaste and a soft-bristled toothbrush under a consistent pressure of 2 N. The use of paired and independent t-tests further ensured statistical rigor, allowing a reliable comparison of changes within and between the two groups, which was an advantage of the present research. Additionally, the inclusion of multiple samples per group minimised variability and enhanced the reliability of the results.

Limitation(s)

The current research has a few limitations that should be acknowledged. While simulated brushing provides valuable insights into the wear and durability of restorative materials, it does not fully replicate the complex oral environment, including variations in temperature, pH, and enzymatic activity. Furthermore, the study's short duration does not account for the long-term effects of oral conditions on these materials. Future research should explore the performance of these materials under conditions that more closely mimic the oral environment. Long-term clinical studies are necessary to validate these findings and assess their implications for real world applications. Additionally, studies investigating modifications to PEEK's composition or surface treatments to enhance its aesthetic properties could expand its clinical utility.

CONCLUSION(S)

Within the limitations of this in-vitro study, both PEEK and indirect composite materials demonstrated comparable resistance to changes in surface texture after simulated brushing conditions; however, the PEEK group exhibited lower hardness and significant colour instability. In contrast, the indirect composite resin showed increased surface roughness after brushing but maintained superior hardness and excellent colour stability. Overall, PEEK was more resistant to surface wear but less colour-stable, while the indirect composite resin displayed better colour stability and higher post-brushing hardness, albeit with greater susceptibility to surface roughness changes. These results suggest that PEEK is more durable and better suited for applications requiring long-term resistance to wear and property stability. Therefore, PEEK is suitable for use in posterior restorations or frameworks, whereas the indirect composite resin could be ideal for anterior restorations. The choice of material should be guided by the specific clinical requirements, balancing mechanical performance with aesthetic demands. Further long-term in vivo studies are recommended to validate these findings and explore material enhancements for broader clinical applicability.

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