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Comparative Evaluation of Two Body Wear of PEEK vs Milled PMMA vs Indirect Composite After Chewing Simulation- An In Vitro Study

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Background: The evolution of aesthetic and bonding techniques has revolutionized restorative dentistry, emphasizing the need for optimal biomaterials. Ceramics and resin composites are now preferred for restorations due to their excellent aesthetic and mechanical properties, surpassing traditional gold alloy restorations. Aim and Objectives: The aim of this study was to compare and evaluate the two-body wear of Polyetheretherketone (PEEK), Polymethyl methacrylate (PMMA), and an indirect composite material following simulated chewing cycles. The objective is to identify the material with the least wear and discuss its implications for use in dental restorations, particularly in situations involving extensive chewing forces and parafunctional habits. Materials and Methods: Cylindrical specimens (10 mm diameter, 6 mm height) were fabricated from polyetheretherketone (PEEK) (BioHpp, Bredent GmbH, Senden, Germany), (Polymethyl methacrylate) PMMA (Aidite, United States), and an indirect composite (Ceramage, GC Corp.) (n=12 per group). A chewing simulator (CS-4, SD Mechatronik, Munich, Germany) subjected the specimens to 60,000 and 120,000 loading cycles against steatite antagonists. Volumetric loss was measured using Geomagic Control X software. Data were analyzed using one-way analysis of variance (ANOVA) and Tukey's test with SPSS version 26.0. Results: PEEK's volumetric loss significantly increased from 0.39 mm^3 (SD = 0.16) after 60,000 cycles to 0.77 mm^3 (SD = 0.29) after 120,000 cycles ($p = 0.031$). PMMA showed a volumetric loss of 0.60 mm^3 (SD = 0.25) after 60,000 cycles and 0.89 mm^3 (SD = 0.47) after 120,000 cycles, with no significant difference. Indirect composite exhibited a volumetric loss of 0.42 mm^3 (SD = 0.19) after 60,000 cycles and 0.69 mm^3 (SD = 0.22) after 120,000 cycles, also without a significant difference. The null hypothesis was rejected. Conclusion: This study reveals key differences in wear behavior among PMMA, PEEK, and Indirect Composite materials. PMMA had the highest wear, PEEK showed intermediate wear resistance, and Indirect Composite had the lowest wear, making it ideal for long-term durability. When choosing materials for specific clinical cases, dentists and prosthodontists should consider these wear characteristics to meet each patient's needs effectively.

Keywords: Polyetheretherketone, Ceramics, resin, dentist, clinical case.

1. Introduction

The evolution of aesthetics and bonding techniques has revolutionized restorative dentistry, highlighting the need for optimal biomaterials. Recently, ceramics and resin composites have become the preferred materials for restorations [1]. They offer excellent aesthetic and mechanical properties, making them ideal for both minor repairs and extensive restorations of severely damaged teeth [2]. These advanced materials and techniques have largely surpassed traditional gold alloy restorations, which were once favored for their superior wear properties.

The natural wear of tooth structure occurs during chewing, influenced by various interconnected factors [3]. This wear can result from the abrasive nature of food (three-body wear) during normal chewing or from attrition due to parafunctional habits like bruxism or grinding, which cause direct occlusal contact [4]. Other factors include the strength of the temporomandibular muscles, enamel quality, and the composition and acidity of saliva, all of which collectively impact the tooth surface over time [5,6].

Excessive wear is a frequent cause of restorative failure from chewing stress, resulting in increased sensitivity, poor occlusal contact, periodontal issues, reduced chewing efficiency, tooth movement, malalignment, weakened masticatory muscles, and altered jaw relationships [7,8]. Effective restorative materials should replicate natural dental structures, using the wear characteristics of enamel and dentin as benchmarks to guide appropriate wear patterns for these materials, which degrade through various mechanisms [9].

Several methods have been proposed for creating provisional restorations [10]. These methods include heat-cured polymethyl methacrylate (PMMA), indirect laboratory composites, and more recently, Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) PMMA and Polyetheretherketone (PEEK) [11]. Heat-cured PMMA was popular due to its ease of use and cost-effectiveness [12]. However, it has limitations such as polymerization shrinkage, poor wear resistance, and color instability. To overcome these drawbacks, CAD/CAM PMMA materials have been introduced. Currently, CAD/CAM technology is increasingly used for provisional restorations, a field previously dominated by acrylic and composite resins. Additionally, there is growing interest in high-density polymers, such as highly cross-linked PMMA and composite resins [13].

Polyetheretherketone (PEEK) has emerged as a revolutionary polymer in contemporary dental research [14]. As part of the poly aryl ether ketone family, PEEK is available in several forms, including pressed blanks (manufactured through CAD/CAM process), pre pressed pellets, and granules [15]. Its exceptional properties have made it widely used in both medical and dental fields, positioning it as a highly promising material for fixed prosthodontics [16].

Indirect restorations using resin composites, such as onlays and overlays, present an effective option for adopting an adhesive and conservative treatment approach [17,18]. Their advantages make them particularly well-suited for extensive occlusal rehabilitations for patients with parafunctional habits and occlusal issues [19]. Additional benefits include their ease of handling and cost-effectiveness. They also facilitate straightforward intraoral adjustments, ensuring proper occlusion and effective surface polishing, which aligns with current clinical requirements and may reduce patient chair time [20, 21]. However, the literature currently lacks evidence comparing the wear properties of different provisional restorative materials. This study aims to compare and evaluate the two-body wear of PEEK, PMMA, and indirect composite materials after chewing simulation. The null hypothesis is that there is no difference in two-body wear among these materials following the simulation. The study objectives include fabricating standardized cylindrical specimens from each material, subjecting them to 60,000 and 120,000 cycles in a chewing simulator, and assessing volumetric loss using Geomagic Control X software before and after simulation. The goal is to identify the material with the least wear and discuss the implications for their use in dental restorations, particularly in cases involving extensive chewing forces and parafunctional habits.

2. Materials and Methods

This experimental study assessed the two-body wear of PEEK, PMMA, and indirect composite materials following chewing simulation. The research was approved by the Institutional Systematic Review Board (SRB/SDC/PROSTHO-2105/24/110) and included a sample size calculation using G*Power software (Heinrich-Heine-Universität Düsseldorf, Germany, Version 3.1). Based on an assumed effect size of 0.8 from similar studies, a significance level (α) of 0.05, a power of 0.85, and a confidence level of 0.95 ($1 - \alpha$), the calculation determined that 12 samples per group were required, amounting to a total of 36 samples [22].

Sample Preparation

An STL file for a disc with a diameter of 10 mm and a height of 6 mm was created using TinkerCad software (Autodesk Inc., United States), in accordance with ISO 14801 standards. This file was exported to the IMES iCore 350i milling machine (IMES iCore 350i, Germany). Group 1 samples were machined from PEEK blanks (BioHpp, Bredent GmbH, Senden, Germany) (Figure 1A). Group 2 samples were milled from PMMA (Aidite, United States) (Figure 1B), and Group 3 samples were made from an indirect composite material (Ceramage by GC Corp.) (Figure 1C). To fabricate the indirect composite samples, clear silicone molds were first created using a PEEK sample. The indirect composite material was then packed incrementally into these silicone molds using Teflon-coated instruments, pressed onto a glass slab to ensure a flat surface, and cured for 3 minutes according to the manufacturer's guidelines. After fabrication, all samples were polished and scanned using a 3Shape lab scanner (3Shape E series, Copenhagen, Denmark.

Figure 1: Sample preparation. A. PEEK samples (Group 1), B. PMMA samples (Group 2), C. Indirect composite sample (Group 3)

Chewing Simulation

To prepare the specimens for testing, fast-setting high-strength plaster (WhipMix Mounting Plaster, Ivoclar Vivadent AG, Schaan Fürstentum, Liechtenstein) was used to mount them. Steatite antagonists, designed to mimic enamel, were attached to aluminum mounts with acrylic resin. These steatite balls, measuring 4 mm in diameter, were placed in the center of each sample. The testing took place in a chewing simulator (CS-4, SD Mechatronik, Munich, Germany), which has four chambers and two movable parts: a vertical bar (Z-axis) and a horizontal table (X-axis). The specimens were fixed to the table, which allowed them to move back and forth. The antagonists were attached to the vertical bar and could move up and down. A 5 kg load was applied to the specimens through the antagonists. The vertical bar held the antagonists, while the horizontal bar had force sensors to measure the applied forces during testing (Figure 2). Incremental loads were added to simulate chewing forces, and the simulations were conducted for 60,000 and 120,000 cycles. After testing, the surface of the specimens was scanned again using the lab scanner.

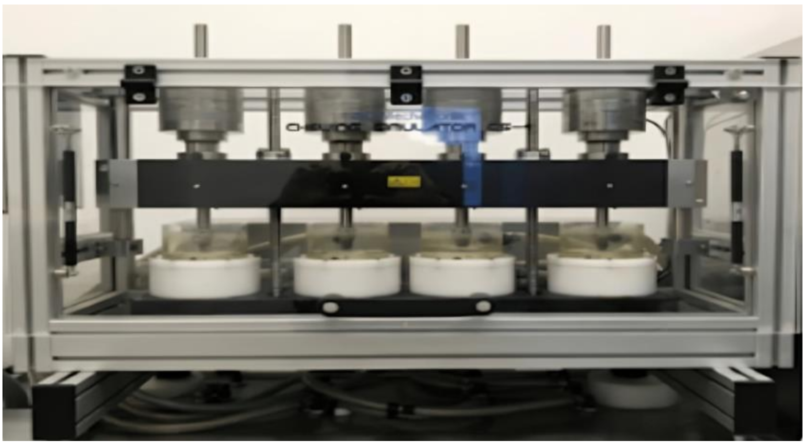

Figure 2: Chewing simulation.

Measuring Volumetric Loss

The samples, which were scanned with a 3Shape lab scanner both before and after the chewing simulation, were then superimposed and analyzed for volumetric loss using Geomagic Control X software (3D Systems, North Carolina, United States).

Statistical Analysis

Data was collected and tabulated in google forms. The differences between the wear of 3 groups were analyzed using one-way Analysis of variance (ANOVA) and Post hoc Tukey's test with SPSS software version 26.0 (Chicago, United States). This analysis was conducted after confirming the normality of the data set, with statistical significance set at 0.05.

3. Results

Table 1 presents the results of the one-way ANOVA comparing volumetric loss of different materials after 60,000 and 120,000 cycles of chewing simulation. For PEEK, the volumetric loss increased from 0.39 mm³ (SD = 0.16) after 60,000 cycles to 0.77 mm³ (SD = 0.29) after 120,000 cycles, with a statistically significant p-value of 0.031, indicating a significant difference. PMMA exhibited a volumetric loss of 0.60 mm³ (SD = 0.25) after 60,000 cycles and 0.89 mm³ (SD = 0.47) after 120,000 cycles, with no statistically significant difference. Ceramage showed a volumetric loss of 0.42 mm³ (SD = 0.19) after 60,000 cycles and 0.69 mm³ (SD = 0.22) after 120,000 cycles, also without a significant p-value. The results suggest that PEEK shows a statistically significant increase in volumetric loss with extended cycling, while PMMA and Ceramage do not exhibit significant changes over the same period. The Tukey HSD test results show significant differences in wear between the groups after both 60,000 and 120,000 cycles. PEEK had less wear than PMMA but more wear than the indirect composite. PMMA showed the most wear among all groups. The indirect composite had less wear than PMMA but more than PEEK after 60,000 cycles and less than PEEK after 120,000 cycles. These results highlight the different wear resistances of the materials tested.

Specimen Material	Volumetric Loss (mm³) Mean (Standard Deviation)		P Value
	60,000 cycles	120,000 cycles	
Polyetheretherketone (PEEK)	0.39 (0.16)	0.77 (0.29)	0.031*
Polymethyl methacrylate (PMMA)	0.60 (0.25)	0.89 (0.47)	
Indirect composite	0.42 (0.19)	0.69 (0.22)	

Table 1: One-way ANOVA to compare volumetric loss after chewing simulator. P value < 0.05 was taken as significant.

Specimen material	Volumetric Loss (mm³) Mean (Standard deviation)		P value
	60,000 cycles	120,000 cycles	
Polyetheretherketone (PEEK)	0.39 (0.16)	0.77 (0.29)	0.031*
Polymethyl methacrylate (PMMA)	0.60 (0.25)	0.89 (0.47)	
Indirect composite	0.42 (0.19)	0.69 (0.22)	

Figure 3 shows the mean wear / volumetric loss of the 3 groups at 60,000 and 120,000 cycles of chewing simulation. PMMA had the highest volumetric loss when compared to PEEK and indirect composite.

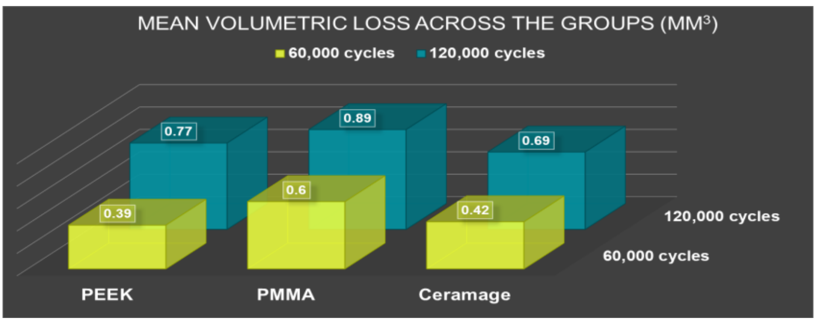

Figure 3: Mean volumetric loss (in mm³) among the samples for various masticatory cycles

4. Discussion

This study compared the two-body wear of PEEK, PMMA, and indirect composite materials after chewing simulations. Results showed that PEEK's volumetric loss significantly increased from 0.39 mm^3 (SD = 0.16) to 0.77 mm^3 (SD = 0.29) after 60,000 and 120,000 cycles ($p = 0.031$). In contrast, PMMA and Ceramage did not show significant changes in wear over the same periods. Thus, PEEK exhibited a significant increase in wear with more cycles, unlike PMMA and Ceramage. Consequently, the null hypothesis, which assumed no difference in wear properties among the materials, was rejected.

Evaluating the wear characteristics of dental materials is crucial for developing effective treatment plans. An ideal restorative material should closely replicate the wear behavior of natural enamel, offering high wear resistance while causing minimal abrasion to opposing teeth [23]. It should also effectively adapt to the forces of chewing, which is crucial for patients with parafunctional habits or occlusal discrepancies [24]. Poly(methyl methacrylate) (PMMA) is recognized for its ease of use and cost-effectiveness. However, our study reveals that PMMA has the highest wear among the materials tested. This finding corroborates earlier research highlighting PMMA's issues with polymerization shrinkage, poor wear resistance, and color instability over time [25]. Despite its common use in provisional restorations, its limitations should be considered, especially for long-term applications exposed to significant masticatory forces. PEEK displayed wear characteristics intermediate between PMMA and indirect composite. While PEEK is valued for its mechanical properties and biocompatibility, it does not achieve the wear resistance seen with indirect composite in our study. Despite its suitability for certain clinical scenarios, PEEK's limitations must be acknowledged, particularly for extended occlusal rehabilitation [26]. Indirect Composite showed the lowest wear among the tested materials, making it a strong candidate for situations where long-term durability and minimal wear are essential. It closely mimics the wear behavior of natural dental tissues, benefiting patients with parafunctional habits or occlusal imbalances [27]. However, it is worth noting that Indirect Composite may entail higher material and fabrication costs compared to PMMA. A study compared the wear resistance of various ceramic and composite restorative materials to a type III gold alloy, finding that composite and the gold alloy exhibited similar wear characteristics [28]. Another study found that milled lithium disilicate exhibited significantly more wear than gold alloy and human enamel, while glaze-fired lithium disilicate and other ceramics showed comparable wear to human enamel [29].

5. Limitations and Future Scope

This study has several limitations. It was conducted in a controlled in-vitro environment, which does not fully replicate the complex conditions in the mouth, such as variations in pH, temperature, and salivary flow. The sample size, though statistically determined, may not capture the full variability of material performance in a diverse population. Additionally, the focus was solely on volumetric loss, excluding factors like surface roughness, microhardness, and effects on surrounding tissues. Future research should include long-term in-vivo studies to evaluate wear characteristics under real-life conditions, considering diet, oral hygiene habits, and varying chewing forces. Investigating these materials' effects on surrounding oral tissues and their interaction with different dental adhesives and cements would provide a more comprehensive understanding. Moreover, studies comparing the cost-effectiveness and patient satisfaction with these materials in various clinical applications would help guide material selection in dental practice.

6. Conclusion

In conclusion, our study demonstrates notable differences in the wear characteristics of PMMA, PEEK, and Indirect Composite materials. Despite PMMA's cost-effectiveness and widespread use, it showed the highest wear. PEEK, while offering better wear resistance than PMMA, did not match the performance of Indirect Composite. Indirect Composite, with its minimal wear, is ideal for situations requiring long-term durability and natural wear behavior. Dentists and prosthodontists should consider these wear properties when selecting materials, tailoring their choices to meet the specific clinical needs of each patient.

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