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Comparative Analysis of Flexural Strength between Heat Polymerized PMMA, Injectable Flexible Nylon-Based Resin, and CAD/CAM (PEEK) Denture Base Materials: An In-Vitro Study

Zieneb Elgarboae, Narjes Mohsen, Fatima Abusua, Sarra Ben Hamida*, Mohamed Elmaroush

Department of Prosthodontics, Faculty of Dentistry, University of Tripoli, Tripoli, Libya

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ABSTRACT

This study aimed to compare the flexural strength of Heat Polymerized PMMA, Injectable Flexible Nylon-Based Resin, and CAD/CAM Polyether Ether Ketone (PEEK) denture base materials. A total of 36 rectangular samples with dimensions of (64mm x 10 mm x 3.3mm) were fabricated from Heat Polymerized PMMA, Injectable Flexible Nylon-Based Resin, and CAD/CAM (PEEK). These samples were divided into three groups of 12 samples. The three-point flexural strength test was carried out using a universal testing machine. A one-way analysis of variance (ANOVA) test was used for statistical analysis. Statistical significance was set at $P \leq 0.05$. The flexural strength of CAD/CAM (PEEK) (137.92 ± 8.92555 MPa) was the highest, followed by Heat Polymerized Acrylic Resin (75.162 ± 9.40870 MPa), and the lowest was for Injectable Flexible Nylon-Based Resin (54.01 ± 20.29325 MPa). Considering the study's limitations, CAD/CAM PEEK showed the highest flexural strength, followed by heat-polymerized PMMA, while injectable flexible nylon-based resin exhibited the lowest strength. These findings suggest that PEEK may provide more durable and reliable denture bases, potentially improving prosthesis longevity and patient satisfaction.

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INTRODUCTION

Dentures are constantly exposed to different forces inside the mouth, which can sometimes cause them to bend or break. This problem is more likely to occur if the material used for the denture base does not have good resistance to bending. For this reason, choosing a material with reliable strength is important to maintain the function and longevity of the prosthesis [1,2].

One of the most important mechanical properties is the ability of the material to resist flexural stress, as this strongly affects how long the denture will last and how well it can withstand daily use [3,4]. During normal function, dentures go through repeated chewing cycles, and if the material lacks adequate toughness, it may weaken over time and eventually fracture [5].

Polymethyl methacrylate (PMMA) remains the material of choice for denture base construction because it combines several advantages, including good esthetics, relatively low cost, and simple processing and repair procedures [6]. However, some cons have been reported, including low flexural strength, elastic modulus, and impact strength, which are considered the main causes of denture fracture [7,8].

Several approaches have been explored to address these limitations, including the introduction of advanced materials, modern fabrication techniques, and various reinforcement methods [9,10]. Reinforcement and modifications to create improved denture base material have been successful to some extent, but they leave room for further enhancement of mechanical properties as well as trial of new materials like CAD/CAM denture base resins [11].

The introduction of nylon-based substances into dental appliance production marked a significant advancement in dental materials. Thermoplastic polymers for prosthetic use were first incorporated in dentistry during the 1950s, primarily in the form of polyamides (commonly known as nylon). By 1962 [12], rapid injection systems were developed to aid in their application. Polyamides gained attention as denture base materials due to their desirable characteristics, including high flexibility, light weight, strong impact resistance, and minimal water absorption and solubility [13]. However, their clinical use is limited by drawbacks such as a low elastic modulus, as well as reduced flexural and tensile strength [14,15].

The fabrication methods play a crucial role in determining the flexural strength of dentures. Traditional fabrication techniques often result in internal flaws, such as porosity, which cause shrinkage and, in turn, negatively impact the mechanical performance of dentures [16]. In order to address the limitations of traditional fabrication methods, the CAD/CAM approach was developed, enabling the production of dentures through the milling of pre-polymerized resin discs [17]. These discs are produced by subjecting the material to

***Corresponding E-mail addresses**: s.benhamida@uot.edu.ly

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significant heat and pressure, thus reducing the chances of shrinkage and porosity due to residual monomer content [18]. CAD/CAM technique uses both PMMA resins and polyether ether ketone (PEEK) material for fabrication [18, 19]. The benefits of the CAD/CAM technique are to improve the structural and mechanical qualities of the materials and enhance their durability.

Polyether ether ketone (PEEK) was first applied in aerospace engineering before being introduced into the medical field, particularly for spinal and hip implants in 1999, owing to its outstanding biocompatibility and chemical stability. Studies have reported that PEEK exhibits lower water absorption and minimal shrinkage compared with polymethyl methacrylate (PMMA). These advantageous characteristics have encouraged its consideration as a potential denture base material, offering improved dimensional stability and durability over conventional options [20]. However, there are fewer details in the literature regarding the flexural strength of PMMA versus Injectable Flexible Nylon-Based Resin and CAD/CAM (PEEK) denture base materials. Thus, this study aimed to compare the flexural strength of Heat Polymerized PMMA, Injectable Flexible Nylon-Based Resin, and CAD/CAM (PEEK) denture base materials.

MATERIALS AND METHODS

In the present laboratory-based study, 36 rectangular samples were fabricated using different denture base materials with dimensions of (64mm x 10mm x 3.3mm) according to ISO -20795-1:2013 standard for denture base testing [21]. For this study, the 36 specimens were allocated into three groups of 12 samples each.

Group I: Heat Polymerized Resin PMMA, subjected to short thermal cycling, manipulated according to the manufacturer's instructions.

Group II: Thermoplastic Injectable Flexible Nylon-Based Resin that was injected and molded.

Group III: CAD/CAM (PEEK), milled from solid blocks using computer-aided design/manufacturing.

The flexural strength of all samples was evaluated using a three-point bending test on a universal testing machine (INSTRON, USA, Model XYZ). This testing setup measures the strength of bars supported at both ends while a load is applied at the midpoint. The apparatus consists of a loading wedge and a supporting wedge, set 50 mm apart. Each sample was positioned at the center, and the loading wedge moved at a rate of 5 mm/min under a maximum load of 500 kg. The flexural strength values were recorded and calculated using the machine's built-in software,

In Figure 1, the flexural strength was calculated using the following formula:

Flexural strength $=\frac{3PL}{2bd^2}$

Where:

P represents the maximum load applied (in Newtons).
L is the span length between the supports (in millimeters).
b is the width of the specimen (in millimeters).
d is the thickness of the specimen (in millimeters).

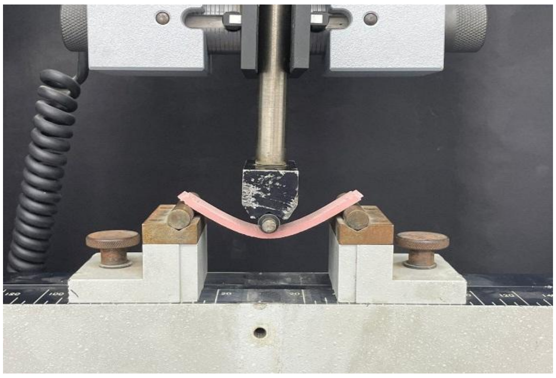

Figure 1. A loading force was applied to the center of each sample

Data was collected and prepared in an electronic database for statistical analysis using SPSS version 26.0 (IBM USA). Data was analyzed with one-way ANOVA, and multiple comparisons were undertaken using Tukey's HSD test. Statistical significance was set at P ≤ 0.05.

RESULTS

The mean and standard deviation, as well as the analysis of variance (ANOVA) test of flexural strength for the three groups (where each study group was comprised of 12 samples) are presented in Table 1. The results showed a statistically significant difference, with a P value ≤ 0.05. For multiple comparisons among the three study groups, the post hoc Tukey test was performed, revealing that the mean flexural strength values of all groups differed significantly (P ≤ 0.05) (Table 2).

Table 1. The descriptive statistics of the flexural strength test on the different study groups

Group	N	Mean (MPa)	Std. Deviation	P value
Heat Polymerized Acrylic Resin	12	75.162	9.40870	P< 0.05
Injectable Flexible Nylon-Based Resin	12	54.01	20.29325	
CAD/CAM (PEEK)	12	137.92	8.92555	

Table 2. Post hoc Tukey test (multiple comparisons between the study groups)

Material	Material	P value
Heat Polymerized Acrylic Resin	Injectable Flexible Nylon-Based Resin	0.002
	CAD/CAM (PEEK)	0.000
Injectable Flexible Nylon-Based Resin	Heat Polymerized Acrylic Resin	0.002
	CAD/CAM (PEEK)	0.000
CAD/CAM (PEEK)	Heat Polymerized Acrylic Resin	0.000
	Injectable Flexible Nylon-Based Resin	0.000

The mean difference is significant at the 0.05 level

DISCUSSION

The samples in the present study were subjected to three-point bending. Heat Polymerization Acrylic Resin denture base material was chosen in this study as it is easily available and is widely used as a denture base resin in our institute, compared with Injectable Flexible Nylon-Based Resin and CAD/CAM (PEEK) denture base materials, respectively.

The results of this study demonstrated significant differences in the flexural strength of the three materials tested: Heat Polymerized Acrylic Resin, Injectable Flexible Nylon-Based Resin, and CAD/CAM (PEEK) (Table 1). The mean flexural strength of Heat Polymerized Acrylic denture base resin was 75.162 MPa, whereas the mean flexural strength of Injectable Flexible Nylon-Based Resin and CAD/CAM (PEEK) were 54.01 MPa and 137.92 MPa, respectively. The ANOVA test revealed a statistically significant difference among the groups ($P \leq 0.05$).

In this study, CAD/CAM (PEEK) showed the highest mean flexural strength, reflecting superior and consistent performance compared to other materials. These results are consistent with Al-Dwairi et al., Dubey et al., and Aguirre et al., who found that CAD/CAM resins had higher impact and flexural strength than conventionally fabricated materials [22-24]. Furthermore, Shrivastava et al. reported that (PEEK) exhibits higher hardness and flexural strength compared to PMMA. As a result, prostheses with a (PEEK) substructure are associated with improved longevity, better prognosis, and enhanced patient comfort and satisfaction [25].

The greater impact and flexural strength of (PEEK) samples, compared to conventional heat-cured ones, may result from their higher degree of polymerization, which enhances their material strength [26]. CAD/CAM resin blocks undergo extensive pre-polymerization, resulting in a densely packed resin structure with minimal porosity [27]. Conventional Heat-Polymerized PMMA often exhibits increased residual monomer content and polymerization shrinkage, which can contribute to structural weaknesses. In contrast, CAD/CAM milling techniques ensure a highly dense and homogeneous material, leading to superior mechanical performance [28,29].

The greater strength of (PEEK) (on a per mass basis) made it a highly desired material for industrial applications, as reported by Schmidlin et al. (2010), who stated that the (PEEK) has a high strength and stability that makes it suitable for high-stress applications, such as temporary abutment for implants while manufacturing of temporary crowns [30].

In contrast, Heat Polymerized Acrylic Resin demonstrated moderate flexural strength with a mean value of 75.162 MPa, which is within the range of 65-90 MPa noted in the study by Chuchulska et al. 2024. This material's performance is applicable with its widespread use in denture fabrication, where moderate strength and ease of processing are required. However, its significantly lower flexural strength compared to CAD/CAM (PEEK) ($p = 0.000$) suggests that it may not be suitable for applications requiring high mechanical resistance [31].

According to the findings of Mohsen et al. (2025), CAD/CAM (PEEK) denture base materials demonstrated significantly superior fracture strength when compared with Conventional Heat-Polymerized and Flexible denture base materials. This improvement in mechanical properties can be attributed to the advanced manufacturing process and inherent characteristics of (PEEK), such as its high modulus of elasticity and resistance to crack propagation. The implication of this finding is particularly relevant in clinical scenarios where mechanical performance is critical, such as in complete dentures or implant-supported prosthesis, where the material is subjected to high masticatory loads. These results suggested that CAM-fabricated PEEK bases could offer a more reliable long-term alternative to conventional acrylic or flexible materials, especially in patients with bruxism or high functional demands [32].

In the present study, the Injectable Flexible Nylon-Based Resin group was found to exhibit the lowest flexural strength, measured at 54.01 MPa. This result contradicts the observations made by Kirad et al. (2020), who reported that Injection molding materials processed through an optimized technique demonstrated improved mechanical behavior, including a notably higher flexural strength of 84.82 MPa. Their study concluded that the injection molding technique enhances both flexural and impact strength when compared to conventional compression molding or heat-polymerized PMMA. The inconsistency between these findings highlights a potential variability in material performance that may be affected by various factors such as variation in polymer composition, molecular structure, processing parameters, and even brand-specific formulations.

These inconsistencies underline the necessity for the standardization of injection-molded denture base resins and more rigorous testing protocols to ensure reproducibility across different clinical settings and manufacturers [33].
Moreover, the study by Takabayashi (2010) emphasized this variability, noting that injection-molded resins often show inconsistent mechanical performance due to the complexity of the fabrication process. He stressed the importance of enhancing the manufacturing workflow to achieve better product uniformity and reliability. The limited mechanical strength of Flexible Nylon-Based Resins, as observed in the current study, suggests that such materials may be more appropriate for clinical situations where flexibility and patient comfort take precedence over mechanical strength. One notable example is their use in removable partial dentures, where adaptability, comfort, and esthetic integration into the oral environment are more important than load-bearing capacity [34].
This view is further supported by Fueki et al. (2014), who reported that flexible resins are frequently chosen not for their strength but for their comfort and esthetic appeal, particularly in cases involving patients with thin oral mucosa or undercuts that complicate the insertion and removal of rigid dentures (35).
It is essential to note that the current investigation was conducted under strictly controlled laboratory conditions, which do not fully replicate the complex and dynamic conditions present in the oral cavity. In vivo, denture base materials are exposed to constant thermal fluctuations, moisture, enzymatic activity, changes in PH, and cyclic mechanical stresses resulting from mastication and parafunctional habits such as clenching or grinding. While laboratory testing provides useful baseline data, it cannot substitute for evaluations under clinically simulated conditions. Further studies should incorporate advanced testing methods that simulate the intraoral environment more closely, such as thermo-cycling to mimic temperature changes and cyclic loading to replicate functional stresses over time. Incorporating such factors would provide a more realistic understanding of how these materials perform during long-term use and could help identify which materials are most suitable for different patient populations and treatment plans.
Moreover, the study's scope was limited by the inclusion of only one commercial brand per material category. This limitation restricts the generalizability of the finding, as the performance of the denture base materials can vary widely between manufacturers due to differences in raw materials, processing techniques, and proprietary additives. For example, even among PMMA-based resins, variations in monomer to polymer ratios, cross-linking agents, and polymerization methods can significantly alter the mechanical properties of the final product. To provide a more comprehensive and clinically relevant evaluation, future research should include a wider range of brands, particularly for commonly used materials like acrylic resins. This would not only allow for inter-brand comparisons but also aid in establishing industry-wide performance benchmarks, helping clinicians make more informed decisions when selecting materials for specific prosthodontic applications.

CONCLUSION

Considering the study's limitations, CAD/CAM (PEEK) showed the highest flexural strength, followed by heat-polymerized PMMA, while injectable flexible nylon-based resin exhibited the lowest strength. These findings suggest that (PEEK) may provide more durable and reliable denture bases, potentially improving prosthesis longevity and patient satisfaction.

Conflict of interest. Nil

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