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Original article

In Vitro Evaluation of the Fracture Strength among Three Different Denture Base Materials

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Abstract
Failure in the form of denture fracture is commonly encountered by both removable prosthodontics wearers and dentists, it is mainly attributed to material properties, technical features, stresses while in function or due to impact as a consequence of dropping the dentures. Traditionally, Heat-Polymerized Polymethylmethacrylate (PMMA) has been the gold standard for denture bases due to its ease of processing and acceptable mechanical properties. However, newer materials, injectable flexible nylon-based resin and CAD/CAM Polyether ether Ketone (PEEK) denture bases are being introduced with claims of superior strength and durability. The aim of this study was to investigate the fracture strength of three commonly used denture base materials in Libya, which may aid in selecting the best material for a given application and predicting potential material behavior under load when holding the durability of the material in mind. A total of 36 samples were tested. These samples were divided into three groups, with 12 samples each: Group I heat polymerized acrylic resin PMMA, group II Injectable flexible nylon-based resin and group III CAD/CAM (PEEK). The fracture strength test was carried out on a universal testing machine at a crosshead speed of 5 mm/min. The results were analyzed using ANOVA, and multiple comparisons were undertaken using Tukey's HSD test. Statistical significance was set at $P \leq 0.001$. The result of this study shows there were significant differences in the fracture strength among the three groups ($P < 0.001$). Moreover, CAD/CAM (PEEK) denture base material exhibited significantly the highest fracture strength (234.17N ± 13.5) whereas the least fracture strength value was measured with Injectable flexible nylon-based resin denture base material (75.25N±10.5). The study concluded that, within the limitations of this study, the results demonstrate that CAD/CAM (PEEK) outperforms Injectable flexible nylon-based resin and heat polymerized acrylic denture base materials in terms of the fracture strength, supporting its potential as an advanced material for denture construction. However, further clinical studies are recommended.
Keywords. Fracture Strength, Denture Base Materials, Libya.

Introduction

Failure in the form of denture fracture is commonly encountered by removable prosthodontics wearers and dentists alike, it is mainly attributed to material properties, technical features, stresses while in function or due to impact as a consequence of dropping the dentures [1,2]. Acrylic-based resins are intensively used in dental practice as denture base materials. However, its resistance to impact and its fatigue failure are somewhat poor. Thus, fracture of conventional acrylic resin denture bases is an ongoing problem in the field of prosthodontic dentistry [3,4]. A survey of removable denture base fractures depicted a ratio of maxillary to mandibular fractures which was generally 2:1 based on repairs performed by commercial dental laboratories [4,5]. With this in mind the increasing need for acrylic resins with better quality is imperative [6].

Attempting to overcome this drawback the development of new and stronger acrylic resins after the introduction and extensive ongoing use of Heat polymerized acrylic resin the Injectable flexible nylon-based resin and Polyether ether ketone (PEEK) for CAD/CAM among other materials were introduced to the clinical world of removable prosthodontics. Methylmethacrylate was first clinically evaluated by Wright during 1937 and found to fulfill virtually all the requirements of an ideal denture base material [7-9]. Two types of Polymethylmethacrylate material were developed based on the method of activation. Heat activated and chemically activated [7,10]. Chemists grafted PMMA resins in 1961 showing increase in resistance to impact fracture [7,11].

Many thermoplastic resins are used in dentistry, such as acetyl resins, PC resins (belonging to the group of polyester resins), polyamides (nylons) and acrylic resins [12]. Nylon was introduced in London in the 1950s as a denture base material, proving to be entirely unsatisfactory due to its reduced ability to resist oral conditions, resulting in swelling of the denture base due to absorption of moisture [7,13]. Thermoplastic resins are a new material, in which a fully polymerized basic material is softened by heat (without chemical changes) and injected afterwards [7,14]. These historic breakthroughs and many more paved the way for even further development and improvements in denture base materials as well as manufacturing and processing techniques.

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Great increase in the recent decade in the utilization of thermoplastic resins in dentistry. The technique used is based on plasticizing the material and only thermal processing is used without any chemical reaction [15]. Thermoplastic polymers are characterized by high fracture strength, among other mechanical properties, but these thermoplastic polymers lack in the natural translucency of Polymethyl methacrylate, but they are very susceptible to wear and tear. However, thermoplastic PMMA have excellent properties, it is difficult to be processed as a result of the high viscosity and processing temperature [16], this is not to be mistaken for the conventional heat -cure PMMA studied in this research; which is known for its high-water absorption, porosity, dimension instability and residual monomer [12].

PEEK has an excellent mechanical property; hence it has been proposed for other prosthodontic applications as well, such as fixed prostheses [17]. The mechanical properties of PEEK do not change during the sterilization process and its elastic modulus is similar to those of human bone, enamel, and dentin, suggesting it to be a suitable restorative material. PEEK features stable chemical properties, biocompatible, wear-resistant, stable at elevated temperatures and insoluble in water. This material also presents low reactivity with other materials, is nonallergic, and has lower plaque affinity than other materials such as metals and resins [18].

As well as PEEK the CAD/CAM were studied, the employment of computer aided designing and computer aided manufacture (CAD-CAM) technology in the fabrication of removable prostheses may eliminate many disadvantages of the conventional acrylic resins [19]. PEEK can be milled using a variety of CAD/CAM systems. Typically, the process involves using specialized software to create a 3D digital model of the desired prosthesis, which is then used to guide a milling machine to carve the PEEK material into the final shape. The milling process can produce highly precise and accurate results, making it a popular choice for manufacturing dental prosthetics, including implant abutments, bridges, and denture frameworks.

Bearing this in mind we have to facilitate and ease the difficult task of choosing the most appropriate materials used in denture base fabrication. This task that lies on the shoulders of dental clinicians and technicians alike. Hence the aim of this study is to shed some light on the fracture strength and evaluate three commonly used denture base materials in Libya by comparing the fracture strength of a variety of materials aids in selecting the best material for a given application and predicting potential material behavior under load when holding the durability of the material in mind. Considering this during the design phase can help assessing and minimizing the risk of failure. On deciding which materials to study the choice of these materials was based on recent modifications and research materials used in the production and making of removable partial and complete dentures holding in mind the differences in the methods of production and the manner in which they are individually used. The aim of this study was to investigate the fracture strength of three commonly used denture base materials in Libya, which may aid in selecting the best material for a given application and predicting potential material behavior under load when holding the durability of the material in mind.

Material and method

The materials chosen for this study were conventional heat-polymerized PMMA (Polymethylmethacrylate), Injectable flexible nylon-based resin, and CAD/CAM (PEEK) denture base materials. A total of 36 samples were tested. These samples were divided into three groups, with 12 samples each. Group I: Heat polymerized acrylic resin PMMA, subjected to short thermal cycling manipulated according to 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.

Table 1. Materials used in the study

Material	Product name	Manufacturer
Heat polymerized acrylic resin	Dentsply	USA
Injectable flexible nylon-based resin	Biosoft	China
CAD/CAM (PEEK)	Asiga	Sydney Australia

Rectangular bar-shaped specimens (64mm×10mm×3.3mm) were prepared for each material group (fig. 1), following the standard dimensions recommended by ISO 1567 for denture base testing [20].

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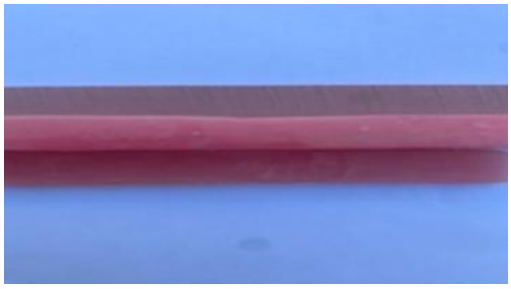

Figure1. Sample of different denture base materials constructed in the study.

The fracture strength was tested by using universal testing machine (INSTRON United State Model XYZ). Each sample was placed horizontally on the two fixed support points, ensuring proper alignment. A steady load was applied to the center of the sample using a universal testing machine at a constant crosshead speed of 5mm/min (fig. 2). As the force was applied, the device continuously measured the applied force (in newtons) using load cell. The test continued until the sample fractured. The maximum force applied before the fracture was recorded and represented the fracture strength of the materials.
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 $P \leq 0.001$.

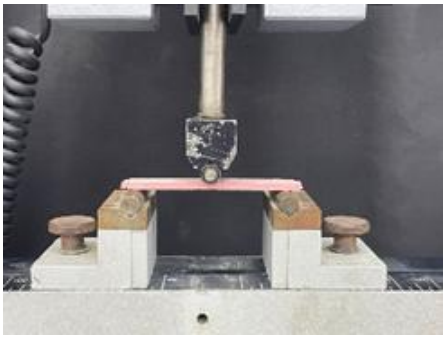

Figure 2. A sample on universal testing machine table.

Results

The mean and standard deviation and ANOVA test of the fracture strength for each study group are presented in Table 2. The one-way ANOVA test demonstrated that there were significant differences in the fracture strength among the three groups ($P< 0.001$).

Table 2. The descriptive statistics of the fracture strengths in the different study groups

Group	N	Mean	Std. Deviation	P value
Heat polymerized acrylic resin	12	82.63N	±9.4	P< 0.001
Injectable flexible nylon-based resin	12	75.25N	±10.5	
CAD/CAM (PEEK)	12	234.17N	±13.5	

The results of ANOVA and post hoc Tukey test for comparing between the groups demonstrates that CAD/CAM denture base material had significantly the highest fracture strength (234.17N ± 13.5) with $P< 0.001$. However post hoc Tukey test showed that there was no significant difference in the fracture strength between Heat polymerized acrylic resin (82.63N±9.4) and Injectable flexible nylon-based resin denture base materials (75.25N±10.5) with $P\geq 0.001$. fig. 3 shows the differences in the fracture strength among three different denture base materials.

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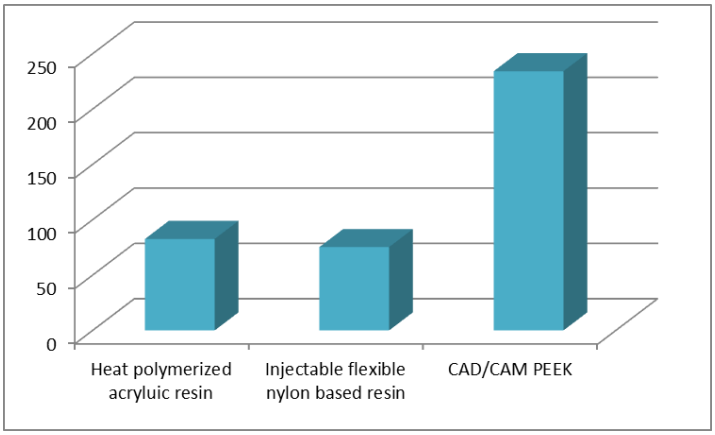

Figure 3. Comparison between the different denture base materials according to the fracture strength.

Discussion

To compare the performance of different denture base resins, various mechanical tests can be performed. In the present study, comparison of the fracture strength between three different denture base materials (heat polymerized acrylic resin, Flexible nylon-based resin and CAD/CAM (PEEK)).

The present study demonstrated that CAD/CAM denture base material exhibits significantly higher fracture strength in comparison to conventional heat polymerized resin and Injectable flexible nylon-based resin denture base material. This finding aligns with previous studies [21, 22] which reported superior mechanical properties of CAD/CAM denture base material in comparison with conventional heat polymerized resin. One of the key advantages of CAD/CAM technology is its ability to fabricate dentures with enhanced mechanical properties. The improved strength characteristics observed in this study may be attributed to the controlled polymerization process and reduced porosity associated with CAD/CAM processing. Traditional 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 [23,24].

Additionally, the study findings are consistent with previous research by Pacquet et al., which highlighted significant differences in flexural and impact strengths among different denture fabrication methods. Their study also confirmed that CAD/CAM PMMA consistently outperforms conventionally processed resins [25]. These results suggest that CAD/CAM dentures offer greater long-term durability and resistance to mechanical failure, making them a preferable choice for clinical applications. Furthermore, our observations support the conclusions of. Al-Dwairi et al. and Aguirre et al, who found that CAD/CAM (PEEK) demonstrates superior impact properties compared to conventional PMMA [21, 26]. The consistent findings across multiple studies reinforce the reliability and effectiveness of CAD/CAM technology in enhancing denture strength and performance.

The findings of the present study confirm that CAD/CAM (PEEK) denture base materials exhibit superior fracture strength compared to conventional heat-polymerized and flexible denture base material. However, the results from previous research by Steinmassl, et al., indicate that the fracture resistance of CAD/CAM resins is highly variable, while some CAD/CAM resins demonstrate significantly higher fracture loads, others do not always surpass the performance of conventional heat-cured or self-curing resins. This variable may be attributed to differences in material composition, processing techniques, and surface properties among CAD/CAM resins. The present study supports the notion that certain CAD/CAM materials, particularly those with enhanced polymerization and reduced porosity, provide improved mechanical strength [27].

Our study also aligns with previous findings regarding the relationship between surface roughness and fracture load. A more homogeneous and dense structure in CAD/CAM (PEEK) may contribute to improved load-bearing capacity. However, the variability observed across different CAD/CAM resins highlights the importance of material selection in clinical applications [28].

Heat polymerized resin and PEEK denture base materials are rigid, making them unsuitable in cases with severe undercuts, as they require blocking of these area. Hence there was a need to have other materials that have better properties and certain amount of flexibility, so that they can be used in undercut areas [29, 30]. Moreover, dentures must have strong fracture strength to prevent fractures from high-impact forces, such as unintentional drops [31]. However, in the recent study demonstrated that the CAD/CAM showed significantly higher fracture strength in comparison to injectable flexible nylon-based resin denture base material, previous researchers' study in 2022 evaluated the impact strength of CAD/CAM-milled, 3D-printed, and polyamide flexible and found that, flexible DBMs showed higher impact strength compared to CAD/CAM-milled resins [32].

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Interestingly, while the present study showed no significant difference in fracture strength between heat-polymerized resin and flexible denture base materials, CAD/CAM (PEEK) demonstrated a notable improvement, reinforcing its suitability for clinical applications where high-stress resistance is required. The lower surface roughness and higher modulus of elasticity of PEEK also contribute to its ability to withstand mechanical loads, making it an excellent alternative to traditional denture base materials [33].
In the present study, samples were fabricated in a size larger than the actual size of the denture base in the oral cavity to enhance measurement of their fracture strength. In clinical conditions, the maximum thickness of acrylic resin in the palate area is 2.5 mm, and increasing the thickness of specimens increases the likelihood of void formation or incomplete polymerization and can compromise the accuracy of the results of this study, it could not completely simulate the intraoral conditions. Therefore, clinical studies are required to confirm the present results.

Conclusion

Within the limitations of this study, the results demonstrate that CAD/CAM (PEEK) outperforms flexible and heat polymerized denture base materials in terms of the fracture strength, that supporting its potential as an advanced material for denture construction. However, further clinical studies are recommended.

Conflict of interest. Nil

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المستخلص

يعتبر الفشل في شكل كسر طقم الأسنان المتحرك من الأمور الشائعة التي يواجهها كل من مرتدي أطقم الأسنان المتحركة وأطباء الأسنان، ويرجع ذلك بشكل أساسي إلى خصائص المواد والميزات التقنية والاجهاد أثناء الاستخدام أو بسبب استضام نتيجة سقوط طقم الأسنان. تقليديًا، كان بولي ميثيل ميثاكريلات المبلمر بالحرارة هو المعيار الذهبي لقواعد طقم الأسنان المتحرك نظرًا لسهولة معالجته و تشكيله و خواصه الميكانيكية المقبولة. ومع ذلك، يتم تقديم مواد أحدث، كراتنج مرن قابل للحقن قائم على النايلون ومادة متعدد ايثر ايثر كيتون كاد/كام المصممه و المصنعة بواسطة الكمبيوتر كقواعد أطقم الأسنان مع ادعاءات بالقوة والمتانة الفائقة. كان الهدف من هذه الدراسة هو التحقيق في قوة الكسر لثلاث مواد شائعة الاستخدام لقاعدة طقم الأسنان في ليبيا، والتي قد تساعد في اختيار أفضل مادة لتطبيق معين والتنبؤ بسلوك المادة المحتمل تحت الحمل مع وضع متانة المادة في الاعتبار. تم اختبار ما مجموعه 36 عينة. تم تقسيم هذه العينات إلى ثلاث مجموعات، كل منها 12 عينة: المجموعة الأولى راتنج الأكريليك المبلمر بالحرارة، المجموعة الثانية راتنج النايلون المرن القابل للحقن والمجموعة الثالثة متعدد ايثر ايثر كيتون كاد/كام المصممة و المصنعة بواسطة الكمبيوتر. تم إجراء اختبار قوة الكسر على آلة اختبار عالمية بسرعة رأس متقاطع 5 مم / دقيقة. تم تحليل النتائج باستخدام اختبار ANOVA و تم اجراء مقارنات باستخدام اختبار Tukey's HDS أظهرت نتائج هذه الدراسة وجود فروق ذات دلالة إحصائية في قوة الكسر بين مجموعات العينات عند $p<0.001$. أظهرت النتائج ان قاعدة طقم الاسنان المصممة و المصنعة بواسطة الكمبيوتر اعلى قوة كسر (13.5 ± 234.17N) بينما تم قياس اقل قيمة قوة كسر في الراتينج المرن القابل للحقن (10.5 ± 75.25N) وخلصت الدراسة إلى أنه ضمن حدود هذه الدراسة، أظهرت النتائج أن مادة متعدد ايثر ايثر كيتون كاد /كام المصممه و المصنعة بواسطة الكمبيوتر تتفوق على وراتينج مرن قابل للحقن قائم على النايلون ومواد قاعدة الأكريليك المصنوعة من البوليمر الحراري من حيث قوة الكسر، مما يدعم إمكاناتها كمادة متقدمة لبناء أطقم الأسنان. ومع ذلك، يوصى بإجراء المزيد من الدراسات السريرية.

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