Original article

Evaluating the Flexural Strength and Charpy Impact Strength of CAD/CAM and Compressed Molded PMMA Dentures: an *in vitro* Study

Asma Abdeewi[1,2]*, Gazia Elbakosh[3], Asam Aljiwiw[4], Tawfik Ajaal[5]

[1]*Libyan Polymer Research Center, Tripoli, Libya*
[2]*Research and Consultancy Center, Sirte University, Sirte, Libya*
[3]*Department of Dental Technology, Faculty of Medical Technology, University of Tripoli, Tripoli, Libya*
[4]*Department of Dental Technology, Faculty of Medical Technology, University of Elmergib, Alkmas, Libya*
[5]*Department of Engineering, Faculty of Engineering, Gharyan University, Libya.*

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Corresponding Email. Asmaa.Abdeewi@prc.ly

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ABSTRACT

Polymethyl methacrylate (PMMA) is a widely utilized polymer in the field of prosthodontics, valued for its versatility in clinical applications and its role in embedding dental specimens for research purposes. Its unique combination of properties—including low density, aesthetic appeal, cost-effectiveness, ease of manipulation, and customizable physical and mechanical characteristics—has made PMMA a preferred biomaterial in the fabrication of complete dentures. Complete dentures constructed from PMMA can be manufactured using two primary techniques: the conventional compression molding (CCM) method and the more recent computer-aided design and computer-aided manufacturing (CAD/CAM) technology. Each technique offers distinct advantages in terms of production efficiency, material consistency, and potential mechanical performance. The objective of this study was to evaluate and compare the mechanical properties of PMMA dentures produced using the CAD/CAM approach with those fabricated through the CCM technique. The experimental design included twenty PMMA denture samples, divided into two groups based on their manufacturing method. Each group consisted of ten samples, with five specimens allocated to flexural strength testing and five to Charpy impact strength testing. Prior to mechanical evaluation, all samples were immersed in artificial saliva at a controlled temperature of 37°C for one week to simulate oral conditions. Mechanical testing revealed variations in the performance of dentures depending on the fabrication technique. These differences suggest that the method of production may influence the clinical suitability of PMMA dentures, particularly when considering their role as the primary treatment option for edentulous patients. However, statistical analysis conducted using SPSS software indicated that the observed differences between the CCM and CAD/CAM groups were not statistically significant. Despite the lack of statistical significance, the results demonstrated that PMMA dentures manufactured using CAD/CAM technology exhibited superior mechanical resistance. This finding supports the recommendation of CAD/CAM-produced dentures as a more robust and reliable option, offering enhanced durability and performance in clinical settings.

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INTRODUCTION

Tooth loss is a significant concern for many individuals, as it affects both functional and psychological well-being. The replacement of missing teeth with artificial substitutes—such as dentures fabricated from acrylic resin—is essential for restoring oral function and maintaining quality of life. The denture base plays a critical role as an intermediary between the artificial teeth and the jaw, transmitting masticatory forces to the underlying tissues (1). Complete denture rehabilitation (CD) remains the most common and widely practiced form of prosthodontic treatment for edentulous patients. An ideal denture base material must be biocompatible, possess favorable physical and mechanical properties, and offer ease of cleaning and repair. It should also demonstrate strong adhesion to denture teeth to ensure clinical longevity (2). Polymethyl methacrylate (PMMA) is currently the material of choice for denture fabrication. First

introduced by Dr. Walter Wright in 1937, PMMA continues to be widely used due to its excellent handling characteristics and reliable performance (3).
Despite its many advantages, PMMA exhibits limitations in fracture resistance (4). Denture fractures caused by flexural strain and impact forces are common concerns among users. As the alveolar ridge undergoes irregular resorption, the denture base must withstand uneven force distribution, making high flexural strength a critical property (5). Flexural fatigue fractures typically result from the gradual propagation of microcracks at stress concentration points, rather than from a single force application. Enhancing the flexural strength of acrylic resin improves its resistance to fatigue failure and reduces the risk of clinical complications (6). Impact strength, defined as the energy absorbed by a material upon sudden impact, is another essential parameter. A denture base with sufficient impact strength can resist fracture from accidental drops, a frequent occurrence in daily use. The method of polymerization used during denture fabrication significantly influences the material's impact strength (7). Failures due to flexural fatigue may result from strong occlusal biting pressures, while impact-related failures are typically caused by accidental trauma. Therefore, evaluating both transverse strength and impact strength is crucial for assessing the durability and clinical reliability of denture base materials (8).
Traditional compression molding techniques, while widely used, are associated with shrinkage and warpage due to the molding process. Porosity within the denture base further contributes to internal stresses, increasing the risk of distortion and mechanical failure (9). These limitations have led to the exploration of alternative fabrication methods, particularly those involving digital technologies. The introduction of CAD/CAM systems has transformed prosthodontic treatment for edentulous patients. These systems streamline the clinical workflow, allowing impressions, interocclusal records, and tooth selection to be completed in just two appointments. CAD/CAM dentures offer numerous advantages for both patients and clinicians. They are milled from pre-polymerized acrylic resin discs manufactured under high heat and pressure, resulting in prostheses that are free from shrinkage, residual monomer, and internal porosities (10). Given these advancements, the present study aimed to conduct an in vitro comparative evaluation of the flexural strength and Charpy impact strength of PMMA denture bases fabricated using two distinct techniques: conventional heat-cured resin and CAD/CAM milling. The findings are expected to contribute to the ongoing optimization of denture base materials and fabrication protocols in prosthodontic practice.

MATERIALS AND METHODS

Materials

PMMA denture base resin material manufactured by a different company, the material is supplied in the form of conventional and CAD. The conventional material primarily consists of resin, composed of polymer and monomer components in powder and liquid form (Ivoclar Vivadent). For the CAD/CAM technique, polymethyl methacrylate (PMMA) discs manufactured by KINGCHR (China), measuring 98 mm in diameter and 25 mm in height, were scanned using the DC5 milling system from Dental Concept Systems GmbH (Ulm, Germany).

Samples Preparation

PMMA denture materials were fabricated using two distinct methods—conventional and CAD/CAM—following the respective manufacturers' protocols. A total of twenty specimens were prepared and categorized into two groups based on the fabrication technique. Each mechanical test group comprised seven samples. Prior to testing, all specimens were immersed in artificial saliva at 37°C for one week to simulate oral conditions. Mechanical properties were evaluated through flexural strength and Charpy impact strength tests. Each sample was fabricated with standardized dimensions of 65 mm × 10 mm × 3 mm.

Compression-molded manufacturing technique

PMMA specimens were fabricated using the lost wax technique. Wax strips measuring 65 × 10 × 3 mm were manually cut using a wax knife. Each strip's dimensions were verified to ensure conformity with the required specifications. Simultaneously, the flasking process was initiated by mixing an improved type of gypsum in accordance with the manufacturer's instructions. The flask was placed in a water bath for 8 minutes to facilitate wax softening. Upon separation, residual wax was removed using hot water, followed by a final rinse with clean water. The flask halves were then allowed to cool to room temperature.
Ivoclar Vivadent resin was prepared by mixing 21 g of polymer with 10 ml of monomer, ensuring complete wetting of the polymer particles. The mixture was covered and left undisturbed for 10 minutes until it reached the dough stage. The resin was then packed into the mold using finger pressure. The flask was sealed using a pneumatic Flaskpress (Coe-Bilt) at a pressure of 6,000 psi and subsequently placed in boiling water for 30 minutes, following the manufacturer's

curing protocol. After curing, the flask was cooled for 30 minutes and immersed in water for an additional 15 minutes before being opened. Once the flask reached room temperature, the resin specimens were retrieved. All samples were manually polished to eliminate surface voids and irregularities. Final finishing and polishing were performed to achieve uniformity. Each sample was measured at five points using a digital caliper (Neiko) to confirm final dimensions of 65 × 10 × 3 mm within a tolerance of ±0.03 mm. All specimens were stored in distilled water at room temperature for one week to ensure proper conditioning, as recommended by the manufacturer.

CAD/CAM manufacturing technique
PMMA resin discs (KINGCHR, China), measuring 98 mm in diameter and 25 mm in height, were mounted into a Vhf K5 milling system (India). Specimen strips with dimensions of 65 × 10 × 3 mm were precisely cut using a lathing machine based on the digital layout. Following fabrication, all specimens underwent initial surface polishing using 400-grit silicon carbide abrasive paper under continuous water flow. Further finishing was performed using sequential sandpapering with a micromotor and handpiece equipped with a mandrel, operated at 5,000 rpm for 90 seconds. Final polishing was achieved by buffing with a pumice slurry to ensure smooth surface quality. Post-polishing, each specimen's dimensions were verified using a digital caliper to confirm conformity with the required measurements.

Artificial Saliva Preparation and Immersion Protocol
Artificial saliva was freshly prepared following the formulation proposed by Fusayama et al. The solution consisted of 0.400 g sodium chloride (NaCl), 0.400 g potassium chloride (KCl), 0.69 g sodium dihydrogen phosphate monohydrate ($NaH_2PO_4 \cdot H_2O$), 0.795 g calcium chloride monohydrate ($CaCl_2 \cdot H_2O$), and 0.005 g sodium sulfide nonahydrate ($Na_2S \cdot 9H_2O$), all dissolved in 1,000 mL of deionized water. The initial pH of the solution ranged between 5.3 and 5.5 and was subsequently adjusted to the desired experimental pH values. Each batch of solution was stored in a separate glass container sealed with a plastic lid to prevent contamination. All specimens were immersed in the artificial saliva at 37°C for a period of seven days to simulate intraoral conditions and typical denture usage. Samples were placed in individual glass bottles to ensure complete and uniform exposure to the solution. Following the immersion period, mechanical testing was conducted to evaluate flexural strength and Charpy impact strength.

Flexural Strength Test
Flexural strength testing was performed on five specimens from each PMMA group following immersion in artificial saliva at 37°C for seven days, simulating intraoral conditions. All samples were fabricated with standardized dimensions of 65 × 10 × 3 mm, by the manufacturer's specifications and ISO 20795-1 guidelines for denture base polymers. Each specimen was mounted on the designated support fixture of a WP300 materials testing machine (20 kN capacity, GUNT Hamburg), configured for three-point bending. The load was applied centrally to the specimen at a crosshead speed of 0.5 mm/min until fracture occurred. The resulting data were used to calculate flexural strength using the standard formula prescribed by ISO 20795-1. The maximum load before fracture was measured. The flexural strength of the specimens was calculated using the standard relation:

$$S = 3LP / 2WT2$$

Where: S = Flexural strength. P = Maximum load before fracture. L = Distance between supports (50 mm). W = Width of the specimen (10 mm). T = Depth (thickness) of the specimen (2.5 mm), which were randomly made of each sample. The data collected and the mean of seven PMMA samples of each group was measured (Conventual, CAD), calculated and analyzed using suitable statistical methods.

Charpy Impact Strength Test
Charpy impact strength testing was performed on PMMA specimens from both the conventional and CAD/CAM groups following immersion in artificial saliva at 37°C for seven days. Testing was conducted at room temperature using a CEAST Resil Impactor tester, with an applied impact energy of 15 joules. Specimens were prepared and notched in accordance with ASTM D256-10 standards. A minimum of seven specimens per group were tested, and the mean impact strength was calculated for each fabrication method (conventional and CAD/CAM). The collected data were statistically analyzed using appropriate methods to evaluate differences in mechanical performance between the two groups.

Statistical Analysis

Parametric tests such as analysis of variance (t-test) is potentially used since the study is designed to look at the impact of only one independent variable on the selected dependable variables, independent sample t-test is carried out to see if there are any significant differences in the means for two groups in the (dependent) variable of interest.

RESULTS

Flexural Strength Result

The mean value for condition of the PMMA CAD / CAM was 108.28, and the mean for condition of the PMMA Conventional is 60.57. The standard deviation for PMMA CAD / CAM is 6.44 and for PMMA Conventional was 4.89. The number of cases in each condition (N) was 7 in figure (1) at $p = 0.000$ graph displays more clarifications about the result of differences.

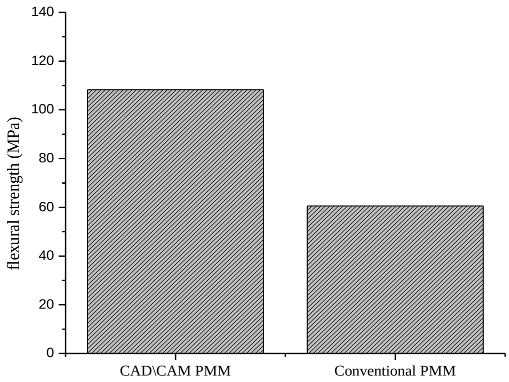

Fig. 1. Comparison between the flexural strength (MPa) of the tested

Charpy Impact Strength Test Result

The mean value for condition of the PMMA CAD\CAM was 27.71, and the mean for condition of the PMMA conventional was 2.54. The standard deviation for PMMA CAD\CAM is 3.25 and for PMMA Conventional is 0.26. The number of cases in each condition (N) was 7 in figure (2) at $p = 0.000$ graph displays more clarifications about the result of differences.

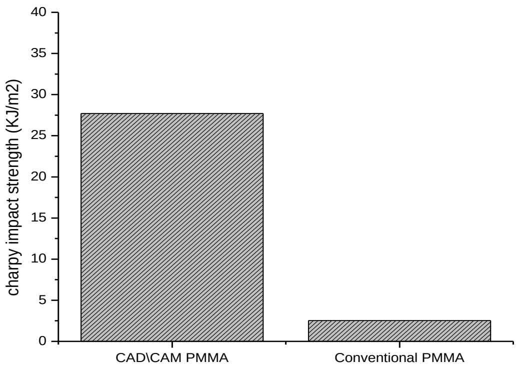

Fig. 2. Comparison between the Charpy impact strength (KJ/m2) of the tested

DISCUSSION

Tooth loss is a major concern for many individuals, and restoring oral function and aesthetics often requires the use of artificial replacements such as acrylic resin-based dentures (Al-Dwairi et al., 2014) [12]. Among the available treatment options for edentulism, complete removable prostheses fabricated from polymethyl methacrylate (PMMA) resin remain one of the most popular and cost-effective solutions (Aguirre et al., 2019) [13]. PMMA is widely used due to its favorable properties, including low density, stain resistance, affordability, ease of handling, dimensional stability in oral environments, and biocompatibility. Despite these advantages, PMMA exhibits limitations in mechanical performance, particularly in terms of flexural and impact strength. Flexural failure typically occurs intraorally due to repeated bending of the denture base, which leads to uneven support over time as a result of progressive and irregular alveolar bone resorption. In contrast, impact failure is usually caused by accidental trauma outside the oral cavity (Al-Dwairi et al., 2014) [14].

This study focused on comparing the flexural and impact strength of denture base materials fabricated using conventional compression molding and CAD/CAM techniques [15]. Flexural strength was measured using a universal testing machine via the three-point bending method, a widely accepted procedure for evaluating polymer materials, as outlined in ISO 20795-1. According to this standard, a minimum flexural strength of 65 MPa is required for clinical acceptability [16]. All tested groups in this study met or exceeded this threshold. Impact strength was assessed using a Charpy impact tester. It is well established that impact resistance is influenced by several factors, including material composition, specimen geometry, fabrication technique, stress concentration points, and testing conditions. Stress concentrators—such as notches, grooves, sharp edges, surface irregularities, and foreign inclusions—are primary contributors to denture fracture under impact loading [17]. The findings of this study are consistent with those reported by Aguirre et al. (2019) and Al-Dwairi et al. (2014), both of whom observed superior flexural and impact properties in CAD/CAM-fabricated PMMA compared to conventionally processed materials [15,18]. Al-Dwairi et al. further confirmed the enhanced durability of CAD/CAM specimens through scanning electron microscopy [18]. These improvements may be attributed to factors such as reduced residual monomer content, higher degree of polymerization, optimized particle size and density, and improved chemical structure of the polymer matrix. Residual monomer, in particular, acts as a plasticizer and can negatively affect flexural strength [19]. The higher flexural and impact strength values observed in the CAD/CAM group may be linked to the advanced polymerization process used during manufacturing. CAD/CAM resin blocks are pre-polymerized to a high degree using sophisticated equipment, resulting in a densely packed resin matrix with minimal porosity and enhanced mechanical integrity [20].

Overall, the results of this study indicate that CAD/CAM denture bases exhibit superior mechanical properties compared to conventional compression-molded counterparts. Clinically, this suggests that CAD/CAM materials may offer improved durability and performance, making them a preferred choice for denture fabrication. However, limitations such as compromised assessment of maxillomandibular relationships, high laboratory setup costs, and feasibility challenges in routine practice must be considered. These factors may necessitate remaking complete dentures, leading to increased time and expense [21]. It is important to note that the present study was conducted in vitro, and the specimens used did not replicate the anatomical form of actual dentures. This limits the direct applicability of the findings to clinical scenarios.

CONCLUSION

The results showed that PMMA CAD\CAM manufacturing method had greater effect on the mechanical flexural strength and mechanical Charpy impact strength properties and provided a higher degree of safety, which comply with the finishing and polishing were done with protocols.

Acknowledgments

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Conflict of interest. Nil

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تقييم قوة الانحناء وقوة تأثير تشاربي لأطقم الأسنان المصنوعة بتقنية CAD/CAM والأطقم المصبوبة بالضغط من PMMA: دراسة مخبرية

أسماء علي إبديوي[2,1]*، جازية البكوش[3]، عصام خليفة الجويو[4]، توفيق الطاهر عجال[5]

[1]المركز الليبي لبحوث اللدائن، تاجوراء-ليبيا
[2]مركز البحوث والاستشارات، جامعة سرت-ليبيا
[3]قسم تقنية الأسنان، كلية التقنية الطبية، جامعة طرابلس، طرابلس، ليبيا
[4]قسم تقنية الأسنان، كلية التقنية الطبية، جامعة المرقب، الخمس، ليبيا
[5]قسم هندسة مواد ومعادن، كلية الهندسة جامعة غريان، غريان، ليبيا

المستخلص

البولي ميثيل ميثاكريلات هو مجموعة واسعة من البوليمرات التي تُستخدم عادةً في تطبيقات مختلفة في طب الأسنان التعويضي. الخصائص الفريدة للبولي ميثيل ميثاكريلات مثل كثافتها المنخفضة، وجمالها، والتكلفة المالية، وسهولة التعامل معها، وكذلك الخصائص الفيزيائية والميكانيكية القابلة للتخصيص، تجعلها مادة حيوية مناسبة وشائعة لهذه التطبيقات السنية. يمكن تصنيع هذه الأطقم الكاملة باستخدام تقنيتين: (i) تقنية التشكيل بالضغط التقليدي (CCM) و (ii)تقنية CAD/CAM. الهدف من هذه الدراسة هو تقييم الخصائص الميكانيكية لطقم الأسنان المصنوعة من البولي ميثيل ميثاكريلات بتقنية CAD/CAMمقارنةً بطقم الأسنان المصنوعة من البولي ميثيل ميثاكريلات بتقنية الضغط التقليدي، وتقنية.CAD/CAM شملت الدراسة عشرين عينة، مقسمة إلى مجموعتين بناءً على تقنية التصنيع التقليدية و(CAD/CAM)، مع تخصيص خمس عينات لكل اختبار. تم اختبار الخصائص الميكانيكية للعينات باستخدام اختبارات "قوة الانحناء" واختبارات قوة الصدمة "شاربي" بعد غمر العينات في اللعاب الصناعي عند 37 درجة مئوية لمدة أسبوع. تشير النتائج إلى أن استخدام تقنيات تصنيع مختلفة لأقراص PMMA يؤدي إلى اختلافات في الخصائص المقاسة التي تؤثر على ملاءمتها كعلاج متاح وحيد للمرضى فاقدي الأسنان. ومع ذلك، أظهرت التحليلات الإحصائية باستخدام أدوات SSPS أن الفروقات ليست ذات دلالة إحصائية بين تقنية CCM تكنولوجيا CAD/CAM على الرغم من عدم وجود دلالة إحصائية. يُوصى بأقراص PMMA المصنعة باستخدام تقنية CAD/CAM بسبب خصائص مقاومتها الميكانيكية الأفضل .

الكلمات الدالة. بولي ميثيل ميثاكريلات، CAD/CAM، التشكيل بالضغط التقليدي، طقم الأسنان، قوة الانحناء، قوة تأثير شاربي.