AJDS ALAZHAR Al-Azhar Journal of Dental Science
Vol. 25- No. 3- 241:246- July 2022
Print ISSN 1110-6751 | online ISSN 2682 - 3314
https://ajdsm.journals.ekb.eg
Restorative Dentistry Issue *(Dental Biomaterials, Operative Dentistry, Endodontics, Removable & Fixed Prosthodontics)*

EVALUATION FOR ELASTIC MODULUS OF CAD-CAM MILLED AND 3D PRINTED DENTURE BASE RESINS

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ABSTRACT

Objective: The objective of this study was to compare the elastic modulus between milled, 3D printed and conventional compression moulded denture base resins (DBRs). **Materials and methods:** Three different types of DBRs were used: milled resin (pre-polymerized PMMA plates) ; a 3D printed resin (photopolymerized resin); and a polymethyl methacrylate (PMMA) heat cured resin (powder-liquid system). Thirty specimens have been constructed with specific dimensions (65mm x10mm x3mm) and divided into 3 groups (10 for each group) according to the type of DBR, Group I contained the milled DBR specimens, Group II contained 3-dimentional printed DBR specimens, and Group III contained conventional compression moulded DBR specimens. The elastic modulus of the 30 specimens were measured and calculated by universal testing machine using three-point loading test. **Results:** The elastic modulus of the milled group was significantly higher than that of the other 2 groups (P<0.05), while the elastic modulus of the compression moulded group was significantly greater than that of the 3D printed group (P<0.05). **Conclusion:** milled DBR show the highest elastic modulus when compared with conventional compression moulded or 3D printed DBRs, while 3D printed DBR shows the lowest elastic modulus.

KEYWORDS: Additive technique, denture base resin, rapid prototyping, subtractive technique, modulus of elasticity.

INTRODUCTION

Polymethyl methacrylate (PMMA) resins are commonly used for the fabrication of denture bases, owing to their good aesthetics, simple processing, and relative ease of repair [1]. However, insufficient mechanical properties render them non-ideal[2]. Furthermore, acrylic resin dentures are prone to fracture, which can occur when the denture is outside the mouth owing to impact or while in use in the mouth due to flexural fatigue caused by frequent masticatory loading [3].

Because alveolar absorption is a gradual and irregular process that creates uneven prosthesis support, high flexural strength is essential for successful denture wear [4]. The denture base material should have a high elastic modulus to guarantee that the stresses encountered during biting and mastication do not cause permanent deformation [5].

The enhancement of PMMA's mechanical properties has been discussed under three different headings: First, the PMMA substitute substance improvement; second, the PMMA formula was

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DOI: *10.21608/ajdsm.2021.81731.1209*

modified by adding a rubber graft copolymer; and third, other substances like carbon fibers, glass fibers, and ultra-high modulus polyethylene were employed to supplement PMMA [6].

Different types of PMMA dentures are currently available. Thermal energy activates benzoyl peroxide, which starts the polymerization process, in heat-activated resins used in compression or injection moulding. Chemically activated or auto polymerized DBRs, on the other hand, do not require heat energy to activate benzoyl peroxide and instead rely on tertiary amines. Because of the residual monomer, dentures created using auto polymerized resins have inferior mechanical qualities than those created with heat-activated resins. Also, because thick specimens are harder to obtain, light-activated resin has better flexural strength than heat-activated PMMA, but it also has more brittleness. Furthermore, incompletely polymerized acrylic resins have inferior mechanical properties [4].

Recent improvements in science and technology have provided digital methods for denture base fabrication, including computer-aided design/computer-aided manufacturing (CAD/CAM) using the subtractive milling process, and three-dimensional (3D) printing using additive manufacturing process. Digital methods allow the production of a denture base in one block and provide the ability to attach prefabricated teeth with an appropriate adhesive. The advantages of digital methods are faster denture base fabrication and fewer phases in the work process, which can reduce the possibility of errors, these bases are milled from prepolymerized resin plates, which promise superior strength and fit and reduced bacterial adhesion [7-9].

Few studies have evaluated the stiffness of new digital DBR materials (milled and 3D printed DBRs), so this study was aimed to examining the elastic modulus of milled and 3D printed DBRs and compare them with heat-polymerized acrylics DBR.

The null hypothesis of this study that there was no significant difference in elastic modulus between the milled DBR, 3D printed DBR and conventional compression moulded DBR.

MATERIALS AND METHODS

Rectangular specimens (in accordance with ISO20795-1; 65×10×3mm) were designed using CAD software (ExoCad, Chairside Cad 2.3 Matera, Germany), producing Standard tessellation language file for this specimen [10]. After approval of the virtual design preview by the investigator and technician, ten rectangular specimens (GI) of a prepolymerized denture base material (AvaDent Digital Dental solutions HQ, Scottsdale, USA) were fabricated by CAD-CAM milling machine (DENTSPLY Sirona In Lab MC X5 laboratory milling machine, Bensheim, Germany) according to manufacturer' instructions. The specimens were milled from Pre-polymerized CAD-CAM PMMA acrylic plates (98-mm diameter×25-mm thick).

The 3D-printed samples (GII) were prepared according to the obtained STL file. Using the STL file, the 3D printing was conducted using an appropriate 3D unit (WANHAO desktop 3D printer, Zhejiang, China), withsubsequent light polymerization done in a suitable device (Anycubic UV Rotary Curing Resin Box) following the manufacturers' instructions. The specimens were printed according to Digital Light Projection (DLP) technology using photopolymerized 3D printed liquid (Harz Labs, Moscow, Russia).

One of the milled specimens used to produce mold to fabricate the conventional DBR specimens (GIII) which processed using conventional method of compression molded technique of heat cured PMMA acrylic resin (Vertex-Dental BV, Soesterberg, Netherlands). All the 30 specimens were prepared and polished by the same operator.

Elastic modulus evaluation:

The elastic modulus of the 30 specimens (Fig. 1) were evaluated using three-point bending test. Prior to testing, these specimens were stored in distilled water at 37 ± 1°C for 7days to simulate the plasticizing effect exerted by the aqueous intraoral environment on the denture base [11]. A computer control, electromechanical universal testing machine was used (Universal testing machine Instron 3345, Buckinghamshire, England). The distance between the two centers of support was set at 50 mm, and then a load cell was applied at the midpoint of each specimen with a crosshead speed of 5 mm/min until fracture (Fig. 2).

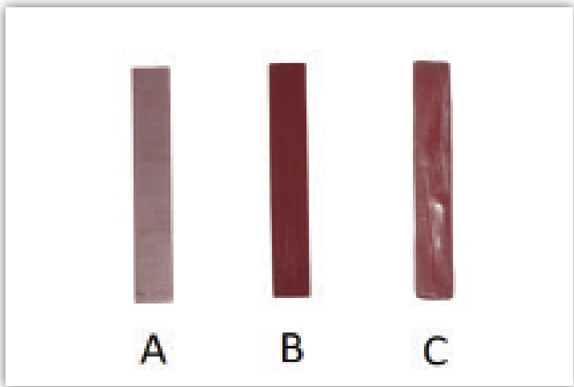

FIG (1) The three types of specimens, (A) milled DBR specimen, (B) 3D Printed DBR specimen, (C) conventional heat cured DBR specimen

FIG (2) The specimen during testing on the universal testing machine

Elastic modulus (E) in mega Pascal (MPa) was calculated using the following equation [12]:

$$E = \frac{FL^3}{4bh^3d}$$

Where (F) is the load or force at which fracture occurred in Newton (N), (L) is the span length of specimen between the supports in millimeter (mm), (b) is the width (mm), and h is the thickness of the specimen (mm), and d is the deflection (mm). Data calculated and recorded using computer software (Bluehill Instron, England).

Data were collected, tabulated, and subjected to statistical analysis using 1-way ANOVA to determine whether significant differences existed between the means of the various studied groups or not. Also, Tukey's pair-wise post-hoc test was employed at the chosen level of probability ($p < 0.05$) using IBM® SPSS® Statistics Version 20 (SPSS, Inc., IBM Corporation, NY, USA.) for Windows and Graph Pad Prism Version 8 (Graph Pad Prism Company, USA).

RESULTS

The informative statistical analysis of different groups and One-way ANOVA test between different groupswere listed in table 1 and figure 3. The statistical analysis of elastic modulus of the three tested groups revealed that the difference between all tested groups was statistically significant as indicated by one-way ANOVA test ($p<0.05$). Where, the GI showed the highest mean value (3240.06±61.23MPa) of elastic modulus, followed by the GIII denture bases (3017.16±215.32MPa). While the lowest mean modulus of elasticity value was recorded with the GII (576.65± 37.73MPa).

Among the groups, Tukey's pair-wise post-hoc test showed statistically significant differences between different groups, there were significant differences between GI and GII, GI and GIII, and GII and GIII ($P<0.05$) as shown in table 2.

TABLE (1): One-way ANOVA test showing mean and standard deviation of the elastic modulus of the different groups.

Variables	Mean (MPa)	SD	*p*-value
GI	3240.06	61.23	
GII	576.65	37.73	0*
GIII	3017.16	215.32	

; significant ($p<0.05$).

TABLE (2): Pair-wise comparisons between different groups using Tukey post hoc test.

Pair-wise Comparisons	*p*-value
GI vs GII	0.0001*
GI vs GIII	0.0021*
GII vs GIII	0.0001*

; significant ($p<0.05$).

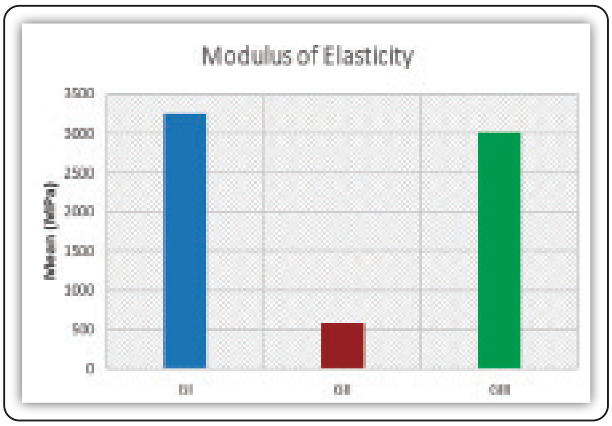

FIG (3) Bar chart of the mean values of elastic modulus for all tested groups.

DISCUSSION

The results of the present study showed that there was statistically significant difference in elastic modulus values (p<0.05) among the different fabrication methods. So, the null hypothesis of this study that would be no significant difference in elastic modulus between the three groups (milled DBR, 3D printed DBR and conventional compression moulded DBR) was rejected.

Elastic modulus reflects the material's stiffness and rigidity. Although the flexibility of the denture base is beneficial in increasing the absorbed energy before fracture, rigidity of the denture framework is a prerequisite for the ability of a denture base to succeed intraorally under high functional loads during mastication and parafunction and, to evenly distribute forces to the underlying structures[13,14]. According to the international standards for polymer materials and ISO 20795-1 for denture base polymers, the 3-point flexural test is a common method for measuring flexural strength and elastic modulus[15,16].

A denture base material with a high elastic modulus can with stand permanent mastication-induced deformation. Elastic modulus is one of the most valuable mechanical properties of the acrylic resin and is influenced by the degree of polymerization reached. When acrylic resin strengths are compared, those with a lower degree of conversion exhibit inferior mechanical properties[5].

The results of the present study revealed that the mean elastic modulus values for all tested manufacturing systems were 3240.06±61.23 MPa, 3017.16±215.32 MPa, and 576.65±37.73 MPa for the milled, compression moulded, and 3D printed manufactured methods, respectively. The elastic modulus reflectsthe stiffness of a material, therefore, denture base that made from milled showed the highest stiffness. However, the denture bases that were made from photopolymerized 3D printed manufacturing methods exhibited the least stiffness. With the recommendation of the ISO 20795–1, which states that the flexural modulus of the processed modulusshould not be lower than 2 GPa, so the denture base that made from milled and compression moulded manufacturing methods in the present study are suitable for clinical use. However, the denture bases that were made from photopolymerized 3D printed manufacturing methods not suitable for clinical use.

The lower mean elastic modulus value of the denture base that made via 3D printing method may be contributed to the lower polymerization conversion, lead to the leakage of residual monomers and act as plasticizer which decreasing the flexural strength of the fabricated denture [11]. Additionally, the denture bases that were manufactured by CAD-CAM milling methods showed the higher mean elastic modulus values among the tested groups, and this may be due to the higher degree of conversion achieved [17]. This may be since the CAD/CAM resins are milled from solid, pre-polymerized plates, and it is reasonable to assume that the plates are polymerized by using equipment capable of providing greater polymerization potential than available with conventional processing methods [18].

The current study's findings demonstrated that denture bases formed via compression moulding had a much greater mean elastic modulus than those created by 3D printing. This could be explained by that the conventional approach achieves a higher degree of conversion and polymerization [17].

The existence of voids and porosities associated with the production process of conventional heat cured PMMA group may explain the superiority of elastic modulus in the milled group over the conventional compression group [12]. This also supports the manufacturers' claim assigning mechanical favorability of CAD/CAM dentures to the polymerization process of PMMA under high pressure and temperature [19].

The study had two major limitations. First, oral conditions were absent in the present research, and second, different testing conditions (dry vs. wet) and different testing media (air or water) were not included. Both may have affected the results. To obtain more comprehensive knowledge on new denture base materials, future studies considering fracture toughness, flexural strength, impact strength, and residual monomer testing are necessary.

CONCLUSION

Based on the findings of this study, it could be concluded that: the milled DBR specimens had a higher elastic modulus than compression molding and 3D printed DBR specimens. The 3D printed DBR specimens showed the lowest elastic modulus than compression molding and milled DBR specimens.

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