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Original Article

Comparative evaluation of flexural strength of denture base resin materials processed using compression molding technique, injection molding technique, and computer-aided design CAM technique: An *in vitro* study

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ABSTRACT

Background: Denture bases undergo repeated flexing during mastication leading to fatigue failure, demanding a high fatigue strength property. Flexural (transverse) strength is required high to prevent catastrophic failure under load for success. Denture base resins are fabricated by three different types of manufacturing: Compression molding, injection molding and computer-aided design (CAD/CAM) milling technique. The study was conducted to identify the denture with the highest flexural strength (Fs) from these methods.

Materials and Methods: In this in vitro study. Three groups of 15 PMMA acrylic denture base resins (total 45) were processed into rectangular plates of size 65mm × 10mm × 3mm. The three groups differed in the method of processing as compression molded, injection molded, and prepolymerized CAD/CAM milled resins. A 3-point bend test was used to measure the Fs. One-way analysis of variance (ANOVA) with the Post hoc Tukey method was used for statistical analysis. Data was statistically significant with Post hoc Tukey method significance at $P < 0.05$.

Results: The mean Fs of CAD/CAM, injection molding, and compression molding manufacturing techniques are 97.46, 84.42, and 71.72 respectively and standard deviation obtained are 9.93, 10.42, and 11.58, respectively. Statistical analysis suggested the CAD/CAM technique as the best method for the fabrication of dentures because it had the maximum mean Fs and the lowest Fs standard deviation when compared with compression molding and injection molding.

Conclusion: Denture bases fabricated through CAD/CAM technique are more sustainable than the compression-molded and injection-molded denture bases.

Key Words: Computer-aided design CAD/CAM technique, compression molding, denture base resins, injection molding

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INTRODUCTION

Polymethyl methacrylate (PMMA) remains the denture base material of choice, although being introduced in 1936.[1,2] Several types of PMMA denture base resin available today are similar in

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composition but small variations lead to different physical properties and processing methods.[3] Dentures made by light-activated demonstrate lower mechanical properties over heat-activated resins.[4] The polymerization shrinkage of PMMA by ordinary compression molding method prompts inaccurate adaptation of the base material to the dental replacement bearing tissues, bringing about a poor border seal. To minimize the dimensional inaccuracies of the compression molding technique, Pryor (1942) developed the injection molding technique as an alternative. In 1970, Ivoclar company introduced a special resin for injection molding.[5]

Computer-aided design/computer-aided manufacturing (CAD/CAM) was introduced in the late 1950s with the introduction of PRONTO, a numerical control programming tool. Dr. Patrick J. Hanratty developed the first CAM software system[6] followed by Dr. Moermann and Dr. Andersson, with CEREC® and Procera® systems for clinical dental restorations.[7] CAD/CAM technology scans the denture base morphology and records the tooth positions. Data are then imported into a virtual tooth arrangement program where teeth can be articulated followed by exposing it to milling device for the fabrication of the complete dentures.[8] Prepolymerized resin pucks are used for milling the denture bases to provide superior strength and fit with an additional advantage of reduced bacterial adhesion and cost-effectiveness to patients and clinicians.[9]

During mastication for several years, denture bases undergo repeated flexing leading to fatigue failure, thereby demanding a high fatigue strength property of denture base resins.[10] The highest stress in a material is experienced at its moment of rupture represented by flexural or transverse strength which is required high to prevent catastrophic failure under load for denture success. With respect to extrinsic factors, the American Dental Association Standard No. 139 in accordance with ISO 20795-1, time and temperature during polymerization and testing affect physical and mechanical denture base properties.[11] Thermocycling negatively affects flexural strength (Fs)[12] hence, conditioning the resin before testing is necessary.

Literature reports numerous studies on denture handling techniques and variation in flexure strength.[13-20] with compression and injection molding being the most popular methods. Ivocap High impact (Ivoclar Vivadent), in combination with injection molding results in improved accuracy of fit.[2] Studies also report the effectiveness of CAD/CAM dentures being superior over conventionally prepared dentures.[21,22] Since the comparison of dentures with different processing methods is essential for the acknowledgment of the denture with the highest Fs, the present study was conducted to compare the Fs of denture base resins fabricated by compression molding, injection molding, and CAD/CAM milling technique. The null hypothesis was, there is no significant difference in the Fs among the three techniques.

MATERIALS AND METHODS

In this *in vitro* study. Forty-five denture base resin specimens (n = 15, each group) (compression molding [Group A], injection molding [Group B], and CAD CA [Group C]) with specified dimensions were fabricated with standardization done using, metal strips of 65 mm × 10 mm × 3 mm [Figure 1] according to the American Standards for Testing and Material.

Compression molding technique

A thin layer of petroleum jelly (Bioline®) was applied on the strips inserting half of its thickness into a dental stone investment with wax sprues (Modelling Wax, Hindustan Dental Products, Hyderabad India Ltd.) attached to the metal mold strips to provide an inlet for the resin mix and facilitate removal of petroleum jelly. After the stone sets, a coat of separating media was applied followed by a second pour. Flask was held in compression till the final set. Wax was boiled out of the flask after the stone set was opened and the preformed strips were retrieved [Figure 2]. The resin (SR Triplex Hot, Ivoclar Vivadent) was hand mixed in ideal mixing ratio according to the manufacturer's instructions. When the material was in the dough stage, it was placed in the hand-warm (approx. 40°C/104°F) isolated flask halves. Flask was closed at 80 bar pressure load and was fixed with a clamp.

The closed flask was placed in cold water and heated up to 100°C/212°F and was let to boil for 45 min; cooled at room temperature for 30 min; subsequently completely cooled with cold water. The cooled flask was opened, and the fabricated strips were retrieved [Figure 3]. Finishing and polishing were done with conventional protocols.

Injection molding technique

Wax duplicates were flasked and invested in Type 3 dental stone [Figure 4]. The flask was heated in a boil-out solution and the wax was flushed out letting the flask cool at room temperature [Figure 5]. Separating media (Separating Fluid; Ivoclar Vivadent AG) was applied to the stone. Premeasured capsules of resin and monomer (SR Ivocap High Impact; Ivoclar Vivadent AG) were combined in a commercial mixer (Cap Vibrator; Ivoclar Vivadent AG) for 5 min. The flask halves were joined in a clamping frame under 29 kN force. The contents of the mixed capsule were inserted into the flask, and the pressure injection apparatus (SR Ivocap System; Ivoclar Vivadent AG) was attached. The pressure apparatus was connected to a compressed air supply (600 kPa) to allow the plunger to descend and inject material into the mold for 5 min on the bench. The assembly was then polymerized in boiling water (100°C) for 35 min, removed, and immediately placed in cold water, maintaining pressure for 30 min to let cool. The cooled flask was opened and the fabricated strips were retrieved [Figure 6]. Finishing and polishing were done with conventional protocols.

Computer-aided design/CAM technique

Prepolymerized PMMA (IvoBase® CAD for Zenotec, Wieland Dental) 12-mm resin blocks were used for the fabrication of specimens using CAD/CAM technology [Figure 7]. The STL (Standard Tessellation Language/Standard Triangle Language) file format was created by 3D systems according to the specified dimensions (65 mm × 10 mm × 3 mm) and the information was sent to CAD software for computer-aided milling (CAM) in Zenotec mini by Wieland Dental [Figure 8]. The resin block was placed at the block holder and the DLC 2.5 × 35 × D3 and DLC 1.0 × 35 × D3 burs by Wieland Dental were inserted in the dedicated slots [Figure 9]. Milling was done for 20–30 min followed by conventional finishing and polishing protocols [Figures 10 and 11].

Finishing and polishing of specimens

All specimens were polished with a 400-grit silicon carbide abrasive paper under running water. Sequential sandpapering using micromotor and handpiece with mandrel was done with 5000 rpm for 90 s for finishing. Polishing was done by buffing with pumice slurry. After polishing, all specimens were checked for their dimensions with a digital caliper.

Thermocycling

Specimens were stored in 37°C distilled water for 24 hr [Figure 12]. Thermocycling was carried out in 500 cycles in a dwell time of 30 s at temperatures of 5°C–55°C [Figures 13 and 14].

The Fs of fracture resistance was measured on a computerized, software-based Universal Testing Machine (UTM) (Acme Engineers, India, Model: UNITEST 10). All 45 samples were subjected to the 3-point bending test at a crosshead speed of 5 mm/min and 50 mm distance with UTM with a load of 250 kg applied at the center of the specimen [Figures 15 and 16]. The specimens were supported on the jigs with a diameter of 10 mm and the span length was 50 mm. Fs was calculated using the formula:

Figure 1: Metal strips.

Figure 2: Flasking for compression molding.

Figure 3: Compression-molded denture base resin specimens.

$$\text{Flexural strength (Fs)} = \frac{3PL}{2bd^2}$$

Where P = maximum load, b = specimen width, L = span length, and d = specimen thickness.

Statistical analysis was performed using IBM SPSS version 21.0 (IBM Corporation, USA). The normality of data was checked and a one-way analysis of variance (ANOVA) followed by *post hoc* Tukey test was applied for statistical comparison keeping significance at $P < 0.05$.

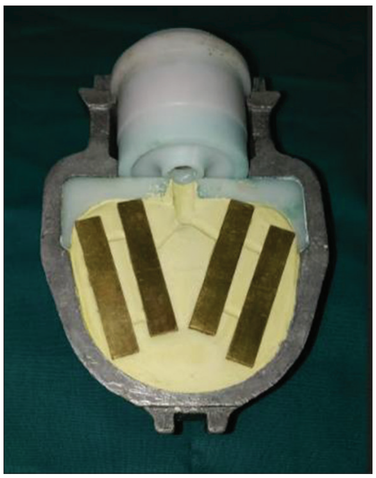


Figure 4: Flasking for injection molding.

Figure 5: Boiled out injection-molded flasks.

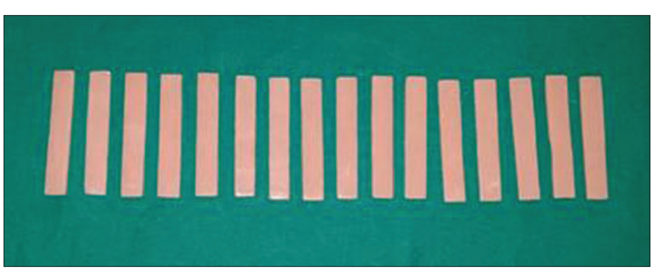


Figure 6: Injection-molded denture base resin specimens.

RESULTS

Descriptive data on mean flexure strength in all three groups are presented in Graph 1 [Figure 17]. Flexure strength was highest with CAD/CAM (97.46 ± 9.93) followed by injection molding (84.42 ± 10.42) and compression molding (71.72 ± 11.58) technique fabrication as shown in Table 1.

Figure 7: PMMA IvoBase® CAD Resin Block. PMMA: Polymethyl methacrylate.

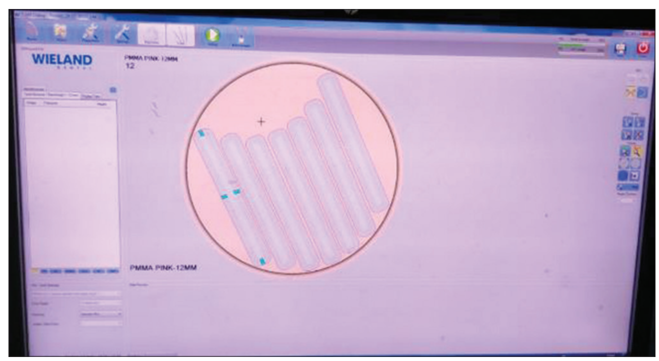


Figure 8: STL file in CAD software arranged in resin block virtually. CAD: Computer-aided design.

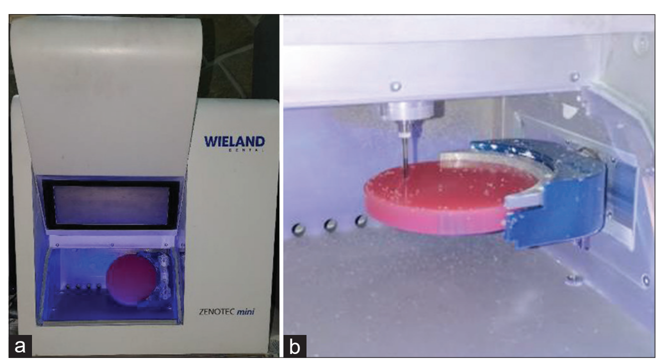


Figure 9: (a) Computer-aided milling (CAM) in Zenotec mini by WIELAND Dental. (b) Resin block placed in holder during milling.

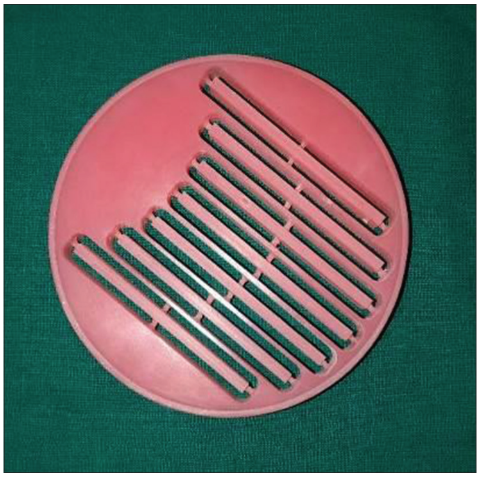


Figure 10: Milled specimens in the PMMA Resin Disc. PMMA: Polymethyl methacrylate.

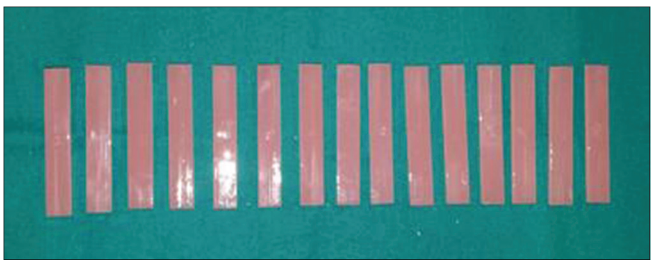


Figure 11: CAD/CAM PMMA Resin Specimens. CAD: Computer-aided design, PMMA: Polymethyl methacrylate.

The one-way ANOVA is used to determine whether there are any statistically significant differences between the means of three or more independent (unrelated) groups.

Graph 2 and Table 2 presents the statistical difference in flexure strength between the groups using one-way ANOVA. Since the P from the one-way ANOVA test is 0.00, which is less than the significance level of 0.05, the null hypothesis is rejected.

At this point, it is important to realize that the one-way ANOVA is an omnibus test statistic and cannot tell you which specific groups were statistically significantly different from each other, only that at least two groups were. To determine which specific groups differed from each other, we used the *post hoc* Tukey test.

Post hoc tests are an integral part of ANOVA. When you use ANOVA to test the equality of at least three group means, statistically significant results indicate that not all of the group means are equal. However, ANOVA results do not identify which particular differences between pairs of means are significant.

Figure 12: Specimens in water bath.

Figure 13: Thermocycling at 5.

Post hoc ("after this" in Latin) tests are used to uncover specific differences between three or more group means when an ANOVA F test is significant.

The *Post hoc* Tukey comparison table shows that all three manufacturing groups depicted different letters in the grouping when the test was conducted. The *Post hoc* Tukey comparison Graph 3 shows that no interval contains 0. Both these findings conclude that data are statistically significant between any two (and all three) groups.

DISCUSSION

Fs comprises three mechanical properties, namely compressive strength, tensile strength, and shear strength. Therefore, the Fs becomes a key factor to be analyzed for the success of a denture base. In the present study, Fs of the denture base resins produced through the CAD/CAM milled technique was

Figure 14: Thermocycling at 55°C.

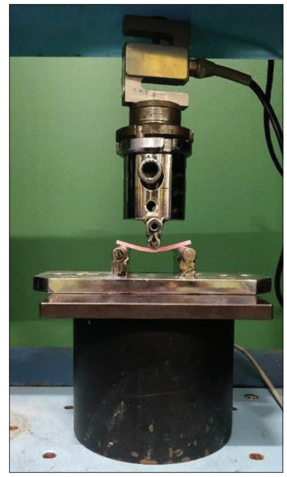
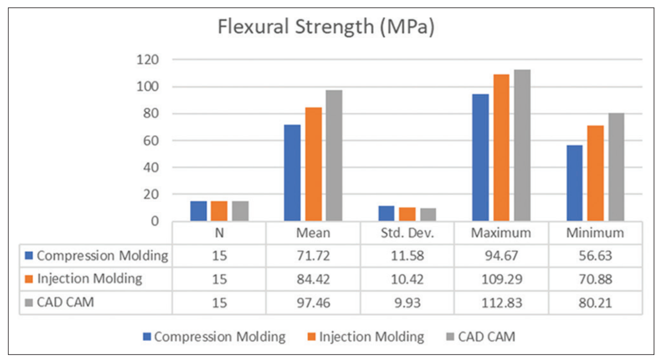


Figure 16: Plastic deformation under load in the 3-point bend test.

Figure 15: Specimens being 3-point bending tested in Universal Testing Machine.



Graph 1: Graphical Analysis: Flexural Strength (MPa) versus different types of manufacturing. CAD/CAM: Computer-aided design/ computer aided manufacturing, SD: Standard deviation.

significantly higher than the ones obtained through the compression molding technique and injection molding technique. The denture base was able to succeed simulation intraorally to high functional loads during parafunction and mastication when subjected to a 3-point bend test.[19,20,23] The 3-point flexural test is commonly used for measuring flexural properties. The acrylic denture base resins should have at least 65 MPa Fs according to the ISO standards.[17] By taking these criteria into consideration, all the groups in this study were suitable for clinical use.

Fs, impact strength, and flexural modulus were observed to be significantly improved in CAD/CAM resin over the conventional heat-cured group.[23] In the present study, injection-molded denture base resin showed higher Fs than the compression-molded technique resins. These results are similar with Gharechahi *et al*. study, with similar methodology.[20] Nandal *et al*. reviewed various advancements in the field of denture base resins and stated that the Fs,

Table 1: Descriptive statistics: Flexural strength (MPa) versus different types of manufacturing

Fs (MPa)	Compression molding	Injection molding	CAD/CAM
n	15	15	15
Mean±SD	71.72±11.58	84.42±10.42	97.46±9.93
Maximum	94.67	109.29	112.83
Minimum	56.63	70.88	80.21

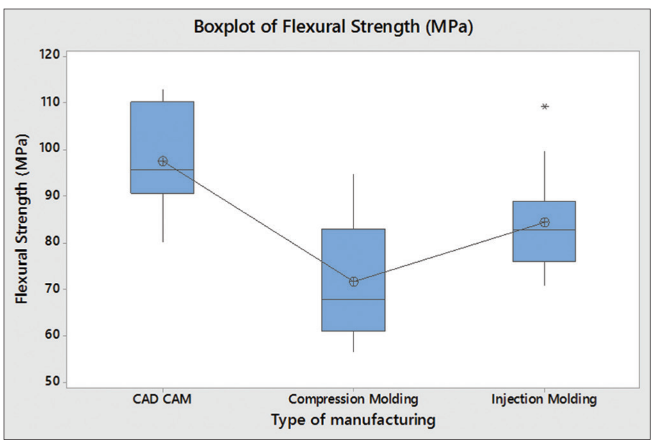
CAD: Computer-aided design, CAM: Computer-aided manufacturing, SD: Standard deviation, Fs: Flexural strength

Table 2: One-way analysis of variance: Flexural strength (MPa) versus different types of manufacturing

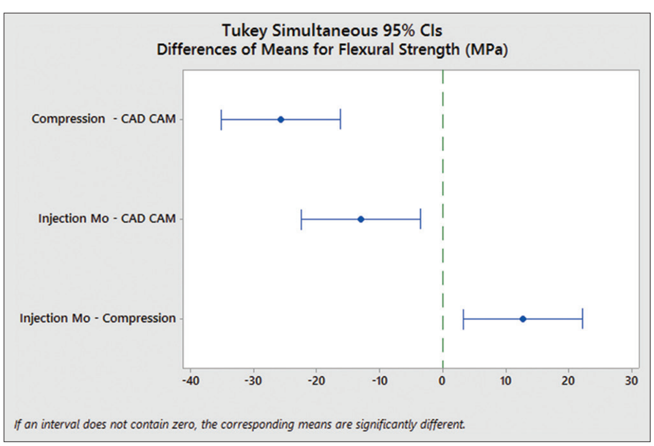
Serial number	*n* (MPa)	Mean±SD (MPa)	95% CI for mean (MPa)		*F*	*P*
			Lower bound	Upper bound		
1	15	71.72±11.58	65.05	78.39	9.81	0.00
2	15	84.42±10.42	77.75	91.09		
3	15	97.46±9.93	90.79	104.13		
Total	45	84.53±14.88	80.68	88.38		

SD: Standard deviation, CI: Confidence interval impact strength, and flexural modulus were observed to be significantly improved in CAD/CAM resin as compared to the conventional heat cure resins.[24,25] Thus, it can be stated that CAD/CAM denture base resin has superior mechanical properties compared to the injection molding technique and compression molding technique. This rejects the null hypothesis of no significant difference in the Fs among the groups.

However, a contrast was observed with the Aguirre study reporting high Fs by compression molding technique over injection molding technique. This can be attributed to different methods used for polymerization wherein polymerization degree affects the Fs.[26] The Fs of CAD/CAM was observed to be higher than the conventional methods, supporting the same reason of variation in results. The conventional compression molding and injection molding techniques have a lower degree of polymerization while CAD/CAM milled denture resins exhibit a superior level of mechanical properties when compared to conventional methods.[27]



Graph 2: Boxplot of one-way ANOVA: Flexural Strength (MPa) versus different types of manufacturing. CAD: Computer-aided design.



Graph 3: *Post hoc* Tukey comparison graph. CI: Confidence interval, CAD: Computer-aided design.

The rigidity of the material is demonstrated by the flexural modulus.[20] Results from this study demonstrated that all three types of denture resins which were tested met the standards according to the standards for ISO-20795-1. Clinically, subclinical deformation of the denture would be observed rather than a fractured resin under load greater than the calculated mean Fs according to this finding. Fs obtained was different from each method because it was statistically significant. The denture bases fabricated from each method have different limits to bear the maximum load. Denture bases fabricated with CAD/CAM method are superior because they have the highest Fs of the three fabrication techniques. Injection-molded denture bases are inferior to CAD/CAM fabricated denture bases; but better than compression-molded denture bases, because compression-molded denture bases exhibited the least Fs. The CAD/CAM and injection-molded resins had higher flexural modulus which led to minimal-to-no deformation before fracture. Although the Fs of the compression specimens was the lowest and demonstrated significant plastic deformation before failure, the product remains a suitable denture base material. Thus, the techniques, advantages, and disadvantages of CAD/CAM conclude that the current innovations and technological developments allow the digital planning and manufacturing of removable dentures from start to finish. Thus, decreasing the chairside and working time for patients and dentists provide superior or satisfactory functional and esthetic outcomes. However, long-term clinical research and additional material-related aspects are required to reach definitive conclusions.

There are certain limitations influencing the outcome; first, the tested specimens did not resemble the shape of an actual denture. Second, the absence of a longer period of thermocycling, cyclic loading; third, manual preparation of samples leading to human error during the preparation and finishing stage leading to slight inaccuracy in the readings.

CONCLUSION

The mean obtained from CAD/CAM, injection molding and compression molding manufacturing techniques are 97.46, 84.42, and 71.72, respectively. The standard deviation obtained from CAD/CAM, injection molding and compression molding manufacturing techniques are 9.93, 10.42, and 11.58, respectively. We had done one-way ANOVA and *Post hoc* Tukey method. The level of significance was set to 95%. The *P* obtained was 0.00 which is <0.05; hence data are statistically significant. *Post hoc* Tukey method was used to determine that every method was statistically different from each other.

Within the limitations of the study, it can be concluded that, Fs of the denture base resin produced by CAD/CAM milled technique was observed to be higher than the denture base resins obtained through compression molding and injection molding, which are the two regular processing methods. The compression-molded resin depicted prominent deformation before fracture with a lower flexural modulus, whereas the injection-molded, and CAD/CAM milled denture resins fractured with minimal to no plastic deformation. Thus, prepolymerized CAD/CAM milled denture bases can be a replacement to conventionally processed denture bases (compression molded and injection molded) where higher bending forces are expected. However, furthermore, extensive research needs to be done as a continuation of the present study to evaluate interferences *in vivo* in patient's oral cavity to compare other mechanical properties such as the flexural modulus, impact strength, flexural fatigue, and fracture toughness of denture resins with larger sample size, better simulation of oral conditions, and long-term clinical trials. The specimens to be tested should be fabricated resembling the shape of an actual denture which may influence the results in future studies and cyclic loading can be used to simulate stress fatigue within the specimens to mimic intraoral conditions.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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