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ORIGINAL RESEARCH

Comparative Evaluation of Flexural and Impact Strength of Denture Base Acrylic Resin using Different Processing Methods - An *in-vitro* Study

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ABSTRACT

Background: One of the chief limitations of Polymethylmethacrylate denture base material is its inadequate mechanical property. Different processing methods of Polymethylmethacrylate have varying influences on the mechanical properties of denture base material.

Aim: The aim of our *in-vitro* study was to comparatively evaluate the flexural and impact strength values between CAD-CAM, Compression-molded and Injection- molded Polymethylmethacrylate specimens.

Materials and methods: A total of 66 acrylic rectangular specimens of ISO Standardization (64 x10 x3.3mm) were fabricated. This study was conducted between three groups: Group I (n=22)-CAD-CAM Milled specimens (Ruthinium, India), Group II (n=22)- Compression-molded specimens (Dental Products of India, Chennai), Group III (n=22)- Injection-molded specimens (SR- Ivocap High Impact, Ivoclar Vivadent). Flexural strength was evaluated using four-point bend test and Impact strength by IZOD Impact tester. Kruskal Wallis unpaired test was used to compare the mean values between groups and Mann Whitney U test was used to carry out pair wise comparison.

Results: Flexural strength of CAD-CAM samples were found to be statistically highest followed by injection molded specimens. Conversely, Impact strength of injection- molded specimens were highest followed by CAD-CAM specimens. Flexural as well as impact strength values were found to be least among compression-molded specimens.

Conclusion: CAD-CAM specimens exhibited higher flexural strength whereas Injection-molded specimens had the highest impact strength.

Keywords: Flexural strength, Four-point bend test, Impact Strength, IZOD impact tester, Polymethylmethacrylate.

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INTRODUCTION

Replacement of missing tooth structures with artificial materials constitutes a significant part of the applications of material science.[1-4] Over the years, extensive research has been conducted in the seek for an ideal denture base material.[3,5,6] In this context, many materials have been evaluated. Various materials have been tried and tested for use as denture base materials, from wood, ivory, bone, gold, porcelain, celluloid, vulcanite, and metals to Polymethylmethacrylate (PMMA) and its advancements.[3,5,7,8,9]

Among the materials tested over the years, Polymethylmethacrylate (PMMA) was found to possess most of the ideal properties required for a denture base material.[5,10] This material has been the denture base material of choice since mid-1940.[1,5,10,11,12] It exhibited such remarkable improvements in its applications, that by 1946, 95% of the dentures were fabricated from this material.[1]

A strong basement is crucial for the construction of a sturdy building; similarly, a favourable denture base is critical for the fabrication of long-lasting, aesthetically pleasing, and biologically acceptable dentures. Though heat-activated Poly methyl methacrylate (PMMA) fulfils most of the ideal characteristics required for a denture base material, it still lacks the adequate mechanical strength requirements necessary for a denture base.[13-15]

Denture fracture may result from two types of forces. These include the extra-oral and intra-oral forces.[16] Extra-oral forces include the impact stresses that act on the dentures when dropped down accidentally.[8] Intraorally, repeated masticatory stresses over a period of time, eventually leads to

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crack propagation and the denture fractures as a result of flexural fatigue.[17-21]

As most of the denture fractures were either caused by flexural stresses or impact failure, evaluation of flexural and impact strength should be considered as unique parameters in evaluating the mechanical properties of the denture base material.[22-25] Denture base material's residual monomer content and mechanical properties are also affected by different processing techniques by which the dentures are processed.[26,27] Therefore the aim of the study was to compare and evaluate the flexural and impact strength of Polymethylmethacrylate (PMMA) denture base material processed by CAD-CAM, Compression-molded and Injection-molded specimens. The null hypothesis presumed was that there would be no difference in the flexural and impact strength between the CAD-CAM, compression and injection molding techniques.

MATERIALS AND METHOD

The present in-vitro study was conducted to comparatively evaluate the effect of different processing methods on the flexural and impact strength of Polymethylmethacrylate (PMMA) denture base material. In this study, a total of 66 rectangular polymethylmethacrylate specimens were fabricated. These were divided and categorized into three groups, with each group containing 22 specimens. Out of 22 specimens in each group, 11 specimens were subjected to flexural strength test and the remaining 11 specimens were subjected to impact strength test.

Materials used in the study:

The following materials were used for the present *in-vitro* study. These include Polyvinylsiloxane putty impression material (Dentsply Sirona Aquasil Soft Putty), pre-polymerized CAD-CAM denture base material (Ruthenium Dental Products Pvt Ltd, India), Heat cure denture base material (Dental Products of India, Chennai), Premeasured Capsules of Resin and Monomer (SR Ivocap High Impact, Ivoclar Vivadent).

Distribution of specimens in groups:

In the study, based on the processing method used, there were three experimental groups. They were categorized as follows:

Group 1: CAD- CAM Technique

Group 2: Compression-molded Technique

Group 3: Injection-molded Technique

Preparation of Samples:

a. Milling of specimens from pre-polymerized CAD-CAM PMMA blank: Prepolymerised CAD-CAM resin blanks were used in the fabrication of CAD-CAM specimens. CAD-CAM resin blank was milled in Computer numerical control (CNC) machine to the desired ISO 20795-1 dimensions 64 x 10 x 3.3 mm to form rectangular specimens. 22 rectangular CAD-CAM specimens were milled to desired ISO dimensions.

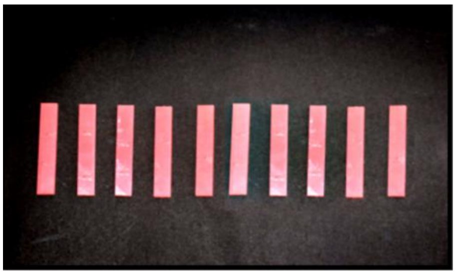

Figure 1: PMMA specimen milled to desired ISO Dimension

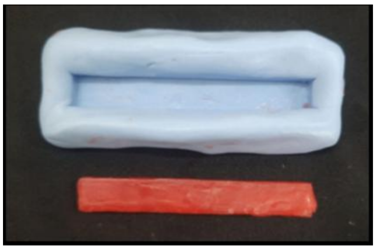

Figure 2: Wax Duplicate

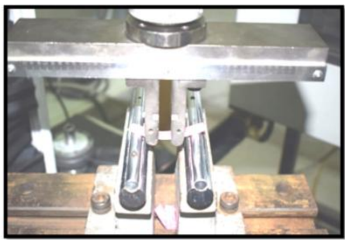

Figure 3: Flexural strength testing of PMMA specimen by four-point bend test

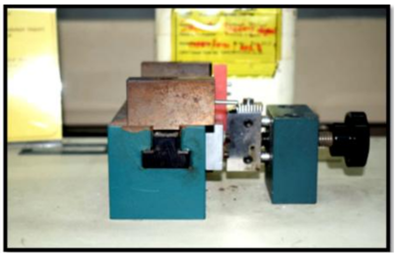

Figure 4: Impact strength testing of PMMA specimen by IZOD

b.Verification of ISO dimensions by Digital Vernier Caliper: ISO dimensions of 64X10X3.3 mm for the specimens were verified with a digital Vernier Caliper.

c.Polyvinylsiloxane putty impression of milled CAD-CAM specimens: The base and catalyst of Polyvinylsiloxane putty impression material were hand manipulated to appropriate proportions. Polyvinylsiloxane (PVS) putty impressions of rectangular CAD CAM specimens were made to create putty matrix.[28]

d. Fabrication of wax duplicates: Modeling base plate wax was melted and dripped into these matrices to produce wax duplicates.[10] (Fig 2). These wax duplicates were the master specimens from which samples for compression and injection molding specimens were fabricated. 44 wax duplicates were formed. Out of 44 wax duplicates, 22 wax duplicates were subjected to compression molded processing technique, and the remaining 22 wax duplicates were subjected to injection molded processing technique.

Flexural and Impact Testing of Specimens

a. Testing of flexural strength of specimens by Four-Point Bend Test: In the present study, the flexural strength of acrylic specimens was evaluated by a four-point bend test (Fig 3). In the four-point bend test, the load applied is halved and the distance between the loads would be half the distance between the supports of the acrylic specimen. Each specimen was placed on support beams with a 50 mm span length. Two load cells were affixed to the specimen by upper anvil assembly at a crosshead speed of 5 mm/min. The moment of fracture was designed as the moment the applied load dropped to zero.

The formula for calculation of flexural strength is

Flexural Strength= 3PL/ 4w

Where P= maximum load (N), L= Distance between lower supports (mm), w= width of specimen (mm), t=height of specimen (mm).

b. Testing of specimens by IZOD Impact Strength Tester: Samples were subjected to an IZOD type impact strength tester using a CEAST impact tester. (Fig 4) . A digital caliper was used to locate the midpoint of the sample. The midpoint is marked using a marking pen. The sample was placed in a metal fixture so that the middle of the sample coincided with the striking pendulum. The acrylic specimen was clamped vertically at one end and a blow to the specimen was delivered to the specimen above the clamped end. In this test, the force was not delivered to the centre of the acrylic specimen. Once the handle was let down, Pendulum stroked the sample until it fractured the material. The energy required to break the sample was measured in joules. Impact strength = Energy (kg cm) / Thickness (cm).

Statstical Analysis:

Kruskal Wallis ANOVA was used to compare between groups and Mann Whitney U-test was used to carry out pair wise comparison. The Normality tests, Kolmogorov-Smirnov and Shapiro-Wilks tests results reveal that this study did not follow normal distribution. Therefore, to analyze the data, non-parametric tests were applied. Kruskal Wallis test was used to compare the mean rank values recorded for all the variables included in the study. Pair-wise comparison was done using Mann-Whitney U test. To analyze the data SPSS (IBM SPSS Statistics for Windows, Version 26.0, Armonk, NY: IBM Corp. Released 2019) was used. Significance level was fixed as 5% (α = 0.05). P-value <0.05 is considered to be statistically significant

RESULTS

In this study, comparison of mean rank for flexural strength among the study group was done using

STUDY GROUP	MEAN RANK	P-VALUE*
CAD-CAM	25.73	0.001
COMPRESSION	10.95	
INJECTION MOULDED	14.32	

***P Value** <0.05 – Statistically significant. Significance level fixed as 5% (α =0.05).

Table 1: Comparison of Mean rank for Flexural strength values (MPa) of PMMA between CAD-CAM, Compression-Molded and Injection-Molded techniques

STUDY GROUP	MEAN RANK	P-VALUE
CAD-CAM	15.91	0.001
COMPRESSION	7.09	
CAD-CAM	15.82	0.002
INJECTION MOULDED	7.18	
COMPRESSION	9.86	0.237
INJECTION MOULDED	13.14	

***P Value** <0.05 – Statistically significant. Significance level fixed as 5% (α =0.05).

Table 2: Pair-wise comparison of Mean rank for Flexural strength values (MPa) of PMMA between CAD-CAM, Compression-and Injection-molded techniques

STUDY GROUP	MEAN RANK	P-VALUE
CAD-CAM	19.91	<0.001
COMPRESSION	6.55	
INJECTION MOULDED	24.55	

***P Value** <0.05 – Statistically significant. Significance level fixed as 5% (α =0.05)

Table 3: Comparison of Mean rank for Impact strength values (KJ/m2) between CAD-CAM, Compression-molded and Injection-molded techniques

STUDY GROUP	MEAN RANK	P-VALUE
CAD-CAM	16.64	<0.001
COMPRESSION	6.36	
CAD-CAM	9.27	0.108
INJECTION MOULDED	13.73	
COMPRESSION	6.18	<0.001
INJECTION MOULDED	16.82	

***P Value** <0.05 – Statistically significant. Significance level fixed as 5% (α =0.05).

Table 4: Pair-wise comparison of Mean rank for Impact Strength values (KJ/m2) between CAD-CAM, Compression and Injection-molded techniques

Kruskal-Wallis test (Table 1). Pair-wise comparison of mean rank among the study group for flexural strength was done using Mann-Whitney u test

(Table 2). Comparison of mean rank for impact strength among the study group was done using Kruskal-Wallis test (Table 3) and pair-wise comparison of mean rank among the study group for impact strength was done using Mann- Whitney u test (Table 4).

DISCUSSION

Mechanical strength of the denture base material is an important criterion that influences the longevity of dentures.[7,10,14,15] Though Poly methyl methacrylate possessed most of the desirable properties required for an ideal denture base material, its major shortcoming was its inadequate mechanical property.[1,10,11,15,22,29]

Over the years, to improve the mechanical properties of traditional PMMA denture base material, research has led to development of high impact denture base material; different processing methods and wide variety of reinforcing materials were introduced. In this study, the sample's dimensions were ISO standardized (64x10x3.3 mm). This standardization was found to be better valid because these were developed and updates with the standards of the opinion of internationally established experts.[30] It was also the most common standardization followed in most of the literature studies involving evaluation of impact and flexural strength.[10,31,32] In accordance with ISO 20795-1, American Dental Association Standard No. 139 describes the effects of time and curing temperature during polymerization and testing of denture base polymers.[10,30,33] As different resins have different formulations, it is important to closely follow the manufacturer's instructions when it comes to mixing time and curing temperature.[33]

For the compression-molded group, the commercial brand that was selected was DPI heat cure material. The reason behind the use of this commercial brand was because of its wide regional applicability as a conventional heat cure denture base material. In most of the literature studies involving flexural and impact strength evaluation in India, DPI was widely chosen.[12,21,30,34] In one of the study by Chhabra, on evaluation of flexural and impact strength between 3D printed denture base resin and DPI heat cure, DPI heat cure resin was found to possess higher flexural and impact strength values when compared to 3-D printed resin.[34] For the injection-molded group, the commercial brand that was selected was SR-Ivocap, The superior mechanical quality and clinical popularity of SR-Ivocap is the reason for using it as a test sample in this study.[21]

There was limited literature available on determination of flexural strength through the four point bend test. In a study by Polyzois et al, they have selected ISO Standardization and four-point bend test for evaluation of flexural strength and bond strength of relined denture polymers.[35] Similar to this study; we have followed the four-point bend test and the ISO specifications.(Table 1) shows the mean rank values for flexural strength among the study groups and CAD-CAM specimens were found to exhibit significant difference when compared to other groups. The mean rank was found to be higher in CAD-CAM group followed by injection moulded group and least was found in compression group. The P value <0.05 was found to be statistically significant. (Table 3) shows the mean rank values for impact strength among the study groups. The mean rank was found to be higher in injection moulded group followed by CAD-CAM group and least was found in compression group. The P value <0.05 was found to be statistically significant.

Flexural strength values were found to be higher in CAD-CAM specimens followed by injection-molded and least in compression-molded specimens. This is in contrast to the findings by Aguirre et al whereby the flexural strength of the compression-molded specimens was higher than injection-molded specimens.[10] This could be attributed to the long curing cycle used in their study for processing of compression-molded specimens whereas in our study, short curing cycle was used. The difference in flexural strength values between short curing and long curing cycle was explained in the study by Banerjee wherein he has explained that short curing cycle leads to faster and incomplete polymerization resulting in higher level of residual monomer content.[26]

The flexural strength values of our study was found to be similar to that of Kirad et al, Chander et al ,Al-Diwari et al and Gharechahi as they have used the same curing cycle as in our study.[11,21,23,30] They have processed PMMA specimens by compression-molding technique using short curing cycle similar to that of our study. Previous studies by Aguirre et al, Kirad et al and Al-Diwari et al reported that the flexural strength values for CAD-CAM specimens were higher than compression and injection-molded specimens similar to the findings of our study.[10,11,21] Higher flexural strength values of CAD-CAM could be attributed to the higher degree of polymerization under conditions of high pressure and temperature.[10,21] There exists a positive co-relation between high pressure and temperature to the degree of polymerization. In a study by Nguyen et al, resin composite blocks polymerized under high pressure of 250 MPa at high temperature of 180 degree Celsius increased the flexural strength as well as hardness of these resin composites. High pressure of up to 500 MPa can be employed, the highest limit being 980 MPa for flexural test specimens.[31]

Since, the CAD-CAM resin blocks were pre-polymerized to a very high degree of pressure and temperature using equipment more sophisticated than conventional methods, a highly condensed resin mass with less residual monomer content is produced. Under high pressure application, PMMA particles swell by absorbing monomer, thereby, the residual monomer content is reduced. This attributes to increased flexural strength properties.[10,21,31] Previous literature shows that milled CAD-CAM dentures exhibited decreased dimensional changes when compared to compression and injection-molded technique.[24] These findings support the less residual monomer content in CAD-CAM specimens. In a study by Pacquet et al, on comparison of flexural strength values between Ivoclar Vivadent commercial brands of compression, injection and CAD-CAM specimens, it was found that the compression-molded specimens exhibited higher flexural strength values than CAD-CAM specimens and least in injection-molded specimens.[36] This difference in flexural strength values between the three groups varies from the findings of our study as in these studies, they have compared between the same commercial brands of CAD-CAM, Compression and Injection molded specimens.

Faot's study found that the addition of reinforcement material affects the impact strength properties. The type of test used for impact strength evaluation, CHARPY or IZOD, can also impact mechanical properties. The notching or unnotching of specimens was also found to influence impact strength properties.[19]

Impact strength values were found to be higher in injection-molded specimens followed by CAD-CAM and least in compression-molded specimens. These findings were in contrast to the results obtained by Kirad et al.[21] where the impact strength of the CAD-CAM specimens was higher than injection-molded and least in compression-molded specimens. In this study, the difference in the findings can be attributed to the different commercial brands of CAD-CAM used in the studies. In another study by Al-Diwari et al, they have found that different brands of CAD-CAM PMMA have inherent variations in their mechanical properties.[11] This difference in mechanical properties can be attributed to the industrial preparation of PMMA disc. With respect to comparison of impact strength values between compression and injection molded specimens, the results of our study was similar to the findings by Kirad et al whereby, Injection-molded specimens exhibited higher impact strength than compression-molded specimens.[21]

In our study, impact strength of injection molded specimen was higher compared to CAD CAM. Resins that claim to be "high impact" (SR Ivocap) may incorporate rubbery co-monomers such as butyl acrylate that result in dispersion of rubber inclusions.[10,19,21] Consequently, the impact strength in increased. The injection molded material used in the current study claims to be a high impact. The manufacturers have specified an increase of 25% impact strength for this material when compared to its predecessors.[21] These resins, being more flexible due to the rubbery matrix; may negatively affect the flexural strength at the expense of increased impact strength.[37]

Previous study by Ansari et al found that injection-molding technique influenced impact strength properties.[17] However, this depends on a variety of processing parameters such as mold temperature, injection speed and pressure, holding pressure and cooling time.

LIMITATIONS

There are few limitations to the present study. This study was conducted in an In-Vitro set up and it can be co-related with clinical studies for more reliable applications. Future studies should focus on clinical evaluation of flexural, cyclic loading and impact strength of PMMA denture base material processed by different processing method. The testing of specimens would have been carried out under moist conditions to simulate the oral environment. Other limitations in this study are cyclic loading or ageing studies could have been done to evaluate the effect of fatigue forces on denture base material over a long period of time. Scanning electron microscope would have been used to evaluate the fractured acrylic specimens. The compression-molded specimens processed by short as well as long curing cycles would have been included for a more valid and reliable comparison. Future studies can be carried out on comparison of mechanical properties between dentures fabricated through additive and subtractive manufacturing methods. In addition to this, studies can also be carried out to evaluate the mechanical properties among different commercial brands of CAD-CAM, Compression and Injection-molded specimens.

CONCLUSION

The flexural strength values of CAD-CAM PMMA specimens was found to be significantly higher followed by injection-molded and least among compression molded PMMA specimens. The mean impact strength values of injection molded specimens was found to be significantly higher than CAD-CAM followed by compression molded specimens. Combining the results of the study with possible future clinical applications of CAD-CAM PMMA, the milled denture bases may be a possible alternate option for patients with bruxism who are more prone to experience heavy masticatory loads. These CAD-CAM processed dentures can be more time-saving and it could be helpful for patients suffering from debilitating conditions. Injection molded dentures can be the other alternative option to CAD-CAM dentures and can be indicated in patients with limited manual dexterity where the chances for dropping the denture accidentally is more probable. Injection molded dentures are less expensive and economical than CAD-CAM dentures which in turn favours its usage. These dentures are also less technique sensitive when compared to CAD-CAM dentures.

CONFLICT OF INTEREST

There is no conflict of interest

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