Comparative Evaluation of Impact and Flexural Strength of 3D Printed, CAD/CAM Milled and Heat Activated Poylmethyl Methacrylate Resins - An In-Vitro Study

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Abstract: ***Purpose**: To evaluate the impact and flexural strength of 3D printed, CAD/CAM milled and heat activated polymethyl methacrylate denture base resins. **Materials & methods**: Sixty specimens were used in this in vitro study and divided into two main groups. Thirty specimens were used to test flexural strength and thirty specimens were used to test impact strength. For flexural strength, all the thirty specimens were divided into three subgroups- Group A, Group B and Group C. Each subgroup consists of ten specimens. Each specimen is of dimension 64 mm x 10 mm x 3.3 mm and were fabricated using 3D milling, CAD/CAM milled and conventional methods respectively. For impact strength, all the thirty specimens were divided into three subgroups- Group A, Group B and Group C. Each subgroup consists of 10 specimens. Each specimen is of dimension50 mm x 6 mm x 4 mm with 1.2mm V shaped notch along its thickness and were fabricated using 3D milling, CAD/CAM milled and conventional methods respectively. **Results**: For flexural strength: Flexural strength of GROUP IB (CAD/CAM milled) was higher than GROUP IA (3D printing) and GROUP IC (Heat activated). The 3D printing group (GROUP IA) exhibited higher flexural strength than heat activated group (GROUP IC). For impact strength: Impact strength of GROUP II A (3D printing) was higher than GROUP II B (CAD/CAM milled) and GROUP II C (Heat activated). The CAD/CAM milled group (GROUP II B) exhibited higher Impact strength than heat activated group (GROUP II C). **Conclusion**: The method of fabrication or the process of polymerisation of polymethyl methacrylate denture base resin have an effect on flexural and impact strength of the PMMA resin denture bases. All the tested specimens had flexural strength higher than the values recommended by ISO. (ISO 20795-1- 65 Mpa). Similarly, the impact strength of all the specimens had values higher than the minimum recommended by the ADA specification (ADA specification no. 12 – 15J/m).***

Keywords: Flexural Strength, Impact Strength, 3D Milling, CAD/CAM Milling, Polymethylmethacrylate resin

1. Introduction

Complete tooth loss (complete edentulism) is of great concern to majority of the elderly as it compromises aesthetics, phonetics and function in the orofacial region leading to a lowered quality of life. [1] One ofthe treatment options for complete edentulism is replacement of teeth by artificial substitutes, such as complete dentures which is an acrylic-based, removableprosthesis thatreplaces theentire dentition andassociated structuresofmaxilla and mandible, [2] which is vital to the continuance of normal life.

Polymethyl methacrylate resin (PMMA) has been the material of choice to fabricate complete dentures ever since 1936, when Dr.Walter Wright described the results of his clinical evaluation of methyl methacrylate resin.[3]Denture base acts as an intermediary between teeth and the jaw to transfer all or part of the masticatory forces to the underlying tissues. Polymethyl methacrylate (PMMA) resin has been widely used as a denture base material due to its desirable properties of excellent aesthetics, low water sorption and solubility, relative lack of toxicity, ability to repair, and simple processing techniques.

However, one of the major problems encountered in the provision of such prosthesis is whether the limitations of strength and design meet the functional demands of the oral cavity.[4]

Impact failure outside the mouth and flexure fatigue failure in the mouth are the two most important causes of fracture of denture base.[5]Therefore, flexural strength testing is one of the most important tests for a denture base material, since it is subjected to a lot of bending forces in the mouth and also alveolar resorption is a gradual, continuous and irregular process that leaves tissue-borne prostheses unevenly supported.[6,7]

Hence, fractures are inevitable because of its unsatisfactory transverse strength, impact strength or fatigue resistance. Attempts have been made to improve the mechanical properties of acrylic resin by giving maximum bulk to the material in the region which is most heavily stressed, by copolymerization, cross-linking and reinforcement with carbon, glass fibers[8], and aramid or nylon fibers.[9]

After more than 100 years of conventional fabrication of complete dentures,[10]computer-aided design/computer-aided manufacturing (CAD/CAM) technology has been recently applied in dentistry for the fabrication of complete dentures, record bases, immediate dentures, and implant-supported overdentures.[11-12]

CAD/CAM milled dentures are also more hydrophobic than conventionally processed acrylic resin, which results in a more bio-hygienic denture.[14-15]Moreover, highly crossed-linked PMMA resin -based blanks are industrially polymerized under standardized conditions at a high temperature and pressure to improve their mechanical properties.[13, 16]

Milled dentures are monolithic, denture base and teeth in one unit or teeth which could also be milled and chemically bonded to the milled denture base. Milled denture base has the advantage of increased strength and reduces fracturing, reduces denture breakage and completely eliminate tooth delamination or loosing. In vitro studies compared the conventionally fabricated complete dentures and CAD milled complete dentures and the results proved that the milled teeth had better resistance to wear when compared to conventionally fabricated teeth.[17]

In 3D printing technology, an object is designed using computer aided design software (CAD) and printed into a three dimensional structure using materials at certain material content (infill) and at specific orientations.[18] Since 3D printing machine is more affordable than the milling machine, it could be possible for the clinician to have an in-house printer for denture fabrication.

To reduce the incidence of fracture of denture bases, a good processing technique that reduces or eliminates residual stress thereby preventing surface defects is essential, Flexural strength, also known as modulus of rupture, bend strength, or transverse rupture strength, is a material property defined as the stress in a material just before it yields in a flexure test. Since, the denture base may fracture for various reasons, it is important that material has high flexural strength since, flexural strength is a combination of compressive, tensile, and shear strengths.

Ideally, the denture base should have a sufficiently high impact strength to prevent breakage on accidental dropping. The processing technique used to polymerize the denture base resin has been found to be an important factor in determining the impact strength. Dentures may be subjected to impact blows in function and more commonly, accidentally out of the mouth.

Hence, the purpose of this study is to evaluate and compare the impact and flexural strength of 3D printed, CAD-CAM milled and heat activated polymethyl methacrylate denture base resins.

2. Methodology

Preparation of the Test Specimens

Sixty specimens were used in this in vitro study and divided into two main groups. Thirty specimens were used to test flexural strength and thirty specimens were used to test impact strength.

Group I: Test specimens for flexural strength (ISO 1567:1999)

All the thirty specimens were divided into three subgroups- Group A, Group B and Group C. Each subgroup consists of ten specimens. Each specimen is of dimension 64 mm x 10 mm x 3.3 mm as shown in Figure 1.

- Group IA: Ten (10) specimens of polymethyl methacrylate were fabricated using 3D printing.
- Group IB: Ten (10) specimens of polymethyl methacrylate were CAD/CAM milled.
- Group IC: Ten (10) specimens of PMMA resin were fabricated using conventional method.

Figure 1: Specimens for flexural strength testing for heat activated, CAD/CAM milled and 3D printed specimens

Group II: Test specimens for impact strength (ISO 1567: 1999)

All the thirty specimens were divided into three subgroups- Group A, Group B and Group C. Each subgroup consists of 10 specimens. Each specimen is of dimension 50 mm x 6 mm x 4 mm with 1.2mm V shaped notch along its thickness as shown in Figure 2.

- Group IIA: Ten (10) specimens of polymethyl methacrylate were fabricated using 3D printing.
- Group IIB: Ten (10) specimens of polymethyl methacrylate were CAD/CAM milled.
- Group IIC: Ten (10) specimens of PMMA resin were fabricated using conventional method.

Figure 2: Specimens for Impact strength testing for heat activated, CAD/CAM milled and 3D printed specimens

Fabrication of 3D printed PMMA specimens (Group IA & IIA):

Twenty 3D printed PMMA specimens were fabricated using fused deposition modelling (FDM). In the FDM 3D printer, the thermoplastic filaments of PMMA spool are supplied from one end and it is heated to their melting points at the nozzle and then extruded, layer-by-layer at 45^{o}orientation and in rectilinear pattern to create one particular 3D object as determined by computer design files.

To test flexural strength, ten specimens of dimension 64 mm x 10 mm x 3.3 mm were fabricated using FDM 3D printer and to test impact strength, ten specimens of dimension 50 mm x 6 mm x 4 mm were fabricated with 1.2 mm V shaped notch, made along the thickness of the block at the middle of the length using a trimmer. All the specimens were fabricated with 50% infill rate and at 45^{o}build orientation.

Fabrication of CAD/CAM milled PMMA specimens (GROUP IB & IIB):

Twenty CAD/CAM milled PMMA specimens were fabricated using Ruthenium PMMA disc to fabricate ten specimens of dimension 64 mm x 10 mm x 3.3 mm for flexural strength testing and ten specimen of dimension 50 mm x 6 mm x 4 mm for impact strength testing using 4 axis milling machine. Thereafter, the milled specimens were cut from the puck and finished using tungsten carbide acrylic burs and silicon carbide papers. A 1.2mm V shaped notch was made along the thickness of the block at the middle of the length using a trimmer for the impact strength specimens. Only one surface was polished and the other surface remains untouched in order to mimic the intaglio surface.

Fabrication of Heat cure PMMA specimens (GROUP IC & IIC)

A stainless steel bar measuring 64 mm × 10 mm × 3.3 mm for flexural strength and 50 mm x 6 mm x 4 mm with 1.2mm V shaped notch for the impact strength specimens were obtained. This will serve as a metal pattern for the production of the acrylic blocks. Metal patterns were invested in an investment flask using dental stone type III, then retrieved after setting of stone. Heat-polymerizing denture base resin polymer and monomer were mixed in the ratio of 3:1 by vol. (2:1 by wt.) and packed in the flask at dough stage. The flask was left under the hydraulic bench press at 1500 Psi for bench curing for 30 min and the clamps were used to tighten and maintain the pressure. The flasked specimens were held in the clamp and processed by submerging in water at 73± 1ºC for one and half hour followed by 100ºC for 30 minutes. After the completion of acrylization, the flask were bench cooled at room temperature for 30 minutes and then immersed under running water for 15 minutes. All the acrylic blocks were trimmed and polished using silicon carbide papers.[19]twenty heat cured PMMA resin specimens were thus fabricated.

The dimensions of each specimen were measured with a digital vernier caliper with a measuring accuracy of ±0.1 mm before it was subjected to flexural and impact strength test.

Testing Flexural Strength

Ten specimens from each group measuring 64 mm x 10 mm x 3.3 mm (Group IA, IB, IC) were subjected to flexural strength testing under three-point loading with a crosshead speed of 5 mm/min in a universal testing machine as shown in Figure 3. The load was applied perpendicular to the center of specimen strips until the deviation of the load-deflection curve and fracture of specimen occurred. Flexural strength was calculated using the formula;

$$FS = 3\ FL/\ (2bd^2)$$

- Where FS is flexural strength (MPa),
- F is the load or force at break (N),
- L is span of specimen between the supports.
- *b* the width (10 mm),
- *d*the thickness (3.3 mm).

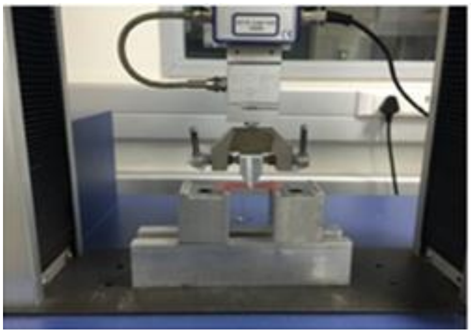

Figure 3: Flexural strength testing for heat activated specimens using universal testing machine

Testing Impact Strength

Ten specimens from each group measuring 50 mm x 6 mm x 4 mm (Group IIA, IIB, and IIC) were subjected to impact strength testing using digital Izod type impact testing machine as shown in Figure 4. The specimen were kept in such a way that notch will be facing towards the pendulum hammer. A 5.5 J pendulum hammer was used to impart the energy at the center of the specimen from the notched side. After deducting the attrition value (0.01J), the net energy absorbed was obtained for each specimens and impact strength was calculated using the following formula;

$$I = Ec/WT$$

- WhereI is the calculated impact strength kJ/m^2
- Ec is net energy absorbed in Joule
- W is the specimen width (m),
- T is the thickness (m).

Figure 4: Impact strength testing of specimens using Izod type impact testing machine

3. Statistical Analysis of Data

The data will be analyzed using the statistical package SPSS version 22.0. The followingstatistical tools will be used to analyze the data.

1) Mean, standard deviation and confidence interval
2) One-way Analysis of Variance followed by Tukey's Post hoc test (If the null hypothesis is rejected)

4. Results

Flexural Strength

Table 1.1: Result of flexural strength of 3D printed PMMA resin

Group Name	Name of specimen	Sample no	Flexural strength (MPa)
Group IA	3D PRINTED PMMA	1	92.5
		2	93.7
		3	94.4
		4	98.4
		5	98.7
		6	91.3
		7	94.2
		8	98.3
		9	93.0
		10	98.9

Table 1.2: Result of flexural strength of CAD/CAM milled PMMA resin

Group Name	Name of specimen	Sample no	Flexural strength (MPa)
Group IB	CAD/CAM PMMA	1	111.8
		2	115.72
		3	103.6
		4	99.4
		5	95.3
		6	106.0
		7	96.24
		8	103.00
		9	93.40
		10	115.70

Table 1.3: Result of flexural strength of Heat Activated PMMA Resin

Group Name	Name of specimen	Sample no	Flexural strength (MPa)
Group IC	HEAT CURE PMMA	1	94.4
		2	99.0
		3	83.1
		4	97.0
		5	95
		6	95.0
		7	94.8
		8	89
		9	96.7
		10	95.0

Table 1.4: Result of mean flexural strength of 3D Printed, CAD/CAM Milled and Heat Activated PMMA

Comparison of mean Flexural Strength (in Mpa) between different study groups using One-way ANOVA Test						
Groups	N	Mean	SD	Min	Max	P-Value
Group IA	10	95.462	2.839	91.30	98.90	0.001*
Group IB	10	104.090	8.109	94.30	115.70	
Group IC	10	93.900	4.580	83.10	99.00	

Impact Strength

Table 2.1: Result of impact strength of 3D printed PMMA resin

Group Name	*Name of specimen*	*Sample no*	*Flexural strength (MPa)*
Group IIA	3D PRINTED PMMA	1	3.20
		2	3.20
		3	3.39
		4	3.40
		5	3.30
		6	3.20
		7	3.40
		8	3.19
		9	3.40
		10	3.09

Table 2.2: Result of impact strength of CAD/CAM milled PMMA resin

Group Name	*Name of specimen*	*Sample no*	*Flexural strength (MPa)*
Group II B	CAD CAM PMMA	1	2.92
		2	2.67
		3	2.69
		4	2.19
		5	2.78
		6	1.89
		7	2.22
		8	2.55
		9	2.76
		10	2.78

Table 2.3: Result of impact strength of Heat Activated PMMA Resin

Group Name	*Name of specimen*	*Sample no*	*Flexural strength (MPa)*
Group II C	HEAT CURE PMMA	1	2.50
		2	2.04
		3	2.01
		4	1.99
		5	1.93
		6	1.80
		7	2.4
		8	1.99
		9	2.35
		10	2.00

Table 2.4: Result of mean impact strength of 3D Printed, CAD/CAM Milled and Heat Activated PMMA

Comparison of mean Impact Strength (KJ/m^2) between different study groups using One-way ANOVA Test						
Groups	N	Mean	SD	Min	Max	P-Value
Group IIA	10	3.267	0.120	3.10	3.40	<0.001*
Group IIB	10	2.537	0.309	1.96	2.97	
Group IIC	10	2.078	0.193	1.88	2.50	

5. Discussion

Loss of teeth is a matter of great concern to a majority of people, and their replacement by artificial substitutes, such as dentures fabricated with acrylic resin, is vital to the continuance of normal life.[1]One ofthe most common economical treatment options for complete edentulism is replacement by an acrylic-based removable prosthesis that replaces the entire dentition and associated structures.[2]

Acrylic resins are used in a various types of dental prostheses, including complete or removable partial dentures, transitional prostheses, and implant-supported prostheses. Most prosthetic acrylic resins consist of polymethyl methacrylate (PMMA) resin.[3]

Polymethyl methacrylate resin is the most commonly used denture base material due to its biocompatibility, ease of handling, dimensional stability in oral conditions, low density, ability to stain, and low cost. However, it is not without limitations , particularly in terms of flexural and impact strength. Flexural failure in the mouth is due to flexing of denture base resin and as resorption of alveolar bone is gradual, continuous and an irregular process, which eventually leaves tissue borne prosthesis unevenly supported contributing to further flexing. Impact failure outside the mouth is due to fall or accident.[5,7,20]

The fracture of polymethyl methacrylate denture base resin remains an unresolved problem and failure is probably because of a multiplicity of factors rather than the intrinsic properties of the denture base material. Various attempts to improve the mechanical properties of polymethyl methacrylate have been made through many avenues along with the reinforcement of denture base. The chemical modification of acrylic resin through the incorporation of rubber in the form of butadiene styrene has been successful in terms of improving the impact strength.[21]However, the incorporation of rubber has not been entirely successful in that it may have detrimental effects on the modulus of elasticity and hence the rigidity of the denture base.

Even though, Polymethylmethacrylate resin (PMMA) satisfies most of the requirements of denture base material in terms of good aesthetics, ease of processing, reparability and reasonable cost, it has relatively poor resistance to impact and flexural forces that may affect the denture design and longevity.[22,23]This property is attributed to the dimensional distortion and processing errors that occurs during the fabrication.[24] To overcome these drawbacks, newer processing techniques have been developed. Digital advancements in denture fabrication with the CAD/ CAM technique has become a rapidly expanding part of the dental market for rehabilitating edentulous patients.[25] Advancement in 3D printing and its application in rehabilitation of edentulous patient is also expanding.

The digital fabrication of complete denture may be processed by CAD/CAM technique or 3D printing technique which first involves digitisation of information with a light scanning technology and then designing with computer aided designing software (CAD), which is then followed by an automatized process of manufacturing (CAM), which can be an additive (rapid prototyping) or subtractive (computerised numerical control milling) process.[26]The advantage of using CAD/CAM technology is that, the resin puck is industrially pre-polymerised under standardized conditions at high temperature and pressure to improve their mechanical properties[13,27]Thus, resulting in a condensed acrylic resin with minimal shrinkage, porosity or free monomer.

However, studies have not compared the flexural and impact strength of 3D printed and CAD/CAM milled denture bases with the heat activated PMMA denture bases. Hence, the present study evaluated and compared the flexural and impact strength of the 3D printed, CAD/CAM milled and conventional heat activated PMMA denture base materials.Denture bases have been shown to flex under the forces generated during mastication, subjecting the acrylic polymer to internal stresses that may result in crack formation and eventually, fracture of the denture.[28,29]

Hence, the flexural strength test, which simulates the load that affects maxillary complete dentures in situ, has been used to evaluate the flexural strength of denture materials.[30,31] In addition to flexural strength, the impact strength plays a vital role because it is related to the ability of the material to withstand impact caused by accidental dropping.[32, 33]

Nogueira et al and Raut et al stated that mechanical properties of PMMA varies depending on the processing technique.[33,34,35]Hence, the present study compared both flexural and impact strength of polymethyl methacrylate processed by three different processing techniques.

Flexural test also analyses all these three mechanical properties (compressive, tensile, and shear strengths).[36, 37, 38, 23]Subjecting denture base to a three-point bend test simulates its ability to succeed intra-orally under high functional loads during mastication and parafunction. Therefore, numerous studies have used this test to evaluate the suitability of novel denture bases.

The present study also compared the flexural strength of polymethyl methacrylate denture base resins processed by 3D printing (GROUP I A), CAD/CAM milled (GROUP I B) and heat activated acrylic resin (GROUP I C). The mean flexural strength were 95.462 Mpa (GROUP I A), 104.09 Mpa (GROUP I B) and 93.9 Mpa (GROUP IC). CAD/CAM milled (GROUP I B) Polymethyl methacrylate specimens had the highest mean flexural strength among the groups in the present study (Table-1.4 & 1.5).

According to ISO 20795-1 for denture base polymers, the standard states that acrylic resins should measure no less than 65 MPa.[39,40]Thus, all samples in the present study were suitable for clinical use.

Prpic et al[41] studied the mechanical properties of 3D-Printed, CAD/CAM, and Conventional Denture base materials and found that flexural strength for the CAD/CAM milled PMMA denture base resin have the highest flexural strength of 119.1 Mpa similar to the present study.

Al-Dwairi et al [42]also found that the flexural strength of CAD/CAM milled resins have the highest mean flexural strength of 123.11 Mpa, when compared to the conventional heat cure acrylic resins.

Aguirre et al[28] in his study compared the flexural strength of denture base acrylic resins processed by conventional and CAD/CAM methods and found that CAD/CAM milled resins have higher mean flexural strength of 146 Mpa which was significantly higher than the conventional compression moulded heat activated resin and injection moulding techniques.

Studies by authors [13, 43, 44]also found that CAD/CAM milled denture base resins had higher fracture toughness than the conventional denture base resins, where in CAD/CAM denture base materials showed higher flexural strength values than heat activated denture base materials. The reason for the improved flexural strength of CAD/CAM milled PMMA may be due to unique processing method of the CAD/CAM, as the CAD/CAM milled PMMA blocks are made under high heat and pressure conditions, which forms a condensed acrylic resin, with minimal shrinkage, porosity, or free monomers[10]

Moreover, the composition and the formation of the PMMA chains explains the superiority of the CAD/CAM PMMA. This also supports the manufacturers' claim attributing to the mechanical favourability of CAD/CAM dentures to the polymerization process of PMMA under high pressure and temperaturethus showing higher flexural strength values of CAD/CAM materials.[41]

The differences in the flexural strength values of 3D printed (GROUP I A), CAD/CAM milled (GROUP I B), and heat-polymerized (GROUP I C) PMMA denture base resin materialsmay probably be due to the use of different brand of materials (manufacturers) in different studies. The possible variation in physical properties between different CAD/CAM PMMA brands may affect the result as reported by Steinmassl et al [13], where different densities among similar dentures fabricated of four different brands of CAD/CAM PMMA showed variation in the result. This might indicate variations in packing density and resultant porosities among different CAD/CAM PMMA brands. However, in the present study, only one brand of CAD/CAM (Ruthinium) was used.

The mean flexural strength between 3D printed (GROUP I A-95.462 Mpa) and heat activated polymethyl methacrylate (GROUP I C- 93.90 Mpa) was not statistically significant (P=0.81), Although ,the 3D- printed material (GROUP I A) had a mean low flexural strength of 95.462Mpa, which was greater than the ISO 20795-1 requirements for flexural strength of 65 MPa.[40]

Hence, it can be used as denture base material as a new option for denture production, but for now, they have lower flexural strength values than most other denture base materials. This low flexural strength can be due to the nature of incremental layers in additive manufacturing technology which may initiate crack propagation and result in a structural failure of the printed material.[45]

In this study, among the tested processing method, conventional heat cured denture base (GROUP I C- 93.90 Mpa) showed the lowest flexural strength. The reason for the low flexural strength of conventional PMMA resin may be due to the rise of temperature at the end of the curing cycle. The free monomer left in the resin as methyl methacrylate boils and creates porosities in the denture base resin and these porosities lead to the formation of stress and cause propagation of cracks within the acrylic.[46]

Rautet al[35] stated that the difference in flexural strength may be attributed to the polymer constituents and to the method of polymerization. The reason for lower mean flexural strength for heat activated PMMA compared with other techniques might be due to presence of large number of porosities.[47] It has been reported that porosity can weaken acrylic resin prosthesis. Porosity can also result in high internal stresses and vulnerability of denture base to distortion and warpage.[39]It was concluded that since these specimen could not be kept under pressure during polymerization process, common defects and internal voids result. Also, it can be due to manually mixing and packing making it difficult to obtain dense specimens.[35]

Impact strength is a measure of the energy absorbed by a material when a sudden blow strikes it.[48,49,50] Small finger notches also occur on the surface of the dentures between the teeth due to defects of trimming and polishing. Since, under impact conditions glassy polymers would show negligible plastic deformation, notching is not necessary to ensure fracture and current practice permits both notched and unnotched specimen to be used. Instead of testing unnotched specimen, ASTM D256 recommends notched specimen in reverse, so that the notch is in the region of maximum compressive and has minimal effect as specimen fractures. [51, 52]
The mean impact strength in this study was recorded with an Izod impact tester for the three test group (Table- 2.1, 2.2 & 2.3). Impact strength data and fracture characteristics depend upon many factors including material selection, the geometry of the specimen, fabrication variables, stress concentrations, and position of specimen and temperature. Stress concentration are the main contributors to impact failure in dentures which include notches, cuts, depressions, sharp corners and grooves, rough or textured surfaces, or inclusion of foreign particles[41]

Impact strength tests are commonly used to evaluate the amount of energy absorbed by materials before they are fractured using the Charpy or Izod configurations. Although their absolute values are different, a good correlation exists between the two methods of impact testing[42,53]The Izod method with notched specimens was selected to perform the impact test in this study,as described by the ASTM -256standard.[7] In the current study, a scaled pendulum (5.5 J) was used to strike the specimens, which causes energy directed towards the notch area to determine the impact energy.[40]

In the present study, all the specimens broke with a sharp fracture for the impact tests. This type of fracture is typical of brittle fracture behaviour characterized by a lack of distortion of the broken parts.[50]

The present study compared the impact strength of polymethyl methacrylate denture base resins processed by 3D printing (GROUP II A) with mean impact strength of 3.27 KJ/m^2, milled pre-polymerized CAD/CAM (GROUP II B) with mean impact strength of 2.537 KJ/m^2 and heat activated (GROUP II C) with mean impact strength of

2.078 KJ/m^2. The results demonstrated significant differences in the mean impact strength among the three groups. The impact strength for the 3D printed PMMA (GROUP II A - 3.27 KJ/m^2) have the highest mean impact strength values among three tested specimens.

Ahn et al [54] stated that the tensile and compressive strengths of the FDM manufactured specimen are greatly influenced by print density (air gap) and raster orientation, while model temperature, material colour. Hence, in the present study, the printing orientation is set up at 45°and infill rate of 50 % with rectilinear infill pattern was used for the 3D printing group. These set up may be the reason for higher impact strength of 3D printed PMMA.

Shim et al.[55] also investigated the effect of printing direction on the bending properties of photopolymer resins, and reported anisotropy in the mechanical properties of the test pieces manufactured in three printing directions printing (0°, 45°, and 90°) and 45°orientation shows higher bending strength. The reason for better impact strength was due to the 45-degree printing orientation which have statistically higher thickness than the other orientations of the other groups.[56,57]

Another reason for the 3D printing group to have the highest impact strength is due to 50% infill rate with rectilinear infill pattern followed in this study which shows higher impact or fatigue life. Increasing the volume faction of the infill structure above 60%, causes a significant increase in strength.[58]

The ultimate strength of the fabricated samples is determined not only by the amount of materials but also by the contact between the parallel tracks. Observation of the manufacturing process showed that, when setting a volume fraction of filling in the range of 20-40%, neighbouring tracks of the same layer do not touch each other. When the parameter is increased to 60% (which corresponds to actual value of 50%), the parallel tracks contact which leads to the formation of a continuous layer and increases the strength of the entire sample.[59]
Khan SA et al [60]stated that rectilinear infill pattern offer the best strength while concentric infill pattern yields the best elongation, which was in agreement with previous study done by

Cabreire V et al[61]where, rectilinear pattern uphold a higher impact resistance than Grid patterns or Honeycomb. The higher impact performance of rectilinear patterns when compared to the Triangle pattern can be related to the transversal geometry, creating more redundancies in the infill. These would absorb more energy during crack propagation. Rectilinear patterns present higher symmetry, effectively combining direct and transversal orientations (vertical and horizontal), which allows for more energy absorption.[62]

The Post hoc test demonstrates that Group II A (3D Printed PMMA) showed significantly highest mean Impact Strength (3.27 KJ/m^2) compared to other 2 study groups at P<0.001, this was followed by Group IIB (CAD/CAM milled PMMA-2.537 KJ/m^2) showing significantly higher mean Impact strength compared to group IIC(Heat activated PMMA-2.078 KJ/m^2) at P<0.001. (Table- 2.4)

The impact strength values of the CAD/ CAM samples in the present study may be correlated to the higher degree of polymerization, which is one of the major factors determining resin strength. Since the CAD/CAM resin blocks are pre-polymerized to a very high degree using equipment more sophisticated than conventional methods, a highly condensed resin mass with minimal porosities is achieved.[13,30]Thus, can be concluded that in these specimens, the amount of residual monomer was less than that in the conventional processing technique and the polymerization was more complete. Conversely, this might be one of the reason for auto-polymerizing resins to exhibit decreased strength and density, and higher porosities.[42]

In the present study, the polymethylmethacrylate denture base was evaluated for impact and flexural strength of 3D printed, CAD/CAM milled and heat activated polymethyl methacrylate denture base resins. It was found that use of different method of fabrication or the process of polymerisation of polymethyl methacrylate denture base resin had an effect on flexural and impact strength on the PMMA denture base resins.

All the tested specimens had flexural strength higher than the values recommended by ISO. (ISO 20795-1- 65 Mpa). Similarly, the impact strength of all the specimens had values higher than the minimum recommended by the ADA specification (ADA specification no. 12 – 15J/m). Hence, 3D printed PMMA resins and CAD/CAM milled PMMA resins may be used as denture base resins in the future.

6. Limitations of the Study

However, the following limitations can be drawn from the present study;
1) Thermocycling used to simulate oral environment was not carried out in this in-vitro study.
2) Further studies on material should be carried out in the shape of denture bases so that it simulates more of clinical condition.
3) Small sample size.

The above mentioned limitations can be improvised by further investigations and studies in the future.
Within the limitations of this study, there is a better scope for the prosthodontist in choosing denture base material with enhanced flexural and impact strength.

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