FLEXURAL STRENGTH OF DENTURE BASE ACRYLIC RESINS PROCESSED BY CONVENTIONAL AND CAD/CAM METHODS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2017

Major Subject: Oral Biology

ABSTRACT

High flexural strength is a desirable property for denture base resins. Currently there is a lack of published studies evaluating the physical properties of newer denture bases such as the CAD/CAM milled bases. The purpose of this study was to compare the flexural strength of three different denture base resins fabricated by compression molding, injection molding, and pre-polymerized CAD/CAM milling. Three groups of ten PMMA acrylic denture base resins were processed into rectangular plates for total sample size of thirty (n=30). The groups differed in their method of processing and resin composition. The three groups were injection molded (SR-Ivocap High Impact, Ivoclar Vivadent), compression molded (Lucitone 199, Dentsply), and pre-polymerized CAD/CAM milled resins (Avadent Digital Dentures). Following storage in water for one week, flexural strength was measured using a 3-point bend test until failure. Kruskal-Wallis and Mann-Whitney tests were used for statistical comparison between groups.

Significant differences in flexural strength was observed among the groups tested. The flexural strength of the pre-polymerized CAD/CAM milled acrylic resin group was higher than that of conventional method groups of compression molded and injection molded. The compression molded group exhibited higher flexural strength than the injection molded group. The results suggest that pre-polymerized milled denture bases may be a useful alternative to conventionally processed denture bases in situations where increased bending forces are anticipated.

ACKNOWLEDGEMENTS

I would like to thank my thesis committee members; Dr. William Nagy, Dr. Elias Kontogiorgos, Dr. David Murchison, and Dr. Ken Chen for their guidance and support. I'd like to especially thank my director, Dr. Nagy, for his guidance, patience, and support throughout residency and in completing this thesis.

Thanks to me loving family, Amber and Jackson, for being patient with me and allowing me to pursue my dreams. To my parents, Velma and Ruben, I wouldn't be where I am today without your support throughout my life. Lastly, to my co-residents, thank you for all the good times and always pushing me to take it the next level.

CONTRIBUTORS AND FUNDING SOURCES

This work was supervised by a thesis committee consisting of Dr. William Nagy, Dr. Elias Kontogiorgos, and Dr. Ken Chen of the Department of Restorative Sciences and Dr. David Murchison of the Department of Diagnostic Sciences.

Statistical analysis of data was conducted in part by Dr. Elias Kontogiorgos. All other work conducted for the thesis was completed by the student independently.

Funds were provided by the Office of Research and Graduate Studies at Texas A&M University College of Dentistry.

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1. INTRODUCTION

In order for a denture base to be successful, it should exhibit several important qualities. According to Zarb, dental resins should be biocompatible, esthetic, cleansable, easily repairable, adhere to denture teeth, and have adequate physical and mechanical properties. (1) It also needs need to be fabricated in an efficient, yet economical manner. Denture base resins should have enough strength and toughness to stand up to forces generated during function while also being dimensionally stable for many years under varying thermal conditions. (2) High flexural strength is critical due to the uneven force distribution the base will endure as the alveolar ridge irregularly resorbs. Therefore, it should be able to resist plastic deformation and fatigue resistance under repeated loads.

Historically denture bases were fabricated from materials such as wood, ivory, and bone. Dental polymers were introduced in 1853 in the form of vulcanized rubber, a plant-derived latex. (2) This material was widely used until the introduction of polymethyl-methacrylate (PMMA) in 1936 which remains the denture base material of choice today. PMMA is the polymer of methyl methacrylate with a chemical formula $C_5H_8O_2$. It is a colorless polymer that goes by the common name of acrylic. PMMA has many physical and mechanical properties which make it a suitable denture base material. It's one of the hardest thermoplastics with a high mechanical strength and modulus of elasticity. Additionally, the low water absorption and dimensional stability over time makes PMMA a capable material for the dynamic oral environment.

Numerous acrylic resins have outperformed PMMA, but most have not made it to clinical dentistry due to difficulties in processing and higher costs. (3) The chemistry of PMMA has evolved over the years. In addition to alteration of polymer chain configurations, multifunctional monomers have been utilized to enhance crosslinking. (2) Although these enhancements have greatly improved several properties of PMMA, it still has the inherent disadvantage of having a relatively low strength. Denture base resin strength is dependent on a number of factors and is non-linear due to plastic deformation that occurs. (2) Clinically, this translates to deformation of the base under heavy loads. While some of the deformation is recovered, some permanent deformation remains.

Several PMMA denture base resin types are available today. Their compositions are similar but small variations lead to different physical properties and processing methods. (2) They're provided in a powder and liquid and used in a ratio of 3:1. The powder typically consists of pre-polymerized PMMA and an initiator, benzoyl peroxide. Additionally, it includes opacifiers, pigments, and glass or nylon fibers to give the PMMA the desired esthetic. The basic liquid consists of methyl methacrylate monomer with an inhibitor, hydroquinone, and a plasticizer, Dibutyl phthalate. Manufactures will combine different monomers and polymers to produce a product with their desirable properties using copolymerization. High impact resistant resins incorporate rubbery comonomers such as butyl acrylate that results in dispersion of rubber inclusions. Therefore, decreasing likelihood of fracture if dropped.

In heat activated resins, thermal energy activates benzoyl peroxide which initiates the polymerization process. The heat may be provided via water bath or microwave energy. Alternatively, the activator can also be a chemical rather than heat. Chemically activated denture base resins, or cold-cure resins, do not require thermal energy but use tertiary amines to activate benzoyl peroxide. Generally, the degree of polymerization reached using chemically activated resins is lower than heat activated resins. This yields excess residual monomer which acts as a plasticizer negatively affecting the physical properties. It’s been demonstrated that dentures made in this manner have lower mechanical properties than those made with heat activated resins. (4) Another type of denture base resin used is light activated denture base resins. These have a matrix of urethane dimethacrylate, microfine silica, and acrylic resin monomers. Visible light activates camphorquinone which serves as the initiator for polymerization. Diaz-Arnold et al. demonstrated these resins have superior flexure strength than all the heat polymerized resins tested but demonstrated greater standard deviations and brittleness. (5)

CAD/CAM (Computer-Aided Design/Computer Aided Manufacturing) was introduced in the late 1950’s with the introduction of PRONTO, a numerical control programming tool. This was the first CAM software system developed by Dr. Patrick J. Hanratty, considered the father of CAD/CAM. (6) Several developments in CAD/CAM technology for dentistry occured in the 1980’s with the help of three pioneers who shaped the current methods used today. Two of them, Dr. Moermann and Dr. Andersson, went on to develop two modern CAD/CAM systems CEREC® and Procera® for clinical dental restorations. (7) Since the turn of the century, this same technology has evolved to include fabrication of complete dentures. The bases are milled from pre-polymerized resin pucks which provide superior strength and fit, reduced bacterial adhesion, and reduced cost to patient and clinician. (8)

Several studies have examined the incidence and causes of denture fractures with broken dentures reported as high as 63% in the first 3 years of service. (9) There is a general trend towards more fractures occurring in the maxilla with an approximate ratio of 2:1 compared to the mandible. (10, 11) Generally, fractures result from either flexural fatigue or impact forces. (3) Fracture due to flexural fatigue is usually explained by the development of microscopic cracks in a stress concentration area. This type of fracture occurs over time and is not due to a single application of force like a fracture due to impact. Stress distribution within dentures has been comprehensively investigated via many methods including finite element modeling, photo-elastic analysis, strain gauges, and holography.(12-15) Maxillary dentures are prone to tensile stresses in the incisor region, both labial and lingual, due to bending deformation. (16) The incisal notch and hard palatal midline are at the center of these concentration points as ridge resorption occurs. Midline fractures have been reported as the second most common fracture site behind denture teeth. (17) There are other contributing factors which may leave a denture more susceptible to fracture. Finite element studies have shown occlusal scheme and location of contacts play a role in maxillary denture fractures. (18) Additionally; diastemas, palatal tori, and sharp frenal notches create localized stress areas causing midline fractures. (9, 15, 19)

To resist these aforementioned complications, there are a number of mechanical properties of interest due to the various stresses these resins may undergo. Denture bases undergo repeated flexing during mastication for several years. Often times this may lead to fatigue failure of the prosthesis. (20) Therefore, a high fatigue strength is a desirable property of denture base resins. Testing fatigue strength is a laborious and very time consuming process compared to measuring other properties. In the event of dropping the prosthesis extra-orally, impact strength becomes critical. This property is the capability of the material to withstand a suddenly applied load. A popular method to measure impact strength is an Izod impact test which uses a single high speed of impact to fracture the sample. Disadvantages of this method are the extrinsic variables inherent in the testing, such as, specimen dimensions, notch depth and radius, impact velocity, and other factors.(21) This suggests that the impact test is better suited for prosthesis design rather than comparing intrinsic properties of materials. Since fracture is frequently preceded by crack formation, a higher fracture toughness is also desirable. (22) This is the ability of the material to resist crack propagation, a critical property for a denture base to possess. Some denture base resins fracture in a smooth, rapid, fashion while others may fracture slowly with a permanent deformation and irregular fracture surface. (23) Flexural strength represents the highest stress experienced within the material at its moment of rupture. Transverse strength is another term used to describe flexural strength, though they are measured the same way. Given the intraoral function of the denture base, a high flexural strength is required to prevent catastrophic failure under load. The ability to withstand high flexural loads is paramount for the success of a denture. One example is in the implant fixed complete denture (IFCD) provisional where the denture is subjected to high flexural loads on either side of each implant. Similarly, in the implant retained overdenture, the remodeling of the alveolar ridge may lead to increased flexural loads as the denture fulcrums over the abutments. Frequently, flexural strength is measured utilizing a three-point flexural test.

The measurement of the physical and mechanical properties of denture base resins is dependent on several extrinsic factors as well. American Dental Association Standard No. 139 in accordance with ISO 20795-1 for denture base polymers describes the effect of time and temperature during polymerization and during testing. (24) Due to variations in the formulation of different resins, manufacturer's instructions for mixing time and temperature must be followed carefully. Also, when running tests, such as the three-point bend, the medium in which it's bent should reproduce the oral environment. Specimens flexed in an aqueous environment exhibit lower strength compared to performing test in air. Additionally, to simulate the oral cavity, conditioning of the resin prior to testing is necessary. It's been demonstrated thermocyling negatively effects flexural strength of denture base resins. (25)

Several studies have compared the flexural or transverse strength of different types of denture base resins and their various processing methods. (5, 23, 26-31) The compression and injection molded are the most popular studied and employed methods used. Lucitone 199 is one of the most studied resins. It has been shown to have superior flexural strength in some studies and is highly regarded in the dental community. Ivocap High impact (Ivoclar Vivadent) is another frequently used resin in combination with injection molding due to its improved accuracy of fit. (2)

The purpose of this study was to compare the flexural strength of three different denture base resins fabricated by compression molding and injection molding, and preprocessed CAD/CAM milling. The null hypothesis was that there is no significant difference in the flexural strength among the three groups.

2. MATERIALS AND METHODS

Pre-polymerized milled rectangular plates (64mm x 10mm x 3.3mm) were ordered from Avadent Digital Dental Solutions. A vinyl polysiloxane putty (3M/ESPE) matrix was created from these specimens. Pink base plate wax was then dripped into the matrix to form wax duplicates. Three groups of ten PMMA acrylic denture base resins were processed into rectangular plates in accordance to ISO 20795-1 (64mm x 10mm x 3.3mm) for total sample size of thirty. The groups differed in their method of processing and resin composition. The three groups were injection molded (SR-Ivocap High Impact, Ivoclar Vivadent), compression molded (Lucitone 199, Dentsply), and pre-polymerized CAD/CAM milled (Avadent Digital Dentures) resins. Plates were finished, polished and stored in distilled water for one week. Flexural strength was measured in a Universal Testing Machine (Instron Ltd.) using a three-point bend test.

2.1 Compression molded fabrication

Wax plates (64mm x 10mm x 3.3mm) were flasked and invested according to manufacturer's instructions in ISO type 3 dental stone (Whip Mix Corp.). The flask was heated in boil out solution for 8 minutes, separated, and the wax flushed with boiling solution (Patterson Dental). The final flush was done with clean water and the halves were allowed to cool to room temperature. ALCOTE Separator (Dentsply) was applied to the stone and allowed to dry. Lucitone 199 Resin (Denstply) was mixed with 21g polymer to 10ml monomer to assure wetting of all polymer particles. The jar was covered and material allowed to reach packing consistency, not sticky or rubbery (10 minutes). Resin was condensed into the mould with finger pressure and the flask was closed in a Pneumatic Flaskpress (Coe-Bilt) under 6000 pounds of pressure. The flask was then loaded in a spring clamp and placed in a Hanau Curing Unit (Whip Mix) for 9 hours at 163^{o}F, followed by 30 minutes in boiling water (212^{0}F) per manufacturer instructions. Bench cooling was allowed for 30 minutes and then the flask was immersed in 70^{o}F water for 15 minutes prior to deflasking.

2.2 Injection molded fabrication

Wax plates (64mm x 10mm x 3.3mm) were flasked and invested according to manufacturer's instructions in ISO type 3 dental stone (Whip mix Corp.). The flask was heated in boil out solution (Patterson Dental) for 8 minutes, separated, and the wax flushed with boiling solution. The final flush was done with clean water and the halves were allowed to cool to room temperature. Separating fluid (Ivoclar Vivadent) was then applied to the stone and allowed to dry. Premeasured capsules of resin and monomer (SR-Ivocap High Impact, Ivoclar Vivadent) were combined and mounted in the Cap Vibrator (Ivoclar Vivadent) for 5 minutes. The flask halves were clamped in a clamping frame under 6000lbs of pressure. The mixed capsule was inserted into the flask and the SR Ivocap pressure apparatus was attached. The pressure apparatus was connected to a compressed air supply (6 bar/ 85 psi) to allow the plunger to descend and press material into the mould. Ten minutes of injection time was programed at room temperature. The assembly was then placed in the polymerization bath at the appropriate water level. Polymerization was allowed to occur for 35 minutes under boiling water. The assembly was then removed and immediately placed in cold water, maintaining pressure, for 30 minutes. The specimens were then deflasked.

2.3 Pre-polymerized CAD/CAM milled

Pre-polymerized CAD/CAM milled rectangular plates were provided from Avadent Digital Dentures and were in final dimensional specifications.

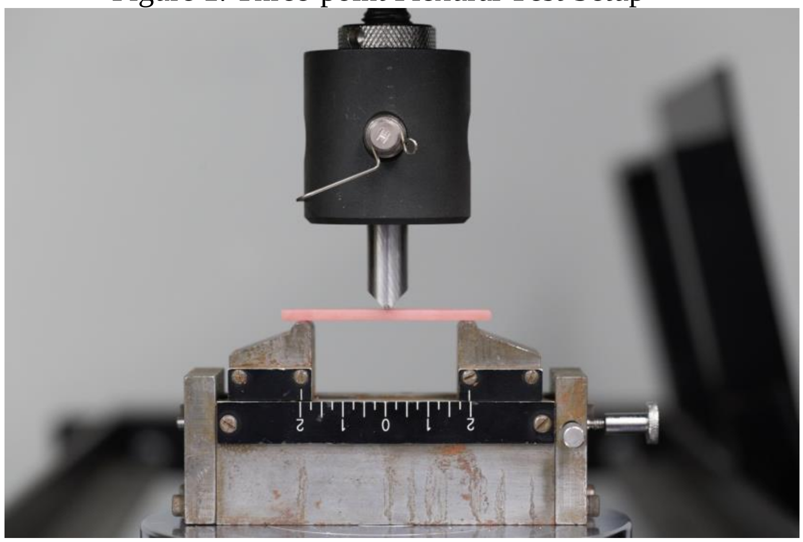
2.4 Preparation of samples for flexural strength test

After processing, samples were evaluated to ensure absence of voids or gross irregularities with 3.5x magnification. The samples were then finished with wet 220 to 600 grit silicon carbide paper (3M ESPE) to a final dimension of 63 x 10 x 3.3mm as measured with digital caliper (Neiko) at 5 points to +-.03mm. Prior to flexural strength test, all samples were stored in distilled room temperature water one week for conditioning.

2.5 Three-point bend test and measurement of flexural strength

Samples were tested using a three-point bend test per guidelines of ISO 20795-1 for denture base polymers. Each sample was placed on circular support beams with a 50mm span. (Figure 1) A load was applied with a Universal Testing Machine (Instron) to the center of the samples at a crosshead speed of 5mm/min until fracture. The moment of fracture was designated as the moment applied load dropped to zero. Data was recorded on Bluehill Sofware (Ver 1.5).

Figure 1. Three-point Flexural Test Setup



2.6 Calculations and statistical analysis

Maximum load exerted was recorded in Newtons (N). Flexural strength (F_s) was then calculated:

Flexural strength (F_s) = $3PL/2bd^2$

P = maximum load   b = specimen width

L = span length   d = specimen thickness

Data was analyzed using statistical software (SPSS 19.0, SPSS Inc). Kruskal-Wallis test evaluated the differences between sample groups (Packed, Injected, Milled) with a significance level of $p \leq .05$. The Mann-Whitney test was performed when a difference was detected between groups with an adjusted significance level set to $p \leq 0.017$.

3. RESULTS

The flexural strength of the pre-polymerized CAD/CAM milled acrylic resin group was higher than that of compression and injection molded groups. The compression molded group exhibited higher flexural strength than the injection molded group. The Mann-Whitney test showed that the difference was statistically significant (P=0.001) between the three groups.

The milled and compression molded resin groups fractured with minimal to no plastic deformation in contrast to the injection molded resin that displayed pronounced deformation. This could be visualized by re-approximating the specimens following fracture. (Figure 2)

The data for the means of flexural strength of the different groups are shown in Table 1 and Figure 3. The mean value (SD) for the pre-polymerized milled samples was the highest with 145.61 MPa (6.58), followed by 116.61 MPa (3.14) for the compression molded group and 86.73 MPa (7.06) for the injection molded group.

Table 2 shows statistical differences between each specific group. When the injection molded group was compared to the compression and pre-polymerized milled groups, significant differences were observed (p=0.001). Likewise, when comparing the compression to the pre-polymerized milled groups, a significant difference was noted (p=0.001).

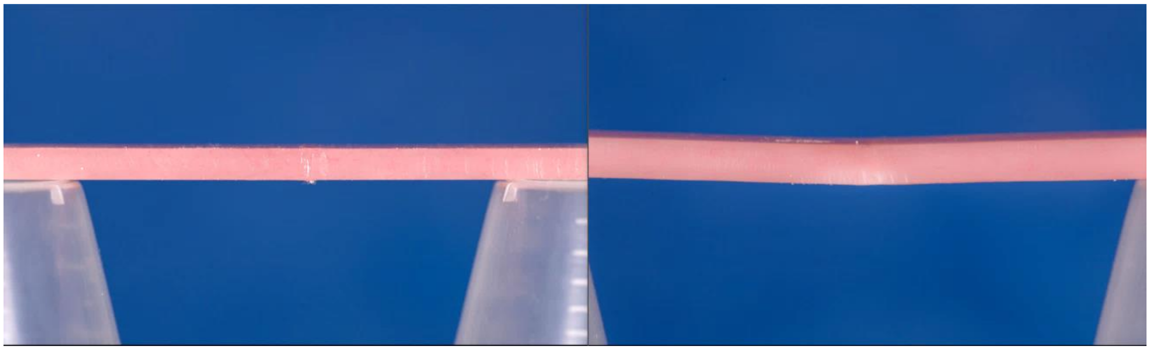


Figure 2. Deformation of Injection Specimen (Right) Compared to Milled Specimen (Left)

Table 1. Descriptive statistics examining flexural strength (MPa) for the 3 groups (Injection, compression, milled).

	Injection	Compression	Milled
N	10	10	10
Mean	86.7341	116.6105	145.6141
SD[a]	7.06461	3.14359	6.57883
Minimum	76.51	110.11	135.52
Maximum	97.31	120.57	153.41

a. Standard Deviation

Table 2. Mann-Whitney Test for differences between 2 groups according to Flexural Strength.

	Injection vs Compression	Injection vs Milled	Compression vs Milled
Mann-Whitney U	0.000	0.000	0.000
Wilcoxon W	55.000	55.000	55.000
Z	-3.780	-3.780	-3.780
Significance*(p≤0.017)	0.001	0.001	0.001

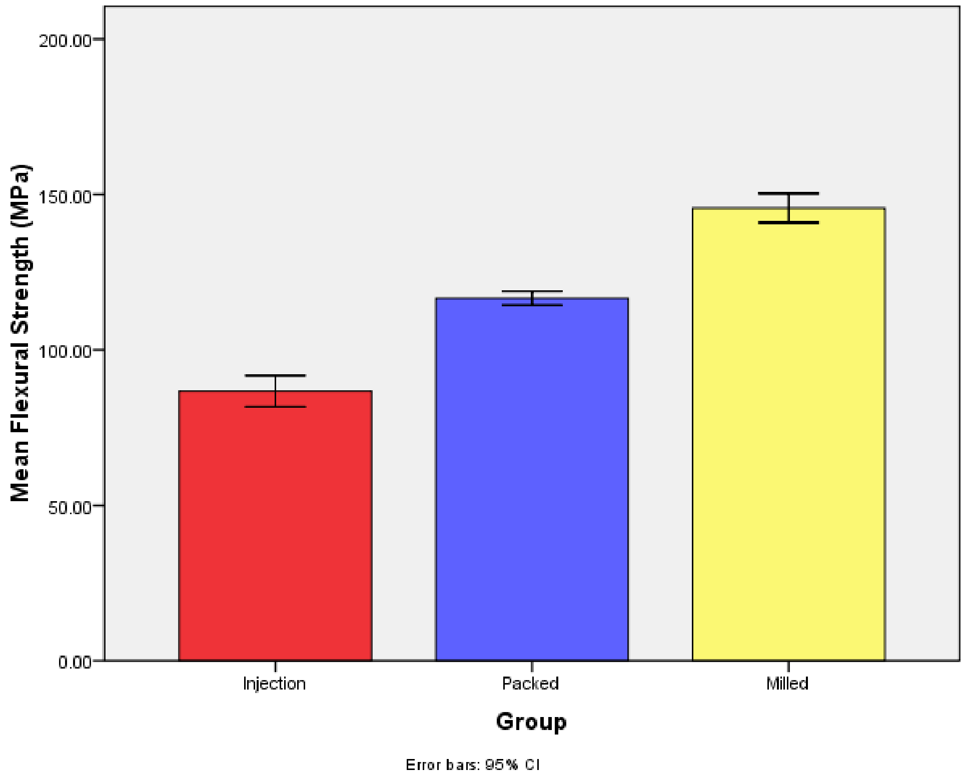


Figure 3. Mean Flexural Strength Bar Graph

4. DISCUSSION

The flexural strength of denture base resins is an important property because when the flexural, or transverse, strength of a material is exceeded, you are also analyzing the compressive, tensile, and shear strengths. Flexural strength is a combination of these three mechanical properties. Subjecting a 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 prior studies have used this test to evaluate the suitability of novel denture bases. According to the international standards for polymer materials and ISO 20795-1 for denture base polymers, the three-point flexural test is the most common method for measuring flexural properties. The standard states that acrylic resins should measure no less than 65 MPa. Thus, all samples in the current study are suitable for clinical use.

The present study compared the mean flexural strength recorded with a universal testing machine for three different resins processed by compression molding, injection molding, and milled pre-polymerized CAD/CAM acrylic resin samples. The results demonstrated significant differences in flexural strength among the three groups. This supports rejection of the null hypothesis that there is no significant difference in the flexural strength among the groups tested. While there is no published literature looking at the pre-polymerized milled resin flexural strength, this data is in disagreement with a previous study comparing compression and injection- molded resin. Gharechahi concluded that injection-molded resins had a higher flexural strength than pressure-packed in his study (26). While his methods were similar to the present study, the compression molded group was processed with an acrylic from a different manufacturer. These differences occurring in most published studies should be considered, as manufacturers do not disclose the composition of their products.

Limitations of the current study were the lack of cyclic loading and thermocycling prior to the three-point flexural test. Also, the samples tested do not reflect the shape of an actual denture. The effect of thermocycling on the flexural strength of denture base resins was examined in a prior study. Thermocyled (5000 cycles) samples of Lucitone 199 displayed significantly lower flexural strength compared to samples that were not thermocycled. (25) This is due to the effect water has on the physical properties of processed polymers. Structural changes occur to the polymer chains as water molecules interfere, acting as plasticizers. As a substitute, the samples in the present study were submerged in de-ionized water for one week to simulate the aqueous intra-oral environment. Additionally, cyclic loading would fatigue the samples to better simulate intra-oral conditions. Although a previous study showed no significant difference in flexural strength between heat polymerized specimens that underwent cyclic loading (10,000 cycles) or not. (5)

The higher flexural strength values of the CAD/CAM milled samples may be attributed to the higher degree of polymerization. One of the major determinants of resin strength is the degree of polymerization achieved. As it increases, so does the ultimate strength of the resin. Using propriety methods, the CAD/CAM milled dentures are milled from a solid pre-polymerized puck. It is assumed these pucks are polymerized to a very high degree using equipment more sophisticated than conventional methods. As a result, it yields a highly condensed and less porous resin. (8) Conversely, this is why chemically activated, or cold-cure, resins exhibit decreased strength and density. Differences in flexural strength may be credited to the different composition of the polymer and monomers. Resins that claim to be “high impact” may incorporate rubbery comonomers such as butyl acrylate that result in dispersion of rubber inclusions. Consequently, the impact strength in increased. The compression and injection molded groups in the current study claim to be high impact. However, it is unknown whether the pre-polymerized milled resin group were. These resins may negatively affect the flexural strength at the expense of increased impact strength due to increased flexibility. (3) An assessment of the samples after fracture revealed much more noticeable permanent deformation of the injection molded resin. This may be related to the amount of rubbery comonomers present in this resin, however this isn’t disclosed by the manufacturer. The SR Ivocap High Impact resin underwent substantially more permanent deformation prior to fracture. Clinically this may lead to subclinical deformation of the denture rather than fracturing under load. The pre-polymerized and compression molded resins displayed more similar fracture characteristics, displaying minimal to no deformation.

This study investigated a specific mechanical property of three commercially available denture base resins. No prior studies have been published examining the mechanical properties of milled denture base resins. Future studies should evaluate other mechanical properties such as the impact strength and fracture toughness of these pre-polymerized milled resins. Avadent Digital Dental Solutions also mills monolithic dentures where the teeth and base are milled from a single piece. They claim these dentures can be up to 8x stronger than ones processed by conventional methods, yet this has not been verified. Clinically, a resin with a higher flexural strength may be less inclined to fracture during function. Thus, using a milled denture base may be beneficial in cases where you anticipate heavier functional loads or a patient suffering from multiple denture fractures not due to accidental drop. Due to cost restraints and ease of conventional denture processing methods, this is not always feasible. Most clinical situations are unique and therefore material selection, depending on the situation, is paramount for denture success. While the flexural strength of the injection molded samples was the lowest, it is still a suitable material and its properties may be advantageous in some clinical situations. For instance, in implant fixed complete dentures (IFCD), occlusal forces are much greater than in a removable complete denture and commonly suffer from fractures. This is usually an emergency and a difficult situation for both the clinician and patient. One solution is to provide a material with the highest flexural strength and prevent the fracture all together. Alternatively, using a material with a low modulus and ability to undergo permanent deformation may prevent the fracture from ever occurring. Future studies may provide guidelines for material selection in dentures for specific clinical situations.

5. CONCLUSIONS

Within the limits of this in vitro study, the flexural strength of a denture base resin may be influenced by the method in which it is processed. Pre-polymerized CAD/CAM milled denture resin exhibited higher flexural strength compared to the two conventional processing methods, compression and injection molded. The milled and compression molded resins fractured with minimal to no plastic deformation in contrast to the injection molded resin that displayed pronounced deformation. The results suggest that pre-polymerized milled denture bases may be a useful alternative to conventionally processed denture bases in situations where increased bending forces are anticipated.

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