A COMPARATIVE EVALUATION OF FLEXURAL STRENGTH OF DIFFERENT DENTURE BASE RESINS PROCESSEDBY CONVENTIONAL AND CAD-CAM METHODS –AN IN VITRO STUDY.

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ABSTRACT

Purpose: The rapid evolution of CAD-CAM technology in prosthodontics has led to the introduction of newer materials that could be precisely milled for the fabrication of dental prostheses. CAD-CAM polymethylmethacrylate (PMMA) and Polyetheretherketone (PEEK) based polymer discs have been introduced by manufacturers which are claimed to be of better mechanical properties; however, a very few published reports that have evaluated mechanical properties of CAD/CAM denture base materials are present. The purpose of the study was to evaluate and compare flexural strength of different Denture Base Resins, including both PMMA and PEEK, fabricated by Conventional and CAD-CAM methods. **Materials and Methodology:** 75 rectangular specimens of dimension 65 mm × 10 mm × 3 mm were fabricated (15 CAD/CAM Ruthiniun PMMA specimens, 15 CAD/CAM Ivoclar PMMA specimens, 15 CAD/CAM Zahndent PMMA specimens, 15 CAD/CAM Victrex PEEK specimens, and 15 conventional Lucitone 199 PMMA specimens) and stored in artificial saliva at 37 ± 1°C for 7 days. Specimens (N = 15) in each group were subjected to the three-point bending test in Universal Testing Machine. The data was analyzed statistically using ANOVA and Post Hoc (Bonferroni) tests. **Results:** It was found that the mean flexural strength was highest for CAD-CAM milled Victrex-PEEK (336.4133 MPa) followed by CAD-CAM milled Ruthinium PMMA, CAD-CAM milled Ivobase CAD PMMA, CAD-CAM milled Zahndent PMMA Denture Base Resin and lowest for Conventional heat polymerized PMMA Denture Base Resin (80.5820 MPa). **Conclusion:** CAD-CAM milled Dentures are superior in terms of flexural strength as compared to the conventionally fabricated Dentures. The newer Denture Base Material, PEEK, used in the study could be a promising Denture Base Resin in terms of fracture resistance and durability because of its high flexural strength. Different brands of CAD/CAM PMMA may have inherent variations in flexural strength.

Keywords: CAD/CAM; PMMA; flexural strength, PEEK.

INTRODUCTION

Despite the advancements in dental treatment possibilities for edentulism, Removable Maxillary and Mandibular Complete Dentures has always remained the treatment of choice, due to anatomical, physiological and financial restrictions.[1] Rohm and Hass in 1936 introduced Polymethylmethacrylate (PMMA) in the form of a transparent sheet and in 1937 Du Dout De Nemours introduced it in powder form. Methyl methacrylate was clinically evaluated by Wright in 1937 and found to fulfil virtually all the requirements of an ideal Denture Base material.[2] The PMMA and its copolymers continued to be the most popular non-metallic materials. The advantages were simple processing technique, stable color, optical properties, adequate strength, economical and other physical properties such as free from toxicity and easy pigmentation, make them ideal materials of choice.[3] High Flexural strength is an essential prerequisite for successful Denture Base materials. However, clinical reports on the fracture of Complete Dentures have indicated that the mechanical properties of PMMA were not completely satisfactory with regard to the longevity of the denture base.[4] So, chemical modifications in the composition of PMMA and alterations in fabrication techniques were attempted to overcome the shortcomings of PMMA acrylic resins.

With the world moving at a rapid pace towards digitalization, recent improvements in science and technology have provided digital methods for denture base production, including computer-aided design-computer-aided manufacturing (CAD-CAM).[5] CAD-CAM dentures offer important advantages over conventional dentures like reduction of residual monomer, improved physical properties of the denture base, reduction in polymerization shrinkage, reducing the number of patient visits, and adhesion of Candida albicans to the denture base.[6] Also, the use of CAD-CAM technology reduces the number of dental technicians required with extensive experience and expertise with traditional fabrication processes.[6]

With the increasing interest in the Complete Dentures fabricated using computer-aided technology, a range of CAD-CAM polymethylmethacrylate (PMMA) based polymer discs have been introduced by manufacturers.[7] These PMMA blanks are polymerized under high temperature and pressure, which promotes the formation of longer polymer chains, leading to a higher degree of monomer conversion and lower values of residual monomer, as well as minimal porosity. The rapid evolution of CAD-CAM technology in prosthodontics has also led to the introduction of newer materials that could be precisely milled for the fabrication of dental prostheses. Polyetheretherketone (PEEK) is one such material. It is a linear, aromatic, semi-crystalline thermoplastic, high performance polymer recently used in dentistry as a framework material for metal-free dental prostheses.[8] Although PEEK is becoming widespread in clinical practice, only a few studies are available focusing on the use of this material for CAD-CAM prostheses.

Hence, an in vitro study was conducted to evaluate and compare flexural strength of different Denture Base Resins, including both PMMA and PEEK, fabricated by Conventional and CAD-CAM methods. The null hypotheses of the study were that no differences would be found between flexural strengths of PMMA and PEEK denture base resins processed by conventional and CAD-CAM methods.

MATERIALS AND METHODOLOGY

The study was divided into five study groups with a total of 75 samples, 15 samples in each group. (Table 1) The samples of each group were prepared according to ISO 20795-1:2013 (E) (Dentistry-base Polymers -- Part I: Denture base polymers). A uniform rectangular shaped samples were fabricated with dimensions of 65 x 10 x 3 ± 2 mm.

a. Fabrication of the Conventional Heat cure PMMA Denture Base Resin samples

A total of 15 rectangular samples were made using modelling wax of the same dimensions i.e., 65x10x3 ±2 mm and measured using a digital vernier calliper. These wax samples were flasked and mould space was prepared by dewaxing. According to manufacturer's instructions, the powder and liquid of Lucitone 199 heat cure resin were mixed in appropriate proportions and the material was packed in the mould cavity. The material was processed using short curing cycle by placing the flasks in constant temperature water bath at 74 ºC for 2 hours and increasing the temperature of water bath to 100 ºC and processing for 1 hour. After curing and slow, uniform cooling, deflasking was done and samples were retrieved. The excess was trimmed and samples were finished using acrylic trimmers and pumice powder. The final dimensions of the samples were again verified using digital vernier calliper.

b. Fabrication of the CAD-CAM milled PMMA and PEEK Denture Base Resin samples

For the fabrication of samples for CAD-CAM milled PMMA and PEEK Denture Base Resin, the virtual design of rectangular shaped samples with the dimensions of 65 x 10 x 3 mm were made with the help of a computer program and then converted into stereolithography (.stl) file. Thereafter, rectangular samples were milled from the pre-polymerized blanks using CAD-CAM milling machine. The milled samples were cut from the blanks and finished using trimmers. The dimensions of the samples were again verified using a digital vernier calliper.

c. Aging of the test samples

Prior to testing, all the samples of 5 groups were stored in artificial saliva (Wet Mouth, ICPA) and kept in the incubator at 37 ± 1°C for 7 days.

Table 1: Study Groups used in the study for the evaluation and comparison of flexural strength

Group	Material name	Polymer type	Manufacturer
Group I	Lucitone 199	Heat polymerized conventional PMMA	Dentsply Sirona
Group II	Ruthinium pink CAD/CAM disc	CAD-CAM based PMMA	Ruthinium Dental Product Pvt. Ltd.
Group III	Ivotion Base	CAD-CAM based PMMA	Ivoclar Vivadent

Group IV	Zahndent pink CAD/CAM disc	CAD-CAM based PMMA	Zhejiang Zahndent Biotechnology Co., Ltd.
Group V	Victrex PEEK 450G	CAD-CAM based PEEK	Victrex

d. Evaluation of flexural strength of the test samples

The samples were then tested for flexural strength using a Universal Testing Machine (SHIMADZU, AG-X plus, 5kN). The three-point bending test was used to measure the flexural strength of the samples. Each sample was placed on a sample fixture supported at two ends with a distance of 50 mm between them. A load cell was applied at the midpoint of each sample with a crosshead speed of 5 mm/min until fracture. Fracture load and load-deflection curves were recorded by the connected computer using software TRAPEZIUM X. The procedure was repeated for all the test samples and the breaking load values recorded.

The flexural strength of each sample was calculated according to the following formula:

FS = 3FL/(2bd2)

where, FS is the flexural strength (MPa), F is the load or force at which fracture occurred (N), L is the span of specimen between the supports (50 mm), b is the width (10 mm), and d is the thickness of the specimen (3 mm).

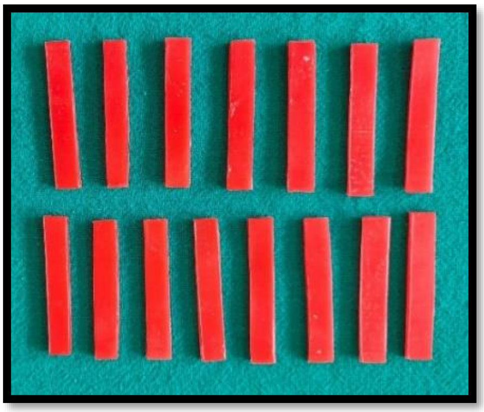


Fig. 1. Rectangular specimens made of modelling wax

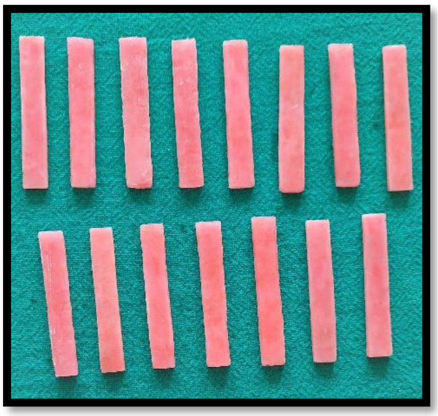


Fig. 2. Conventional heat cure (Lucitone 199) samples

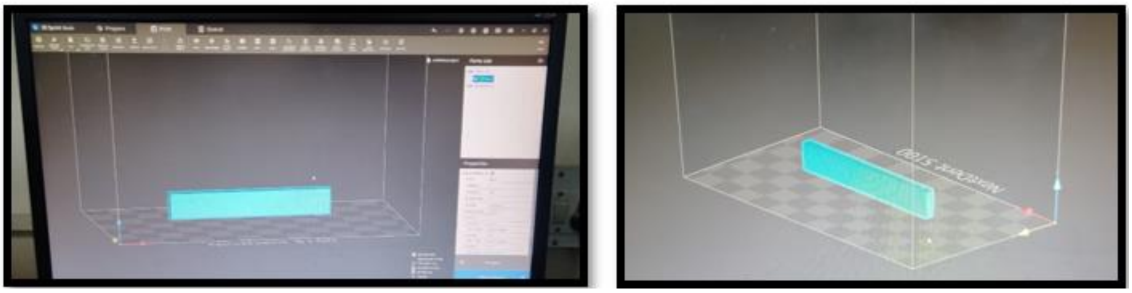


Fig. 3. Virtual designing of CAD-CAM samples

Fig. 4. Milling of CAD-CAM samples

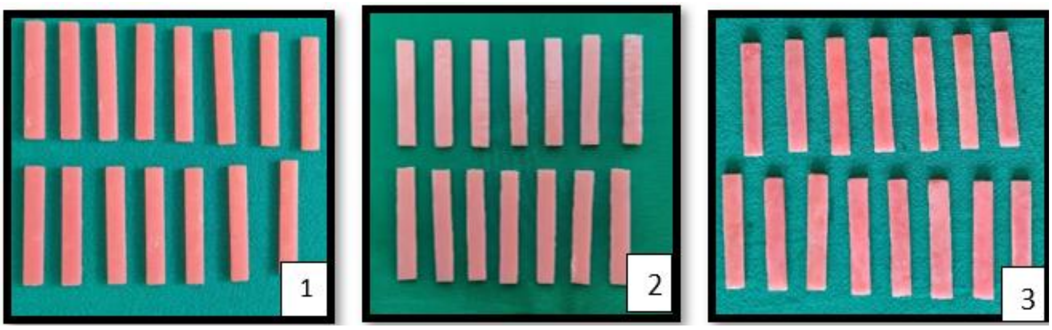


Fig. 5. CAD-CAM samples: 1) Ruthinium 2) Ivotion 3) Zahndent

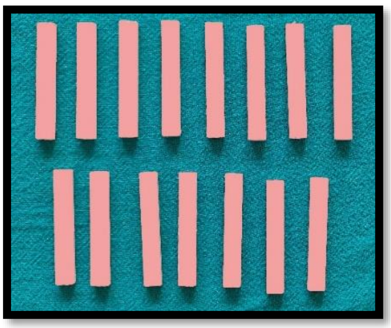


Fig. 6. CAD-CAM samples Victrex PEEK

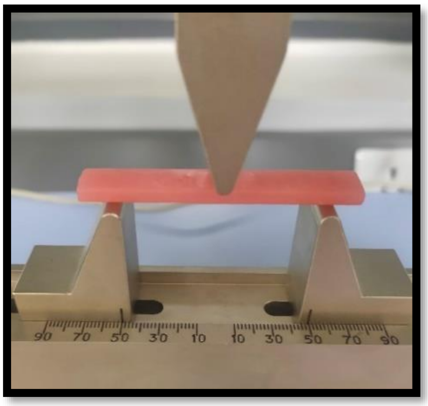


Fig.7. Sample supported at two ends with a span of 50 mm between them

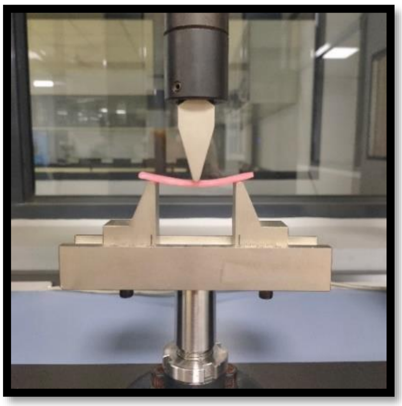


Fig. 8. Flexure seen in the sample of PMMA before fracture

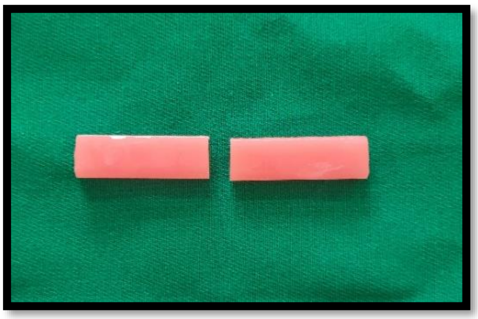


Fig. 9. Fractured PMMA sample

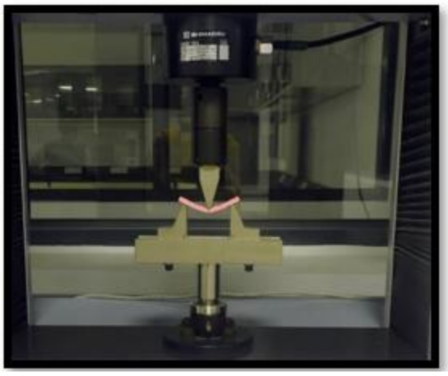


Fig. 10. Significant bending seen in the PEEK sample without fracture

RESULTS

The data was analyzed statistically using ANOVA and Post Hoc (Bonferroni) tests to calculate mean flexural strength and standard deviation for each group. (Table 2) Post-Hoc (Bonferroni) test showed the comparison between each group and it was analyzed that the difference between mean flexural strengths among all groups were significant as p-value came out to be less than 0.05. (Table 3)

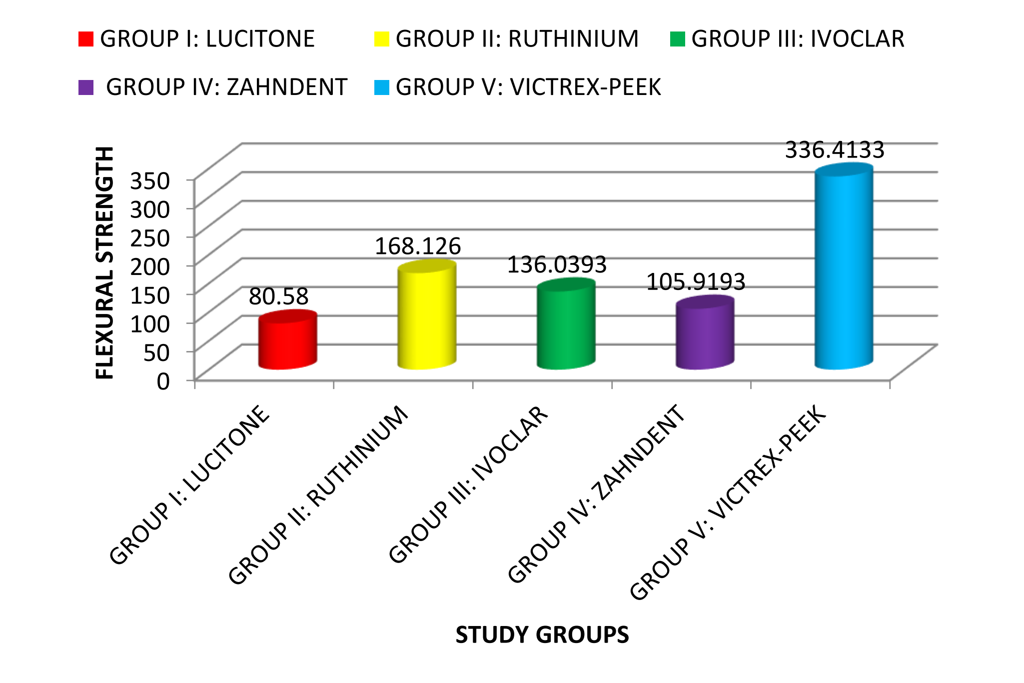
Table 2: Mean flexural strengths of all five study groups

Group	No. of samples	Minimum	Maximum	Mean (MPa)	Std. Deviation
Group I	15	60.57	98.76	80.5820	11.65848
Group II	15	136.66	188.78	168.1260	13.58081
Group III	15	111.35	193.16	136.0393	22.33716
Group IV	15	76.23	179.47	105.9193	29.29342
Group V	15	328.76	342.95	336.4133	4.75904

Table 3: Comparison mean of different groups using one way ANOVA

Groups	No. of samples	Minimum	Maximum	Mean	Std. Deviation	p-value
Group I	15	60.57	98.76	80.58	11.658	<0.0001
Group II	15	136.66	188.78	168.12	13.580	
Group III	15	111.35	193.16	136.03	22.337	
Group IV	15	76.23	179.47	105.91	29.293	
Group V	15	328.76	342.95	336.41	4.759	

It was found that the mean flexural strength was highest for CAD-CAM milled Victrex-PEEK Denture Base Resin followed by CAD-CAM milled Ruthinium PMMA Denture Base Resin, CAD-CAM milled Ivobase CAD PMMA Denture Base Resin, CAD-CAM milled Zahndent PMMA Denture Base Resin and lowest for Conventional heat polymerized PMMA Denture Base Resin. (Graph 1)



Graph 1: Comparison of mean flexural strength of different study groups

DISCUSSION

High Flexural strength of Denture Base material is a very important factor for Denture durability and prevention of failures under flexural forces in the oral cavity. 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.[5] The three-point bending flexural test, adopted by International Standards for Polymer Materials, including ISO 1567:1999 Dentistry-Denture base polymers, is the most common technique of measuring flexural properties of Denture Bases. The acceptable clinical value of flexural strength for Denture Base Resins is set to be not less than 65 MPa.[9] In this study, the three-point bending test was performed on a Universal Testing Machine with a loading force applied to specimens at a crosshead speed of 5 mm/min.

Acrylic resins were introduced to dentistry in 1937 following which various materials have also been introduced in material science, but none of them closely mimics the oral soft tissue as it does.[7] Since its introduction, it is routinely and successfully being used for the fabrication of full and partial prosthesis owing to its outstanding properties.[10] Polymethylmethacrylate (PMMA) satisfies most of the requirements of Denture Base Materials in terms of excellent dimensional stability in oral environment, low cost, light weight, acceptable aesthetics, and the ease of fabrication and repair, etc. However, there are many concerns related to the use of PMMA, including Denture fracture caused by water sorption and impact, as well as the decreased flexural strength, porosity, and polymerization shrinkage.[11] Studies done by Phoenix, Meng, and Latta suggested that PMMA is the most popularly used material for removable prosthodontics, but its low strength results in the failure of the prosthesis. To overcome the shortcomings of PMMA, alterations of the mechanical properties of PMMA by chemical modification or by adding material into the resin have been attempted from time to time.[12]

Over the past 25 years, Computer Aided Design and Computer Aided Manufacturing (CAD-CAM) technology has become extremely popular. CAD-CAM was introduced in dentistry in the year 1989, by Mormann & Brandestinni in Germany and today, it is widely used in all the branches of Prosthodontics.[13] It is being used, in dental laboratories and in dental offices, to design and machine various restorations viz. veneers, inlays, onlays, crowns, fixed dental prostheses, implant abutments, cast removable partial dentures and even full-mouth rehabilitation. Using these CAD-CAM technologies, various types of restorations and dental prostheses can not only be designed but also machined with accuracy and precision.[13] Digital methods allow the production of a Denture Base in one block and provide the ability to attach prefabricated teeth with an appropriate adhesive. The advantages of digital methods are faster Denture fabrication, more precision and fewer phases in the work process, which can reduce the possibility of mistakes.[5]

With the recent increased interest in CAD-CAM fabricated Dentures, a range of CAD-CAM PMMA-based polymers have been introduced by the manufacturers. These are available as PMMA-discs which are prepolymerized under high temperature and pressure in a moisture-free environment and have a highly crosslinked polymer-monomer structure. Several studies have investigated the physical properties of these PMMA-discs.[11] Al-Dwairi et al. investigated the mechanical properties, including the flexural strength, flexural modulus, and impact strength of PMMA-discs, and they were significantly higher than those of a conventional heatpolymerizing PMMA resin.[14] Xia Wei et al investigated leaching of residual monomer and biological effects of four types of conventional and CAD-CAM dental polymers on human gingival fibroblasts and concluded that CAD-CAM dental polymers have favorable biocompatibility due to lower residual monomer, which provides scientific evidence to the controversy of biocompatibility of conventional and CAD-CAM dental polymers.[15]

CAD-CAM technology has also led to the introduction of an increasing number of machinable materials suitable for dental prostheses. One of these materials is polyetheretherketone (PEEK), a high-performance polymer recently used in dentistry with favourable physical, mechanical and chemical properties. PEEK is claimed to have better properties in parallel with existing materials.[8] PEEK is a material with high biocompatibility, good mechanical properties, high temperature resistance, chemical stability, low plaque affinity, polishability and good wear resistance.[8] The studies done by Kurtz, Zhang et al. suggested that PEEK, which was being used in industries, has a potential for biomedical applications also. According to Brillhart and Botsis and Sobieraj and Rimnac, properties such as solvent resistance, biocompatibility, and modulus of elasticity which is same as that of the bone make PEEK a good candidate for medical and dental applications.[10] PEEK could also be used as a framework material for Complete Dentures in order to decrease Denture deformation responsible for midline fractures.[10] It is seen that PEEK absorbs less water than PMMA, even if it is immersed for 10 days at 121°C.[10] PEEK does not possess any shrinkage during processing, while around 2% of linear shrinkage and 7% of volumetric shrinkage is seen in PMMA.[10] Hence, it can be said that PEEK remains chemically inert and PEEK can be thought to be a novel material to substitute PMMA. However, information about its flexural strength and hardness as compared to heat-cured PMMA is scarce. A very few studies have been done to assess the mechanical behaviour of PEEK when it has to be utilized as a Denture Base Material.[10]

The moist oral environment is reported to decrease the flexural strength of Denture Bases, as a result of the plasticizing effect exerted by saliva molecules that are able to penetrate the denture base.[17] Water sorption is a well-known diffusion phenomenon in which water molecules penetrate the denture base polymer. The absorbed water displaces the polymer chains, penetrate the polymer network of resin, and reduce the intermolecular force creating internal stress and cracks formation which results in weak mechanical properties.[17] Repeated wetting and drying of the Denture was reported to cause irreversible warpage in the polymer.[18] ANSI/ADA Specification No. 12 identifies guidelines regarding the testing and acceptance of Denture Base Resins.[19] According to this the sample is soaked in distilled water for 7 days and weight of the sample is compared with the baseline value.[19] Mukul Saxena et al studied the time dependent effects of artificial saliva on the flexural strength of three commercially available Denture Base acrylic resin.[20] To simulate the intraoral environment to some extent and the plasticizing effect exerted by saliva molecules on the Denture Base in the oral cavity, the specimens in the study were stored in artificial saliva (Wet mouth, ICPA) and kept in an incubator at a temperature of 37ºC for 7 days prior to testing.

All the groups in the study demonstrated flexural strength values above the minimum flexural strength recommended for Denture Base Materials i.e., 65 MPa. The mean flexural strength for CAD-CAM PMMA Denture Base Resins were 168.12 MPa, 105.91MPa, and 136.03 MPa for Ruthinium, Zahndent and Ivobase CAD, respectively which was found to be far superior than the mean flexural strength of 80.58 MPa for conventional PMMA heat cure Denture Base Resin, Lucitone 199. The superiority of flexural strength in the CAD-CAM PMMA groups may be attributed to the unique processing method of the CAD-CAM PMMA discs in which high temperatures and pressure values are used for polymerization.[14] Murakami et al reported an improvement in some mechanical properties of conventional PMMA when treated under high pressures, given the consequent elevation in the average molecular weight of the PMMA polymer matrix in addition to decreased concentrations of residual monomers and internal voids.[16] The results obtained in the present study are in accordance with the studies conducted by Srinivasan et al., Aguirre et al., and Hada et al. They all concluded that milled PMMA had better mechanical properties than heat-polymerized PMMA.

The CAD-CAM Denture Base resins in this study showed the highest flexural strength of all PMMA test groups. Their clinical performance should provide an edge over all the other Denture Base Materials. Thick Denture Bases provide more resistance to fracture, especially for midline and incisor areas. However, bulky material will promote gag reflex, phonetic changes, loss of retention, and consequently patient discomfort. According to the results of this study, thinner Dentures with better mechanical properties are anticipated with the advent of CAD-CAM dentures, which will increase patient satisfaction.

In the study, the mean flexural strength for Victrex CAD-CAM PEEK Denture Base resin came to be 336.41 MPa, the highest among all the groups. The difference in the values of flexural strength of PMMA and PEEK was highly significant. PMMA specimens fractured after application of maximum load whereas PEEK specimens did not fracture but showed significant bending. The results obtained in the study are in agreement with the study done by Muhsin et al.[21] PEEK denture bases had higher impact and tensile strength than PMMA.[21] Similar results were found by Spardha Shrivastava et al in their study where they compared mechanical properties of PMMA and PEEK.[10] The mechanical properties like flexural strength and hardness values for PEEK are superior to that of PMMA.[10] Thus, PEEK could be regarded as a promising material suitable for Denture Bases providing resistance to notch concentration and fracture . Midline fracture of single Maxillary Complete Denture Base especially in patients who have retained their natural mandibular teeth is an inevitable problem and one of the attributed causes is flexural fatigue due to cyclic loading.[22] In such cases PEEK can substitute PMMA Denture Base Resins in the field of Prosthodontics. Therefore, prosthesis fabricated with PEEK as a substructure may have a great impact on its prognosis and might also enhance the patient acceptability. Though PEEK is already being used as a forerunner material in spinal implants in orthopaedics, the usage of PEEK polymer material in Prosthodontics is yet to gain momentum.

CONCLUSION

Within the limitation of this study, the present in vitro study concludes that the mean flexural strength of CAD-CAM milled PEEK Denture Base Resin was highest among all study groups followed by CAD-CAM milled PMMA Denture Base Resin and the value of mean flexural strength was lowest for the conventional heat polymerised PMMA Denture Base Resin. This shows that CAD-CAM milled Dentures are superior in terms of flexural strength, fracture resistance and durability as compared to the conventionally fabricated Dentures. CAD-CAM methods of fabricating Complete Dentures can reduce working time for both patients and clinicians and provide satisfactory functional and esthetics outcomes. The prepolymerized Denture Base Resins can be a replacement to conventionally processed Denture Base Resins at situations where higher flexural forces are expected. The newer Denture Base Material, PEEK, used in the study could be a promising Denture Base Resin in terms of fracture resistance and durability because of its high flexural strength and it can substitute PMMA Denture Base Resins in the field of Prosthodontics in near future. Although this study involved in vitro evaluation of flexural strength of different denture base resins, it is still predictive of clinical situations. Further in vivo studies are recommended for the same.

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