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Comparative Evaluation of Flexural Strength And Microhardness of Two Different Ceramic Reinforced 3-D Printed Resins with CAD-CAM Milled and Conventional Tooth Coloured Heat Cured Polymethylmethacrylate Resins as Long-Term Provisional Restorative Materials: An in Vitro Study

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Abstract

Background:

Long-term provisional restorations play a crucial role in complex clinical scenarios, Implant-supported prostheses, full-mouth rehabilitation cases & Maxillofacial Prosthodontics. Understanding the mechanical properties such as flexural strength and microhardness of newer commercially available provisional restorative materials is necessary to select an optimum material for long-term provisional fixed dental prosthesis. This Research study was conducted to evaluate and compare the Flexural Strength and Microhardness of Two Different Ceramic-reinforced 3-D Printed Resins with CAD-CAM Milled and Conventional Tooth Coloured Heat Cured Polymethylmethacrylate Resins as Long-Term Provisional Restorative Materials.

Methods:

Twenty-one specimens of dimensions 25 mm × 2 mm × 2 mm (ADA-ANSI specification #27) were fabricated each using: Group A (Control group)-Conventional tooth colored heat cured polymethylmethacrylate resin (DPI Heat cure tooth moulding powder), Group B-CAD-CAM milled resin, Group C- Ceramic reinforced polymer 3-D printed resin (Temporary CB resin) and Group D- Ceramic reinforced polymer 3-D printed resin (Permanent CB resin). Flexural strength and microhardness were measured and the values obtained were evaluated.

Results:

The measured mean flexural strength values (Mega Pascals) were 39.41 (Group A), 153 (Group B), 124.91 (Group C), and 136.50 (Group D). The measured mean microhardness values (Knoop hardness number) were 37.9 (Group A), 40.5 (Group B), 34.67 (Group C), and 43.88 (Group D). The difference in flexural strength and microhardness values of the three groups was statistically significant according to the analysis of variance (ANOVA) as well as the intergroup comparison done using Tukey's honest significant difference (HSD) Post Hoc test ($P < 0.05$).

Conclusions:

Flexural strength with higher values in Group B were noted and the Microhardness test showed higher

values in Group D.

Keywords: Computer-Assisted Designing and Computer-Assisted Milling, provisionals, rapid, prototyping

Introduction

The rehabilitation of partially edentulous patients using fixed dental prostheses is a well-established treatment protocol since decades. The role of a dental professional while replacing lost part of a tooth or teeth is to restore the form and function of it as well as provide an artificial substitute that stimulates the natural tooth and is accepted by the patient. The various steps involved in fixed prosthodontics include proper diagnosis and treatment planning, preparation of abutment teeth, provisionalization and finally a definitive prosthesis. As the fabrication of a fixed prosthesis incurs time and arduous efforts, it becomes mandatory to provide a provisional restoration until the fabrication of a fixed definitive prosthesis.

Provisional restorations have become a vital diagnostic assessment tool to evaluate function, color, shape, contour, occlusion, periodontal response, implant healing, and overall esthetics. They provide a template for directing treatment outcomes aesthetically, phonetically, and functionally [1]. It serves as a blueprint for the final restoration. The value of the acceptable provisional restoration is measured not only in terms of satisfactory esthetics but also in the preservation of the health of the periodontium. Provisional restoration actually treats the supporting structures and prepares them for the acceptance of the final restoration. Thus, a well prepared provisional restoration not only restores the form and function of the lost part of the tooth or teeth but also provides great comfort to the patient. These restorations are also used as diagnostic aids when correcting occlusal planes, altering vertical dimensions, recontouring the gingival contours & predicting the shape & colour of the final restorations [2].

Conventionally, various materials and methods have been used to fabricate a provisional restoration that is aesthetic, user friendly & most importantly having good mechanical properties. These materials used for fabrication of single unit and multi-unit provisional restoration, are mostly resin-based such as polymethylmethacrylate, polyethylene and bis-acrylate composite resins. However, they have certain limitations such as high polymerization shrinkage, degradation of resin matrix, water sorption etc [3,4]. With the recent advancements in technology such as computer-aided design-computer-aided manufacturing (CAD-CAM) and three-dimensional printing (3-D Printing) it has become possible to overcome limitations of the conventional PMMA based resin materials as they exhibit good dimensional stability & ease of fabrication [5]. CAD-CAM, i.e., subtractive technologies have emerged in recent years for various applications including provisional restorations fabricated by milling the resin-based blanks which are cured under optimal conditions. They exhibit improved mechanical properties and reduce chairside time. It is one of the fundamental pillars within current Prosthodontics for the fabrication of long-term provisional restorations, demonstrating great clinical success attributed to the technological advances and the series of innovative materials currently being used [6]. Long term provisional restorations are crucial in situations wherein the patient must use the provisional restorations for an extended period such as Implant supported prosthesis, full- mouth rehabilitation cases & Maxillofacial Prosthodontics [3].

Proper knowledge and understanding of material properties is an important aspect which governs the success and longevity of a restoration. Primary material of choice provisional restorations includes polymer-based materials, such as PMMA resin. The PMMA resin blocks for the CAD-CAM systems have cross-linked structures, which provide improved mechanical properties over conventional gold standard heat cured polymers [7].

To solve certain drawbacks of this technology, most importantly being material wastage, additive manufacturing technology has recently been introduced for the manufacture of long-term provisional restorations, as an alternative to the subtractive technique, because of its ability to manufacture unlimited objects, due to manufacturing time, called rapid prototyping (RP) which includes 3-D printing. It is being used in Prosthodontics to fabricate physical models, surgical guides, extraoral maxillofacial prostheses, and recently in fixed Prosthodontics for long-term provisional FDPs. One attractive feature of this process is that there is no wastage of the material [8].

In choosing a provisional restorative resin material, certain important factors need to be taken into consideration that includes clinical desirability, adequate working time, ease of mix and repair, biocompatibility with the pulp and soft tissue, dimensional stability during and after fabrication, shade selection, and colour stability [9].

Understanding the mechanical properties such as flexural strength, impact strength, microhardness and dimensional stability of these newer commercially available materials is necessary to select an optimum material for long term provisional fixed dental prosthesis.

Amongst these properties, the flexural strength and microhardness of long-term provisional restorative materials are important, particularly when the patient must use the provisional restoration for an extended period in complex clinical scenarios, Implant supported prosthesis, full-mouth rehabilitation cases & Maxillofacial Prosthodontics [10].

In this study we have compared the flexural strength & microhardness of recently introduced 2 different ceramic reinforced 3-D printed resins, CAD-CAM milled polymethylmethacrylate resin with our gold standard conventional tooth coloured Heat cured polymethylmethacrylate resin as long- term provisional restorative materials. It is claimed by the manufacturers to have better mechanical and aesthetic properties compared to the gold standard conventional tooth coloured Heat cured polymethylmethacrylate resin which need to be further verified. However, there is a scarcity of literature on the determination of properties of these materials as long-term provisional materials fabricated by utilizing recent technologies. Hence this study has embarked upon the evaluation of the flexural strength and microhardness of two different ceramic reinforced 3-D printed resins with CAD-CAM milled polymethylmethacrylate resin and conventional tooth coloured heat-cured polymethylmethacrylate resin as long-term provisional restorative materials.

Materials and Methods

The present study was conducted to evaluate the flexural strength and microhardness of two different ceramic reinforced 3-D printed resins with CAD - CAM milled and conventional tooth coloured heat cured polymethylmethacrylate resin as long-term provisional restorative materials.

Methodology:

GROUP	PROCEDURE	SAMPLES
A	CONTROL GROUP – Conventional tooth coloured heat cured polymethylmethacrylate resin	21

	(DPI Heat cure tooth moulding material)	
B	CAD-CAM milled polymethylmethacrylate resin (Bloomden, Bioceramics Co.Ltd)	21
C	Ceramic reinforced 3-D printed temporary resin (Temporary CB resin, Formlabs)	21
D	Ceramic reinforced 3-D printed permanent resin (Permanent CB resin, Formlabs)	21

Fabrication of standardized dies:
A brass metal mold of standard dimensions 25mm (length) X 2mm (width) X 2mm (thickness) as per ADA/ANSI Specification number 27 [1] was fabricated for the preparation of samples.
This die was used to prepare total 21 samples.

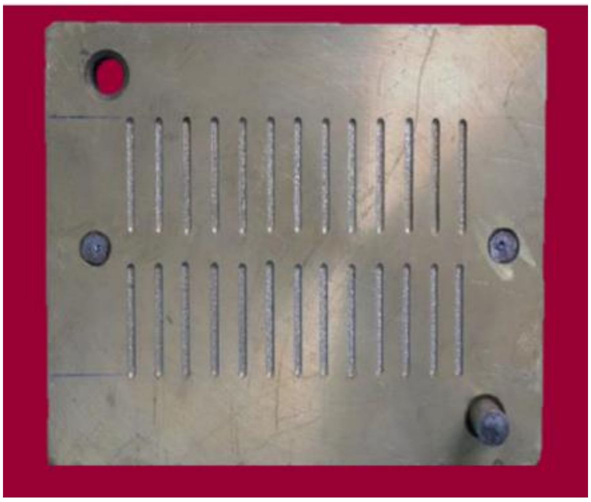


Figure no.1- Brass Metal Mold As per ADA/ANSI Specification number 27

Preparation of samples:
Preparation of samples for the control group
Group A samples – Conventional tooth-coloured heat cured polymethylmethacrylate resin

Preparation of samples for the control group
The brass metal die was thoroughly cleaned and a thin layer of separating medium was applied uniform-

ly. Using the measuring cylinders, polymer and monomer were manipulated in the ratio of 3:1 by volume mixed in a ceramic bowl with a mixing spatula and allowed to reach the dough stage, then kneaded and packed in the mould. Trial closure was performed with a Hydraulic press machine. The flask was clamped and pressure was maintained for 1 hour to allow proper penetration of monomer into the polymer, even flow of the material and outward flow of excess material. To cure the material the flask was immersed in water in an acrylizer unit at room temperature. The curing temperature was maintained at 74^0C for ninety minutes followed by boiling at 100^0C for one hour. After completion of the polymerization cycle, the mould was removed from the water bath and allowed to bench cool to room temperature. The samples were then de-flashed and finished using finishing and polishing burs and checked for any surface defects and dimensions, by visual examination and by using a digital calliper. Processed samples which did not meet the above specifications {25 mm (length) × 2 mm (width) × 2 mm (thickness)} were discarded.

Preparation of samples for experimental groups:

Group B samples- CAD-CAM milled polymethylmethacrylate resin

To fabricate CAD-CAM milled polymethylmethacrylate resin samples, polymethylmethacrylate resin blanks were used. The rectangular block was virtually designed according to specific dimensions (25mm X 2mm X 2mm as per ADA/ANSI Specification number 27). The computer file in STL format was transferred to Ceramill Mind (CAD program), and the samples were transferred to the CAD-CAM milling machine. The samples were milled from two prepolymerized PMMA blanks (Bloomden, Bioceramics Co.Ltd) of shade A2. Conventional cutters` and trimmers were used for finishing and polishing within the milling machine.

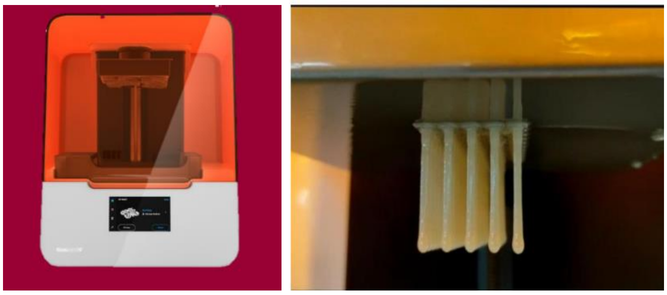
Figure no 2– Milling of CAD-CAM resin disc to form Group B samples

Group C - Ceramic reinforced 3-D printed temporary resin samples and

Group D- Ceramic reinforced 3-D printed Permanent resin samples

To fabricate Ceramic reinforced 3-D printed samples, Formlabs Form3B printer with the ability to print layer thickness of 25 microns and Formlabs Temporary CB resin and Permanent CB resin were used. An STL file of the dimension (25mm X 2mm X 2mm as per ADA/ANSI Specification number 27) was sent to the 3D printing Software. A 3D computer file was made. The samples were photopolymerized using a concentrated beam of ultraviolet light onto the surface of a stainless steel platform filled with liquid photopolymer resin. The light beam drew the object onto the surface of the liquid, and each time a layer of resin was polymerized. The process was repeated to form the entire layer of the sample, until the samples as designed according to dimensions (25mm X 2mm X 2mm as per ADA/ANSI Specification number 27) were produced. The samples were polished and checked for their dimensions with a digital caliper.

Figure no 3- 3-D Printing Group C samples (Ceramic reinforced 3-D printed temporary resin) & Group D samples (Ceramic reinforced 3-D printed permanent resin) in Formlabs Form3B printer



Flexural strength testing of samples:
In the current study post-fabrication of all the samples, the flexural strength was measured in a Universal Testing Machine (Instron Ltd. 2519-107). A sample was placed on the rollers in such a way that the centre of the sample coincided with the centre of the distance between the rollers. This whole unit was then mounted on the lower jaw of the Universal Instron testing machine and the stress applicator rod was fixed on the upper jaw of the Universal Instron testing machine. A load was applied in the centre of the sample until fracture occurred. This way three- point bending test was done for each sample. In this study, a loading force was applied to samples at a cross-head speed of 1 mm/min according to ISO 6872:2008 [4].
The flexural strength was calculated using the following formula:
$\sigma = 3FL/2bd2$
Where,
σ = Flexural strength
F = Load (force) at the fracture point (N)
L = Length of the support span (mm)
b = Width of sample (mm)
d = Thickness of the sample (mm) [4].

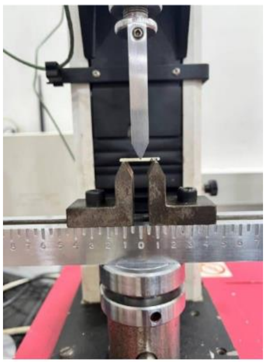


Figure no 4 – Samples placed on Universal Testing Machine – Instron for flexural strength evaluation.

Microhardness testing of samples:

The fractured specimens were used to determine the microhardness. A microhardness tester Shimadzu Co. HMV-2T E (163034601466) was utilized for the same. Surface hardness was determined by loading each specimen for 15 s with a force of 50 g, after mounting it on the microhardness tester [4]. A rhomboid-shaped indentation was obtained on each specimen and its image was transferred to the computer monitor with the help of a microscope present along with the microhardness tester. The longest diagonal of the diamond indentation was marked and Vickers hardness number was calculated with the help of the software. It was then converted to Knoop hardness number (KHN)

The equation for calculating the Vickers Hardness number is as follows:

$HV = 1854.4\ (P/d^2)\ \text{kgf mm}^{-2}$

HV = Vickers hardness number

P = Load (kgf)

d = Length of the diagonal (mm)

The equation for calculating Knoop Hardness number is as follows:

$Hk = 14228\ (P/d^2)\ \text{kgf mm}^{-2}$

Hk = Knoop hardness number

P = Load (kgf)

d = Length of the diagonal (mm) [4].

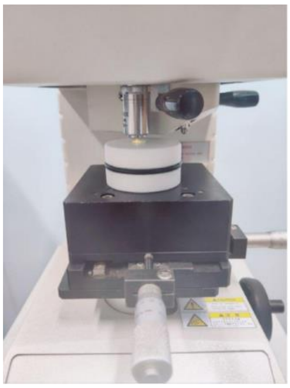


Figure no 5– Samples placed on Microhardness Testing Machine for microhardness evaluation.

Data collection for Flexural Strength

Universal Testing Machine (Instron) was used for testing the flexural strength.

Flexural strength was calculated in Mega Pascal (MPa).

Data collection for Microhardness

Microhardness Tester was used for testing the microhardness. Microhardness was calculated in Vickers hardness number (VHN) and then converted to Knoop Hardness number (KHN).

Data Management & Analysis Procedure

Data obtained was compiled on an MS Office Excel Sheet (v 2019, Microsoft Redmond Campus, Redmond, Washington, United States). Data was subjected to statistical analysis using Statistical package for social sciences (SPSS v 26.0, IBM). Descriptive statistics like Mean & SD for numerical data has been depicted.

Data Analysis plan and methods

Normality of numerical data was checked using Shapiro-Wilk test & was found that the data followed a normal curve; hence parametric tests have been used for comparisons. Intergroup comparison (>2 groups) was done using one-way ANOVA followed by pair-wise comparison using a post hoc test. For all the statistical tests, $p<0.05$ was considered to be statistically significant, keeping α error at 5% and β error at 20%, thus giving power to the study as 80%.

* = statistically significant difference ($p<0.05$)

** = statistically highly significant difference ($p<0.01$)

= non significant difference ($p>0.05$) ... for all tables

RESULTS

This study was carried out to evaluate and compare the flexural strength and microhardness of two different Ceramic reinforced 3-D Printed Resins with CAD-CAM Milled and Conventional Tooth Coloured Heat Cured Polymethylmethacrylate Resins as Long-term Provisional restorative materials. Samples were divided into four different groups:

Group A (Control Group) - Conventional tooth coloured heat cured polymethylmethacrylate resin (DPI Heat cure tooth moulding material)

Group B - CAD-CAM milled polymethylmethacrylate resin (Bloomden, Bioceramics Co.Ltd)

Group C- Ceramic reinforced 3-D printed resin (Temporary CB resin, Formlabs)

Group D - Ceramic reinforced 3-D printed resin (Permanent CB resin, Formlabs)

The samples were evaluated for flexural strength and microhardness and their readings were recorded in Table 1 and Table 2 respectively.

- Data obtained was compiled on a MS Office Excel Sheet (v 2019, Microsoft Redmond Campus, Redmond, Washington, United States).
- Data was subjected to statistical analysis using Statistical package for social sciences (SPSS v 26.0, IBM).
- Descriptive statistics like Mean & SD for numerical data has been depicted.

Normality of numerical data was checked using Shapiro-Wilk test & was found that the data followed a normal curve; hence parametric tests have been used for comparisons.

Intergroup comparison (>2 groups) was done using one-way ANOVA followed by pairwise comparison using a post hoc test. For all the statistical tests, $p<0.05$ was considered to be statistically significant, keeping α error at 5% and β error at 20%, thus giving power to the study as 80%.

Table 1- Intergroup comparison of Mean, Standard Deviation, Standard of Error of readings of Flexural strength and Microhardness.

						95% Confidence Interval for Mean					
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	F value	p value of one way ANOVA
Flexural strength	A	21	39.14619	4.298952	.938108	37.18933	41.10305	30.900	44.530		
	B	21	153.00476	6.089325	1.328800	150.23293	155.77659	144.210	162.700	2928.790	.000**
	C	21	124.91048	3.677594	.802517	123.23646	126.58450	116.900	129.420		
	D	21	136.50619	2.234418	.487590	135.48910	137.52329	133.230	141.100		
	Total	84	113.39190	44.478391	4.852990	103.73950	123.04431	30.900	162.700		
Microhardness	A	21	36.87476	.570882	.124577	36.61490	37.13462	36.050	37.900		
	B	21	39.00048	.668210	.145815	38.69631	39.30464	37.920	40.500	480.515	.000**
	C	21	33.33714	1.105351	.241207	32.83399	33.84029	30.020	34.670		
	D	21	42.59667	.797197	.173963	42.23379	42.95955	41.340	43.880		
	Total	84	37.95226	3.471599	.378782	37.19888	38.70565	30.020	43.880		

There was a statistically significant difference seen for the values between the groups (p<0.01) for Flexural strength with higher values in Group B (CAD-CAM milled polymethylmethacrylate resin) and for Microhardness test higher values were observed in Group D (Ceramic reinforced 3-D printed Permanent CB resin).
* = statistically significant difference (p<0.05)
** = statistically highly significant difference (p<0.01)
# = non significant difference (p>0.05) ... for all tables.

Table 2 - Inter group Pair wise comparison using Tukey HSD Post Hoc Tests

						95% Confidence Interval for Mean					
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	F value	p value of one way ANOVA
Flexural strength	A	21	39.14619	4.298952	.938108	37.18933	41.10305	30.900	44.530		
	B	21	153.00476	6.089325	1.328800	150.23293	155.77659	144.210	162.700	2928.790	.000**
	C	21	124.91048	3.677594	.802517	123.23646	126.58450	116.900	129.420		
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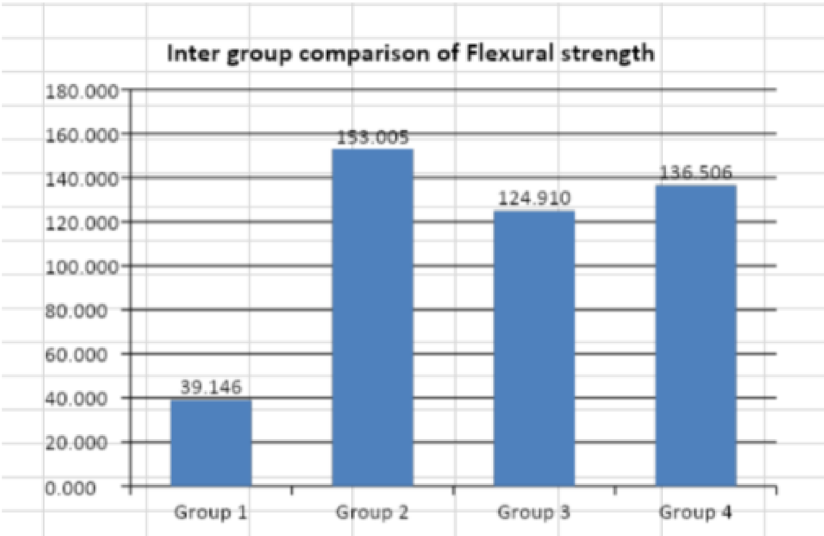
	B	21	39.00048	.668210	.145815	38.69631	39.30464	37.920	40.500	480.515	.000**
	C	21	33.33714	1.105351	.241207	32.83399	33.84029	30.020	34.670		
	D	21	42.59667	.797197	.173963	42.23379	42.95955	41.340	43.880		
	Total	84	37.95226	3.471599	.378782	37.19888	38.70565	30.020	43.880		

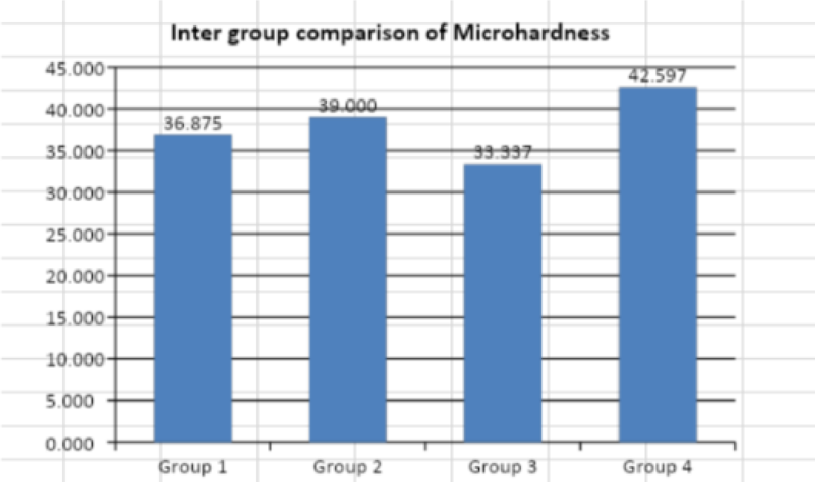
There was a statistically highly significant / significant difference seen for the values between all the pairs of groups (p<0.01, 0.05).

Graph 1- Intergroup comparison of Flexural strength



X axis- Groups 1 (A), Group 2 (B),Group 3 (C) and Group 4 (D)
Y axis- Maximum Flexural strength

Graph 2 - Intergroup comparison of Microhardness



X axis- Groups 1 (A), Group 2 (B),Group 3 (C) and Group 4 (D)
Y axis- Microhardness

Table 3 - Tests of Normality

		Shapiro-Wilk		
	Group	Statistic	Df	p value
Flexural strength	A	.881	21	.015
	B	.921	21	.092
	C	.872	21	.010
	D	.934	21	.167
Microhardness	A	.927	21	.121
	B	.953	21	.385
	C	.886	21	.019
	D	.935	21	.177

$p>0.05$ indicates normality is followed.

The following were the observations based on the readings and the statistical analysis

The results of this comparative study obtained through statistical analysis indicate that,

- There was a statistically significant difference seen for the values between the groups ($p<0.01$) for Flexural strength with higher values in Group B (CAD-CAM milled polymethylmethacrylate resin) followed by Group D (Ceramic reinforced 3-D printed Permanent CB resin) and Group C (Ceramic reinforced 3-D printed Temporary CB resin). Group A (Conventional tooth coloured heat cured polymethylmethacrylate resin) showed the least values.
- Microhardness test showed higher values in Group D (Ceramic reinforced 3-D printed Permanent CB resin) followed by Group B (CAD-CAM milled polymethylmethacrylate resin) and Group A (Conventional tooth coloured heat cured polymethylmethacrylate resin). Group C (Ceramic reinforced 3-D printed Temporary CB resin) showed the least values.
- The intergroup comparison also shows that there was a statistically significant difference seen for the values between the control group and experimental groups ($p<0.01$).

Discussion

Provisional fixed dental prostheses (FDPs) are an essential component of fixed prosthodontic treatment until the Definitive prostheses are fabricated. The Provisional FDPs must satisfy the biological, mechanical and esthetic requisites [1]. The ultimate goal of Provisional FDP is to establish or maintain an environment in which the oral hard and soft tissues can function within physiologic limits and provide a pleasing esthetic result. It can also provide an important tool for the psychological management of patients until the definitive restorations are luted. A well-fabricated provisional not only provides a preview of the future prosthesis but also enhances the health of the abutment and the periodontium [11].

The duration between the preparation of the abutment and placement of the definitive prostheses can vary from a few days to several weeks or even several months for complex cases when additional interdisciplinary therapies like extensive periodontal treatment, intentional endodontic treatment, orthodontic stabilization, restoration of lost vertical dimension of occlusion or progressive increase in vertical dimension of occlusion and full mouth rehabilitation is required. In such clinical scenarios, placement of a provisional prosthesis becomes imperative to maintain occlusal stability, function and esthetics [12]. An optimal provisional restoration must be resistant to occlusal forces, stable during function, durable, chemically inert and esthetically acceptable. However, the provisional restorations meant for long-term use should be able to resist both the functional and para-functional forces and to permit the patient to allow proper oral hygiene maintenance. The provisional restorations are prone to fracture, which may lead to biological, functional, and esthetic problems. For a provisional restorative material to last longer in the oral cavity, higher values of flexural strength and microhardness are demanded. Therefore, the selection of appropriate material and technique for fabrication of long-term fixed provisional restoration is considered to be critical in fixed prosthodontic treatment [10]. So this study was conducted to evaluate which provisional restorative material and fabrication technique would result in high values of flexural strength and microhardness.

Conventional PMMA resins are mono-functional, low molecular- weight, linear molecules that exhibit low strength. Heat-cured polymethylmethacrylate acrylic resin is inherently stronger, has greater stability, and has less residual monomer content than auto polymerized resin. It also has the advantages of color stability and good dimensional stability as compared to auto polymerized resin [4]. Lang et al, investigated fracture resistance of provisional fixed partial enture (FPD) materials after storage for 14 days in distilled water and artificial aging and found low mechanical fracture behaviour of PMMA materials tested because of deformation during oral simulation. They also found that PMMA materials showed water absorption up to 32µg/mm [13].

CAD-CAM milling of PMMA blanks (subtractive method) has been used in the fabrication of provisional Fixed Dental Prosthesis for the past few years. CAD-CAM PMMA-based polymers have chemical structure similar to that of conventional PMMA materials. Manufacturing under industrial conditions permits high-density polymer-based restorations which offer favourable mechanical behaviour and biocompatibility. CAD/CAM PMMA-based polymers have improved mechanical properties as they are highly cross- linked, more homogenous and have low water sorption and solubility [4]. Rekow et al reviewed the CAD/CAM PMMA resin used in Dentistry and proposed its use for provisionalization [14].

Alp G. et al compared the flexural strength of CAD-CAM PMMA based polymers and conventional provisional resin materials using 3-point bend test and the results revealed that flexural strength of CAD-CAM PMMA- based polymers was greater and the least flexural strength was exhibited by conventional PMMA resin [15].

Alt V. et al investigated the influence of fabrication method, storage condition and use of different materials on the fracture strength of provisional FDPs using CAD-CAM technologies and resin-based blanks cured under optimal conditions. They concluded that CAD-CAM specimens exhibited increased mechanical strength and had less porosity within the restoration [9].
Therefore, 3D printing technologies (additive method) were introduced to overcome the drawbacks of the subtractive technique. These methods gained popularity as additive techniques (layer upon layer). It basically produces solid layers using a concentrated UV light beam that moves on a photosensitive liquid polymer resin placed on a platform. As the firstlayer is polymerized, the platform is lowered a few microns and the next layer is cured. This process is repeated until the whole solid object is completed. The object is then rinsed with a solvent and placed in a UV oven to thoroughly cure the resin [4].
Rapid Prototype (3D printing) resin has been used in the production of various dental prostheses like making complete dentures, making dental casts models, fabrication of patterns for Cast Partial Dentures (CPD), crowns, copings/ resin patterns for the same, surgical templates for guided surgery of implants and fabrication of maxillofacial prostheses [8].
Compared to CAD-CAM milling, the 3D printing technique reduces the manufacturing time and causes less wastage of raw material; thus, it can be a cost-effective option for fabricating provisional crowns in FDP. However, in spite of its versatile usage, there is a paucity of data on its role in the fabrication of long-term provisional fixed dental prostheses. Provisional FDPs should resist wear to help maintain the position of prepared teeth and meet the esthetic needs of the patient [12].
Flexural strength and microhardness are an important criterion in determining the mechanical strength and rigidity of the material. Flexural strength, also known as modulus of rupture or bend strength is a material property, defined as the stress in a material just before it yields in a flexure test [16].
Microhardness or indentation hardness is the hardness of the material exposed to low applied loads. Clinical scenarios involving long-span edentulous cases, patients with parafunctional habits and interdisciplinary treatment protocols requiring extended duration will all require a provisional material with adequate flexural strength and microhardness property [17].
Microhardness can be used as an indicator of density, and it can be hypothesized that a denser material would be more resistant to wear and surface deterioration. The surface microhardness of a material is a complex mechanical property affected by several other properties, including strength, proportional limit and resistance to abrasion.
Thus, keeping in mind the challenging clinical scenarios that demand the use of long-term FDPs, this study was conducted to comparatively evaluate the manufacturing technique and material of provisional FDPs on mechanical properties like flexural strength and microhardness of provisional restorations which were fabricated using the following:

- Conventional Heat cured PMMA Provisional crown and bridge resin (Group A)
- CAD-CAM milling of PMMA blanks (Subtractive method) (Group B)
- 3-D printing of Temporary polymethylmethacrylate resins (Additive method) (Group C)
- 3-D printing of Permanent polymethylmethacrylate resins (Additive method) (Group D)

In this study, the samples were prepared according to ADA/ANSI Specification number 27 for determining flexural strength and microhardness. A Brass metal mold of standard dimensions 25mm (length) X 2mm (width) X 2mm (thickness) was fabricated for the preparation of Group A samples (Control group). For the fabrication of samples for Group A (control group), a mixture of polymer monomer in the ratio of 3:1 by volume as per the manufacturer's instruction was followed and samples were fabricated. For

the fabrication of samples for experimental Group B, samples were milled from two pre-polymerized PMMA blanks (Bloomden, Bioceramics Co.Ltd). The rectangular block was virtually designed according to specific dimensions (25mm X 2mm X 2mm as per ADA/ANSI Specification number 27) and converted to STL format. The computer file was transferred to CAM program and the specimens were milled. For fabrication of Group C and D samples, Ceramic reinforced 3-D printed samples Temporary CB resin and Permanent CB resin), Formlabs Form3B printer and Formlabs Temporary CB resin and Permanent CB resin were used. An STL file of the dimension (25mm X 2mm X 2mm as per ADA/ANSI Specification number 27) was sent to the 3D printing Software. The samples were photopolymerized using a concentrated beam of ultraviolet light onto the surface of a stainless-steel platform filled with liquid photopolymer resin. The samples were polished and checked for their dimensions with a digital caliper. Following the fabrication of samples, they were numbered according to the groups eg; For
the control group (Conventional tooth coloured heat cured polymethylmethacrylate resin)- A1 – A21), for experimental Group B (CAD-CAM milled polymethylmethacrylate resin) - B1 – B21, for experimental Group C (Ceramic reinforced 3-D printed temporary resin)- C1-C21 and for control Group D (Ceramic reinforced 3-D printed Permanent resin) (D1- D21).

In the current study, the flexural strength was measured in a Universal Testing Machine (Instron Ltd.) using a three-point bend test. A loading force was applied to samples at a cross-head speed of 1 mm/min according to ISO 6872:2008. This methodology was similar to a study conducted by Digholkar S, Madhav VN, Palaskar J in 2016 [4]. Rekow proposed the CAD-CAM approach for provisional restoration which offered favourable mechanical behavior and biocompatibility. Hence it was used as one of the fabrication techniques in Group B (CAD-CAM milled polymethylmethacrylate resin) [14].

The range of flexural strength values obtained in Control Group A (Conventional heat cured PMMA crown and bridge resin) was from 38 MPa to 43 MPa, with a mean of 39.15 MPa. The range of flexural strength values obtained in Experimental Group B (CAD-CAM milled polymethylmethacrylate resin) was from 144 MPa to 162 MPa, with a mean of 153 MPa. The range of flexural strength values obtained in Experimental Group C (Ceramic reinforced 3-D printed temporary resin) was from 116 MPa to 129 MPa with the mean of 124.91 MPa. The range of flexural strength values obtained in Experimental Group D(Ceramic reinforced 3-D printed Permanent resin) was from 133 MPa to 141.1 MPa with a mean of 136.50 MPa. On an intergroup comparison between the Control Group A (Conventional heat cured PMMA crown and bridge resin) and Experimental groups – Group B (CAD-CAM milled polymethylmethacrylate resin), Experimental Group C (Ceramic reinforced 3-D printed temporary resin) and Experimental Group D (Ceramic reinforced 3- D printed Permanent resin), highest flexural strength was found in the Experimental Group B (CAD-CAM milled polymethylmethacrylate resin) which was 153 MPa, followed by the Experimental Group D (Ceramic reinforced 3-D printed Permanent resin) which was 136.50 MPa, Experimental Group C (Ceramic reinforced 3-D printed temporary resin) which was 124.91 MPa and least flexural strength was found in Control Group A (Conventional heat cured PMMA crown and bridge resin) which was found to be 39.41 MPa. Flexural strength values of Group B (CAD-CAM milled polymethylmethacrylate resin), Group C (Ceramic reinforced 3-D printed temporary resin), and Group D (Ceramic reinforced 3-D printed Permanent resin) was higher and statistically significant than those of the conventional Heat cured PMMA group ($P < 0.01$).

The material used for CAD-CAM milling in this study, CAD-CAM PMMA, Bloomden, Bioceramics, is a cross-linked polymer of PMMA resin. The cross-linking consists of methacrylic acid ester-based polymers. According to Edelhoff et al, these high-density polymers based on highly cross-linked resins are

manufactured in an industrial process, thus, exhibiting superior mechanical properties [18]. These findings are similar to the research conducted by Alt et al, who investigated the influence of fabrication method, storage condition, and use of different materials, on the fracture strength of provisional 3-unit FDPs using CAD- CAM technologies and resin-based blanks cured under optimal conditions [9]. Also, CAD-CAM milling of provisional prostheses results in denser prostheses as compared to layer-upon-layer printing by 3-D printing technique. As there is a correlation between the density of the material and flexural strength and hence taking these factors into consideration, it can be stated that Group B (CAD-CAM milled polymethylmethacrylate resin) samples exhibited increased mechanical strength and had less porosity within the restoration. Thus, it can be proposed that it was due to these optimal curing conditions, the Group B (CAD-CAM milled polymethylmethacrylate resin) samples showed the highest flexural strength in this study. A product made by Rapid Prototyping is influenced by the technique of fabrication utilized. The technique can cause shrinkage of the specimen during building, post-curing and due to the
thickness of layers it results in staircase effect as proposed by Rekow et al [14]. Therefore, it can be postulated that Group C (Ceramic reinforced 3-D printed temporary resin) and Group D (Ceramic reinforced 3-D printed Permanent resin) has lesser flexural strength than Group B (CAD-CAM milled polymethylmethacrylate resin). The amount of filler content is greater in Group D (Ceramic reinforced 3-D printed Permanent resin) as compared to Group C (Ceramic reinforced 3-D printed temporary resin). Hence, the flexural strength is greater in Group D (Ceramic reinforced 3-D printed Permanent resin) as compared to Group C (Ceramic reinforced 3-D printed temporary resin).
Conventional methacrylate resins are mono-functional, low molecular-weight, and linear molecules that exhibit decreased strength. The strength of the material, polymerization shrinkage and other properties also depend on the residual monomer content. Therefore, Group A (Conventional heat cured PMMA crown and bridge resin) could have led to lesser flexural strength values in these samples when compared to Group B (CAD-CAM milled polymethylmethacrylate resin) samples. The results of our study were congruent to the studies conducted by Karthikeyan et al in 2020, compared the flexural strength among CAD-CAM Milled and heat-cured polymethylmethacrylate resin provisional restoration and concluded that there is a significant difference in the flexural strength between the CAD-CAM provisional restoration and heat cured provisional restoration. CAD -CAM resin group specimens exhibited higher flexural strength values followed by heat cured resin group [19]. Isil Karaokutan, Gulsum Sayin, and Ozlem Kara in 2015, stated that PMMA-based CAD-CAM fabricated provisional crowns show higher fracture strength than directly fabricated crowns [20]. Rayyan et al in 2015, compare the color stability, water sorption, wear resistance, surface hardness, fracture resistance, and microleakage of computer-aided design/computer-aided manufacturing (CAD-CAM) fabricated interim restorations with those of manually fabricated interim restorations.
CAD-CAM interim crowns showed improved color stability and physical and mechanical properties compared to conventionally fabricated crowns [21]. CAD-CAM fabrication is applicable for long-term clinical interim restorations. The results of all these above-mentioned studies are in confluence with the present study.
Apart from flexural strength, the microhardness of provisional FDPs was evaluated in this study using the microhardness tester. The range of microhardness values obtained in Control Group A (Conventional heat cured PMMA crown and bridge resin) was from 36.05 KHN to 37.9 KHN, with a mean of 36.87 KHN. The range of microhardness values obtained in Experimental Group B (CAD-CAM milled

polymethylmethacrylate resin) was from 37.92 KHN to 40.5 KHN, with a mean of 39 MPa. The range of microhardness values obtained in Experimental Group C (Ceramic reinforced 3-D printed temporary resin) was from 30.02 KHN to 34.67 KHN with a mean of 33.33 KHN. The range of microhardness values obtained in Experimental Group D (Ceramic reinforced 3-D printed Permanent resin) was from 41.34 KHN to 43.88 with a mean of 42.59 KHN. On an intergroup comparison between the Control Group A (Conventional heat cured PMMA crown and bridge resin) and Experimental groups – Group B (CAD-CAM milled polymethylmethacrylate resin), Experimental Group C (Ceramic reinforced 3-D printed temporary resin) and Experimental Group D (Ceramic reinforced 3-D printed Permanent resin), highest microhardness was found in the Experimental Group D (Ceramic reinforced 3-D printed Permanent resin) which was 43.88 KHN followed by Experimental Group B (CAD-CAM milled polymethylmethacrylate resin) which was 40.5 KHN, followed by the Experimental Group C (Ceramic reinforced 3-D printed temporary resin) which was 34.67 KHN and the least with Control Group A (Conventional heat cured PMMA crown and bridge resin) which was found to be 37.9 KHN. The difference in microhardness of the three groups was statistically significant ($P < 0.01$). The 3-D printed resins contain multifunctional cross-linked monomers and other inorganic fillers which are said to increase the hardness of these resins compared to PMMA. The findings of this study were also similar to the result obtained by Diaz-Arnold et al. who found out that all composite resin materials exhibited superior microhardness over the traditional methyl methacrylate resins throughout a 14-day interval of investigation. According to them, these resins contain inorganic fillers to increase their resistance to abrasion and decreased polymerization shrinkage in comparison to PMMA material used in the other groups [6]. Jain S, Sayed ME, Shetty M et al in 2022, performed systematic review and meta- analysis comparing the physical and mechanical properties of 3D-printed provisional Fixed dental prostheses resin materials with CAD-CAM milled and conventional provisional resins. It was concluded that 3D-printed provisional Fixed dental prostheses resin materials have superior mechanical properties compared to CAD-CAM milled and other conventionally fabricated ones. Three-dimensionally printed provisional crowns and Fixed dental prostheses materials can be used as an alternative to conventional and CAD-CAM milled long-term provisional materials [22]. Rayyan MM et al in 2015, compared the color stability, water sorption, wear resistance, surface hardness, fracture resistance, and microleakage of CAD- CAM fabricated interim restorations with those of manually fabricated interim restorations. It was concluded that CAD-CAM interim crowns showed improved color stability and physical and mechanical properties compared to conventionally fabricated crowns [21].

Al-Qahtani AS et al in 2021, compared the surface roughness, hardness, and flexural strength of interim indirect resin restorations fabricated with CAD-CAM, 3D printing and conventional techniques and concluded that the 3D-printed provisional restorative resins showed flexural strength and micro-hardness comparable to CAD-CAM fabricated specimens, and surface micro-roughness for printed specimens was considerably higher compared to CAD-CAM and conventional fabrication techniques [23]. The results of the present study were in accordance to all the above mentioned studies documented in literature.

Limitations of this study:

1. Although stringent standardization protocol was followed, this in vitro endeavor has few limitations. Since it was an in vitro type of study, no in vivo flexural strength and microhardness testing conditions were employed to simulate the oral environment. There is a difference between forces experi-

enced by long-term fixed provisional prostheses intraorally as compared to that of the forces exerted by testing machine. In vivo conditions need to be considered for a fairer execution of the study.
2. Although the results seem to be promising regarding the mechanical properties of flexural strength and microhardness of long-term provisional restorative materials but other properties like physical (water sorption, impact strength, hardness), chemical and biological properties were not evaluated and need to be explored.

Recommendations for further research:
1. There is a vast scope in the future to study other properties like marginal fit, transverse strength, color stability, etc.
2. In vivo studies of these properties should be done in near future.
3. A simultaneous evaluation of the mechanical and aesthetic properties of the long-termprovisional restorative materials resin is recommended
4. It is mandatory to research different techniques possible to comparatively evaluate influence of different commercially available 3-D printers and CAD-CAM milling machines on the mechanical properties of long-term provisional restorative materials.

Conflict of Interest
No potential conflict of interest declared

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