Original Article

A comparative evaluation of vertical marginal fit of provisional crowns fabricated by computer-aided design/computer-aided manufacturing technique and direct (intraoral technique) and flexural strength of the materials: An *in vitro* study

Ishita Dureja, Bhupender Yadav, Puja Malhotra, Nupur Dabas, Akshay Bhargava[1], Ripul Pahwa

Department of Prosthodontics, Faculty of Dental Sciences, SGT University, Gurgaon, Haryana, [1]Department of Prosthodontics, ITS Dental College, Greater Noida, Uttar Pradesh, India

Abstract

Background: With the advent of new provisional crown materials, it has become imperative to evaluate their marginal fit and strength to select the ideal provisional crown material.

Aim: The purpose of this *in vitro* study was to evaluate and compare the vertical marginal fit and flexural strength of provisional crowns prepared using computer-aided design-computer-aided manufacturing (CAD-CAM) temporary material versus those fabricated using bis-acrylic composite-based autopolymerizing resin material.

Materials and Methods: Eighty samples were divided into two equal Groups (I and II). Group I consisted of forty samples that were evaluated for flexural strength and Group II consisted of forty samples that were evaluated for their vertical marginal fit. Group I was subdivided as Group IA, i.e., bis-acrylic composite-based autopolymerizing resin material (Protemp™ 4) blocks and Group IB, i.e., CAD/CAM provisional material blocks. Similarly, Group II was subdivided as Group IIA, i.e., bis-acrylic composite-based autopolymerizing resin material (Protemp™ 4) crowns and Group IIB, i.e., CAD/CAM provisional material crowns. Marginal adaptation was evaluated using stereomicroscope and image analyzing software to measure the amount of marginal gap. For flexural strength, all specimens were subjected to a standard compression load in the universal testing machine until fracture occurred. Data were analyzed using Student's *t*-test ($P = 0.001$).

Results: CAD/CAM provisional crowns showed better marginal adaptation (34.34 μm) as compared to bis-acrylic composite-based autopolymerizing resin material (Protemp™ 4) crowns (63.42 μm) ($P < 0.001$). The flexural strength of CAD/CAM blocks (94.06 megapascals [MPa]) was not statistically different from bis-acrylic composite-based autopolymerizing resin material (Protemp™ 4) blocks (101.41 MPa) ($P > 0.001$).

Conclusion: Protemp™ 4 and CAD/CAM provisional materials have comparable flexural strength. However, the marginal fit of temporary crowns fabricated by CAD/CAM was found to be superior to the ones fabricated using bis-acrylic composite-based autopolymerizing resin material (Protemp™ 4).

Keywords: Flexural strength, marginal fit, provisional crown

Address for correspondence: Dr. Bhupender Yadav,
Department of Prosthodontics, Faculty of Dental Sciences, SGT University, Gurgaon, Haryana, India.
E-mail: drbhupinderyadav@gmail.com

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INTRODUCTION

The word provisional means established for the time being.[1] A provisional restoration functions as an interim restoration from the time the tooth is prepared for restorative procedures until the final prosthesis is cemented in place in the mouth.[2,3]

The demand for tooth-colored restorations has increased over the past decade. Provisional restorations need to be as esthetic and as strong as the permanent restorations, especially if planned for the anterior zone of the mouth. Polyethyl and Polymethyl methacrylates (PMMAs) have been the most commonly used conventional chairside materials used in direct and indirect restorative procedure.[4] Bis-acrylic, based on multifunctional methacrylic acid esters, has evolved as the material of choice for provisional restoration because of its easy manipulation intraorally and also because its mechanical properties are comparable to those of conventional materials. Although the chair-side fabrication of interim restorations is very common, it has its own drawbacks, for example, the mixing procedures may incorporate voids that could adversely affect the mechanical strength, surface texture, and precise fit of the restoration. In addition, these restorations have a low flexural strength.[5]

To overcome these disadvantages of conventional provisional materials, computer-aided design and computer-assisted manufacturing (CAD/CAM) system was developed in 1980, to simplify the technique and thus reduce the chairside fabrication time of provisional restorations.

The long-term success of crowns and fixed partial dentures (FPDs) largely depends on the accuracy of fit between the restoration and prepared tooth structure. Marginal fit of an interim crown should be as precise as the definitive restoration to prevent irritation or inflammation of the periodontal pulpal tissues and to ensure a satisfactory result.

The most common cause of failure of provisional restorations is fractures.[6] Although provisional restorations should be designed in such a way that failures are minimal, fractures can still occur. This may cause discomfort for the patient as well as financial and economic loss. Thus, the mechanical strength properties such as flexural strength and fracture toughness of provisional materials are of utmost importance and should be considered to ensure the clinical success of provisional restorations.[7]

Provisional prosthesis may be required for a short term (until the definitive restoration has been fabricated) or long term (when a patient requires a longer course of treatment such as in full-mouth rehabilitation, orthodontic or endodontic procedures). Hence, provisional restorations form an integral part of the conventional fixed prosthodontic treatment besides the provisional restorations may also aid in making a final diagnosis, develop a treatment plan, allow hard or soft tissue healing, and communicate with the laboratory for the optimal success of the final restoration.[8,9]

Little research has been published comparing the efficacy of the marginal fit and flexural strength of direct interim long-term fixed prosthesis relative to those fabricated with the CAD/CAM technique. Therefore, the purpose of this *in vitro* study was to evaluate and compare the vertical marginal fit and flexural strength of provisional crowns prepared using CAD-CAM temporary material with bis-acrylic composite-based autopolymerizing resin material.

MATERIALS AND METHODS

The study was conducted in the Department of Prosthodontics, Faculty of Dental Sciences, SGT University. This study was conducted in two parts. In part 1, the flexural strength of the two materials, i.e., CAD/CAM blocks (vitang temp blocks) and bis-acrylic composite-based autopolymerizing resin material, i.e., Protemp™ 4 (3M ESPE, Seefeld, Germany) was evaluated and compared.

In part II, the vertical marginal fit of the crowns made from the aforementioned materials was evaluated and compared.

Fabrication of samples (n = 40)

Fabrication of sample blocks from Protemp™ 4 (Group IA)

A block of dimensions (17 mm × 5.5 mm × 6 mm) was prepared using modeling wax. A mold of this prepared block was made using addition silicone (putty consistency) to serve as an index. The components of Protemp™ 4 restorative material were mixed as per the manufacturer's instructions, i.e., through a self-mixing gun and injected into the prepared putty index and were allowed to set for 1 min. Thereafter, it was retrieved from the mold and kept for 2 min for the final setting. Twenty such blocks were fabricated with Protemp™ 4 provisional material. Samples were finished and polished using rotary rubber cups with a handpiece (ECO-450 Marathon), speed ranging from 2000 to 5000 rpm. A clinically acceptable surface finish was obtained. The movement of the bur was unidirectional and held parallel to the specimen in the horizontal plane. In the end, all the samples were rubbed with ethanol to get a glossy and shiny surface.

Fabrication of sample blocks from computer-aided design/computer-aided manufacturing block (Group IB)

Exocad (GmbH, Darmstadt.Germany) and Sum 3D software (3D biocad, Renton, WA) were used to design and mill 20 blocks of dimension (17 mm × 5.5 mm × 6 mm) made from CAD-Temp blocks. Exocad software transformed the optical data of the desired dimension into an accurate three-dimensional digital model. Then, CAD-Temp block was clamped in milling chamber of Roland DWX-50 (5-axis) machine, and milling burs (2 mm and 1 mm drills) were used for the milling of the samples [Figure 1].

Fabrication of provisional crowns (n = 40)

Master die

A mandibular left first molar, 36 typodont tooth (Nissin, Germany), was prepared for a full ceramic crown with 2-mm occlusal reduction; the convergence angle of the wall was prepared to be approximately 6° and the shoulder of 1 mm using a high-speed handpiece operating with water coolant. Four points were engraved using a round diamond bur below the facial, lingual, and proximal (mesial and distal) finish line of the prepared molar. These points acted as standard reference points, which helped in the measurement of the samples. A reusable mold of the prepared segment was made from addition cure polyvinylsiloxane elastomeric material. A wax pattern was fabricated out of this mold using inlay wax. The wax pattern was cast using induction casting machine (Ducatron). After that, it was finished and polished in the conventional manner.

Fabrication of bis-acrylic composite-based autopolymerizing resin crown using Protemp™ 4 (Group IIA)

An impression of the lower left first molar, 36 typodont tooth, was made before any preparation was done to serve as an index for the fabrication of the provisional crowns using addition silicone (putty consistency and light body). The components of Protemp™ 4 restorative material were mixed through a self-mixing gun and injected into the indexed impression. The indexed impression was placed on the master die until the mixed material completely set (1 min 40 s). Thus, 20 direct provisional crowns were fabricated. The crowns were finished and polished using rotary rubber cups with a handpiece (ECO-450 Marathon), speed ranging from 2000 to 5000 rpm and were examined to detect any defects circumferentially. In the end, all the samples were rubbed with ethanol to get a glossy and shiny surface.

Figure 1: Milled computer-aided design/computer-aided manufacturing samples

Fabrication of computer-aided design/computer-aided manufacturing temporary material crowns (Group IIB)

Exocad and Sum 3D software were used to design and mill 20 interim fixed dental prostheses (FDPs) made from CAD-Temp blocks. Optical impression of master die was made. Exocad software then transformed the optical data for master die into an accurate three-dimensional digital model. Finally, CAD-Temp block was clamped in milling chamber of Rolland DWX-50 (5-Axis) machine, and the milling burs (2-mm and 1-mm drills) were used for the milling of the samples. Following milling (CAM), the sprue was cut off using a fine cross-cut tungsten carbide bur, and the samples were examined for the presence of any defects or cracks. The interim FDPs were polished with a silicone polisher and seated on the master die.

Testing of samples for flexural strength

In part 1 of the study, forty samples of Group I were loaded under a standard compression load at a crosshead speed of 1 mm/min and the force recorded using the universal testing machine (UTM) (Asian UTM, LRX 2K5, Hants, UK) with a 2500 Newton-loaded cell for 3 min. A plunger with a steel ball (4.24 mm diameter) was used to transmit the compressive force until fracture occurred. The load was applied to the center of the specimen. Loading was continued until fracture occurred [Figure 2]. The load at fracture was recorded (in Newton).

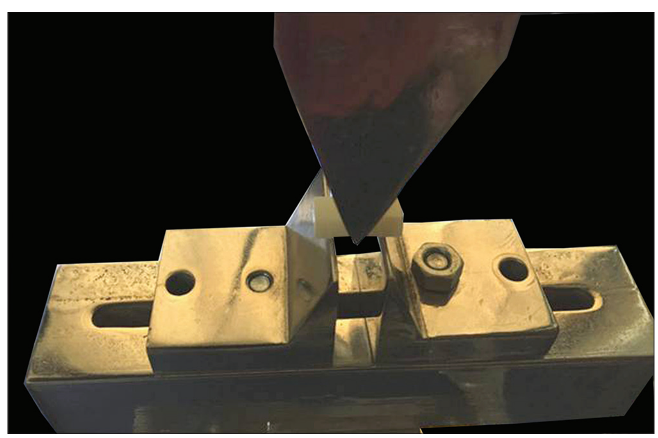

Figure 2: Samples placed in universal testing machine for testing flexural strength

Testing for marginal fit of the samples

In part 2 of the study, 40 samples for Group II were checked for marginal fit. Crowns were tested for marginal adaptation using (Stereomicroscope Magnus MSZ-TR Olympus, India Pvt. Ltd) at ×40 magnification. The specimens were placed under the microscope and photographed using a camera that was connected to the microscope [Figure 3]. The images were then transferred to image analysis software program (Magnus Pro, Magnus Analytics, New Delhi) that measured the vertical marginal gap, from the four reference points at the edge of the shoulder finish line of the dies to the inferior edge of the interim FDPs. The results from each reference point were compiled, and the average of four surfaces was calculated for each specimen. Finally, an overall average of the marginal gap was calculated for each test group.

Statistical analysis

Statistical analysis was performed using descriptive and analytical data. $P < 0.001$ was considered statistically significant. Data were presented as means and standard error (SE) values. Results of marginal adaptation and fracture resistance were analyzed using Student's *t*-test.

RESULTS

Marginal adaptation

The group vertical gap mean value and SE of CAD/CAM and Protemp™ 4 are listed in Table 1. The mean gap difference of the two materials was compared using Student's *t*-test. Protemp™ 4 showed significantly higher mean gap than CAD/CAM temp, $P < 0.001$ [Figures 4, 5 and Table 2].

Flexural strength

The breaking load values were converted to flexural strength using the formula:

Flexural strength = $\sigma = 3\ FL/2\ bd^2$

The values obtained were recorded in MPa which form the basic data of the study. Data were subjected to statistical analysis (Student's *t*-test). The flexural strength mean and SE of both CAD/CAM and bis-acrylic composite-based autopolymerizing resin material (Protemp™ 4) are listed in Table 3. Student's *t*-test showed that there was no significant difference between flexural strength of CAD/CAM blocks and Protemp™ 4 blocks ($P > 0.001$) [Table 4].

Table 1: Comparison of mean marginal fit (μm) of computer-aided design/computer-assisted manufacturing and Protemp™ 4 crowns

	CAD/CAM (μm)	Protemp™ 4 (μm)
Lingual	28.52	70.24
Buccal	61.78	93.88
Mesial	27.48	44.60
Distal	19.73	45.05
Mean	34.34	63.44

CAD: Computer-aided design, CAM: Computer-assisted manufacturing

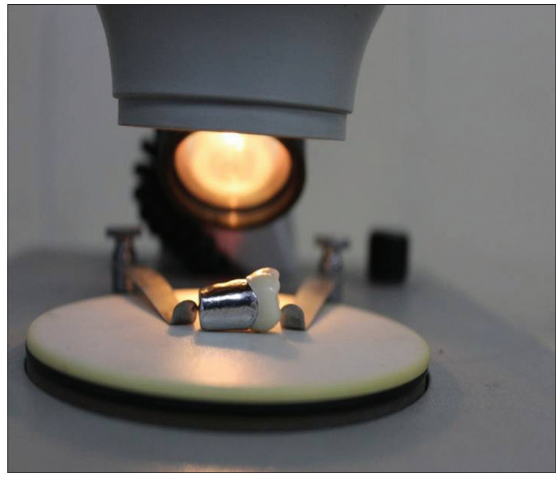

Figure 3: Vertical marginal fit using stereomicroscope

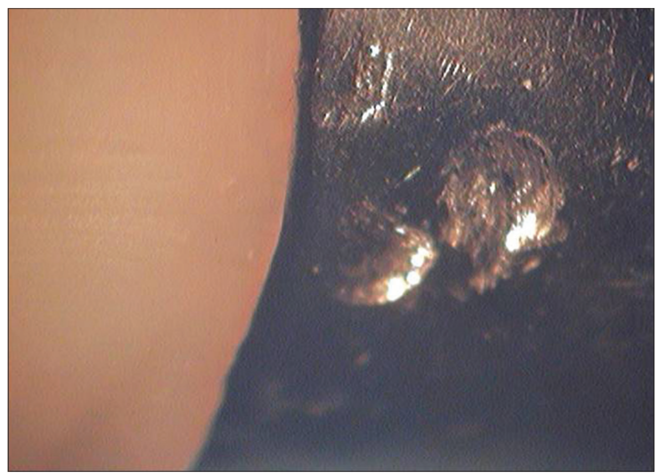

Figure 4: Marginal fit of computer-aided design/computer-aided manufacturing provisional crown

Figure 5: Marginal discrepancy of Protemp™ 4 provisional crown

Table 2: Student's *t*-test statistics of mean vertical marginal fit of computer-aided design/computer-assisted manufacturing and Protemp™ 4 crowns

Surfaces	Group	*n*	Mean	SD	*t*	*P*
Lingual	CAD-CAM	20	28.52	10.12	6.329	<0.001*
	Protemp	20	70.24	27.69		
Buccal	CAD-CAM	20	61.78	15.00	5.97	<0.001*
	Protemp	20	93.88	18.79		
Mesial	CAD-CAM	20	27.48	9.35	3.505	0.001
	Protemp	20	44.60	19.74		
Distal	CAD-CAM	20	19.73	6.78	5.478	<0.001*
	Protemp	20	45.05	19.53		

*The mean difference is significant at the 0.001 level. SD: Standard deviation, CAD: Computer-aided design, CAM: Computer-assisted manufacturing

Table 3: Comparison of mean flexural strength (MPa) of computer-aided design/computer-assisted manufacturing and Protemp™ 4 blocks

	CAD/CAM	Protemp™ 4
Flexural strength (MPa)	94.06	101.41

CAD: Computer-aided design, CAM: Computer-assisted manufacturing

Table 4: Student's *t*-test statistics of mean flexural strength of computer-aided design/computer-assisted manufacturing and Protemp™ 4 blocks

	Group	*n*	Mean	SD	*t*	*P*
Flexural strength (MPa)	CAD-CAM	20	94.06	18.23	0.862	0.394
	Protemp™ 4	20	101.41	33.54		

SD: Standard deviation, CAD: Computer-aided design, CAM: Computer-assisted manufacturing

DISCUSSION

Temporary crown and bridge restorations provide interim protection, mastication, esthetics, and positional stability while the definitive restoration is being fabricated. "Temporary" and "provisional" are terms that are synonymous in dentistry.[9] The importance of provisional restorations cannot be overemphasized in prosthodontics. The most important role that a provisional restoration plays is to stabilize and protect the existing tooth structure after tooth preparation. Besides, temporary crowns also act as interim prosthesis in cases where treatment gets delayed as in orthodontics, implants, etc. Therefore, temporary materials are required to be tough and fracture resistant, should be esthetic, and maintain the positional stability. With the advancements in esthetic restorative materials, such as composites and ceramics, the temporary materials have also shown marked improvement in terms of strength, esthetics, and biocompatibility. At present, numerous provisional materials are available for the effective restoration of prepared teeth which fall into two basic types, based on their chemistry with each category having distinct advantages and disadvantages.[10] They are broadly classified into two distinct categories, i.e., prefabricated crowns and chemical-cured materials. Prefabricated crowns are available in many forms such as cellulose acetate, polycarbonate, and aluminum for a variety of single-unit applications and are used for short-term to long-term coverage of the prepared tooth. Prefabricated provisional crowns have the advantage that they provide accurate anatomy and the ability to fit while conforming to the margin.[3] Chemically cured materials which are most commonly available in powder/liquid form have been used for fabrication of temporary restorations since the late 1930s for both single- and multiple-unit cases. The oldest group of polymer-based direct temporary materials is the acrylic MMA/PMMA resins. The other provisional materials available fall into the composite-resin category. These can be further subdivided into bis-acryls, bisphenol A-glycidyl methacrylate (bis-GMA), and urethane dimethacrylate resins. Bis-acryls resins have many advantages when compared to methacrylates such as improved esthetics, but due to their brittleness, they may not be suitable for long-span FPDs. The more recent provisional material introduced is the bis-GMA resins. These offer the advantages of better fracture resistance and better esthetics permitting their use in anterior zones where esthetics are critical and in cases when long-span FPDs may be indicated. Finally, the most recent material in this chain is urethane dimethacrylates resins which have continued the trend of enhancing the advantages of their predecessors in terms of strength and esthetics.[9]

Protemp™ (3M ESPE, St. Paul, MN, USA) was introduced as a newer material in bis-GMA resins. They have undergone several modifications as provisional restorative materials.[11] The most recent innovative product from 3M ESPE and the Protemp™ family of temporary products is Protemp™ 4 Crown Temporization Material, and since literature is lacking in studies regarding its mechanical properties, it formed one of the test materials for the present study.

The disadvantages of chairside fabrication of provisional restorations are that it affects the mechanical strength as well as its surface texture and fit, for example, mixing procedures and filling the over impression might lead to incorporation of voids, compromising the mechanical strength.[12,13] CAD/CAM technologies used to fabricate temporaries may solve some of these issues.

The introduction of CAD/CAM has revolutionized modern dentistry. It has led to the evolution of "tooth in a day" restoration. Restorations fabricated by means of CAD/CAM technology are known to be stronger and more accurate with easier manipulation. Similarly, CAD/CAM provisional restorations are predicted to have good mechanical properties, so they may present a solution for long-term/long-span interim restorations where strength and color stability are required.[14,15] Because CAD/CAM PMMA blocks are industrially polymerized under optimum manufacturing conditions, such conditions offer those interim restorations' better mechanical properties than those that are manually fabricated. Moreover, the improved fit of the milled CAD/CAM provisional lowers the risk of bacterial contamination of the tooth and prevents damage to the pulp from excessive temperature changes.[16,17]

Therefore, the purpose of the present *in vitro* study was to evaluate and compare the vertical marginal fit and flexural strength of two commercially available provisional crown materials, i.e., CAD/CAM temporary material and bis-acrylic composite-based autopolymerizing resin material, using stereomicroscope and UTM, respectively.

Traditional methyl methacrylate resins are monofunctional, have a low molecular weight, and are linear molecules that exhibit decreased strength and rigidity.[18] However, bis-acryl composite resins are difunctional, and thus, they are capable of cross-linking with another monomer chain. This cross-linkage provides strength and durability to the material.[19] In the present study, the mean flexural strength of bis-acryl composite-based autopolymerizing resin material (Protemp™ 4) was 101.41 MPa which was much higher when compared to traditional monomethacrylates as presented in previous literature.[16] Nejatidanesh *et al*.[20] found that bis-acryl provisional materials showed higher flexural strength than methacrylate resins. Lang *et al*.[21] compared two PMMA and four composite temporary materials in an artificial oral environment and found that the highest strength values were accompanied by low fracture rate in the composite-based group.

In the present study, the mean flexural strength value of CAD/CAM blocks was 94.06 Mpa which was almost within the range of a previous study done by Ehrenberg *et al*.,[22] who compared the mechanical properties of three provisional blocks CAD-Temp, Telio CAD, and artBloc Temp. Digholkar *et al*.[23] compared the flexural strength and microhardness of provisional restorative materials fabricated utilizing rapid prototyping, CAD-CAM, and conventional method and reported that CAD-CAM-based provisional had the highest flexural strength. Stawarczyk *et al*.[24] compared machine-made temporary (artBloc and CAD-Temp) to direct restorations and the egg-shell temporaries. He reported a flexural strength of 45 MPa for CAD-Temp which was almost half of the flexural strength obtained for the CAD blocks used in the present study.

One of the inherent problems associated with provisional restorations made directly in the mouth is the marginal discrepancies that may be due to polymerization shrinkage of the material. This problem is significantly greater with PMMA provisional materials and is comparatively less with bis-acryl composite resin materials but still poses a problem which was highlighted by Nivedita and Prithviraj in their research.[25]

In the present study, the vertical marginal fit was observed on all the four surfaces (mesial, distal, buccal, and lingual). The mean value obtained for the vertical marginal discrepancy of Protemp™ 4 crowns was 63.42 μm which showed significantly higher marginal discrepancy than those fabricated from the CAD/CAM provisional blocks, i.e., 34.34 μm ($P < 0.001$). This result was consistent with a study by Yao *et al*. in which it was found that the CAD/CAM provisional crowns had lower marginal gaps compared to direct provisional crowns.[14]

On evaluating the results of the present study, it was observed that there was a significant difference between the Marginal Fit of bis-acrylic composite-based autopolymerizing resin (Protemp™ 4) crowns and CAD/CAM provisional crowns. However, there was no significant difference between the flexural strength of bis-acrylic composite-based autopolymerizing resin (Protemp™ 4) blocks and CAD/CAM provisional materials blocks.

One of the limitations of this present study was that no fatigue loading was applied to the provisional materials. Further clinical studies are required regarding the marginal fit and flexural strength of the provisional materials which may add to a conclusive decision of the present study.

CONCLUSION

Under the limitations of this study, the following conclusions can be drawn:

1. Protemp™ 4 and CAD/CAM provisional materials showed comparable flexural strength
2. CAD-CAM crowns showed a more accurate and precise marginal adaptation. The mean difference in the marginal fit of these two materials was observed to be ±29.1 μm which was statistically significant.

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Conflicts of interest

There are no conflicts of interest.

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