ORIGINAL RESEARCH

Comparison of Fracture Resistance of Three-unit Provisional Fixed Dental Prostheses Fabricated Using Conventional and Digital Methods

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Abstract

Purpose: To compare the fracture resistance of three-unit (3-unit) provisional fixed dental prostheses (FDPs) fabricated using conventional, computer-aided design and computer-aided manufacturing (CAD/CAM) and three-dimensional (3D) printing methods.

Materials and methods: Mandibular right second premolar and second molar typodont teeth were prepared and a metal die was fabricated. Five specimens of each 3-unit FDP were fabricated using self-cure (conventional), with 3D printing and CAD/CAM techniques. Specimens were placed on the universal testing machine and subjected to an axial load. The maximum force which led to the fracture of the FDP was recorded. Tukey's test for pairwise comparison of fracture strength was used and a one-way analysis of variance (ANOVA) was used for intergroup.

Results: Maximum fracture resistance was seen in the CAD/CAM group (2510.3 N), followed by 3D printed (2182.9 N), and least in the self-cure group (1940.9 N). ANOVA for intergroup comparison showed a statistically significant difference in fracture resistance between the three groups ($p < 0.001$). A statistically significant difference in fracture resistance *via post hoc* Tukey's was seen in group I and group II ($p < 0.001$), and between group II and group III ($p = 0.015$). There was no significant difference found in between group I and group III ($p > 0.05$).

Conclusion: Computer-aided design and computer-aided manufacturing milled and 3D printed 3-unit provisional FDP showed significantly better fracture resistance compared to the conventional FDP. Interim restorations fabricated using these advanced techniques provide stronger, more reliable, and conservatively produced provisional restorations.

Keywords: Bridge, Computer-aided design and computer-aided manufacturing, Fracture resistance, Provisionalization, Provisional restoration, Three-dimensional printing.

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Introduction

Provisional FDP play important role in restorative procedures. They function for the time span between tooth preparation and the cementation of the final prosthesis. Under certain situations where these provisional FDPs are required for a longer period of time, such as during orthodontic treatment procedures, full mouth rehabilitation cases, lab delays, or unavailability of the patient.[1] A provisional FDP should offer protection to the pulp, provide maintenance of periodontal health, and have a compatible occlusion and tooth position. It should also provide fracture resistance, sustain functional loading, maintenance of interabutment alignment, be easy to contour, have color stability, and adequate translucency.[1,2] These provisional FDPs also serve as a guide for the final outcome in terms of patient comfort, esthetics, contour, margins, proximal contacts, and occlusion.[3]

Temporaries have been fabricated using various materials and techniques such that they are esthetic while having high strength and hardness. Such materials are mostly resin based and with different methods of polymerization, having different filler compositions, and types of monomers.[3] Such materials are polyvinyl ethyl methacrylate, polymethyl methacrylate (PMMA), bisphenol A glycidyl methacrylate, polyethylmethacrylate, composites containing bis-acryl, and resins of urethane dimethacrylate.[1,3]

Since the past few decades, CAD/CAM and 3D printing have been popularized as methods applicable in dentistry, and this can be attributed to technological advancements such as digital impressions and their designing and milling methods.[4] The conventionally made provisional FDPs have a margin of error, setting contraction and expansion depending upon the material property; besides this, it also takes up more chairside time by the clinician.[3] An additional appointment may also be required for its cementation, whereas the provisional FDPs fabricated by digital methods not only have excellent accuracy but also save up chairside time and fewer appointments.

The fracture strength of the provisional FDPs has to be high in order to resist daily wear and function adequately under intraoral

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conditions. Currently, there is sparse literature on fracture resistance of the printed provisionals.[1,5]

Therefore, this study was conducted with the objective of evaluating the fracture strength of provisional FDPs fabricated using CAD-CAM, 3D, and conventional methods. The proposed null hypothesis of the study was that no significant difference would be observed between the fracture resistance of provisional FPDs fabricated *via* CAD-CAM, 3D printing, and the conventional method.

Materials and Methods

Preparation of the Metal Die

A mandibular typodont (Nissin PRO2001-UL-SP-FEM-32, Kyoto, Japan) mandibular right second molar and second premolar were prepared to be used as abutments, with the mandibular right first molar being the missing tooth. The preparation was made following these specifications: 2 mm occlusal reduction, 1.5 mm axial reduction, 1 mm round chamfer finish line, and 6° convergence angle. The prepared teeth were used as a guide for metal die fabrication (Fig. 1).

Digital Scanning and Designing

An extraoral scanner was used to scan the metal die (Medit Identica T500, Seoul, Korea) to obtain a 3D model of the prepared teeth. CAD software (exoCAD; exoCAD, Darmstadt, Germany) was used to design the 3-unit restoration. A stereolithography/standard tessellation language (STL) format was generated, which was then used for milling and 3D printing.

Fig. 1: Metal die

Manufacturing the Test Specimen

Computer-aided Design and Computer-aided Manufacturing Milled Provisional FDP

Ceramill TEMP (Amann Girrbach, AG, Austria) PMMA resin blanks (100% by weight, PMMA) were used to fabricate specimens for the CAD/CAM group. The CAD design was transferred in STL format to the CAM software and the specimens were fabricated by the milling unit. The specimens were milled in PMMA blanks (Ceramill TEMP) of shade A2 (Fig. 2A).

Three-dimensional Printed Provisional FDP

The previously generated CAD design was then transferred to the CAM software of the 3D printer (ASIGA MAX 3D printer, Sydney, Australia) in the same format. DentaTOOTH (ASIGA, Sydney, Australia), microhybrid resin, shade A2, was used to fabricate the provisional FDP. The print layer thickness of 50 µm was maintained for all specimens. 90% isopropyl alcohol was used to remove resin residues by dipping the specimen in it and brushing them (Fig. 2B).

Conventional Self-cure Resin Provisional FDP

A silicon putty index (Zhermack SpA, Zetaplus, Badia Polesine, Italy) of the milled provisional bridge was used to fabricate the autopolymerized provisional FDP. A self-cured PMMA provisional restorative material (DPI, Mumbai, India) was then mixed according to the manufacturer's recommendations and loaded into the silicone putty index (Zhermack SpA, Zetaplus, Badia Polesine, Italy) and placed on to the metal die, once set it was removed, finished, and polished (Fig. 2C).

Three groups (five specimens per group) were obtained:

- Group I of autopolymerized PMMA (control group).
- Group II of CAD/CAM milled PMMA (subtractive manufacturing).
- Group III of 3D printed microhybrid filled composite resin (additive manufacturing) (Table 1).

Specimens from all three groups were stored in 1 L of distilled water for 5 days before testing.

Fracture Strength Testing

All 3-unit provisional FDPs were adapted on the metal die and subjected to an axial load on the Universal Testing Machine (Praj metallurgical laboratory, Pune, Maharashtra, India) at a crosshead speed of 2 mm/minute, a metal ball of 5 mm diameter was used at the central pit of the pontic, the force was parallel to the long axis of the tooth and loaded until fracture occurred. The maximum force at which the fracture occurred was recorded (Fig. 3).

Figs 2A to C: Specimens: (A) CAD/CAM milled; (B) 3D printed; (C) Conventional self-cure

Statistical Analysis

The data obtained was compiled on a Microsoft Excel sheet. The SPPSS software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.) was used for statistical analysis. Mean and standard deviation (SD) was calculated for each group. One-way analysis of variance (ANOVA) was used for intergroup comparison of fracture strength and Tukey's honestly significant difference *post hoc* test for pairwise comparison. $p < 0.05$ was considered to be statistically significant.

Results

The mean fracture resistance of each group is shown in Figure 4.

Group I (conventional) had a mean of 1940.9 N, group II (CAD/CAM) 2510.3 N and group III 2182.9 N (3D method). CAD/CAM has the maximum fracture resistance, followed by 3D and then conventionally fabricated provisionals.

The mean difference, SD values, with a 95% interval of the maximum force of each group, are shown in Table 2.

The fracture strength of the three tested groups as a graphical representation of maximum force (N) at the fracture point central pontic is shown in Figure 4. Data has been presented as mean ± SD.

ANOVA for intergroup comparison showed a statistically significant difference in fracture resistance between the three groups ($p < 0.001$).

Post hoc Tukey's test showed there was a statistically significant difference in fracture resistance between group I and group II ($p < 0.001$) and between group II and group III in fracture resistance ($p = 0.015$). No statistically significant difference was observed between the fracture resistance in group I and group III ($p > 0.05$).

Also, the predisposition of the fracture line in the current scenario was toward the connector between the premolar and pontic, indicating the connector at the premolar to be a weaker link as compared to the connector at the molar.

Table 1: Provisional materials used in the study

Material	*Type*	*Fabrication technique*	*Manufacturer*
DPI self-cure tooth material	Methyl methacrylate	Conventional direct	DPI-TM RR Cold Cure, DPI, India
Ceramill TEMP	Highly polymerized PMMA	CAD/CAM milled (subtractive manufacturing)	Amann Girrbach, AG, Austria
ASIGA dentaTOOTH	Microhybrid composite resin	CAD/CAM printed (additive manufacturing)	ASIGA, Sydney, Australia

*PMMA, polymethylmethacrylate; CAD/CAM, computer-aided design and computer-aided manufacturing

Table 2: Pairwise comparison in fracture resistance

					95% confidence interval	
Group		*Mean difference (I-J)*	*Standard error*	*Significance*	*Lower bound*	*Upper bound*
Group I (autopolymerized)	Group II	−569.40000* N	97.69684 N	**<0.001***	−830.0419 N	−308.7581 N
	Group III	−242.00000 N	97.69684 N	0.070	−502.6419 N	18.6419 N
Group II (CAD/CAM)	Group I	569.40000* N	97.69684 N	**<0.001***	308.7581 N	830.0419 N
	Group III	327.40000* N	97.69684 N	**0.015***	66.7581 N	588.0419 N
Group III (3D)	Group I	242.00000 N	97.69684 N	0.070	−18.6419 N	502.6419 N
	Group II	−327.40000* N	97.69684 N	**0.015**	−588.0419 N	−66.7581 N

*The mean difference is significant at the 0.05 level; Bold values shows statistically significant difference between the test groups, which is when $p < 0.05$

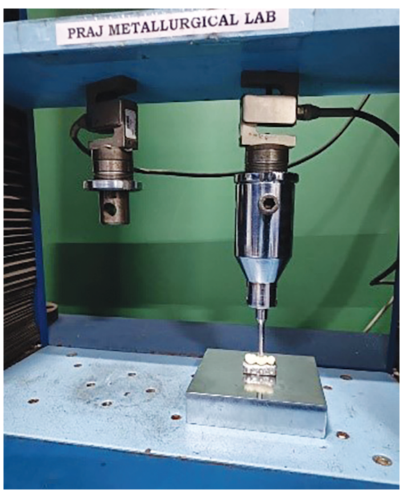

Fig. 3: Specimen testing under the universal testing machine

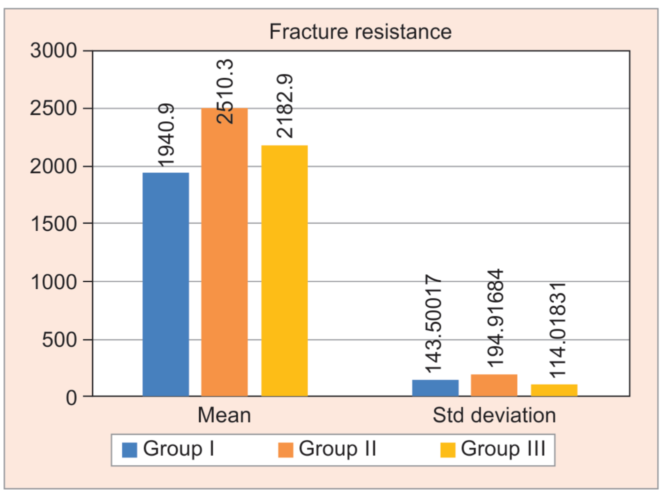

Fig. 4: Mean fracture resistance and standard deviation of the three groups in a bar graph representation

Discussion

Provisional restorations have often not been given due importance as they are mainly used for short durations. Alongside maintaining the biological, esthetic, and mechanical requirements, they also act as a guide to the final restoration.[6,7]

High-density polymer-based restorations are manufactured under industrial conditions permits, which offer biocompatibility alongside favorable mechanical behavior.[8,9] Rekow et al.[10] proposed provisionalization after reviewing the CAD/CAM systems used in dentistry. CAD/CAM restorations have also reduced chairside time. Hardware has become affordable, software user friendly, fabrication of provisional takes lesser time, milled restorations have better anatomy, marginal adaptation, contacts and contours are more accurate.[9] The provisional CAD/CAM material used in this study was a highly polymerized PMMA polymer that had highly cross-linked resins manufactured in an industrial process that has a well-controlled environment that minimizes flaws and contamination while maintaining the pressure during the polymerization process.[8]

To overcome certain drawbacks with CAD/CAM, such as excess waste material, 3D printing technology has gained popularity for provisional restoration fabrication because of its ability to manufacture *via* an additive mechanism, thus reducing waste, reducing manufacturing time, etc.[12,13] Several authors have mentioned that better mechanical properties of restoration as observed in a 3D printed restoration as it sustains cracks, high resolution of construction is which is attributed to the bond strength between each layer.[14–18]

Ibrahim et al.[19] established that the vertical orientation of printing is the factor that attributes to greater fracture resistance in the printed restoration group. Furthermore, Tahayeri et al.,[5] observed that the mechanical properties of restorations were affected by the thickness or thinness of the resin layer, lower directly attributed to more interface generation, and increased polymerization. Due to these factors, a 50 μ at a 90° print orientation was chosen for this study.

However, Ibrahim et al.[19] in their study, showed different values; and found that milled provisional restorations had lower resistance to fracture than 3D-printed provisional restorations. This study was carried out with solitary crowns and not with bridges, whereas FDPs in the present study were fabricated with uniform pontics and contact areas which can have a fluctuating effect on the results. Similarly, monolithic disc industrial manufacturing processes have greater resistance when compared to printed provisionals due to their high degrees of monomer conversion and better reticular compaction of the PMMA structure.[20–25]

A 3D printed product also has influencing factors by the various fabrication techniques used. It is a technique-sensitive mechanism as a 3D printed specimen shows decreased bond strength between the newly added and formed layers and also may cause postcuring shrinkage of the specimen. Additionally, STL file format data conversion and manipulation may also result in some changes.[19] Therefore, the lesser fracture resistance of 3D printed FDPs in this current study when compared to CAD/CAM milled FDPs could be attributed to the above-said reasoning.

This study reveals that the provisional restorations fabricated *via* CAD/CAM technique have a reasonably greater fracture strength than those fabricated using the 3D printing technique or *via* conventional methods. More homogenous structures, as seen in industrial CAD/CAM PMMA-based, along with a decreased number of free monomers, thus decreased chances of porosity.[20] This leads to decreased water absorption of these materials in comparison to the hand-mixed self-cured PMMA resins. This could explain the superior mechanical properties of CAD/CAM PMMA-based polymers over conventional PMMA resins and 3D-printed resins.

The molecular structure and nature of the material preparation may be the attributing factors to inferior mechanical properties in self-cured monomethacrylate (hand-mixed) provisional restorations.[21] Difficulty in preventing air entrapments when then leads to porosities due to the hand mixing of monomethacrylate resins may be an attributing factor to compromised mechanical strength, whereas lesser air entrapment is seen with the self-mixing cartridge delivery system of the bis-acryl resin. CAD/CAM technology has a wide variety of applications in the present dental practice, they are used for provisional restoration manufacturing and have great clinical success attributed to technological advances and the series of innovative materials currently being used.[8,9]

There is sparse data with respect to the fracture strength of 3D printed and CAD/CAM provisional FDPs. Those fabricated *via* the conventional method have been used as a gold standard for decades. The aim of the present study was to evaluate and compare the fracture resistance of provisional FPDs fabricated using additive and subtractive techniques. The proposed null hypothesis of the study was rejected as a significant difference was observed between the fracture resistance of provisional FPDs fabricated *via* CAD/CAM, 3D printing, and the conventional method.[26–28]

Intentional exclusion of the temporary luting cement was done to omit an additional influencing variable. An assumption was made that the luting cement would have led to an increase in the fracture strength of the provisional. At this age of digitization, there is limited literature on the subject of mechanical properties of interim milled and printed restorations, so more studies are required to investigate and establish differences between the two.

Conclusion

Within the limitations of this *in vitro* study was concluded that:

- The PMMA CAD/CAM milled 3-unit provisional bridge showed the highest fracture resistance amongst the groups compared, also when compared to provisional manufactured through additive manufacturing 3D printing.
- The 3D printing technique produces stronger provisionals and is a more reliable manufacturing method for interim restoration fabrication when compared with the conventional method.
- Even though the printed restorations have lower stress values when compared with the milled provisionals, they can find application in conditions where lower chewing loads are seen and in the absence of any parafunctional habits.

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