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The effect of fabrication methods (conventional, computer-aided design/computer-aided manufacturing milling, three-dimensional printing) and material type on the fracture strength of provisional restorations

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ABSTRACT

Background: Fracture is the most common reason for the failure of provisional restorations. This study aimed to assess the effects of the fabrication method (conventional, computer-aided design/computer-aided manufacturing [CAD/CAM] milling, three-dimensional [3D] printing) and material type on the fracture strength of provisional restorations.

Materials and Methods: In this *in vitro* study, 60 provisional restorations were made through the conventional (Tempron and Master Dent), CAD/CAM milling (Ceramill and breCAM.HIPC) and 3D Printing (3D Max Temp) methods based on a scanned master model. The provisional restorations were designed by the CAD unit and fabricated with milling or 3D printing. Then, an index was made based on the CAD/CAM milling specimen and used for fabricating manual provisional restorations. To assess the fracture resistance, a standard force was applied by a universal testing machine until the fracture occurred. One-way ANOVA and Tukey's test were used to compare the groups ($\alpha = 0.05$).

Results: The mean fracture strength was significantly different among the five groups ($P < 0.001$), being significantly higher in the breCAM.HIPC group ($P < 0.001$), followed by the Tempron group ($P < 0.05$). However, the three other groups were not significantly different ($P < 0.05$).

Conclusion: Despite the statistical superiority of some bis-acrylics over methacrylate resins, the results are material specific rather than category specific. Besides, the material type and properties might be more determined than the manufacturing method.

Key Words: Computer-aided design/computer-aided manufacturing, fracture strength, provisional restoration, three-dimensional printer

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INTRODUCTION

Provisional restorations are an essential part of fixed prosthesis treatments. They are characteristically similar to and practically as important as permanent restorations. Underrating the importance of provisional restorations is likely to negatively affect the quality of treatment.[1] Provisional restorations not only protect the pulp and periodontal tissues but also help diagnose and maintain function and esthetics. They should be durable to function in the long run

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and maintain the patient's health in case of delayed fabrication of final restoration due to problems such as temporomandibular joint disorders or periodontal diseases.[1-3]

Fracture is among the most common reasons for the failure of provisional restorations. The mechanical properties of restorative materials determine the restoration behavior and resistance against the functional forces within the oral cavity. These features affect clinical conditions such as changes in vertical dimension in full mouth reconstruction, long-span prostheses, treatment of temporomandibular joint disorders, or patients with parafunctional habits. However, fracture of provisional restoration may even occur under normal biting forces.[2,4,5]

Provisional restorations are directly or indirectly made in the office or laboratory either manually or digitally, the latter of which includes methods such as computer-aided design/computer-aided manufacturing (CAD/CAM) and three-dimensional (3D) printers. Digital fabrication methods exclude the errors such as internal and marginal adaptation that are probable in the manual method. CAD/CAM milling is used in subtractive and additive fabrication modules. In subtractive manufacturing, a resin block is milled to create the digitally designed shape. Due to the high degree of conversion of monomer to the polymer during the resin block polymerization, these provisional restorations are stronger and more accurate than those made through conventional techniques. However, this method has shortcomings such as wasted materials, restricted range of motion, and diameter of the milling bur, which does not allow precise reconstruction in certain areas. In additive manufacturing, different materials are used to create products through the incremental accumulation of powder and liquid. The recently introduced 3D printing system (additive manufacturing) has addressed the flaws of CAD/CAM milling (subtractive manufacturing). This system facilitates manufacturing complicated structures with less material than the milling method.[3,6-8]

With the rapid development of 3D printers, various resins are used to make copings for porcelain-fused-to-metal restorations, provisional restorations, partial prosthetic frames, orthodontic models, surgical guides for implants, as well as prostheses. Additive printing is done through various methods such as stereolithography, fused deposition molding, selective electron beam melting, laser power forming, and inject printing.[6,9] Given the need for further evaluation of the prostheses made by 3D printers, the present study was designed to assess the effect of fabrication method (conventional, CAD/CAM milling, and 3D printing) and material type on the fracture strength of provisional restorations. The null hypothesis was that the fabrication method and type of material would have no significant effect on the fracture strength of provisional restorations.

MATERIALS AND METHODS

In this *in vitro* study, the master model was a left maxillary first molar typodont tooth prepared for ceramic restoration. The reduction was 1 mm on the axial wall and 1.5–2 mm on the occlusal surface, with a shoulder margin prepared with a flat-end cylindrical diamond bur. The prepared typodont tooth was duplicated with an elastomeric material. A wax duplication was prepared and cast with nickel–chromium alloy (Formula 45, USA) to make the master model, based on which the provisional restorations were fabricated, and fracture strength was measured. The master model was attached to a base on which multiple anti-rotation grooves were designed for firm placement of the conventional restoration. To fabricate the specimens, a special tray was made of light-cured resin to take an index from the provisional CAD/CAM milling restoration placed on the master model. Table 1 displays the details of employed materials.

A total of 60 specimens (n = 12 per group) were fabricated through the conventional, CAD/CAM milling, and 3D printing methods (3D Max Temp); each of the conventional (Tempron and Master Dent) and CAD/CAM milling (Ceramill and breCAM.HIPC) methods were used for two different materials. Accordingly, the five groups included conventional-Tempron, conventional-MasterDent, 3D printed-MAX Temp, CAD/CAM milling-Ceramill, and breCAM.HIPC.

In the CAD/CAM milling groups, to design the provisional restorations on a virtual abutment, the master model was scanned with a desktop scanner (Ceramill Map 600; Amann Girrbach, Germany) and a Spotcheck spray scanner (Magnaflux; Spotcheck, SKD-S2, UK); scanned images were saved as STL files. The provisional restoration was designed with anatomical contours, cement space of 65 µm, and a distance margin of 1 mm in the CAD unit (Ceramill

Table 1: The provisional materials used in this study

Materials	Type	Manufacturer
Tempron	Auto-polymerized acryl	GC America
Ceramill temperature	CAD/CAM milling PMMA	Amann Girrbach, Germany
3D maximum temperature	3D-printed PMMA	DMAX, Korea
breCAM.HIPC composite	CAD/CAM milling composite	bredent, UK
Master-dent	Auto-polymerized composite	Dentonics, Inc., Monroe, NC, USA

CAD/CAM: Computer-aided design/computer-aided manufacturing; 3D: Three-dimensional; CAM HIPC: Bredent Computer-aided Manufacturing .High Impact Polymer Composite; PMMA: Poly Methyl Methacrylate

Mind; Amann Girrbach). The specimens of Ceramill TEMP (PMMA, Amann Girbach) and breCAM.HIPC (High Impact Polymer Composite, Bredent) were fabricated by using 5-axis milling machine (Ceramill Motion 2; Amann Girrbach).

In the 3D printing group, the design files were transferred to the 3D printer (Hunter; Zhejiang Flashforge 3D Technology Co., China), which used digital light processing technology and specimens were made with light-cure 3D MAX-Temp resin (DMAX; Korea). The printed restorations were rinsed with 99% methanol for 5–10 min according to the manufacturer's instructions and stored in a cold water chamber under ultraviolet curing for 45 min.

To fabricate the conventional provisional restorations, the temporary restoration made through CAD/CAM milling was placed on the master model and an index was made with polysiloxane impression material (Optosil/Xantopren, Kulzer GmbH, Germany), which was further used as the template for the conventional specimens.

To assess the fracture strength, the specimens were placed on the master model in a universal testing machine (K-21046; Walter+bai, Switzerland), and subjected to standard pressure at a crosshead speed of 1 mm/min and a load cell force of Fmax = 20 KN. A plunger with a steel ball (4.24 mm in diameter) transferred the compressive load on the central fossa until a fracture occurred. The force leading to fracture was recorded in Newton as the fracture strength.

Kolmogorov–Smirnov, one-way ANOVA, and Tukey's *post hoc* test were done through SPSS software (version 22; SPSS Inc., Chicago, IL, USA) for the statistical analysis of the fracture strength with respect to the fabrication methods and materials ($\alpha = 0.05$).

This research was approved by the Ethical Committee of Azad University of Isfahan Medical Sciences (#23810201901051).

RESULTS

On confirming the normal distribution ($P > 0.05$), one-way ANOVA revealed the mean fracture strength to be significantly different among the five groups ($P < 0.001$). It was the highest in CAD/CAM milling-breCAM.HIPC (2999.2 ± 394.4 N), followed by the conventional-Tempron group (1473.9 ± 151.2 N) and the lowest in CAD/CAM milling-Ceramill group (1150 ± 185.1 N) [Table 2]. Pairwise comparison of the groups through Tukey's *post hoc* test showed the mean fracture strength in both CAD/CAM milling-breCAM. HIPC ($P < 0.001$) and conventional-Tempron groups were significantly different from the other four groups ($P < 0.05$). No significant difference existed between Ceramill Temp and Master Dent ($P = 0.78$), Ceramill TEMP and 3D Max Temp ($P = 0.28$), and Master Dent and 3D Max Temp ($P = 0.42$) [Table 3 and Figure 1].

DISCUSSION

The null hypothesis was rejected as the results showed that the fracture strength could be affected by both the fabrication method and the employed material. Among the five tested groups, CAD/CAM milling-breCAM.HIPC group had the highest fracture strength. BreCAM.HIPC is an amorphous, highly cross-linked composite with a high-molecular-weight, which is expected to have better mechanical properties than conventional methacrylates and composite polymers. Being made under pressure (250 bar) and heat (about 120°C), breCAM.HIPC is a greatly strong and durable restorative material.[3,10,11] The second highest fracture strength was seen in conventional-Tempron, which is a methacrylate polymer from the polyethyl methacrylate subgroup. Methacrylate provisional restorations are said to bend without fracture during flexural strength testing; thus, these specimens were subjected to the maximum force by the universal testing machine.[12]

According to Heying, the flexural strength of polyethyl methacrylate and vinyl-ethyl methacrylate could not be measured since these materials are too elastic for fracture strength testing. Neither all bendable materials are weak nor all stiff materials are strong. The ability of a material to absorb stress and have a high elastic/plastic deformation may be more important than high flexural strength and minimal elastic/plastic deformation, which make the material more fragile and potentially prone to fracture in the oral cavity.[13]

Conventional provisional materials have two different chemical compositions, including mono-methacrylates or acrylic resins and dimethacrylates or bisacrylic/composite resins (bisphenol A-glycidyl methacrylate [Bis-GMA] and urethane dimethacrylate). Provisional 3D printable materials seem to follow the same classification; however, the manufacturers refuse to release detailed information. It is still not known whether the chemical composition of 3D printing provisional materials is similar to conventional provisional materials and no inclusive investigation has ever analyzed this issue. Moreover, the behavior of 3D printing materials in the oral cavity has not been well elucidated over time and requires further study.[14]

Digital light processing and stereolithography systems use the 3D photopolymerization method, which makes these systems fragile due to the formation of a heterogeneous polymer network with high cross-linking. This problem can be managed through using dual-cure materials to improve the polymer networks and mechanical properties of 3D printing materials. Besides altering the chemical composition of photopolymers, adding flexible oligomers such as siloxane (a semi-organic compound with excellent structural flexibility) to photopolymers can alter the mechanical properties and enhance the strength of these materials. Tending to migrate to areas with lower surface tension, siloxanes move toward the surface of each layer, act as a filler between the layers of the polymer matrix, change the surface properties, and consequently strengthen the material.[15]

The 3D-printed products are strongly influenced by manufacturing technique. The mechanical properties of printing materials are also affected by several other factors like the fabrication parameters, the addition of reinforcing materials to the printed resins, layer thickness, and printing direction.[16] Concerning the printing direction, Alharbi *et al.*[17] found that the horizontally printed provisional restorations had significantly lower compressive strength than the vertically printed ones. In the horizontally printed specimens, the interlayer connection was in the loading direction, and the tensile stress created in the middle of the material led to the separation and slipping of the layers on top of each other.

In the present study, the specimens were printed horizontally with layers parallel to the loading

Table 2: The mean fracture strength (Newton) in the study groups

Fabrication method	Material	Mean±SD	*P*
CAD/CAM milling	Ceramill temperature	1150.2±185.1	<0.001
CAD/CAM milling	breCAM-HIPC	2999.2±394.4	
Conventional	Tempron	1473.9±151.2	
Conventional	Master-dent	1177.4±124.7	
3D printing	3D maximum temperature	1257.1±242.5	

CAD/CAM: Computer-aided design/computer-aided manufacturing; 3D: Three-dimensional; SD: Standard deviation; breCAM.HIPC: Bredent Computer-aided Manufacturing .High Impact Polymer Composite

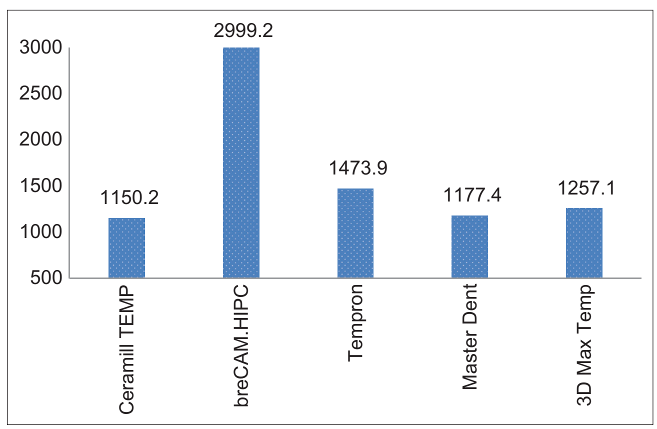

Figure 1: Mean fracture strength.

Table 3: Pairwise comparison of the mean fracture strength between the groups (Tukey's *post hoc* test)

Materials	breCAM.HIPC	Ceramill temperature	Tempron	Master dent	3D maximum temperature
breCAM.HIPC	-	<0.001	<0.001	<0.001	<0.001
Ceramill temperature	<0.001	-	0.002	0.78	0.28
Tempron	<0.001	0.002	-	0.004	0.03
Master dent	<0.001	0.78	0.004	-	0.42

3D: Three-dimensional, breCAM.HIPC: Bredent Computer-aided Manufacturing .High Impact Polymer Composite direction, which could reduce the fracture strength. Furthermore, the layered nature of printed materials in additive fabrication may initiate crack propagation and structural fracture. The interlayer joint is weaker than the intralayer joints. In 3D-printed resins, the thickness of the print layer affects the mechanical properties, i.e. the thinner layers have more interlayer interfaces, which increases the risk of crack propagation from the interfaces.[17]

In contrast, Tahayeri *et al*.[18] detected no statistical difference in the mechanical properties of printed specimens with layers of 25, 50, and 100 µm thickness. They also found that 25- and 100-µm thick layers had higher stress peaks than 50-µm thick layer, indicating that there are other adjustments to the print parameters on the mechanical properties of these materials besides layer-to-layer interactions. The mechanical performance of printed materials might improve significantly after polymerization and during postpolymerization processes. Joshi[19] compared the physical and optical properties of materials used to make provisional restorations and fixed dental prostheses through CAD/CAM milling and 3D printing. The results showed that PMMA CAD/CAM milling specimens had higher flexural and fracture strength than 3D-printed resins.

The mechanical features of 3D printable restorative materials used in the current study were sufficient for an intraoral provisional restoration. Bis-acrylic resins generally contain multifunctional monomers (such as Bis-GMA or TEGDMA) that increase the strength due to cross-linking with other monomers. Ordinary methacrylate resins are monofunctional with low molecular weight and linear molecules of little strength. Contrarily in the present study, the fracture strength of conventional Master Dent was lower than Tempron.[20]

This finding was consistent with that of Haselton *et al* who reported lower flexural strength for some bis-acrylic products than the methacrylate resins. They stated that although some bis-acrylics were statistically superior to methacrylate resins, the results were material-specific rather than category specific.[21] In line with the present study, Sharma *et al*.[22] detected relatively better flexural strength in methacrylate groups compared with the composite groups. That study reported PMMA as a better provisional restorative material in the long run, especially in case of parafunctional habits or for the long-span prosthesis.

In the present study, the fracture strength of the CAD/CAM milling-Ceramill group was the lowest, most probably due to the trauma caused during the milling process; implying the importance of material type and resistance against trauma and stress of milling. Diamond milling burs may cause some degree of roughness and fine cracking on the restoration. The shape, number, and size of diamond grains, as well as the direction of machining and the surface properties of milling material, are also important. Coarse diamond burs create deep defects on the restoration surface, while fine burs leave ductile-type damages.[23] Abdullah *et al*.[23] noted that not all provisional restorations in the CAD/CAM milling group had a higher fracture strength than the conventional provisional materials.

Alt *et al*.[24] compared the fracture strength of provisional fixed dental prosthesis fabricated by CAD/CAM milling with the conventional method. The CAD/CAM milling specimens were composite blanks fabricated and cured in ideal conditions with conventional provisional composites and prefabricated PMMA blanks. They found that fixed dental prosthesis fabricated through CAD/CAM milling had higher mechanical strength compared with a direct fixed dental prosthesis made of the same material. Seemingly, composite materials have certain advantages over PMMA materials and, therefore, should be considered for provisional restoration fabricated through CAD/CAM milling. Alt *et al*.'s findings were consistent with those of the current research. In the present study, provisional CAD/CAM milling composite restorations had significantly higher fracture strength than both CAD/CAM milling PMMA and conventional composite restorations, indicating the significant effect of material type.

Among the limitations of this study was the *in vitro* nature, which did not thoroughly simulate oral conditions and the interactive effect of factors such as saliva, food components, and beverages. Yet, the current results obtained under controlled conditions can be a predictor of clinical performance. Moreover, the provisional cement was deliberately precluded, and the effect of this additional variable was not assessed; as it was already assumed to increase the fracture strength. Further studies are recommended to address these issues.

CONCLUSION

The present findings showed that provisional restorations fabricated with CAD/CAM milling are stronger than those made with the conventional method. Moreover, it can be concluded that the fracture strength of provisional restorations is more affected by the chemical composition of the material, than the manufacturing method. Among the studied materials, breCAM.HIPC is the best and Ceramill Temp is the least favored material for making provisional restorations.

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Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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