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Fracture Resistance of Provisional Crowns Fabricated by Conventional, CAD/CAM, and 3D Printing Techniques

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KEYWORDS

Provisional Restorations, CAD/CAM, 3D Printing, Conventional.

ABSTRACT

Purpose: The aim of this study was to compare fracture resistance of provisional restorations fabricated with conventional manual procedure, CAD/CAM milling and 3D Printing techniques. **Materials and Methods**: one human upper first premolar was prepared and duplicated using epoxy resin to produce twenty one dies. Accordingly, a total of (N=21) provisional crowns were constructed. The Constructed provisional restorations were divided into 3 groups according to the method of construction (n=7 for each group), Group 1: Provisional crowns were constructed using conventional manual technique, Group2: Provisional crowns were constructed using CAD/CAM milling technique, Group3: Provisional crowns were constructed using 3D Printing technique. All Provisional crowns were bonded to their corresponding epoxy resin dies by using CharmTemp ZONE temporary cement and subjected to thermocycling procedure simulating approximately one month of clinical situations **Results:** Statistical analysis showed that the fracture resistance of CAD/CAM samples (group 2), recorded the statistically significant highest mean fracture resistance value (910.20 ± 118.95), followed by 3D Printing samples (group 3) (720.80 ± 129.57), while the lowest value was recorded for Conventional samples (group 1) (626.71 ± 103.23). ANOVA test showed that there was no significant difference between 3D Printing samples (group 3) and Conventional samples (group 1). **Conclusion:** CAD/CAM provisional crowns have superior strength than 3D Printing and conventional crowns.

- Paper extracted from Master Thesis titled "Marginal Accuracy, Internal Adaptation and Fracture Resistance of Provisional Crowns Fabricated by Conventional, CAD/CAM, and 3D Printing Techniques"

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INTRODUCTION

The interim restoration is a critical phase in fixed prosthetic treatment. This type of restoration serves after tooth reduction till the final cementation. An adequately fabricated interim is essential in attaining an efficient final restoration [1].

Whilst the period of temporization, most of the information regarding esthetics, occlusion, and function is made clear to the fixed prosthodontist. The main aim of this type of restoration is the provision of aesthetics, positional stability of the prepared tooth, pulp protection, and soft tissue management [2]. Its importance increases greatly for oral rehabilitation cases that needs long-term provisionalization [3].

Methacrylate or Bis-GMA are two main types of resinous material that are frequently used for the construction of interim restoration. Ease of repair, adequate fit at the margins, and high strength properties make polymethyl methacrylate resin (PMMA) the most frequently used type of resin. Although, this material exhibits a release of exothermic heat upon setting, polymerization shrinkage, and low stain resistance. Recently, it was reported that Bis-GMA composite resin has better esthetics and could overcome the other disadvantages of PMMA [4].

Interim restoration construction could be either manual or digital, direct or indirect [5]. Subtractive or additive fabrication of digital type of interim is advent.

Interim restoration fabrication methods can be direct or indirect, manual or digital. In turn, there are two kinds of digital manufacturing of interim restorations; subtractive or additive [5]. Nowadays, the process of virtual designing and construction of dental prostheses becomes valid and reliable through the introduction and development of Computer-aided design technology. This virtual design is followed by processing with either additive production (3D printing) or subtractive production (milling) [5].

Subtractive ways of fabrication of temporary restorations are made by milling the resin blocks[6]. Restorative materials used for this purpose are known for their low shrinkage upon polymerization together with the lack of exothermic reaction [7]. In addition to the well-known advantages of CAD/CAM restorations, namely increased productivity and reduced laboratory time in comparison to man-made ones. However, there are some shortcomings of this kind of prosthesis such as the constraints of analysing a complicated shape, particularly for the intaglio surface of restoration because of the cutting instruments' limited angle and size [8].

Furthermore, 3D Printing as an additive way of construction is believed to be more reliable in making benefit of the material than the subtractive milling way. The 3D Printing process, known as quick production via prototyping or additive manufacturing, constructs the prostheses in a layer by layer form using the data of CAD [5]. The process of 3D printing starts by providing a 3D file on the computer system followed by producing a series of slices in cross-sectional form. This is followed by sequential printing of each slice to the other to manufacture any prostheses in their three-dimensional form. The mechanism of this technology relies on directing and focusing an ultraviolet beam of light onto a liquid photopolymer. Then a layer of resin is cured when the light beam draws the object to the surface of the liquid photopolymer-containing platform [9].

Failure of temporary restorations occurs most frequently due to fractures. Consequently, this particular type of restoration should be constructed to avoid fracture. Therefore, its mechanical strength should be considered particularly in long-term conditions to provide clinical success [3]. The fracture strength of the material is greatly dependent upon its type. Recently, it has been reported that Bis-GMA resins have more strength than PMMA and PEMA types of resin. However, it was revealed that the fracture is dependent on the material itself rather than its type, because some Bis-GMA groups had high mean fracture strength while others exhibit low performance in comparison to PMMA [10].

The null hypothesis of the present study was that there would be no significant difference in the fracture resistance between provisional crowns fabricated using either digital technology (CAD/CAM and 3D Printing) or manually fabricated technique.

MATERIAL AND METHODS

1) Sample size calculation:

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference between different tested groups regarding fracture resistance and mode of fracture. By adopting an alpha (α) level of 0.05 (5%), a beta (β) level of 0.2 (20%) i.e. power=80% and an effect size (f) (0.738) and (0.811) respectively - calculated based on the results of previous study [(11)]. The predicted sample size (N) was a total of (21) samples i.e. (7) samples per group. Sample size calculation was performed using G*Power version 3.1.9.7[2] [(12)].

2) Teeth selection, preparation and duplication

One anonymous extracted sound maxillary first premolar was selected from oral and maxillofacial surgery clinic, faculty of Dental Medicine for girls, Al-Azhar University, Egypt, and used in this study. This premolar was embedded in the center of plastic cylinder (2cm height and 1.5cm diameter) filled with epoxy resin in order to construct epoxy resin block. This premolar was prepared to receive an all ceramic crown. The preparation was carried out by using CNC (centroid milling machine) with 2mm occlusal reduction, 1.5mm axial reduction, 1mm deep chamfer finish line circumferentially at 1mm above the cementoenamel junction, and a convergence angle of 6 degree [(13)].

Each premolar was duplicated by using silicon molds fabricated from silicone duplicating material (Replisil 22 N, Dent-e-con, Germany) to form 21 epoxy resin dies, then resin based provisional restoration were fabricated for each epoxy resin die. Constructed provisional restorations were divided into 3 groups according to the method of construction: (n=7 for each group). Group 1: Provisional crowns constructed using conventional manual technique using Protemp™4 (3M ESPE, Germany), Group2: Provisional crowns constructed using CAD/CAM milling technique using TelioCAD disc (Ivoclar Vivadent, Liechtenstein, Germany), Group3: Provisional crowns constructed using 3D printing technique using NextDent C&B (Vertex Dental, Netherlands).

3) Construction of temporary crowns:

3-a) Construction of CAD/CAM provisional crowns, group (2):

- *Scanning the preparation:*

DS MIZAR (EG solutions, Italy) 3D extra-oral scanner was used to scan the prepared die to get 3D virtual image.

- *Designing the restoration:*

The Exocad Software, (DentalCAD 3.0 Galway) was used to design a virtual model. Restoration anatomy from dental databases libraries was selected and the cement space was set at 0.05 mm [(14)]. When the final virtual restoration was designed, the information was sent through STL file to the milling machine.

- *Milling process:*

The designed STL file was used to mill the crowns after selecting the type and size of disc for fabrication of provisional crowns. TelioCAD disc (Ivoclar Vivadent, Liechtenstein, Germany), was placed in the spindle of the 5axis milling machine (D15; Yenadent Ltd., Istanbul, Turkey). Wet milling of selected PMMA disc was carried out using carbide burs.

3-b) Construction of 3D Printed temporary crowns, group (3):

The same CAD/CAM STL file was sent to Chitubox Pro Software after finishing the milling process. This software was used for preparing the file for printing. Ten fixing structures were inserted on the side surface of the crown and then detecting the printing direction of the crown in horizontal orientation, (Fig.1). Adjusting the printing process parameters was carried out. When the final virtual restoration was designed, the information was sent through STL file to the 3D Printer (Anycubic Photon SE) (Anycubic Technology Co., Shenzhen, China) which is LCD based. NextDent C&B (Vertex Dental, Netherlands), resin was used and poured into a container specially fabricated to be accurately fit in the printer and the building process was started.

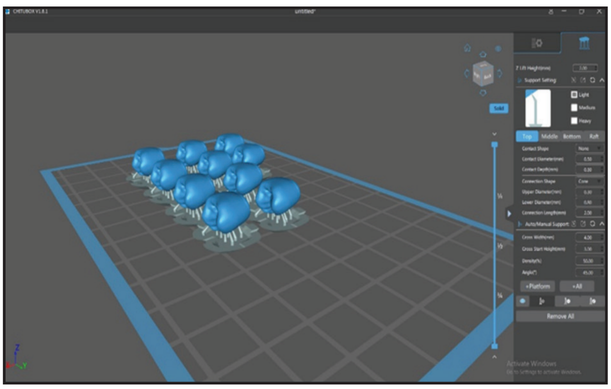

Figure (1) Crowns design in the Chitubox Pro software in a horizontal direction with ten supporting structures attaching them.

Crowns were built layer-by-layer, a thin layer of polymer is cured and hardened by UV radiation., The platform was then lowered or raised as the UV light cured the next layer while the preceding layer was still being cured. The procedure was repeated until the full crown was complete. Post processing curing of the 3D Printed crowns was done by using (Bredent, bre.Lux Power Unit 2, LED Full Range System) (which is an Ultraviolet light curing box suitable for post curing 3D Printing resin materials to ensure that Next Dent materials obtain the full polymerization and superior mechanical properties), for 15 minutes according to manufacturer instructions. After manufacturing, all samples were finished and polished.

3-C) Construction of conventional manual provisional crowns, group (1):

Protemp™4 (3M ESPE, Germany) was used to construct provisional crowns in group (1). An impression of a previously constructed CAD/CAM provisional crown was taken using silicon (Zhermack, Zetaplus, Badia Polesine, Italy) to serve as an index for standardization of group (1) samples.

Protemp™4 was mixed through the self-mixing gun and directly injected into the silicon index, which was then placed on the epoxy die and held in place until the mixed material completely set. The crown was examined to detect any defects then finished and polished using rotary rubber cups (SofLex™ Disc 3M ESPE, Germany) following manufacturer's instructions.

4) Cementation procedure:

For the cementation of crowns on their corresponding epoxy resin dies, CharmTemp ZONE temporary cement (Dentkist, South Korea) was used. The cement was mixed according to manufacturer's instructions. All samples were cemented to their corresponding dies using a specially constructed loading device under a load of 3 kg [15] during the cementation.

5) Thermocycling:

Samples were subjected to 1000 cycles which correspond to approximately one month of service inside the oral cavity [16] Thermal cycles between the temperature range of 5-55 ^{0}C in distilled water (dwell time: 25 seconds with a pause time of 10 sec.). this whole procedure were done by the aid of thermocycling unit.

6) Fracture resistance determination:

After putting each sample on the machine, a computer-controlled materials testing machine, (Fig.2), (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a load cell of 5 kN was used to test it. In Newtons, the amount of force required to fracture was calculated.

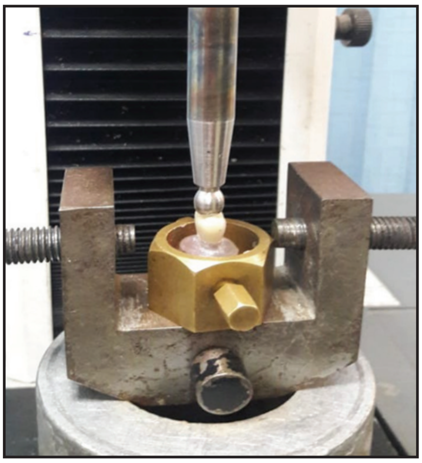

Figure (2): A computer-controlled materials testing machine

Evaluation of fracture pattern of the tested samples was done using magnifying lens (X=12), and it was classified according to Burke's classification[17], table (1).

Table (1) *Burke's classification:*

Classification	Pattern of fracture
Class I	Minimal fracture or crack in crown
Class Il	Less than half of crown lost
Class Ill	Crown fracture through midline; half of crown displaced or lost
Class IV	More than half of crown lost
Class V	Severe fracture of tooth and/or crown

Statistical Analysis

Quantitative data were statistically analyzed for significance using One Way ANOVA and post hoc test, and presented as numbers and percentages. While qualitative data were analyzed using Chi-Square test, and presented as mean and standard deviation.

RESULTS

The results showed that fracture resistance of CAD/CAM provisional crowns (group 2), recorded the statistically significant highest mean value (910.20 ± 118.95), followed by 3D Printing provisional crowns (group 3) (720.80 ± 129.57), while the lowest value was recorded for Conventional provisional crowns (group 1) (626.71 ± 103.23). ANOVA test showed that, there was no significant difference between 3D Printed samples (group 3) and Conventional samples (group 1).

Table (2) *Comparison between the three studied groups regarding fracture resistance (N)*

Groups	Fracture resistance		Test value•	P-value	Sig.
	Mean ±SD	Range			
Conventional	626.71 ± 103.23 ^{a}	456.4 – 716.3	10.526	0.001	HS
CAD/CAM	910.20 ± 118.95 ^{b}	732.10 – 1089.2			
3D printing	720.80 ± 129.57 ^{a}	513.2 – 879.2			

P > 0.05: Non significant; P <0.05: Significant (S); P <0.01: Highly significant (HS; Different superscript letter indicate significant difference between groups)

Regarding the type of failure; table (3) shows the prevalence of different fracture types in each group. No statistically significant difference was found between the three studied groups regarding mode of failure with p-value = 0.256.

Table (3) *Mode of failure corresponding to the three groups*

Mode of failure	Conventional	CAD CAM	3D printing	Test value*	P-value	Sig.
	No. = 7	No. = 7	No. = 7			
I	0 (0.0%)	2 (28.6%)	1 (14.3%)	7.767	0.256	NS
II	1 (14.3%)	3 (42.9%)	1 (14.3%)			
III	3 (42.9%)	2 (28.6%)	4 (57.1%)			
IV	3 (42.9%)	0 (0.0%)	1 (14.3%)			
V	0 (0.0%)	0 (0.0%)	0 (0.0%)			

*P >0.05: Non significant (NS); P <0.05: Significant (S); P <0.01: Highly significant (HS) *: Chi-square test*

DISCUSSION

The information regarding fracture resistance of 3D printed interim restorations, compared to those obtained using subtractive CAD/CAM technique and conventional manual technique, is still lacking.

The current study aimed to evaluate the fracture resistance and pattern of failure of provisional restorations constructed with three different materials and fabrication techniques, by evaluating the greatest load at the moment of fracture.

In the current study, it was hypothesized that there will be no difference between the fracture resistance of provisional crowns fabricated by CAD/CAM, 3D Printing and conventional techniques. However, the null hypothesis was rejected as the results showed that milled provisional crowns had higher fracture resistance than 3D Printed and conventional crowns.

In the present study the CAD/CAM group recorded the statistically significant highest mean fracture resistance values compared to 3D Printing and Conventional groups.

The results of the present study agree with another study [18] in which the mean fracture resistance of CAD/CAM PMMA provisional restorations was significantly higher than bis-acrylic and self-cured composite restorations. Thus, CAD/CAM PMMA was indicated for the construction of interim restorations owing to its good fracture resistance on clinical performance.

Another study [19] concluded that manufacturing procedures and tooth type influenced the fracture resistance of screw-retained implant-supported interim crowns. Milled samples resulted in significantly higher fracture resistance compared with the DLP additive manufactured groups.

Another study [20] found that provisional restorations from the computer-assisted milling group were more resistant to fracture than provisional restorations from rapid prototyping.

CAD/CAM PMMA discs (as Telio Cad used in this study) are prefabricated monomethacrylate-based PMMA discs with high strength and long-chain, linear molecules with minimal intermolecular crosslinking. These discs are industrially fabricated with expected fewer pores and defects. Thus, their inherent strength is high [21].

In the present study, mean fracture resistance values of 3D Printed crowns were not significantly different from the conventional group. A previous study [22] found that 3D printed samples had comparable modulus to Jet (conventionally cured provisional material), but significantly lower than Integrity (conventional material). It was thus proposed that both restorative dental material and systems in the printed three-dimensional form, provided good strength properties to be used intraorally as a provisional restoration [22].

A previous study [23] analyzed and compared the mean flexural strength values of interim crowns constructed by three different techniques. The milled group was higher (104.20 MPa) compared to the specimens of a conventional group (95.58 MPa) and the least flexural strength was recorded for the printed group (79.54MPa). It was found that the PMMA resins in its 3D-printed design showed peak stress that is comparable to that of Bis-GMA ones and was significantly higher than conventional PMMA [22].

3D Printing is influenced by the technique of photocuring utilized. In this study LCD photocuring technique with Anycubic Photon SE printer was used. An interesting point in the photopolymerization by LCD of 3D printing unit, is its very weak light intensity, owing to the passage of 10% of the light through the LCD screen while the rest of the light intensity (90%) is absorbed by LCD screen which in turn results in a prolonged time of printing and low conversion degree, thus the precision of LCD printing technology is inferior to the DLP printing [24].

Furthermore, printing orientation or building direction is one of the first and most important steps in 3D printing techniques. Materials printed vertically with the load perpendicular to the layer orientation exhibit higher compressive strength than materials printed horizontal [25]. In the present study, the crowns were horizontally printed leading to a decrease in fracture resistance.

Moreover, due to the mosaic concept of CAD, the conversion of CAD to 3D Printed parts frequently results in flaws and inconsistencies, particularly on curved surfaces. Furthermore, the formation of gaps between subsequent material layers causes additional porosity during manufacturing, which may have a negative impact on mechanical properties due to reduced interfacial adhesion between printing layers [26]. All these factors had contributed to low fracture resistance values obtained with the 3D Printing group.

However, other studies [3,27] disagreed with these results where 3D Printed provisional crowns reported superior fracture resistance values over the milled provisional crowns. Yet, the technique of 3D Printing was different from that used in the present study.

Group 1 showed the lowest resistance of fracture; the conventionally fabricated crowns. The values were statistically insignificant from group (3) values. Samples of group (1) were manufactured manually, which depends to a great extent on the worker's skills with several processing steps, which may lead to inaccuracies. Other drawbacks of traditional provisional restorations include poor mechanical properties, a decrease of marginal integrity, and poor colour stability due to a porous surface that attracts stains. Furthermore, high polymerization shrinkage is expected, with heat generation, water sorption, and resin matrix degradation being of concern [1].

It was stated in study [28] that the normal biting force in young adults and adults ranged between (262-345)N. In the present study the fracture resistance values obtained ranged from (626.71-910.20) N. These values are above the normal bitting forces.

Based on the results of fracture mode analysis there was no statistically significant difference between the three tested groups. CAD/CAM, group (2) had the most prevalence of classII fracture while 3D Printing, group (3) was most commonly reported with classIII fracture and Conventional, group (1) had classIII and class IV fractures.

CONCLUSION

Within the limitations of the current study, CAD/CAM constructed provisional crowns have higher fracture resistance values compared to 3D Printed and conventional crowns.

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Declaration of Conflict of Interest

The authors declare that they have no conflict of interest.

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