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The Effect of Thermocycling on Fracture Resistance of CAD- CAM and 3D Printing Provisional Prosthesis

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Abstract

This study aims to assess how thermal cycling affected the fracture strength of temporary restorations made using additive 3D printing procedures and computer-aided design- computer-assisted manufacturing (CAD/CAM), subtractive (milling) methods.

For full coverage crowns, a dento form upper molar tooth was created. A second oral scanner digitally scanned developed model. Duplication of the metal dies was made using the master die (chrome cobalt alloy). A total of 40 samples were created and split into two groups: 20 were created using CAD/CAM technology with a (Bilkim) CAD PMMA disc and 20 were created using 3D printing with Asiga dentatooth resin. Thermal cycles (1250 cycles, 5-55 °C) were applied to 10 samples from each group. After that, a universal testing device determined the fracture resistance for each sample.

The mean with standard deviation values of fracture resistance were recorded for the milled group before thermocycling (560.50 ±83.581 newton) and after thermocycling (901.00± 311.598 newton) meanwhile the mean ± stander deviation value was recorded with the printed group before thermocycling (1972.50±399.181 Newton) and after thermocycling (2284.10±239.001 Newton), it was found that the printed group recorded statistically significant higher fracture resistance mean value than the milled group.

Provisional crowns constructed using the 3D printing technique showed higher fracture resistance compared to the temporary milled crowns.

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Keywords: 3D printing; CAD/CAM; Fracture strength; Polymer materials; Thermocycling.

1. Introduction

The terms temporary, interim, or provisional restoration is a fixed or removable dental restoration that is fabricated to improve aesthetics, stabilization and function for an appropriate period of time, and then it must be replaced by a permanent dental prosthesis. a properly constriction provisional prosthesis is necessary for achieving a successful final restoration [1]. Provisional restoration has many functions, such as preventing bacterial contamination, protection of pulpal, stabilization of occlusal relationships, prevent rotation of the tooth from its normal position (supra or infra occlusion). Its significance grows in cases of oral rehabilitation that requires long-term treatment of six to twelve weeks or more [2], and then insertion of the temporary prosthesis, which is regarded as intermediate therapy, is required in cases of complete restorations where numerous teeth are involved [3]. Understanding the numerous specifications for interim restorations is also essential, such as the stabilization of tooth position, which calls for minimal accuracy in addition to sufficient structural and wear resistance, and adherence to aesthetic standards while retaining their polish and shine [4]. When choosing materials for interim restorations, physical, mechanical, and handling considerations must be taken into account to sure the material meets the specific needs of each clinical situation. The biocompatibility of material with soft tissues and its bio tolerance are two more key factors to take into account because some materials may create a risky exothermic reaction [5]. For temporary restorations, polymeric resin is frequently used, and it was first produced using several methods direct, indirect, and indirect-direct methods [6]. However, the advances in materials and technology contributed to the introduction of the milling technique (subtractive manufacturing) and 3D printing technique (additive manufacturing) [7]. The technique of the milling (CAD/CAM) is now widely used in most contemporary dentistry facilities and by certain physicians working chairside. subtractive techniques, such as temporary restorations made by milling resin blocks that have been properly cured [8]. Different resins are being utilized in the recently discovered 3D printing process, which is expanding quickly. Additive manufacturing is involved (layer upon layer). It is capable of producing exact prostheses with little material waste. It is thought to be quicker and less expensive than milling. Since there is no application of force, it is passive and can generate finer details (undercuts & better anatomy) [9]. The 3D printing methods include stereolithography, digital light processing, selective laser sintering and fused deposition modeling [10]. Fractures are a frequent reason for provisional restoration failure, and while it is recommended that interim restorations be built to prevent fractures, they can still occur. Both pains for the patient and financial loss could result from this.

Nomenclature			
CAD/CAM	Computer-aided design and computer added manufacture	P	P- value
3D printer	Three-dimensional (3D) printing or additive manufacturing	PMMA	Polymethylmethacrylate

As a result, to ensure clinical effectiveness, the mechanical strength of interim restorations is essential and should be considered, especially in long-term scenarios [11]. Data shows the fracture resistance of three- dimensional printed provisional prosthesis compared to milled prosthesis has limited and needs further investigations. This is why the present study assessed the long-term 3D printed provisional restoration's fracture resistance. The current study objective is to assess and contrast the fracture resistance of interim crown restorations made using CAD/CAM and 3D printing.

2. Materials and Methods

A dentoform upper molar tooth (dentoform, Nissin Dental Product Inc., Tokyo, Japan) was used in this study as a model [12]. According to the standard protocol, the tooth was prepared of all ceramic crown, with 1.5 mm reduction from occlusal and axial, and 1.2 mm in thickness of finishing line on a chrome cobalt alloy master model with a crown fixed denture prosthesis [13]. Tow type of materials used in this study 3D printing resin (Asiga dentatooth, Bourke Road, Australia), and (PMMA) CAD/CAM disk (Bilkim, Ismir, turkey).

2.1. Design of Restoration

Scanning the master cast was done to get a 3D virtual crown using 3D shape extra-oral scanner (shinning 3D scanner, Germany). The process of scanning took approximately 1 minute. The finish line could be identified using the virtual model created by the 3D shape software from scanned images, and margins could be detected automatically. This was done to choose the tooth anatomy from dental database libraries that matched it, identifying any undercuts in the abutment and determining the depth of the preparation from all angles, The occlusal thickness was then measured from the central fossa and corrected to be 1.5 mm for the uniformity of all samples after the cement space had been set up using the software [14].

2.2. Crown Fabrication

2.2.1. CAD/CAM process

The data set was transferred to a CAD/CAM unit (K5 Germany) for the milling then carefully removed from the blocks. The provisional prostheses produced have 2 mm occlusal, and 1.5 mm axially thickness, and used the carbide burs for cutting the milling CAD disc (Bilkim, Ismir, turkey) [14], (Fig. 1).

2.2.2. 3D Printing process

Rapid prototyping samples (3D printing) were obtained by transferring the same CAD design to the CAM software of the 3D printer (Asiga Bourke Road, Australia) as a file in Stereo lithography format. For post-curing 3D printing, resin materials are used a 3D print box an Ultraviolet lightbox, to ensure that resin materials obtain complete polymerization and high mechanical properties [4], (Fig. 2).

2.3. Thermocycling

From each group, ten samples were subjected to thermocycling. The cycles used were 1250 cycles which represent three months inside the oral cavity. The temperature of thermal cycles extremes of 5 °C and 55 °C in distilled water (dwell time: 25 seconds, pause time:10 seconds) were performed in the thermocycling unit. The specimens were placed in a container in thermocycler, then inspected for cracks or fractures after each loading phase [14].

2.4. Fracture resistance test

All specimens were subjected to the compressive load. The chrome cobalt alloy prepared tooth model was placed in a universal testing machine for fracture testing. The samples were placed on a model. Specimens were subjected to a compressive load at a 90-degree angle to the center of the specimen until fracture at a crosshead speed of 1 mm/min was recorded using a metal ball of 5mm diameter at the central pit parallel to the long axis of the tooth until failure occurred [15]. Maximum force at fracture was recorded, optical evaluation of fracture patterns [11], Fig. 3.

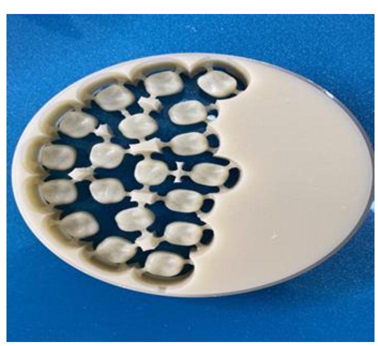

Fig 1. Interim crowns samples made from PMMA CAD/CAM disk resin after milling process

Fig 2. Interim crowns sample made from 3D printing resin after printing process

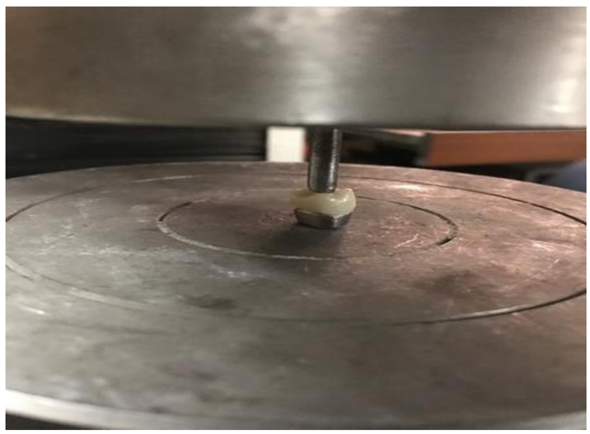

Fig 3. 3D printing acrylic resin sample under the universal testing machine for fracture test

3. Results

Descriptive statistics are shown in Table 1 for fracture resistance test before and after thermocycling process which included (minimum, maximum value, mean, and stander deviation). The results indicated that the highest mean value of fracture resistance of CAD/ CAM groups (901.00 newton) after thermocycling, while the lowest mean value (560.50 newton) was before thermocycling. The highest mean value of fracture resistance of 3D printer after thermocycling (2284.10 newton), while the lowest mean value (1972.50 newton). In this study, t- test type of statistical analysis was used for comparison of fracture resistance for 3D printer group versus CAD/CAM group before thermocycling (11.328 newton), P=.000 (High Significant), and after thermocycling (10.467 newton) P=.000 (High significant), this shown in Table 2. Bar charts of mean value of fracture resistance of experimental groups before thermocycles and after thermocycling are shown in Fig. 4.

Table 1 Descriptive statistics of fracture resistance for the experimental groups (in newtons)

Groups	No. of samples	Minimum	Maximum	Mean	Stander deviation
CAD CAM group\Before thermocycling	10	440	670	560.50	83.581
CAD CAM group\After thermocycling	10	600	1525	901.00	311.598
3D printer group\Before thermocycling	10	1500	2800	1972.50	399.181
3D printer group\After thermocycling	10	1903	2650	2284.10	239.001

Table 2 Comparison of fracture resistance of experimental groups before and after thermocycling using t-test statistical analysis

Groups	t- test	P-value
3D printer group versus CAD/CAM group before thermocycling.	11.328	P=.000 (High significant)
3D printer group versus CAD/CAM group after thermocycling.	10.467	P=.000 (High significant)

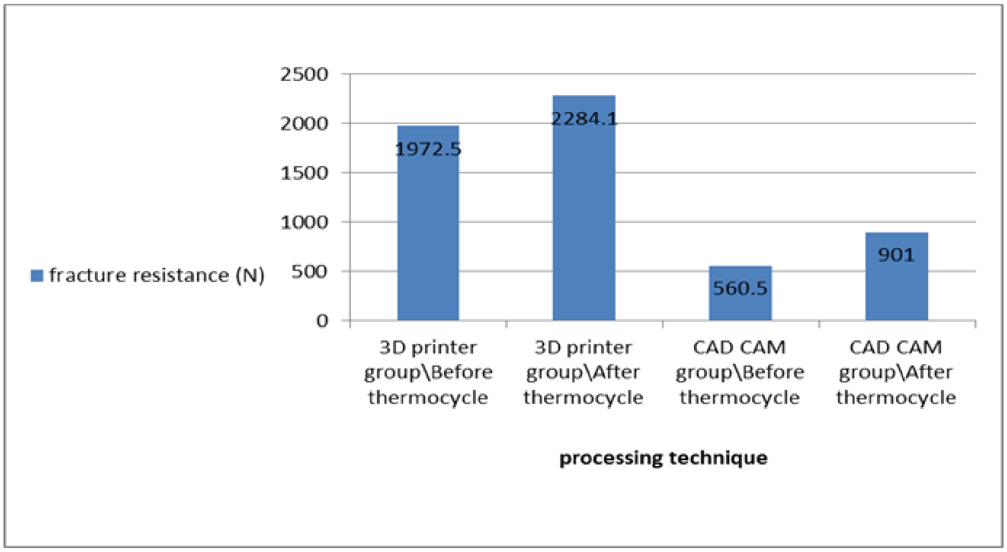

Fig 4. Bar charts showing the mean value of fracture resistance (in newtons) before and after thermocycle of the studied groups

4. Discussion

Provisional prosthesis is a necessary part of fixed prosthodontics treatment. It must provide biologic, esthetic, and mechanical requirements, such as functional load resistance, removal force resistance, and maintenance of abutment alignment [1]. Due to improvements CAD/CAM systems and materials, CAD/CAM technology was recently used for the fabrication of provisional prostheses. Despite the clinical success, it was noted that CAD/CAM technology had some drawbacks, including small discrepancies, excessive material waste, and lengthy fabrication times. The cost of CAD/CAM technology is another disadvantage. Additionally, the intricacy of the product, the size of the tooling, and the characteristics of the materials all have an impact on the accuracy [7]. Recently, 3D printing technology has been used to manufacture temporary restorations. It has numerous advantages over CAD/ CAM, it can print small and large objects, unlike CAD/ CAM milling is limited to the size of blocks. Rapid prototyping is a speedier manufacturing approach. In the 3D- printing processes, the material was deposited layer by layer to create the final 3D shape, therefore less material was wasted, decreasing expenses, and mechanical properties were improved as there were no cracks in addition to producing a less expensive interim restoration, high level of building resolution, smooth printing surfaces, and high strength (between layers) [16].

The extra-oral scanner from the same company, 3D shape, was used in the current investigation to achieve consistency. The (Stereolithography) file was used for both processes, and 3D shape software was used to design all of the manufactured intermediate repairs. The cement space was measured and adjusted for all specimens in the current investigation using 3D shape software during the designing processes. It was around 0.030 mm [7]. Through the use of the same software, the occlusal thickness of every crown was regulated to be 1.5 mm from the central fossa. To mimic the clinical setting, thermal cycling was applied to the samples from both groups. This provides information on the durability of provisional prosthesis inside the mouth cavity. To simulate the chemical impact of an aqueous environment and temperature change on resin-based materials, wet circumstances and thermocycling were also taken into consideration, it was found that the 3D printed group recorded statistically significant higher fracture resistance mean value than CAD/CAM group [17]. The values of the 3D printed group produced are beyond the normal masticatory forces which clinically range between (360 - 900 newton) at the posterior region, this means it is within the clinically acceptable range of masticatory force [19]. The higher fracture resistance of 3D-printed group could be attributed to the layered nature of the 3D-printed structure. The chemical connection between layers gives the structure its comparatively strong strength. The present study use of 3D printed interim crowns with vertical building orientation may also have contributed to the printed group's higher scores for fracture resistance. This outcome is consistent with the discovery of. The researchers found that samples printed vertically with layers parallel to the load direction had greater fracture resistance than specimens printed horizontally with layers parallel to the stress direction (Ibrahim et al., 2020) [14]. The present study thin printed layer thickness may also be responsible for the 3D printed group's higher fracture resistance. It was about 62 microns during the building process. These findings were concurrent with (Tahayeri et al., 2018) [20] who discovered that vertically printed samples with layers perpendicular to the load direction has higher fracture resistance than the horizontally printed samples with layers parallel to the stress direction. Furthermore, the enhanced fracture resistance of the printed group could be due to the current study's short printed layer thickness special Nextdent curing unit. These findings were in agreement with Tahayeri et al. (2018) [20] who they concluded that the post curing process of 3D printed crowns can result in a higher degree of conversion and decrease the presence of residual monomers then enhance the fracture toughness and strength. However, the results of the current study were not in agreement with the findings of (Digholkar et al., 2016) [18] who they found that the cause may be related difference in method and material the interim crowns fabricated by the 3D printing technique produced lower fracture resistance than CAD/CAM technique. This was attributable to the specimen's shrinkage during construction and after curing. Additionally, some alterations could be made as a result of data conversion and manipulation when being formatted for (Stereolithography). On the other hand, the parallel lines and tiny grooves that can be seen on the surface of the milled samples may be the cause of the milled group's lower values of fracture resistance. This may be related to the nature of the milling method, as these lines may eventually result a flaw or fracture with repeated use [14]. In this study the 3D printing group after thermocycling showed highly significant fracture resistance in comparison to the CAD/CAM group, the scientific explanation of the previous study mention the result that the CAD/CAM block used in the present study acetal blank according to the manufacture recommendation, contained a higher percentage of residual monomer in comparison to 3D printing groups in addition to the different technique of fabrication this made the CAD/CAM interim restoration lower fracture resistance than 3D printing interim restoration.

5. Conclusion

1. Provisional crowns fabricated using the 3D printing method showed higher fracture resistance compared to CAD/CAM provisional crowns under thermocycling loading.
2. Additive manufacturing of provisional crowns using the 3D printing technique could be considered a reliable and conservative technique for a produced strong fracture resistance provisional prosthesis.
3. The fracture strength of CAD/CAM provisional prosthesis showed clinically acceptable values under thermo-mechanical loading for crown and bridge application.

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