



The effect of thermo-cycling on fracture strength of 3D printing and PMMA interim prostheses

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Abstract

Aim of the study: This study compared the fracture resistance of three-dimensional printing (3D) interim restoration with that polymethylmethacrylate (PMMA), interim restoration.

Materials and methods: In the present study upper molar (dentoform) tooth was prepared for full coverage crowns. The prepared model was digitally scanned by extra-oral scanner. Duplication of the master die into metal dies (chrome cobalt alloy). Totally, 40 samples were divided into two groups (20) using 3D printing (asiga dentatooth resin material), and (20) Polymethylmethacrylate PMMA (integra) resin material. Ten samples from each group were subjected to thermo-cycles (1250 cycles, 5-55 °C). The fracture resistance was then measured for all samples with a universal testing machine.

Results: In SPSS, the mean \pm Stander deviation values of fracture resistance were recorded for the acrylic PMMA group before thermo-cycling (1703.30 \pm 376.659 Newton) and after thermo-cycling (1460.30 \pm 364.260 Newton), while the mean \pm Stander deviation values were recorded for 3D printing group before thermo-cycling (1972.50 \pm 399.181 Newton) and after thermo-cycling (2284.10 \pm 239.001Newton). It was found that 3D printing recorded a significantly higher fracture resistance mean than PMMA groups.

Conclusion: 3D printing interim prostheses recorded higher fracture resistance compared with PMMA interim prostheses.

Keywords: PMMA acrylic; interim restoration ; 3D printing ; thermo cycling.

INTRODUCTION

A fixed or removable dental prosthesis known as interim restoration is made to improve stabilization, function, and appearance for a prolonged length period before being replaced by a permanent dental prosthesis. A successful final restoration depends on a correctly made preliminary restoration⁽¹⁾.

The temporary repair protects the tooth's pulp from germs, stabilizes occlusal connections, and prevents the tooth from rotating out of the supra- or infra-occlusion plane. When oral rehabilitation requires a long period of time at least 6 to 12 weeks, its significance increases dramatically⁽²⁾. When multiple teeth are involved in complete restorations, using of a temporary prosthesis, which is regarded as an intermediate

treatment, becomes crucial⁽³⁾. It's also critical to understand the many criteria for interim restorations, such as the need for marginal precision, wear resistance, adequate structure, and compliance with aesthetic standards while retaining the teeth's polish and luster⁽⁴⁾. The physical, mechanical, and handling features must be taken into account when choosing a material for temporary restorations in order to make sure that it satisfies the demands of each individual clinical scenario. Because some materials produce potentially dangerous exothermic reactions, it is also crucial to take into account a material's biocompatibility and bio tolerance with soft tissues⁽⁵⁾.

Temporary restorations usually use polymeric resin and numerous techniques can be used to create temporary repairs. Direct, indirect, and indirect-direct manual processes were used to start it off. Poly(methyl methacrylate, or PMMA), which has excellent strength, color stability, and repair ability, is a favored material for temporary restorations. Using self-cured PMMA for chair side fabrication results in pulpal tissues irritation because it exothermic reaction and a polymerization shrinkage that could distort the repair⁽⁶⁾. Additive manufacturing, sometimes known as 3D printing, is currently a widely used technology in most contemporary dentistry facilities and by certain practitioners working at the chair side. Different resins are being utilized in the recently discovered 3D printing process, which is expanding quickly. Additive manufacturing is involved (layer upon layer). It has the capacity to produce accurate prostheses with little material waste⁽⁷⁾. It is thought to be quicker than other techniques, and since there is no application of force, it is passive and can generate finer details (undercuts & better anatomy). But limited shade options, a less polished surface due to the staircase effect and anisotropy, and the need for pricey post-processing for ceramic are drawbacks of 3D-printed structures⁽⁸⁾. Stereolithography (SLA), Digital light processing (DLP), Selective

Laser Sintering (SLS), and Fused Deposition Modeling are examples of 3D printing techniques (FDM)⁽⁹⁾. While temporary restorations should be made to prevent failure, fractures can still happen. Fractures are a common reason why provisional restorations fail, especially when the temporary restoration must be used by the patient for an extended period of time. When temporary restoration displays Para functional tendencies, or when long- spen restoration, like fixed partial bridges, are planned, the patient may experience discomfort and financial loss as a result. Thus, to ensure the clinical effectiveness of temporary restorations, their mechanical strength is crucial and should be taken into consideration, especially in long-term situations⁽¹⁰⁾. Additionally, the majority of research only tested material qualities using thermo cycling or water storage, which may not accurately reflect the oral situation, which included both thermo-cycling and cyclic occlusal loading⁽¹¹⁾. Before and after replicating a thermo-cycling process, this study assessed the fracture resistance of two different commercially available provisional crown and bridge materials. Which received the highest load. Data comparing the fracture resistance of interim restorations created via 3D printing to restorations made of PMMA acrylic is somewhat scarce and need more research. This is why the present study assessed the long-term 3D printed provisional restoration's fracture resistance. The current study's objective was to assess the fracture resistance of PMMA and an interim crown made via 3D printing.

MATERIALS AND METHODS

Upper molar tooth (dentoform) (Nissin Dental Product Inc., Tokyo, Japan) was used in this study as a model⁽¹²⁾. The tooth was prepared according to the standard protocol of all ceramic crown, with occlusal reduction and axial reduction of about 1.5 mm and a finishing line of a suitable thickness of 1.2 mm⁽¹³⁾, on the master model made from

(chrome cobalt alloy). The materials used in this study are shown in Table 1.

1. Design of Restoration:

Extra-oral scanner 3D shape (Shining 3D scanner, Germany) was used to scan the master cast to get 3D virtual interim crown. The process of the scanning took approximately 1 minute. The 3D shape software calculated a virtual model from scanned pictures which was ready for identification of the finish line and an automatic margin finder was used for margin detection. Selecting the tooth anatomy from dental databases libraries was carried out that matched the anatomy of the tooth. Detecting the presence of undercut in the abutment, and detecting the preparation depth from all aspects. The cement space was set up through software and the occlusal thickness was then measured from the central fossa and adjusted to be 1.5 mm for the standardization of all samples, and then transfer the file to a printed machine to print the virtual model from 3D printing dental wax, this shown in Figure 1.

2. Crown Fabrication

2.1. 3D Printing group:

3D printing (rapid prototyping) samples were obtained by software of the 3D printer (Asiga Bourke Road, Australia) as a file in STL format. The 3D print box is an Ultraviolet light box suitable for post-curing 3D printing resin materials to ensure that NextDent materials obtain the full polymerization and superior mechanical properties as shown in Figure 2.

2.2. Acrylic group:

For the conventional direct technique, 20 samples of interim restorative materials were directly fabricated using the over-impression technique. Silicones (Polycondensation for, laboratory protechno, Spain) for laboratory impression material was used. Impression material was mixed and it was placed in the casted master model. After setting, the impression was removed and controlled for any damage to the contour. The self-cure

PMMA interim material was mixed and placed into the over impression. After setting according to the manufacturer's recommendation, the over impression was cut into two pieces, and the temporary crown material was carefully removed, this procedure was used for all 20 samples.

3. Thermo-cycling:

Ten crowns per experimental group were subjected to the thermo-cycling, the cycles used were 1250 cycles which corresponds to 3 months of service inside the oral cavity. Thermal cycles with temperature extremes of 5°C and 55°C in distilled water (dwell time: 25 seconds, pause time: 10 seconds) were performed in the thermo-cycling unit. The specimens were placed in a container in thermo-cycler⁽¹⁴⁾.

4. Fracture resistance test:

The compressive load is applied to 10 spacemen from each group prior to thermo-cycling and 10 spacemen during thermo-cycling. The tooth model constructed with chrome-cobalt alloy was put in a universal testing device for fracture testing. The samples were put on a mock-up until fracture occurred at a crosshead speed of 1 mm/min. Specimens were subjected to a compressive stress at a 90-degree angle to the specimen center Figure 3.

RESULTS

Descriptive statistics are shown in Table (2) for fracture resistance test before and after thermo-cycling which included (minimum, maximum value, mean, and Standard deviation). The results indicated that the highest mean value of fracture resistance of self-cure PMMA groups was 1703.30 (Newton) before thermo-cycling, while the lowest mean value was 1460.30 (Newton) after thermo-cycling. The highest mean value of fracture resistance of 3D printer after thermo-cycling was 2284.10 (Newton), while the lowest mean value was 1972.50 (Newton) before thermo-cycling. A paired t-test was used for the comparison of fracture resistance before thermal cycling and after thermal cycling for 3D printer group $P=0.048$

(significant) and for the self-cure PMMA group $P=.160$ (No significant), as shown in Table (3) Table (4) displays the results of an unpaired t-test, which revealed a non-significant difference between the acrylic group and the 3D printer group before thermo-cycling and a higher significant difference after thermo-cycling ($P=.000$). Bar charts of the mean value of fracture resistance of experimental groups before thermal cycles and after thermal cycling shown in (Figure 4). All data were analyzed using SPSS statically analysis.

DISCUSSION

For dentists, achieving full coverage restoration is crucial for meeting the molar teeth functional and aesthetic requirements. Thus, searching for new materials becomes necessary to find a repairable, low-cost, and custom-made material. Such materials might allow easy preparations, shorter chair side time, good retention, well-fitting, and much easier placement protocol. Thus, in this study, two tested materials were chosen to determine which had better mechanical properties.

All of the materials chosen for this investigation had modulus of elasticity that are close to those of enamel. As a result, they provide a certain amount of stress relief and cushioning for the periodontal ligament and other supporting tissues of the restored tooth as well as the opposing dentition. All of those materials also have the benefit of being quickly and easily mended intra-orally. Because they are made to order, they are more suited to the prepared tooth than prefabricated equivalents⁽¹⁵⁾.

Self-polymerizing PMMA materials don't need any special instrument and can be easily fabricated and have low-cost. In conjunction with an intraoral scanner, 3D printing crowns can be constructed chair-side in the clinic. According to our research, 3D-printed resin exhibits a much higher mean force than self-cured PMMA interim prosthesis.

This study's findings support the hypothesis that the 3D-printed interim prosthesis has greater compression fracture strength than the

self-cured PMMA. The greater flexural strength compared to self-cured PMMA may help to explain the fracture strength of 3D-printed resin. Because bending at the beginning of compression will result in greater flexural strength, the 3D-printed resin provisional prosthesis was less likely to shatter because the bending action absorbs initial stress.

Since the self-cured PMMA had to be manually mixed before being injected into the putty matrix, where homogeneity of the interim was not guaranteed and the material density may vary, it makes sense that the self-cured PMMA provisional prosthesis had a lower fracture force than the 3D PMMA interim prosthesis⁽¹⁶⁾.

All investigated materials showed fracture strength at loads greater than the highest loads that would typically occur in the mouth. According to research, a human produces a force of about 40 (Newton) while swallowing, 170-881 (Newton) when chewing nuts, and 39-788 (Newton) for equivalent mastication loads. Additionally, in the posterior (molar) area, this amount of force increases to an ideal range between 200-540 (Newton). As a result, in the oral environment, these materials might not be able to endure strong occlusal stresses⁽¹⁷⁾. Many printer settings can be adjusted by the operator, including, position on the build platform, print orientation, and the arrangement of supporting structures. Association between print orientation and strength has been shown in earlier studies. The direction of the specimen is printed layer by layer on the 3D printer platform is referred to as print orientation. Because different directions need different numbers of fabrication layers, the print orientation has an impact on printing time. Given how printing time relates to production costs, it is a crucial process parameter to optimize⁽¹⁸⁾.

This study shows that resin restorations produced using 3D printing are more stress-resistant than prostheses made using conventional methods. When temporary resins are broken, fixed, and then broken

again, they get weaker. Therefore, the higher fracture strength of resin interim restoration by using the 3D printer in the processing technique has the potential to increase clinician productivity while using low energy and producing low material waste⁽¹⁹⁾. Regarding the fracture resistance results, the lower fracture resistance values of manually fabricated crowns seen in this study can be explained by the polymerization procedure and the larger residual monomer ratio in comparison to 3D printed crowns.

In a laboratory setting, thermo-cycling can replicate the dynamic nature of the oral environment and occlusal stresses throughout the provisionalization process. Prior to thermal cycling, there was no statistically significant difference between the mean fracture resistances of the two approaches. One technique for enhancing the fracture resistance of dental resin is the addition of fillers that stop crack lines. Crack lines are obstructed by the filler particles, which causes them to pin and bow in between these particles. Increasing the fracture energy and plane strain fracture as a result toughness of this substance. In contrast, moist storage or accelerated aging have hydrolytic effects that cause the filler particles to pull away from the resin by dissolving the silane link between the fillers and the resin. Additionally, it has a plasticizing impact on the resin matrix addition and favorably influences the material's fracture resistance through isotropy and high degrees of conversion. Further material embrittlement was brought on by thermo mechanical cycling, which may have been brought on by the material's polymerization reaction maturing as a result of heat. During the polymer verification stage, certain active components such free radicals, active monomers, and photoinitiators become trapped in the polymer network, leading to incomplete polymerization. Several studies have found that polymerization is still occurring when heated⁽²⁰⁾. Bayoumi et al, concluded that resins are indigenously brittle and their brittleness increases with aging⁽²¹⁾.

As stated earlier, industrial 3D printer PMMA has a more homogeneous structure, fewer free monomers and lower porosity. Therefore, the water absorption of these materials was lower, This could explain the superior fracture resistance after thermo-cycling⁽²²⁾.

Conclusion

The mean fracture force of a 3D-printed resin prosthesis is much higher than that of a self-cured PMMA prosthesis. Temporized delivery and increased fracture strength of interim prosthesis are shown using additive fabrication.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Table 1. Materials used in this study:

| Name of Product | manufacture | materials | Number of sample |
|------------------|------------------------|------------------------|------------------|
| Asiga dentatooth | Bourke Road, Australia | 3D printing | 20 |
| integra | Ankara, Turkey | Polymethylmethacrylate | 20 |

Table (2): Descriptive Statistics of fracture resistance in (Newton) of experimental groups

| | No. | Minimum | Maximum | Mean | Stander deviation |
|--------------------------------|-----|---------|---------|---------|-------------------|
| 3D printer Before thermo-cycle | 10 | 1500 | 2800 | 1972.50 | 399.181 |
| 3D printer after thermo-cycle | 10 | 1903 | 2650 | 2284.10 | 239.001 |
| Self-cure Before thermo-cycle | 10 | 1080 | 2030 | 1703.30 | 376.659 |
| Self-cure after thermo-cycle | 10 | 870 | 1820 | 1460.30 | 364.260 |

Table (3): Paired t-test statics of comparison of fracture resistance of studied groups before and after thermo-cycles

| | Studied groups | P-Value |
|------------------|---|----------------------|
| 3D printer group | Before thermo cycle After thermo cycle | P=.048 (Significant) |

| | | |
|-----------------------------|---------------------|--------------------------|
| Self-cure PMMA group | Before thermo cycle | P=.160 (Non-Significant) |
| | After thermo cycle | |

Table (4): Comparison of fracture resistance (Newton) of provisional materials before and after thermao-cycling

| | t- test | P-Value |
|---|---------|---------------------------|
| Acrylic group Vs 3D printer group after thermal cycling | 7.050 | P=.000 (High significant) |
| Acrylic group Vs 3D printer group before thermal cycling | 1.403 | P=.194 (Non-significant) |



Figure (1): 3D printer virtual wax model of provisional crown



Figure (2): 3D printing resin interim sample

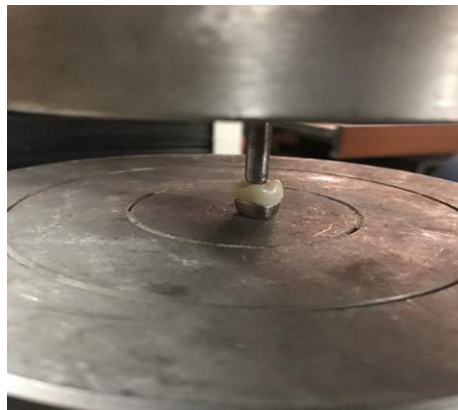


Figure (3): Acrylic PMMA sample under universal testing machine for fracture testing

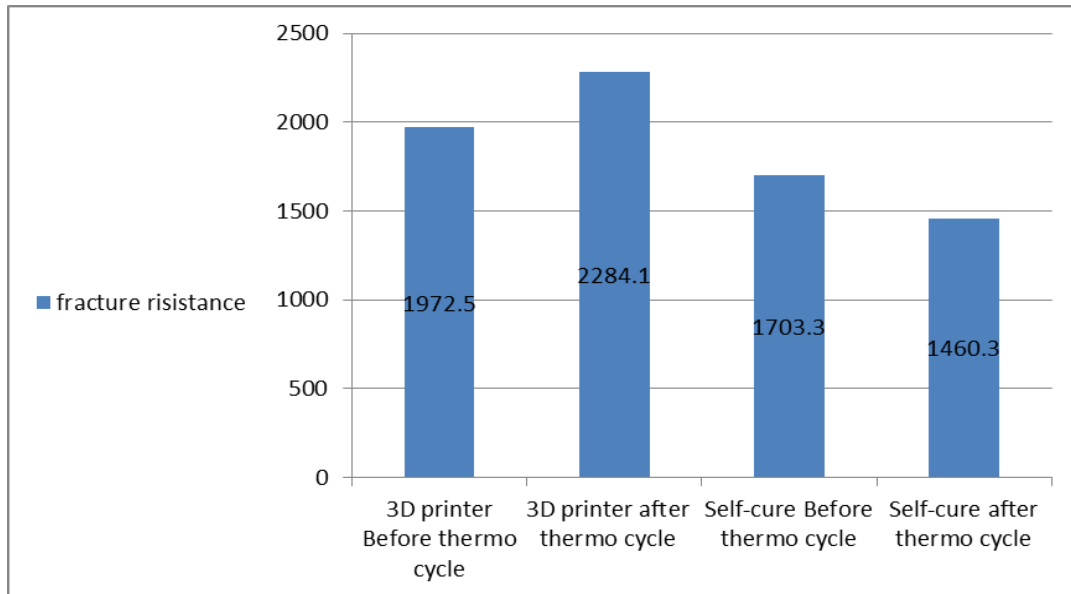


Figure (4): Bar charts of the mean value of fracture resistance in (newton) before and after thermal cycles of experimental groups