Comparative mechanical testing for the digitally produced provisional fixed partial denture prostheses to the conventional method: in-vitro study

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Abstract:

Purpose: To examine and compare the fracture strength of digitally produced interim
materials to the conventional chairside method for implant-cemented fixed partial denture prostheses. **Materials and Methods:** Three groups of seven specimens each were produced: group A, 3D-printed with VarseoSmile Temp material (Bego); group B, milled using Telio CAD material (Ivoclar Vivadent), and group C, conventional chairside manufacturing method using Luxatemp material (DMG). All groups were cemented using FujiCEM 2 (GC) to Standard Abutments (SIC) placed in artificial Sawbones blocks. The fracture strength was performed using universal testing machine Z010 (ZwickRoell). Statistical analysis of the resultant maximum forces was performed using SPSS (version 25.0, IBM) software (Mann-Whitney U test, \( P < .05 \)). Results: The mean fracture strength of the printed provisional fixed partial dentures was 260.14 ± 28.88 N, of the milled interim fixed partial dentures was 663.57 ± 140.55 N, and for the control group reached 266.65 ± 63.66 N. Data showed a significant deviation of the normal distribution Kolmogorov-Smirnov test > .05 for all groups. Conclusion: Milled provisional fixed partial dentures showed a higher fracture resistance compared to 3D-printed and control chairside groups. However, for 3D-printed and control groups, no such difference could be detected. *Int J Prosthodont* 2021. doi: 10.11607/ijp.6440

**Introduction:**

The patient’s poor oral hygiene levels can result in the loss of natural dental structures leaving no other option than extraction. A reduced number of teeth decreases the masticatory performance, which can decrease the quality of life \(^1\). Therefore, the demand of fixed prosthesis including partial dentures and implants increases \(^2\). In the scenario of prolonged dental gaps without treatment the applied bite forces on the remaining teeth can result in increased abrasions during mastication. Furthermore, increased abrasions can cause loss of the vertical dimension of occlusion (VDO) \(^3\). In case of VDO loss or especially in bruxism
patients the occlusal lifting during prosthetic construction is considered important. Therefore, the provisional material requirements for withstanding mastication forces with ability to keep the occlusion stable along with aesthetic restoration and phonetic conservation is considered mandatory \[^{4-10}\]. The prosthetic production techniques for provisional restorations can be either via laboratory conventional method or digitally using computer aided design and computer aided manufacturing (CAD/CAM) technology, which is being widely used in daily clinical practice\[^{11}\]. Several studies have already shown that the prosthetic structures produced by CAD/CAM systems provide a quality standard that is able to tie that of conventional methods\[^{12-14}\].

The complexity of the prosthetic implant treatment restorations is directly correlated to the patient’s occlusion. The importance of the provisional restoration is that while it functions as a transitional stage it also is important for treating modality for the shaping of soft tissue, occlusion stability and patient acceptability \[^{15}\].

The usage of the interim restorations is considered a transitional stage. While all of the different provisional materials can withstand the mastication forces, they ultimately differ and can thus result in different usages depending on the material’s chemical and mechanical characteristics. Thus, systematic fracture strength testing for the interim materials using in-vitro testing is considered valuable.

In general, provisional materials can be divided into two main groups, long-term materials (for example milled and 3D printed resin) and short-term materials (for example chairside manufacturing direct restorations). The chemical components are considered a main factor in enhancing the physical characteristics of the materials. This is reflected within their fracture resistance when tested by mechanical force exertion. The long-term interim materials can be produced by milling which consists of polymethylmethacrylate (PMMA) and is
characterized by an acceptable esthetic result, high flexural strength, abrasion durability, and reduces the risk of abrasion to the antagonist [16]. Furthermore, the 3D printed resin presents itself as durable esthetic restoration possibility for implant cemented fixed partial denture prosthesis [17], however, its recent development has limited amounts of available data for its fracture strength compared to the milled and direct chair side provisional materials. Therefore, the aim of the present investigation was to evaluate the mechanical efficiency of implant cemented fixed partial denture prosthesis produced via CAD/CAM technology and comparing it to the chair side technique as a control group.

**Materials and methods:**

Three different groups with seven specimens each were constructed. Group A, 3D printed via digital light processing technology (DLP) using Varseo S printer (BEGO, Bremen, Germany) with VarseoSmile Temp A2 resin (BEGO, Bremen, Germany). Group B, the inLab MC X5 (Dentsply Sirona, Bensheim, Germany) was used to mill all specimens from Telio CAD discs (Ivoclar Vivadent, Schaan, Liechtenstein). The control was group C, in which specimens were directly constructed via Luxatemp material (DMG, Hamburg, Germany) using conventional construction technique. The specimens in both groups A and B were designed identical using computer-aided dental system program (3Shape, Copenhagen, Denmark) and Autodesk Netfabb (San Rafael, CA, USA).

The post processing of the 3D printed specimens was performed according to the manufacturer’s instructions. Unheated reusable ethanol with a concentration of 96% and ultrasonic was used to clean the specimens for 3 minutes followed by 2 more minutes of a second ethanol bath of the same concentration. The specimens were withdrawn from the ethanol bath and dried with compressed air. Surface polymerization was undertaken using nitrogen gas (1.0-1.2 bar) and otoflash (BEGO, Bremen, Germany) with 10 Hz. 1500 flashes
were made twice, the model was flipped after the first session to equally cover both sides. After eliminating all printable supports the specimens were cemented onto the implants, while the post processing of the milled specimens was performed with cleaning and polishing paste and for the control chair side group, the specimens were polished and cleaned using finishing burs. All groups were characterized by the manufactured method and material used.

A study conducted by Holmer et al who used the FujiCem 2 to bond two printed dental resin materials for shear bond testing \(^{(18)}\). Accordingly, in the present investigation, the resin modified glass ionomer cement Fuji CEM 2 (GC, Tokyo, Japan) was used for cementation. The Fuji CEM 2 is characterized with its high compressive and flexural strength. It has a broad range of dental indications including bonding to printed dental resin and milled PMMA materials. Therefore, Fuji CEM is a suitable luting cement to be used in all groups.

The cementation was performed using the slide and lock cementation technique which ensured the same mixing ratio for all specimens by following the manufacturer’s instructions.

All specimens were cemented on implants (SIC, Basel, Switzerland) which were drilled into artificial bony blocks (Sawbones, Vashon Island, Washington, USA). Afterwards, the fracture strength test was performed with a universal testing machine Z010 (Zwick/Roell, Ulm, Germany). According to the ISO 11405/2003 as recommended to 0.75 ± 0.3 mm/min \(^{(19)}\). The forces were loaded with ball diameter 2.5 mm with the machine parameters for the preload force set to 1 N at a distance of 1mm (figure 1).

The ball made of hardened metal loaded the specimen at the pontic of the fixed partial denture prostheses in a parallel direction of force to the prostheses \(^{[4]}\). The forces were loaded on the fixed partial denture prostheses until the breaking point was reached. All
results were recorded in N (Newton) with the maximum displacement value for each specimen (Table 1,2,3).

**Results:**

The fracture surface of the specimens in both groups was obviously recognizable at the fixed partial denture prostheses connector regions (Fig.2).

The U-test indicated a significant influence of the provisional material on the flexural strength of the provisional fixed partial denture prosthesis (p<0.001).

Using the t-test to compare the milled group B and manually produced control group C showed a statistically significant difference (p<0.05). For 3D-printed group A and control group C no such difference could be detected (p>0.05).

For 3D-printed group A and milled group B the Mann-Whitney U test indicated a significant difference (p<0.05). The Data showed a significant deviation of the normal distribution K-S-Test > 0.05 for all groups. The mean value of printed interim fixed partial prostheses testing was 260.14N ± 28.88, for the milled provisional prostheses testing was 663.57N ± 140.55, while the control group reached 266.65N ± 63,66.

The maximum deformation was recorded at 2.4mm when applying 729N to milled material group A. The printed material in group B showed maximal deformation in two specimens with approximately 2.2mm when applying 316N or 263N. In control group C a maximum deformation of 2.7mm with an applied force of 277N could be observed. It is to be noted that the average range of posterior occlusal bite force is clinically less than within this investigation. Finding the material-specific properties in-vitro was the main aim of the present investigation, not its relevance to natural bite forces. The primary systematic in-vitro testing is important for fundamental understanding of the materials used.

All group values are illustrated by force-displacement graph using SigmaPlot software (SYSTAT Software, San Jose, California, USA) (Fig.3).
Discussion:

The aim of the present investigation was to evaluate the influence of material selection and digital production methods on the fracture resistance. The results of this investigation have shown that the mean value of 3D printed materials regarding the fracture strength was significantly lower compared to the milled durable provisional materials.

Regarding materials and methods, all specimens of group A and B were 3D designed using dental system program (3Shape, Copenhagen, Denmark) and Autodesk Netfabb (San Rafael, CA, USA). Printed specimens were produced using 3D printer Varseo S (Bego, Bremen, Germany), while in the milled specimens inLab MC X5 (Dentsply Sirona Inc., Bensheim, Germany) was used. Group C was manufactured by duplicating a printed bridge (Fig.4).

DLP printing is based on a localized photopolymerization process triggered by UV radiation in a bath of liquid monomers, oligomers and photo-initiators. It is capable of producing a variety of highly complex, three-dimensional structures from micro to mesoscale with microscale architecture and submicron accuracy \(^{(20)}\). Accordingly, the precision of 3D printed objects is considered highly precise \(^{(21)}\). As 3D printing for provisional restorations is a comparably new technique only few data sets are available for direct comparison to other printed materials.

The possible reason for the Telio CAD fracture resistance in comparison to 3D resin material likely is the PMMA chemical component, which is characterized by its resistance to high forces \(^{(22)}\). Another factor that might have influenced the results is the production method, in which the 3D printing is a layer by layer production of an object while milling is cutting of a solid block to produce the object \(^{(23)}\).

Regarding manually fabricated temporary restorations the long-term mechanical properties and colour stability are inferior \(^{(24)}\). These properties are affected by the poor conditions of fabrication. In contrast to the CAD/CAM techniques there is no chance of optimum
polymerization conditions with no interference from water, because the provisional restorations are immediately exposed to the moisture of oral cavity by direct contact with the saliva and suffer polymerization inhibition by the oxygen. The provisional restorations fabricated from blocks or printed, whether polymethylmethacrylate or dimethacrylate, have superior mechanical properties to those fabricated by conventional direct techniques (25-27). In the present investigation these superior properties manifested in a significantly smaller connector size in the digitally designed groups compared to the manually manufactured specimens. The fracturing occurring in the connector regions could implicate lower fracture forces and flexibility in identically designed digitally and manually manufactured dental partial prothesis, however several other aspects require further investigation to fully understand the mechanical behavior (Fig.2).

In addition, several studies showed that inferior surface hardness, flexure strength, and fracture resistance are reported for manually fabricated interim restorations compared with CAD/CAM-fabricated interim restorations (27-29). However, in their in-vitro study Rayyen et al. have investigated that also all specimens from the manually fabricated group exceeded 600 N in the fracture resistance test, which is the threshold for withstanding occlusal load in the posterior region (27,30).

Clinical circumstances cannot be simulated entirely in-vitro with standardized test. It is possible however to find material-specific properties in-vitro. The primary systematic in-vitro testing is important for fundamental understanding of the materials used. Provisional restorations must fulfil the biocompatibility, aesthetic, mechanical functional resistance and maintenance of abutment alignment [7]. The most commonly used technique is the fracture resistance in which the mechanical testing of the specimens can be simply evaluated. In the present investigation it was shown, that the 3D printed provisional fixed partial denture prosthesis have comparable fracture resistance and flexibility while possessing lower deviation within their group to conventionally manufactured control group.
Furthermore, significant difference between the milled material group and the other two groups respectively were found. This investigation is in line with Yao et al. who found that Telio CAD material is considered as a durable provisional restoration (31).

This result can be due to chemical components with PMMA, which provides greater physical and mechanical properties (22). Furthermore, the maximum deformation was recorded with 2.4mm when applying 729N in milled group. In the printing group, the maximum deformation was determined in two specimens to be 2.2mm when applying 316N and 263N and in the control group 2.7mm with an applied force of 277N. This means that all investigated materials are in the same range of flexibility for significant different loading forces.

In the literature fracture resistance values for interim restorations are well investigated and can be found, with CAD/CAM materials usually having higher values than chair side manually fabricated provisional materials (25-27). Therefore, the focus of the present study was to compare digitally to chair side produced interim restorations.

The finding of this investigation was also similar to the result obtained by Lee et al who found out that the marginal and internal fit of the interim restoration have a more outstanding 3D printed method than the CAD/CAM milling method (32). According to the results obtained by Jeong et al the accuracy of the 3D printing method is superior to that of the milling method (33). It is difficult to compare the fracture resistance data of the 3D resin and Telio CAD obtained in the present investigation to those of other similar protocols. This is due to the fact that every study is performed with different devices as well as with different operators. The average value of the printing is greater than or equal to the average value of milled (P<0.001).
3D printing and milling accomplish the same things: creating a part from a base material – except they work in completely opposite ways. The milling process is a subtractive production method while the 3D printing is an additive production method. This additive process makes 3D printers flexible enough to create a variety of outputs, limited only by the capability of the printer. 3D technology for use in the production of medical and dental products use unique FDA-approved materials, the printing provisional dental materials are considered highly expensive compared to interim Telio CAD. The production time of a printed and milled fixed partial denture prostheses was not the same, however as it is not the present investigation main purpose, it was not further investigated. The machine expenses and operating costs for the 3D printers are considered higher.

Further investigations should be performed to investigate this result in depth summing up, the absolute data for fracture resistance. The obtained values should be compared only inside the same study. In general, this investigation results are near to the study conducted by Anthony Tahayeri (33,34).

**Conclusion:**

Within the limitations of this in-vitro study, and on the basis of the results obtained, it can be concluded that although the milled specimens reached higher stress than the printed test, the results they reached are still considered acceptable for masticatory forces because the average range of posterior occlusal bite forces clinically is less than the average range obtained in this present investigation.

**Conflict of interests:**

The authors declare that they have no conflict of interests.

**References:**


Figures:

**Fig.1:** Metal ball with 2.5 mm diameter loaded at the centre of the bridge pontic

**Fig.2:** Image with the full bridge to illustrate the fracture behavior in a printed group specimen.
Fig. 3: Comparative graph illustrating the forces loaded on all groups
Fig.4: Control group duplicating and manufacturing method
<table>
<thead>
<tr>
<th>Specimens</th>
<th>Telio-CAD</th>
<th>Displacement</th>
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<tr>
<td>1</td>
<td>729 N</td>
<td>2.4 mm</td>
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<tr>
<td>2</td>
<td>432 N</td>
<td>1.9 mm</td>
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<td>3</td>
<td>691 N</td>
<td>1.8 mm</td>
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<td>4</td>
<td>896 N</td>
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<td>5</td>
<td>676 N</td>
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<tr>
<td>6</td>
<td>616 N</td>
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</tr>
<tr>
<td>7</td>
<td>605 N</td>
<td>1.1 mm</td>
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**Table 1:** Maximum forces of displacement in milling material
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<td>252 N</td>
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<tr>
<td>2</td>
<td>220 N</td>
<td>0.8 mm</td>
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<tr>
<td>3</td>
<td>316 N</td>
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<td>4</td>
<td>256 N</td>
<td>1.6 mm</td>
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<tr>
<td>5</td>
<td>248 N</td>
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<tr>
<td>6</td>
<td>266 N</td>
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</tr>
<tr>
<td>7</td>
<td>263 N</td>
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**Table 2:** Maximum forces of displacement in 3D printing material
<table>
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<th>Displacement</th>
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<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>221 N</td>
<td>1.4 mm</td>
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<tr>
<td>3</td>
<td>276 N</td>
<td>2.7 mm</td>
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<td>4</td>
<td>226 N</td>
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<td>5</td>
<td>245 N</td>
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<td>6</td>
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<tr>
<td>7</td>
<td>381 N</td>
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**Table 3:** Maximum forces of displacement in chairside material