In - vitro Flexural Strength Assessment of 3D Printed Custom Resins for Temporary Fixed Dental Restorations

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Abstract: ***Purpose**: The aim of the research was to compare the flexural strength of a 3D printed cylindrical bars manufactured of custom made resins. **Methods**: Three types of resins: White Resin®, Model Resin® and Dental LT Clear Resin® (Formlabs™) were combined and mixed in different proportions. The newly created resins were used for 3D printing of a cylindrical test samples. The specimens were subjected to a three - point bending test. **Results**: The results were compared according the standards ISO 10477 and ISO4049. The samples with higher proportion of Model Resin and Dental LT Clear Resin showed higher flexural strength. **Conclusion**: The created resins with high proportion of White Resin are suitable for single unit temporary restorations in the frontal area, while these ones with high concentration of Model Resin and Dental LT Clear Resin are appropriate for multiple unit provisional restorations in the distal area due to their good flexural strength and unsatisfactory shade color.*

Keywords: prosthetic dental medicine, temporary restorations, fracture strength, additive manufacturing

1. Background

According to Glossary of Prosthodontic terms "A provisional restoration is a transitional restoration that provides protection, stabilization and function before fabrication of the definitive prosthesis" [1].

The temporary restoration protects the abutment teeth from mechanical, thermal, bacterial and chemical irritations, prevents their migration, restores the chewing and phonetic function and also the esthetics [2, 3, 4, 5].

There are many conventional techniques for fabrication of a provisional restorations such as the direct, indirect and direct - indirect method. Each of them has certain disadvantages, such as increased chair - side time and poor marginal adaptation in the direct method, and additional laboratory phases in the other two techniques [6, 7].

Alternative of the conventional methods is the CAD/CAM manufacturing, which allows digitalizing most of the steps of the fabrication of a provisional restoration [8]. The milling machines in the subtractive manufacturing are unable to shape complex details such as undercuts and their using leads to loss of raw material, that can't be reused again. In opposite, the additive manufacturing gives the opportunity this material to be used again, so it is more cost effective and shortens the fabrication time [9, 10].

The stereolithography (SLA) is one of the most common types of the additive manufacturing and is used for making temporary crowns and bridges, surgical guides, working models casting models [11, 12, 13, 14].

Intra - orally the interim restorations are subjected to complex mastication forces with a significant amount of flexural stresses. The flexural strength of the material is the maximum stress that it can resist before failure, when subjected to bending load [15]. The required flexural properties are highly dependent on the clinical applications. For temporary restorations that are subjected to large masticatory stresses, high flexural strength is needed. One of the most common method for determining the flexural strength of the materials is the three - point bending test. The minimum flexural strength for Polymer - based materials is described in ISO 10477 and ISO 4049 [16, 17].

2. Materials and Methods

Ten custom made resins were used in different combinations and proportions:

1) White Resin / Model Resin in ratio 9: 1 in shade B2according to Vita Classic;
2) White Resin / Model Resin in ratio 8: 2 (B3);
3) White Resin / Model Resin in ratio 7: 3 (B4);
4) White Resin / Model Resin in ratio 6: 4 (B4);
5) White Resin / Model Resin in ratio 1: 9 (A4);
6) White Resin / Dental LT Clear Resin in ratio 9: 1 (B1);
7) White Resin / Dental LT Clear Resin in ratio 4: 6 (B1);
8) White Resin / Dental LT Clear Resin in ratio 3: 7 in shade 3M1 according to VITA 3D Master;
9) White Resin / Dental LT Clear Resin in ratio 2: 8 (4M1);
10) Model Resin / Dental LT Clear Resin in ratio 5: 5 (B4).

The test samples were designed using CAM software (AutodeskMeshmixer®) in cylindrical shape with length 45mm and diameter 3, 75mm (Fig.1), and exported as a standard tessellation language (STL) file to a 3D - printing software (PreForm® 3.5, Formlabs™). And were oriented diagonally to the printing platform. The layer height was set on 50µm (Fig.2). The flexural strength specimens were fabricated with SLA printer Form 2® (Formlabs™). After the manufacturing were cleaned with isopropanol in Form Wash (Formlabs™) and placed for post polymerization process for 60 min at 60°C in Form Cure (Formlabs™).

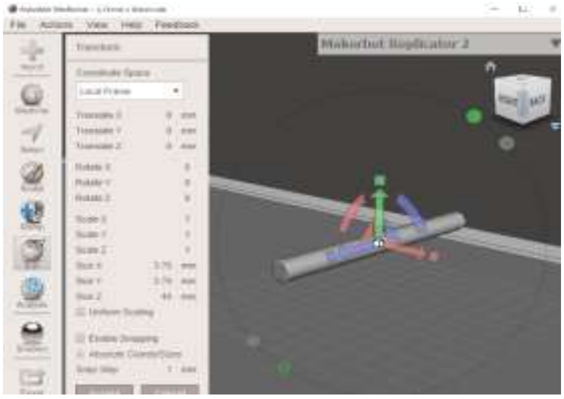


Figure 1: Design of the test samples in Autodesk Meshmixer®

Figure 2: The diagonal oriented test samples with support structures

Three hundred test samples were made: thirty specimens for each resin group (Fig.3).

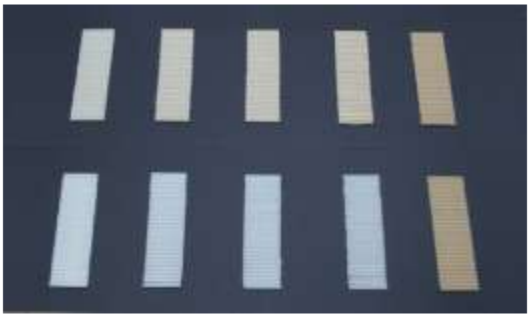
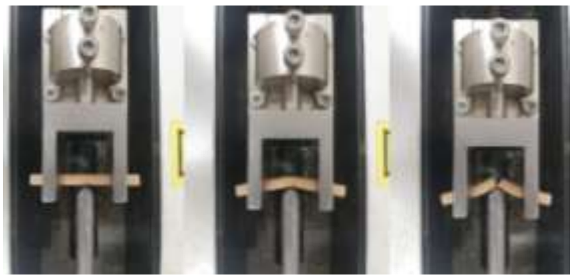


Figure 3: The 3D printed specimens divided in ten groups according the combination and ratio of the resins.

The three - point bending test was performed in micro - pressure and micro - tension universal testing machine LMT 100 (LAM Tehnologies, Italy) (Fig.4). The results were registered and recorded using special software - LMT1xx Ver 1.12 (LAM Tehnologies, Italy).



(a) (b) (c)

Figure 4: a) Start of the testing; **b)** The applied load leads to deformation in the test sample; **c)** Fracturing of the specimen and end of the testing

The maximal flexural strength was calculated in megapascals with the equation: $\sigma = (8. F. l) / \pi. d^3$, where F is the maximum load in Newtons, l is the distance between the supports (20mm) and d is the diameter of the specimen (3, 75mm).

3. Results

A comparative analysis of the change in maximum load at different concentrations of White Resin® was performed. The results showed a significant difference in maximum load at the concentrations and a tendency to its decrease with increasing concentration of White Resin® (F=112.87; p<0.001) (Table 1).

Table 1: Mean and Standard Deviation of the maximum load in the concentrations of White Resin in Newtons

Concentration of White Resin (ml)	No. of specimens	Mean of the maximum load (N)	Standard Deviation (SD)	Standard Error of Mean (SEM)
0.1	30	497,5333	48,67821	8,88738
0.2	30	432,3000	32,62340	5,95619
0.3	30	408,8333	59,91435	10,93881
0.4	30	371,6000	27,75086	5,06659
0.6	30	354,4000	24,74783	4,51832
0.7	30	337,8000	30,80237	5,62372
0.8	30	317,3000	14,47030	2,64190
0.9	30	299,1500	36,39372	4,69841
Total	270	368,6741	72,85070	4,43355

A significant negative correlation was found between the flexural strength and the concentration of White Resin (r= -0.839; p<0.001). It shows that the higher ratios of the resin lead to lower flexural strength (Fig 5).

The test samples with 10% concentration of White Resin showed the highest mean of the flexural strength with 480, 6 MPa, while these specimens with 90% concentration have the lowest mean with 289 MPa (Fig.6).

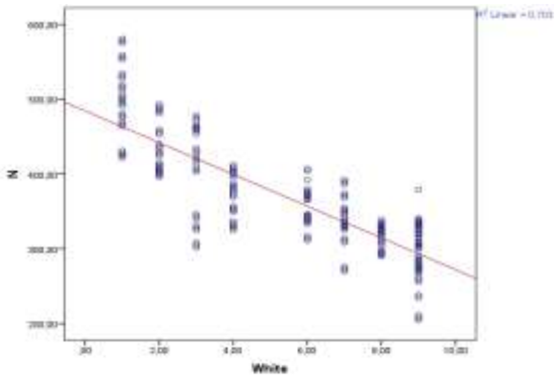


Figure 5: Correlation analysis between the maximum load and the concentration of White Resin

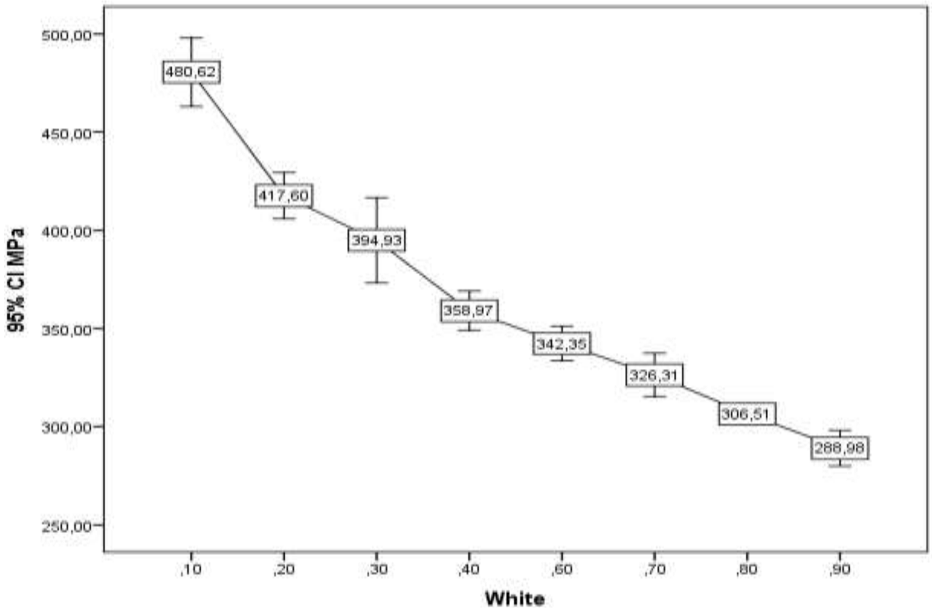


Figure 6: Mean of the flexural strength in different concentrations of White Resin

A comparative analysis of the concentrations of Dental LT Clear Resin revealed significant difference in their maximum load in favor of the higher ratios of the resin (F=55.81; p<0.001) (Tab.2).

Table 2: Mean and Standard Deviation of the maximum load in the concentrations of Dental LT Clear Resin in Newtons

Concentration of Model Resin (ml)	No. of specimens	Mean of the maximum load (N)	Standard Deviation (SD)	Standard Error of Mean (SEM)
0.1	30	297,9333	39,43212	7,19929
0.5	30	461,6667	61,39096	11,20841
0.6	30	371,6000	27,75086	5,06659
0.7	30	408,8333	59,91435	10,93881
0.8	30	432,3000	32,62340	5,95619
Total	150	394,4667	72,88602	5,95112

A positive correlation was found between the maximum load and the concentration of this resin. (Fig.7)

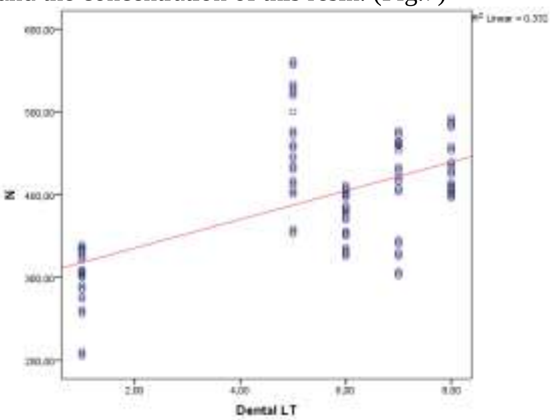


Figure 7: Correlation analysis between the maximum load and the concentration of Dental LT Clear Resin.

The test samples with 50% concentration of Dental LT Clear Resin showed the highest mean of the flexural strength with 445, 9 MPa, while these specimens with 10% concentration have the lowest mean with 287, 8 MPa (Fig.8).

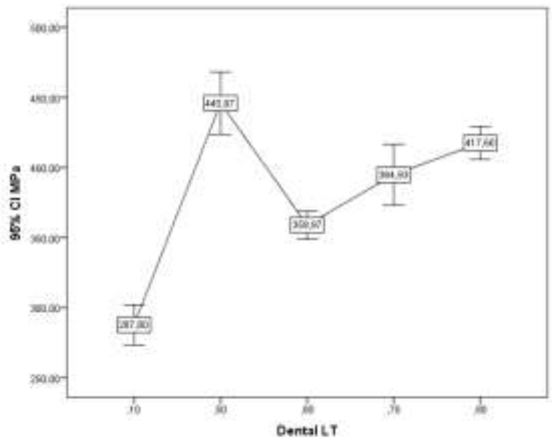


Figure 8: Mean of the flexural strength in different concentrations of Dental LT Clear Resin

The comparative analysis of the maximum load in different concentrations of Model Resin showed tendency of increasing the strength with increasing the amount of the resin (F=132.02; p<0.001) (Tab.3). The lower concentrations of Model Resin are related with lower maximum load values.

Table 3: Mean and Standard Deviation of the maximum load in the concentrations of Model Resin in Newtons

Concentration of Model Resin (ml)	No. of specimens	Mean of the maximum load (N)	Standard Deviation (SD)	Standard Error of Mean (SEM)
0.1	30	300,3667	33,71532	6,15555
0.2	30	317,3000	14,47030	2,64190
0.3	30	337,8000	30,80237	5,62372
0.4	30	354,4000	24,74783	4,51832
0.5	30	461,6667	61,39096	11,20841
0.9	30	497,5333	48,67821	8,88738
Total	150	378,1778	83,81625	6,24729

A positive correlation was found between the maximum load and the concentration of the resin. (Fig.9) The test samples with 90% concentration of Model Resin showed the highest mean of the flexural strength with 480, 6 MPa, while these specimens with 10% concentration have the lowest mean with 290, 1 MPa (Fig.10).

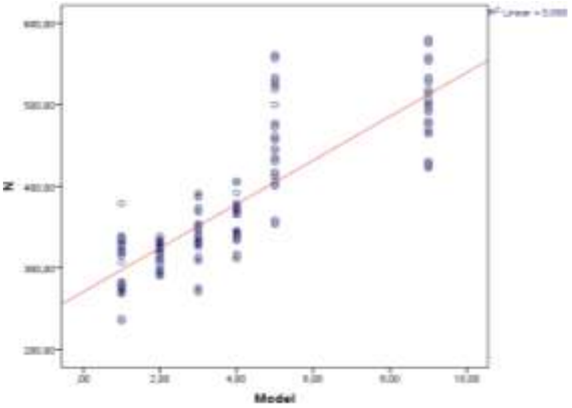


Figure 9: Correlation analysis between the maximum load and the concentration of Model Resin.

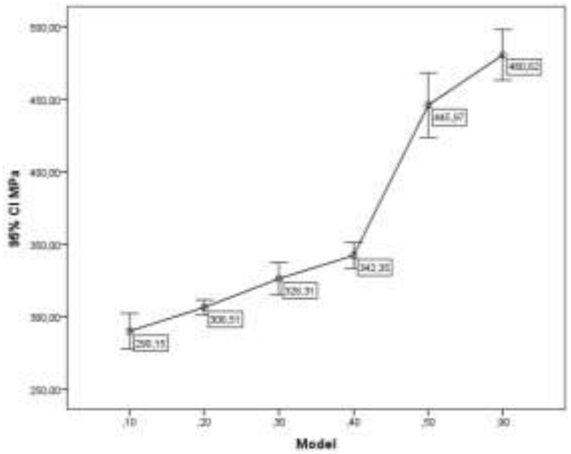


Figure 10: Mean of the flexural strength in different concentrations of Model Resin.

4. Discussion

In this in vitro research, ten custom made 3D printing resins were studied for flexural strength with three - point bending test. The results from the tests and the statistical analysis showed, that the achieved resins have different mechanical properties depending of the initial resins - White Resin, Model Resin and Dental LT Clear Resin. It has to be considered, that the specimens were printed in diagonal orientation and different printing orientation could lead to similar but different values.

The mechanical tests were selected on the basis of the international standards: ISO 10477 "Dentistry - polymer - based crown and bridge materials" and ISO4049" Dentistry - polymer - based restorative materials". According to ISO 10477, the flexural strength of the material has to be ≥50 MPa, and in ISO 10477 is has to be minimum100 MPa. Although there is a significant difference in the flexural strength of the three used starting resins, all of them achieved more than the minimum limit of 50 MPa and 100 MPa.

The combination White Resin / Model Resin in ratio 1: 9corresponding to shade A4 / 4M3 showed the highest flexural strength - 480.62 MPa, but according to its color characteristics there is a significant deviation, which is visible to the patient. The provisional restorations made of this resin are characterized by high mechanical properties, but with low aesthetics, which makes them suitable for restorations in the distal areas of the dentition, because the higher mastication forces. The high flexural strength makes this newly created resin suitable for provisional bridge restorations.

In the test samples with a high concentration of White Resin, lower values of flexural strength are observed, but they have high aesthetic characteristics, which makes them more preferred by patients, especially in the frontal area of the dentition. White Resin / Model Resin - in a ratio 9: 1and shade B2/1M3 (300 MPa) and White Resin / Dental LT Clear Resin - in a ratio 9: 1and shade B1/0M3 (298 MPa). In order of this they could be used for single - unit restorations as like temporary crowns.

The combination of the two resins ModelResin / Dental LT ClearResin in a ratio 5: 5 and shade B4/4M3with a positive relationship between the resin concentration and the flexural strength, also shows high mechanical properties - 446 MPa. However, the darker shade makes the structures suitable for the distal area of the dentition.

The optimal resin for temporary restorations, which achieve both high aesthetic and mechanical properties, is the combination White Resin/ Dental LT ClearResin in a ratio 4: 6 (B1/2M1). In this combination, the concentration of White Resinis responsible for achieving one of the most preferred by the patients shade (B1), corresponding to the color of bleached teeth, while the concentration of Dental LT ClearResin is associated with good mechanical properties (350 MPa flexural strength). Based on this, the resin is suitable for use in both the frontal and distal areas of the dentition. Also, the concentration of Dental LT ClearResin upto 60% is associated with the translucency of the teeth and contributes to an imitation of the enamel and achieves a closer to the natural color.

5. Conclusion

All of the tested custom - made printing resins specimens, have shown flexural strength above the minimum required in ISO 10477 and ISO 4049. The mechanical properties depend of the ingredients in the resin. The high proportion of Dental LT Clear Resin and Model Resin positively affects the flexural strength but have not good enough aesthetics. The big concentration of White Resin causes lower flexural strength. Although, the values are above the ISO standards for polymers, the usage of the resins with high concentration of White Resin is more appropriate for single - unit restorations in frontal area, where the aesthetic is more required.

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