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Original article

MAXIMUM BITE FORCE IN FIXED PRELIMINARY PROSTHETICS

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ABSTRACT:

Background: Maximum bite force is the maximum force that a pàtient can reproduce without causing periodontal pain in teeth.

The study aimed to clinically investigate the maximum bite force in patients prosthetized with test specimens of preliminary constructions (with/without reinforcement) and derive recommendations for practice.

Methods: A total of 30 patients (18 males and 12 females), aged between 45 and 59 years, with distal partially edentulous conditions, were treated with preliminary constructions (PCs) at the Faculty of Dental Medicine, Medical University – Sofia. For the study of each patient, four identically shaped bridge constructions from different materials were fabricated in the laboratory: a metal-ceramic bridge; a subtractive PMMA bridge; an additive solid bridge; additive bridge with reinforcement. The study of the maximum bite force for the different constructions was carried out using a universal gnathodynamometric system.

Results: The Friedman test revealed a statistically significant relationship between the maximum bite force and the type of preliminary construction, $p < 0.001$. The subsequent post-hoc pairwise analysis provided clarifying data on the differences between the types of constructions, as follows:

The metal-ceramic construction demonstrates a significantly higher maximum bite force (median median 117 N) compared to the other constructions: printed-reinforced (median median 105 N; $p = 0.001$); printed (median median 77 N; $p < 0.001$); and milled (median 86 N; $p < 0.001$).

Conclusion: Since metal-ceramic frameworks are inherently permanent prosthetic constructions, the scientific focus of our study is on the other three groups of preliminary constructions, each of which may be the object of choice in long-term preliminary prosthetics.

Keywords: preliminary constructions, maximum bite force, fixed prosthetics,

BACKGROUND

In certain clinical indications, preliminary prosthetic bridgework may have a longer intraoral stay of 14-21 days, which is usually required for the laboratory fabrication of permanent restorations. According to the time of use, preliminary bridges can be defined as short-term, medium-term and long-term, with an intraoral stay of up to 1 month, 1 to 6 months, and 6 months to 2 years, respectively [1]. Medium- or long-term preliminary prosthetics with fixed constructions create conditions for better predictability of outcomes in complex prosthetic treatment. For this purpose, preliminary constructions (PCs) must be fully functional throughout the period of their use. Therefore, materials and methods for their fabrication and reinforcement are of scientific and clinical interest [2, 3, 4]. Conventional methods of fabricating preliminary constructions involve taking an impression of the patient's dentition, creating a prototype of the future PC, and fabricating it by using clinical, laboratory, and combined methods.

Digital technologies (CAD/CAM) for preliminary prosthetics are entering daily practice and significantly shorten the time for fabrication of constructions in the clinic and laboratory [5, 6]. They can be divided into two main types: subtractive methods, in which the desired construction is obtained by subtraction from fabricated blocks or additive methods, in which the construction is fabricated by layering the materials. Historically, the methods that are initially implemented in dentistry include those of fabricating PCs by removing (milling) a fabricated workpiece that has been pre-polymerized under ideal conditions. The preferred material in preliminary prosthetics is polymethyl methacrylate (PMMA), with improved mechanical properties through additional covalent bonds in the polymer network, the so-called cross-linked polymers [7, 8, 9, 10, 11].

Historically newer, the methods of adding the material layer-by-layer [12, 13, 14, 15] allow the fabrication of constructions with more complex geometries and convoluted elements, but have a more sensitive handling protocol [17]. Three-dimensional "printing" methods, the most commonly used for dental purposes, include the following abbreviations: DLP (Digital Light Processing), FDM (Fused Deposition Modelling), SLA (Stereolithography), SLM (Selective Laser Melting) and SLS (Selective Laser Sintering) [9, 10].

Mechanical properties of modern materials, such as flexural strength, modulus of elasticity, maximum fracture strength, and the methods for reinforcement of PCs at a planned intraoral stay of 1 to 6 month are of current scientific interest and determine the need for a modern answer to questions essential for science and practice. Therefore, these were the subject of our study under #4874/ 19/07/ 2023 project of Medical University – Sofia and #D-163/ 03/08/2023 Contract for funding research under the GRANT-2023 Competition. Reinforcement of preliminary fixed prosthetic constructions is a method aimed at increasing the mechanical stability and reducing the likelihood of fracturing, which is a problem in clinical practice, especially in bridge constructions. The results obtained allow the identification of the three types of experimental bodies made of polymeric materials with/without reinforcement, with the best studied performances, as follows: solid experimental bodies made of Temporary CB Resin (FormLabs, USA) CAD-CAM printable resin; experimental bodies made of Temporary CB Resin (FormLabs, USA) CAD-CAM printable resin reinforced with Fiber Splint One Layer (Polydentia, Switzerland) glass filament, and experimental bodies made of DD temp MED (Dental Direkt GmbH, Germany) CAD-CAM fabricated PMMA. The first two material types had the highest values for the modulus of elasticity, with high values for flexural strength. The third material showed the highest values for flexural strength, with high values for the modulus of elasticity.

For the clinical validation of these results, a gnathodynamometric study of patients prosthetized with the studied materials was necessary.

The study aimed to clinically investigate the maximum bite force in patients prosthetized with test specimens of preliminary constructions (with/without reinforcement) and derive recommendations for practice.

MATERIAL AND METHODS

Material

A total of 30 patients (18 males and 12 females), aged between 45 and 59 years, with distal partially edentulous conditions, were treated with test specimens of preliminary constructions (PCs) (with/without reinforcement) at the Faculty of Dental Medicine, Medical University - Sofia. Before inclusion in the study, all patients signed an informed consent form. The patients were selected based on the condition that at least one abutment tooth was present in the posterior region (premolar or molar) as an abutment with a distal or mesial extension.

For the study of each patient, four identically shaped bridge constructions from different materials were fabricated: **A.** Metal-ceramic bridge (metal SLM BEGO, Wirobond C+; ceramic VITA, VMK Master); **B.** Subtractive PMMA bridge (Dental Direkt, DD temp MED); **C.** Additive solid bridge (FormLabs, Temporary CB Resin); **D.** Additive bridge (FormLabs, Temporary CB Resin) with Interlig reinforcement (Angelus, Brazil), fixed in the canal with Kulzer, Dentalon Plus self-polymerizing plastic.

The study of the maximum bite force (MBF) for the different constructions was carried out using a universal gnathodynamometric (tensometric) system, developed and subject to industrial property (utility model # 4238 U1) (Figure 1, 2).

Fig. 1. Universal gnathodynamometric system (utility model # 4238 U1)

Fig. 2. Maximum bite force testing.

Methods

To achieve the goal, the following clinical-laboratory protocol was followed:

1. The abutment teeth were vertically prepared with an intrusion into the gingival sulcus of about 0.5 mm.

2. Clinical provisional crowns were made from TempSpan material, Pentron, using previously laboratory-fabricated vacuum-formed foils for provisional constructions.

3. After a one-week intraoral stay of the provisional crowns with trial cementation, impressions were taken separately from both complete dental arches using A-silicone Zhermack, Elite HD+, through a one-step two-component (paste and cream) impression technique. Interocclusal relationships in central occlusion were recorded using A-silicone Kulzer, Variotime Bite.

4. Working models with mobile abutment replicas were poured in the laboratory, manually articulated, and then scanned with Schütz, Tizian Smart-Scan Plus laboratory scanner, and transferred to the Exocad DentalCAD dental CAD software.

5. The projects were digitally designed for preparing:

a. Solid preliminary construction;

b. Preliminary construction with a channel (r = 1.5 mm) located on the lingual side, starting up to 1 mm apical to the anatomical equator;

c. Framework for a metal-ceramic bridge.

6. Based on the digital projects, four types of constructions were manufactured:

a. Metal-ceramic bridge (metal SLM BEGO, Wirobond C+; ceramic VITA, VMK Master);

b. Subtractive PMMA bridge (Dental Direkt, DD temp MED);

c. Additive solid bridge (FormLabs, Temporary CB Resin) (Figure 3);

d. Additive bridge (FormLabs, Temporary CB Resin) with reinforcement (Interlig, Angelus, Brazil) (Figure 4), fixed in the channel with Kulzer, Dentalon Plus self-polymerizing plastic, following the methodology (Figure 5).

7. The constructions were laboratory-adjusted to working models, mounted on an articulator with average values of Amann Girrbach, Artex CN.

8. After removing the clinical preliminary construction and cleaning the temporary cement, the four test constructions were tried and adjusted to fit the abutments, proximal, occlusal, and articulatory contacts.

9. Each preliminary construction was temporarily fixed onto the abutments using an antiseptic mouth gel, Pierre Fabre's Elugel. Three consecutive measurements of the maximum bite force were then taken on each bridge abutment using a gnathodynamometer. For the examination, after positioning one jaw of the gnathodynamometer in contact with the occlusal surface of the bridge abutment, each patient was instructed to bite down using the force by squeezing (Figure 2). The patient should cease at the first sensation of discomfort. In no case should the patient experience pain. The examination was repeated three times for each bridge abutment, and the highest measured value was recorded in a table. This method was used to measure the values for all four constructions during a single visit.

10. The metal-ceramic construction was permanently fixed in place.

Fig. 3. Design of an additive solid bridge before 3D printing.

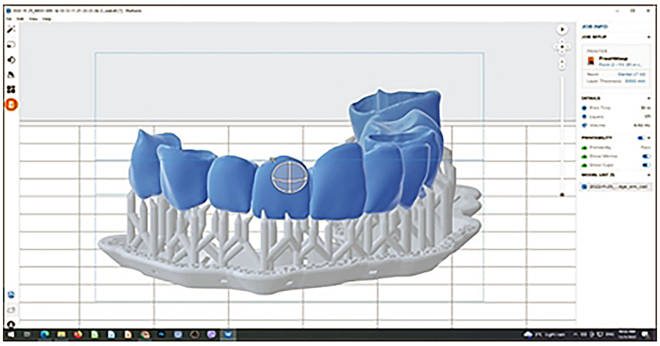


Fig. 4. Design of an additive solid bridge with reinforcement channel before 3D printing.

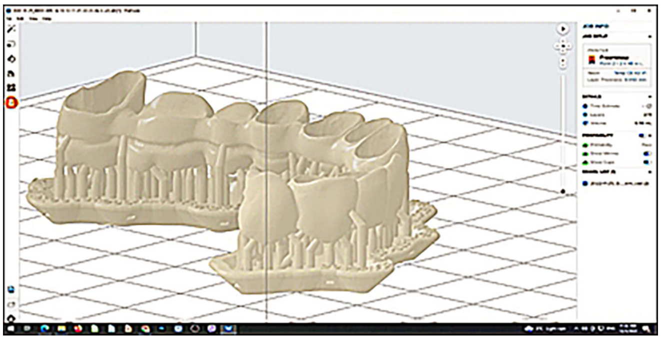
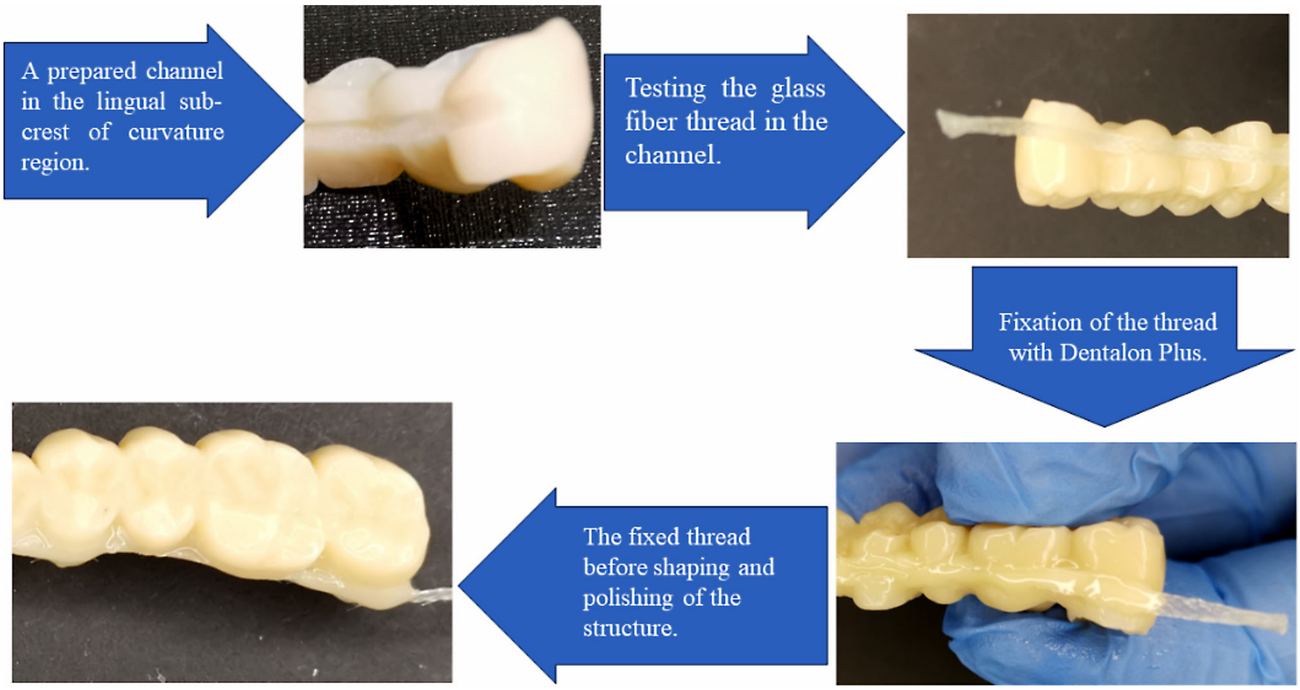


Fig. 5. Reinforcement technique.



Statistical Analysis

The statistical analysis of the data was conducted using the IBM SPSS Statistics for Windows, Version 27.0 (Armonk, NY: IBM Corp.). The maximum bite force in the patients with the four types of fixed prosthetic constructions (milled, printed, printed-reinforced, and metal-ceramic) showed a lack of normal distribution according to the Shapiro-Wilk test (Shapiro-Wilk $p > 0.01$ for all four constructions). Due to the lack of normal distribution, the central tendency is represented by the median and the interquartile range (IQR).

The Friedman test for more than two related samples was used to statistically compare the types of constructions.

. Post-hoc pairwise comparisons between the four types of preliminary constructions were carried out using the Bonferroni test with control for Type I error. All statistical analyses were conducted at an acceptable Type I error level, *alpha* = 5%. Statistical significance is indicated with *, and the results were interpreted as significant at $p < 0.05$.

RESULTS

The results obtained allowed the four types of preliminary constructions to be compared regarding the maximum bite force recorded for **molars and premolars in total**. The Friedman test revealed a statistically significant relationship between the maximum bite force and the type of preliminary construction, $p < 0.001$. The subsequent post-hoc pairwise analysis provided clarifying data on the differences between the types of constructions, as follows:

1) The metal-ceramic construction demonstrates a significantly higher maximum bite force (median median 117 N) compared to the other constructions: printed-reinforced (median median 105 N; $p = 0.001$); printed (median median 77 N; $p < 0.001$); and milled (median 86 N; $p < 0.001$).

2) The printed-reinforced construction emerges as the second highest in terms of maximum bite force following the metal-ceramic construction, with a significantly higher median than the other two constructions, including the printed ($p < 0.001$) and the milled ($p = 0.004$).

3) The printed construction exhibits the lowest maximum bite force and shows a significant difference from all other constructions.

4) The milled construction is characterized by a significantly higher maximum bite force compared to the printed construction, but significantly lower than the other two types of constructions (Table 1).

Table 1. Results of the Friedman test and pairwise comparisons between the four types of preliminary constructions regarding the maximum bite force for molars and premolars in total.

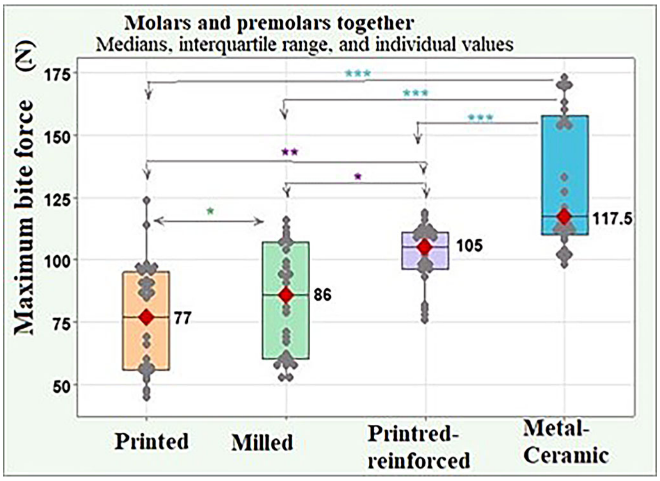
Construction	Median (IQR)	Min. – Max.	Friedman test, p-value	Pairwise comparisons, p-value
Metal-ceramic (1)		98 – 173	<0.001	1→2: 0.001 1→3: <0.001 1→4: <0.001 2→3: <0.001 2→4: 0.004 3→4: 0.021
Printed-reinforced (2)	105 (15.00)	76 – 119		
Printed (3)	77 (39.25)	45 – 124		
Milled (4)	86 (47.00)	53 – 116		

IQR: interquartile range; Min. – Max.: Minimum – Maximum value.
For pairwise comparisons, the Bonferroni test was used with control over Type I error.

In Figure 6, box plots of the medians, interquartile ranges, and individual values of the maximum bite force for the studied preliminary constructions are presented.

A clear significant difference between the metal-ceramic construction and the other three is outlined, as well as a significant difference between the printed-reinforced construction in comparison to the printed and milled ones.

Fig. 6. Box plots of the maximum bite force for the studied types of preliminary prosthetic constructions, for molars and premolars in total.



*Statistical significance at p <0.05; **Statistical significance at p <0.01; ***Statistical significance at p ≤0.001

The comparison of the maximum bite force for the four types of preliminary constructions that have at least one abutment tooth (a molar) also showed a significant relationship with the type of preliminary construction (p < 0.001), as we found for molars and premolars in total. The pairwise comparisons outlined the following (Table 2):

1. The metal-ceramic construction is characterized by significantly higher maximum bite force (median 157 N) than the other three constructions, as follows: printed-reinforced (median median 111 N; p = 0.011); printed (median median 95 N; p < 0.001); milled (median median 107 N; p < 0.001).

2. The printed-reinforced construction shows significantly higher maximum bite force than the printed one (p = 0.007) and no significant difference compared to the milled one (p = 0.396).

2. The printed-reinforced construction shows significantly higher maximum bite force than the printed one (p = 0.007) and no significant difference compared to the milled one (p = 0.396).

3. The printed construction has the lowest median value and, as already shown, differs significantly from the metal-ceramic and the printed-reinforced, but regarding the milled one, the difference does not reach statistical significance (p = 0.157).

4. The milled construction shows significantly lower maximum bite force compared to the metal-ceramic one, but does not differ significantly from the other two types of constructions.

Table 2. Results of the Friedman test and pairwise comparisons between the four types of preliminary constructions regarding the maximum bite force for molars.

Construction	Median (IQR)	Min. – Max.	Friedman test, p-value	Pairwise comparisons, p-value
Metal-ceramic (1)	157 (15.00)	112 – 173	< 0.001	1→2: 0.011 1→3: < 0.001 1→4: < 0.001 2→3: 0.007 2→4: 0.396 3→4: 0.157
Printed-reinforced (2)	111 (4.00)	99 – 119		
Printed (3)	95 (8.00)	85 – 124		
Milled (4)	107 (16.00)	91 – 116		

IQR: interquartile range; Min. – Max.: Minimum – Maximum value.
For pairwise comparisons, the Bonferroni test was used with control over Type I error.

The significant difference between the metal-ceramic construction and the other three types is clearly outlined, but the remaining differences do not reach significance in molars, except for that between the printed-reinforced and the milled construction.

The comparison of the maximum bite force of the four types of preliminary constructions that have at least one abutment tooth (a premolar) also shows a significant relationship between the type of preliminary construction and the maximum bite force (p < 0.001). The following trends emerge from the pairwise comparisons (Table 3):

1. The metal-ceramic construction is associated with significantly higher maximum bite force (median 110 N) compared to the other three constructions, as follows: printed-reinforced (median median 96 N; p = 0.034); printed (median median 56 N; p < 0.001); milled (median median 60 N; p < 0.001).

2. The printed-reinforced construction shows significantly higher maximum bite force than the printed (p < 0.001) and the milled (p = 0.024) constructions.

3. The printed construction has the lowest median value and differs significantly from the metal-ceramic and the printed-reinforced, but compared to the milled one, the difference does not reach statistical significance (p = 0.396).

4. The milled construction shows significantly lower maximum bite force compared to the metal-ceramic one but does not differ significantly from the other two types of constructions.

Table 3. Results of the Friedman test and pairwise comparisons between the four types of preliminary constructions regarding the maximum bite force for premolars.

Construction	Median (IQR)	Min. – Max.	Friedman test, p-value	Pairwise comparisons, p-value
Metal-ceramic (1)	110 (11.00)	98 – 127	< 0.001	1→2:0.034 1→3:< 0.001 1→4:< 0.001 2→3:< 0.001 2→4:0.024 3→4:0.396
Printed-reinforced (2)	96 (19.00)	76 – 111		
Printed (3)	56 (6.00)	45 – 96		
Milled (4)	60 (11.00)	53 – 81		

IQR: interquartile range; Min. – Max.: Minimum – Maximum value.
For pairwise comparisons, the Bonferroni test was used with control over Type I error.

The results obtained allow the main observed trends to be summarized as follows: A statistically significant relationship was found between the type of preliminary construction and the bite force. The metal-ceramic construction showed a statistically significant highest maximum bite force compared to the other three constructions, both for molars and premolars in total and for molars and premolars separately. The second highest maximum bite force was found for the printed-reinforced construction, with significantly higher values compared to the milled and printed construction in the overall analysis and for premolars, and a significantly higher value compared to the printed one for molars. The third highest maximum bite force was observed for the milled construction, which showed a significantly higher value compared to the printed construction in the overall analysis for molars and premolars, but did not reach significance for molars and premolars separately, most likely due to the smaller sample size. The lowest maximum bite force was found for the printed construction, both in the overall analysis and for molars and premolars separately.

DISCUSSION

The performed literature search has shown that until now, no studies have been conducted to measure the maximum bite force in preliminary fixed prosthetic constructions with/without reinforcement.

Suralik KM, et al. [18] tested the fracture strength of test specimens (three-unit bridge constructions consisting of two abutments and one bridge body) made of self-polymerizing PMMA, milled from PMMA discs and printed using the SLA technology in laboratory conditions. The authors found significantly higher median fracture strength values for the printed specimens, which corresponds to the comparative analysis of the values observed in our study of the maximum bite force.

Apostolov N. [19] conducted a study on the values of maximum bite force in natural dentition of men and women in the frontal, left and right molar areas using a gnathodynamometer. The author found the highest values in the distal areas of the dentition compared to the frontal area. The data derived from our study are similar: the measured median values for the maximum bite force in the molar bridge bodies are higher than those in premolars. In the same study, Apostolov N. [19] found mean values of maximum bite force in adult patients with natural dentition, as follows: frontal area 115.08 N, left molar area 278.41 N and right molar area 277.25 N.

The masticatory system, prosthetized with preliminary constructions, develops a force potential limited by the patient's subjective feeling of mechanical resistance. This is reflected in the values of the realized maximum bite force. The statistical analysis of the data obtained during the clinical study of the maximum bite force allows us to confirm the working hypothesis and derive the following order of priority of the values for the differences between the types of constructions:

I. Metal-ceramic constructions. During the preliminary prosthetics with such constructions, the studied group of probands showed significantly higher median values of the maximum bite force (median 117 N) compared to the other constructions: printed-reinforced (median 105 N; $p = 0.001$); printed (median 77 N; $p < 0.001$); milled (median 86 N; $p < 0.001$). Since metal-ceramic frameworks are inherently permanent prosthetic constructions, the scientific focus of our study is on the other three groups of preliminary constructions. The discussion of the obtained results allows the remaining three types of PCs to be arranged in descending order, as follows:

1) Printed constructions of Temporary CB Resin (FormLabs, USA), reinforced with Interlig glass fibers (Angelus, Brazil), coated with liquid photopolymer. The stud-

ied group of probands presented results of the median values, outlining the better durability of these constructions, with a significantly higher median than the other two constructions, the printed ($p < 0.001$) and the milled one ($p = 0.004$).

2) Milled constructions of DD temp MED (Dental Direkt GmbH, Germany), pre-polymerized with PMMA. When treated with these constructions, the patients developed statistically significantly higher median values of the maximum bite force compared to those who were prosthetically treated with printed constructions, but significantly lower than those treated with the other two types of constructions – metal-ceramic and printed-reinforced.

3) Printed constructions of Temporary CB Resin (FormLabs, USA). Preliminary prosthetics with these constructions showed the lowest median values of maximum bite force. This group was statistically significantly different from all other types of constructions.

As an unreinforced material, factory-polymerized PMMA, milled by using the digital CAD/CAM methodology, has the advantages of a faster and more cost-effective manufacture, with mechanical properties superior to printed material.

The preliminary constructions, printed of Temporary CB Resin (FormLabs, USA), manufactured additively by using the SLA CAD/CAM methodology, showed the lowest performance in testing the maximum bite force, which has also been confirmed by the laboratory studies conducted under #4874/ 19/07/2023 project of Medical University – Sofia.

CONCLUSIONS

Considering the results obtained, the following can be summarized:

1. The clinical study of maximum bite force confirms that metal-ceramic fixed constructions can be the object of choice when treatment with long-term preliminary fixed bridge constructions is required.

2. Modern digital methods for manufacturing preliminary constructions for medium- and long-term preliminary prosthetics provide new, broad-spectrum opportunities for optimizing treatment protocols in fixed prosthodontics. Since printed preliminary constructions reinforced with glass fibers coated with composite resin show statistically significantly better results in testing the maximum bite force compared to the group of unreinforced milled specimens, we believe that reinforced, additively manufactured preliminary constructions are the optimal option for medium—and long-term preliminary prosthetics.

3. Unreinforced factory-polymerized PMMA for milling also allows for the realization of very good strength potential. Digital subtractive and additive laboratory technologies are a promising and predictable method for manufacturing preliminary fixed prosthetic constructions and can be reasonably recommended as the methods of choice for preliminary fixed prosthetics, according to the economic and time priorities foreseen in the treatment plan.

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