Accuracy evaluation of fixed prosthetic constructions made by milling and printing technologies and the influence of temperature changes

H Galeva†*, T Uzunov1, Y Sofronov2 and G Todorov2

1 Faculty of Dental Medicine, Medical University, Sofia, Bulgaria
2 Technical University of Sofia, 8 St. Kliment Ohridski blvd., Sofia, Bulgaria

*E-mail: dr.hrgaleva@gmail.com

Abstract. The aim of this study is to evaluate the internal and external fit accuracy of fixed metal-ceramic prosthetic constructions made by milling and printing technologies and the influence of temperature changes on this accuracy. An acrylic resin tooth was prepared according to the standard guidelines for a metal-ceramic crown. A standard intraoral silicone impression was taken and a stone model was prepared. The stone model was scanned by an extraoral digital scanner and a digital copy of the prosthetic field was created. The digital copy was used to create a digital prototype of the future metal substructure for the metal-ceramic crown. Using the same data, the metal substructure was formed once by milling technology, and once by 3D-printing technology. The internal surface of both samples was measured. The stone model preparation surface was also measured. All data were compared to the digital prototype. According to the standard technology, a dental technician applied ceramic material, by hand as usual, in layers and the constructions were sintered. After the thermal procedure, once again the substructure’s internal surface was measured and compared with the previous data. The constructions were finished by glazing by the dental technician applying the last layer ceramic and sintering it. The construction’s internal surface was again measured and the data obtained were compared with the previous data. Conclusion about the influence of the temperature changes caused by the sintering process on the metal substructures was made using the data acquired by all the measurements made between the different stages. The difference in the internal fit of the constructions made by the milling and the 3D-printing technology will not affect to crown’s ergonomics. The quality of the internal fit for the construction made by milling technology is better than this made by 3D-printing technology. Unnoticeable changes in the internal surface were found after the temperature changes caused by the process of sintering for both types of constructions. Both types of technologies could be used to produce high quality accurate metal substructures for the needs of the fixed prosthetic dental medicine. The temperature changes caused by the sintering process during the standard metal-ceramic technology have a small influence to the construction’s internal fit.

1. Introduction
Metal-ceramic constructions are among the most commonly used in the contemporary dental practice. They combine excellent functional and aesthetic qualities [1]. This type of construction is based on a metal wrapped in a ceramic, thus combining the good mechanical properties of metal alloys with the aesthetic properties of ceramics. The conventional technology consists of a producing process whereby

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everything is made by hand. The metal substructure is modeled of dental wax and cast of metal followed by additional cleaning and processing. Finally, the ceramics are applied again by hand by a dental technician. The application is done layer by layer followed by heating [2]. In this process, the ceramic shrinks by approximately 18%. The procedure ends with the glazing of the porcelain and again by a subsequent heat treatment [3].

The introduction of CAD/CAM systems in the dental practice makes it possible not to perform manually some of these processes. Thus, almost the entire procedure of producing metal-ceramic prosthetic constructions could be digitalized – from the impression to the metal base. This implies a greater accuracy of the constructions, and only the ceramic remains to be applied by hand [4]. There are several production methods that can be used in CAD/CAM technologies. They are generally divided into two types – when material is removed and when material is added. In the first case, milling machines are used. They can be with three to five rotation axes. Using additional techniques, the material is powdered and added layer by layer (the most common layer thickness is 20 μm) [5, 6].

Many studies have compared the accuracy of the classical metal-ceramic method with the results obtained by using CAD/CAM systems. The results obtained vary.

Majoo Kim et al. did not find a significant difference in the accuracy of the constructions made by the classical lost-wax method and those made by the milling-sintering method [7]. Other authors found a relationship between the production method and the accuracy of the constructions when comparing the casting method, the milling technology and the selective laser melting [8]. Hao-Sheng Chang et al. compared the lost-wax technique, CAD/CAM and the 3D-printing methods. They established a significant difference in the accuracy of the different production methods (<0.005). According to their research, the lost-wax method is more accurate [9]. In contrast, other studies comparing cast and milled constructions gave preference to the milled technology [10].

No consistent results were obtained by the studies comparing the milling and the additive technologies. Zuskova et al. investigated the difference in the results for milled and laser-sintered constructions. They obtained a negligible difference of 0.04 μm [11]. Other authors compared the milling methods and the 3D printing methods and found a statistically significant difference between the results. They gave preference to the 3D printed constructions [12].

Despite the difference in the results, all researches indicated results that are acceptable for the clinical practice.

The production of metal-ceramic constructions does not end with the metal substructure. It is completed after the application and firing of the necessary layers of ceramics. According to Sabit Melih Ates et al., the accuracy of the marginal adaptation of the metal base decreases when an increasing number of heat treatments of the ceramics are applied. However, the construction’s marginal fit remains within clinically acceptable limits [13]. The negative effect of repetitive heat applications on the marginal adaptation was confirmed by Musa Aykent Altintas et al. [14].

2. Materials and methods
An artificial plastic tooth (first upper right molar) was prepared for a full metal-ceramic crown. The preparation was made according to the standard guidelines – the marginal design is on the gingiva’s level; with a 0.6-mm-wide rounded shoulder the proximal surfaces converge in occlusal direction with a five-degree angle. Diamond rotary tools NTI-Kahla GmbH (Germany) were used. A two-layer full-arch impression was taken in two stages. Additional silicone (Zhermack hydorise putty and light body) and standard full-arch tray were used to take an impression from the plastic model. A gypsum model (Gypsum class 4, Elite rock) with removable dies was produced. These techniques and the materials were chosen as being the most commonly used in the daily dental practice.

The gypsum model was scanned by a laboratory digital scanner (Ceramill Map 400) and a digital copy was created (figure 1).
Figure 1. Digital copy of the prosthetic field.

It was followed by a digital design by using the Exocad dental software. A suitable tooth was chosen from the digital library and its size was reduced to parameters acceptable for the future metal substructure of the metal-ceramic crown and a cement thickness of 0.5 mm (figure 2).

Figure 2. Tooth selection from virtual library.

The data was saved in an STL file. It was used to produce two types of metal substructure – the first one made by a CAD/CAM milling machine (DMG/MORIUltrasonic 20) (figure 3), and the second one, by a 3D-printing machine (STM 125) (figure 4).

Figure 3. Milled metal substructure.

Figure 4. 3D-printed metal substructure.

Co-Cr metal alloy/powder was used for both constructions. Their internal surfaces were measured by a coordinate measuring machine (Optiv Performance) as a preparation of the stone model which was scanned. All the data were compared with the digital model of the prosthetic field and the results were saved (figure 5).
Figure 5. Comparison of the internal surfaces.

An experienced technician applied ceramic on both samples, layer by layer, according to the standard technology, by hand. The constructions were sintered. After the thermal process their internal surfaces were measured once again with the same coordinate measuring machine and the data were saved. Both constructions were finished by glazing. The internal surface of the completed crowns was measured again by the same scanner. The data were saved.

All measurements data were compared with the digital model made based on the scanned stone model. Conclusions were made about the effect of the temperature changes in the metal substructures produced by the different technologies.

3. Results
The research conducted showed the greater accuracy of the metal substructures made by milling compared to those made by 3D-printing technology. The average difference in terms of internal accuracy of the constructions was 60 μm.

The examination of the internal surfaces after the first stage of ceramic application and firing did not show any difference with the initial measurements of the metal bases.

After the final ceramic application and firing, a minimal reduction of the internal accuracy of both types of constructions – milled and printed, was registered.

4. Discussion
CAD/CAM systems are easy to work with and the time required is reduced, which makes them increasingly preferred for the everyday workflow. However, the use of two different materials in the manufacture of metal-ceramic constructions requires the use of a hybrid technology, whereby the ceramic is manually added after the production of the metal substructure [3]. Using a hybrid technology requires checking the accuracy of the different CAD/CAM manufacturing technologies and how the manual application and the heating of the ceramic affect it.

The purpose of this study is to evaluate and compare the internal and external fit accuracy of metal substructures for fixed prosthetic constructions made by milling and 3D printing and to investigate the influence of the temperature changes.

Some authors, as Kim M et al. and Chang H S et al., found the lost-wax technique more accurate than the digital methods. Chang et al. compared the marginal gap of three groups of constructions: made by casting, by selective laser sintering and by milling [7, 9]. The smallest gap was found for the construction made by the conventional method, where the deviation was 76 – 61 μm. The results for the selective laser sintering and the milling were respectively 116 – 92 μm, and 121 – 98 μm [9]. The same methods were studied by Maltzahn et al.; they found that the selective laser sintering was less accurate [10]. Shaaban et al. compared the marginal fit of constructions made by lost wax and milling and achieved better results by using the milling method [10].

A small number of studies have only been published dealing with the effect of ceramic heating on the metal base of the construction. Some of them, as that of Ates et al., showed a dependence on the number of temperature changes [13]. Their study confirmed the negative effect of the repetitive temperature changes on the accuracy of the final constructions. However, the final result is acceptable for clinical purposes.
5. Conclusions
Based on this study, the following conclusions are made: the milling method yields better results than the 3D-printing. The frequent temperature changes caused by the heating of the ceramic degrade the accuracy of the metal substructures regardless of the production method used. Both types of constructions are clinically acceptable.

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