EVALUATION OF DIMENSIONAL ACCURACY AND DENSITY OF DENTAL STRUCTURES MANUFACTURED BY DIFFERENT TECHNOLOGIES

Viktoria Rajtukova[1], Bibiana Ondrejová[1], Andrea Sinčák Konečná[2], Jana Hlubeňová[1], Radovan Hudák[1]

[1]Department of Biomedical Engineering and Measurement, Faculty of Mechanical Engineering, Technical University of Košice, Košice, Slovakia

[2]Department of Conservative and Prosthetic dentistry, Stomatological clinic, Louis Pasteur University Hospital, Košice, Slovakia

Abstract

This study focuses on the fabrication and analysis of a total of 90 dental structures (metal parts of dental prostheses – coping, bridges) of 3 types made of cobalt-chromium alloy through different fabrication technologies which include casting, additive manufacturing by selective laser melting (SLM) and subtraction technology by CNC milling. The manufacturing accuracy analysis was carried out by comparing the nominal model and the actual model obtained by 3D scanning of the fabricated dental structures in GOM Inspect software. Density measurements were performed by helium-based gas pycnometry. The data obtained were statistically analysed and a statistically significant difference was confirmed between the subtraction and additive technology. Based on the available manufacturing technologies, materials and equipment used to fabricate the samples for this study, it can be concluded that dentures fabricated by 3D printing are more accurate than dental structures fabricated by milling or casting technology.

Keywords

dental structures, additive technology, subtraction technology, casting

Introduction

Dentures play a key role in restoring oral function and aesthetics in patients [1]. They are exposed to various forces and environments in the oral cavity, which places emphasis on durability and functionality, which is also provided by the most used material in denture fabrication, specifically CoCr alloys [2].

The conventional process of fabricating metal dentures is a casting method in which accuracy is affected by the manual ability and experience of the dental technician. Precise dimensional accuracy is essential in the manufacture of dentures to ensure proper fit and function in the patient's mouth. Various manufacturing technologies such as casting, CNC milling, and additive manufacturing are used in the fabrication of dentures such as dental bridges [3]. These technologies have different strengths and limitations, and it is important to evaluate their dimensional accuracy to determine their suitability for specific dentures. In addition, the density of the manufactured dentures is another important aspect to consider. This can be measured and compared across different manufacturing techniques to assess their quality and durability [4].

However, with additive manufacturing technologies such as 3D printing, there is the potential to produce high-quality ceramic dentures with complex geometries in a more efficient and controlled manner [5, 6].

Material and methods

In the present study, three technologies—conventional casting, CNC milling and 3D printing method with SLM technology—were compared to fabricate restorations of three clinical types (crown, three-unit bridge and eight-unit bridge) from CoCr alloy. In addition to dimensional accuracy, density

testing using gas pycnometry was performed on the fabricated dentures to estimate the quality aspect of the materials used in fabrication. The aim of this study was to evaluate all the data obtained and to identify a suitable method of denture fabrication with ideal mechanical and dimensional properties within the range of technologies used [7].

Plaster models of three clinical cases (crown, three-unit and eight-unit bridge), with a preparation convergence of approximately 3–10°, a cervical-occlusal reduction of 3–4 mm and a bevel preparation, were created as part of the study. Each type of denture was fabricated by three different technologies, and a total of 90 dentures were fabricated and analysed.

Methodology of dental structures manufacturing

The first group of specimens produced by conventional technology was created by casting an impression of a plaster model and creating split models from a Co-Cr based material, Heraenium Pw (Kulzer, Germany). All specimens were fabricated and prepared by a single dental technician (Fig. 1).
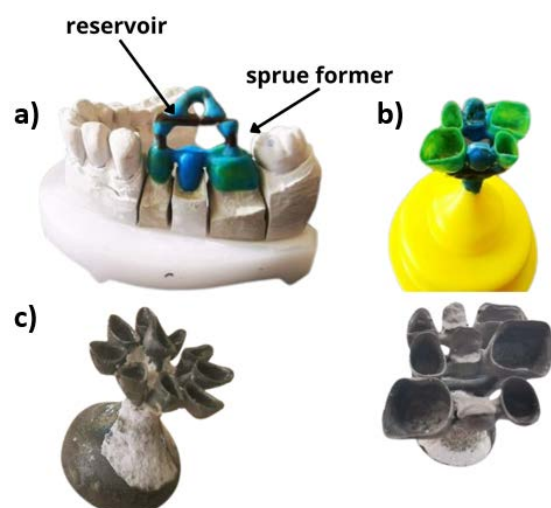

Fig. 1: Procedure of denture fabrication by conventional casting technology: a) modelled structure made of wax on a plaster model, b) a wax pattern of the prosthesis, c) casted dental bridges.

As a basis for the fabrication of dentures by innovative manufacturing technologies (subtractive and additive), plaster models were scanned with an S900 ARTI dental scanner (Zirconzahn, Italy). After exporting the data to the Zirconzahn Modellier v.9 software (Zirconzahn, Italy), digital models of the dentures were modelled and imported into the respective software for the respective technologies.

Another group of samples was fabricated on a Mlab Cusing R 3D printer (GE Additive, USA) using Selective Laser Melting (SLM) technology from Co-Cr

StarBond Easy Powder 30 metal powder (Scheftner, Germany). In CAMBridge v. 2.4.1.2 software (3Shape, Denmark), the digital restorations were positioned on the build-up plate so that the occlusal portions were directed towards the build-up plate, and subsequently a support structure was generated. The specimens were thus ready for printing and production by additive manufacturing proceeded. After fabrication, the specimens were annealed in an oven and machined by the same dental technician (Fig. 2).
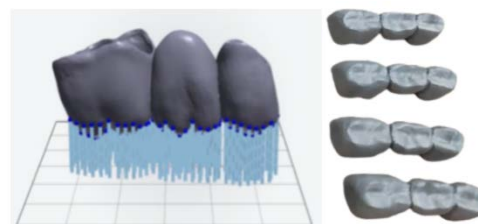

Fig. 2: Software interface for setting support and subsequently produced samples with additive technology.

The third technology to produce dentures was subtraction—CNC milling on Ceramill Motion 2 (Amann Girbach, Austria) using Ceramill Sintron (Amann Girbach, Austria) Co-Cr-based pressed powder plate. The digital model had to be flattened to avoid overlapping of the digital models and an optimal support was designed. After all the necessary steps, the data was imported into the Ceramill Match CNC milling machine software (Amann Girbach, Austria). After milling, the specimens were then annealed and manually processed (Fig. 3).

Fig. 3: Software interface for setting up the support and subsequently produced samples by CNC milling.

Dimensional accuracy analysis methodology

All samples were then scanned using an S900 ARTI dental scanner and imported into GOM Inspect v. 2022.0.6. software (ZEISS, Germany). The dimensional accuracy of the samples produced by the two different innovative methods was compared. The casting method was not compared and analysed because it is a manual fabrication process and does not involve the modelling of a digital 3D model against

which the dimensional accuracy could be compared. Three groups were defined for the evaluation of dimensional accuracy (Fig. 4). This comparison provided the data used to compare the two manufacturing technologies.
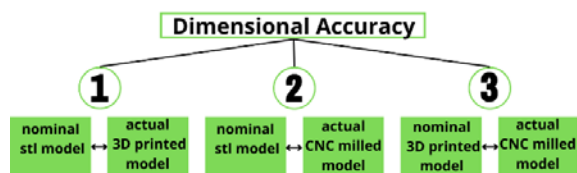

Fig. 4: Methodology for evaluating dimensional accuracy of three groups.

The comparison of the dimensional accuracy was performed with the GOM Inspect software (Fig. 5). In each pair of comparison samples, one was labelled as nominal and the comparison sample was labelled as actual (Fig. 4).

Comparison of dimensional accuracy was performed using GOM Inspect software (Fig. 5). In each pair, the nominal and actual samples were compared.
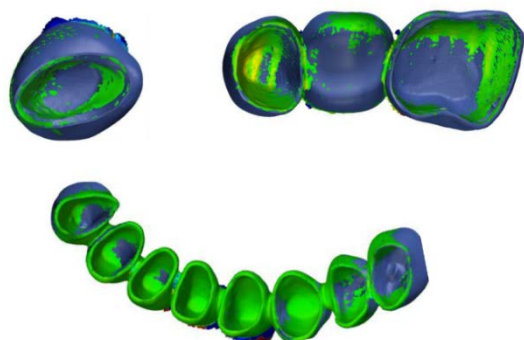

Fig. 5: Visualization of dimensional accuracy evaluation in GOM Inspect software.

Methodology for density analysis of manufactured dental structures

Five samples from each method (casting, additive manufacturing, milling) were measured using an AccuPyc II 1345 pycnometer (MICorp., Georgia, USA), the density of each sample was measured in 10 cycles. The measurement was carried out according to ASTM B923 (Standard Test Method for Metal Powder Skeletal Density by Helium or Nitrogen Pycnometry) and USP 699 (Gas Pycnometric Density of Solids) norms. The standard density values for the material used were compared with the density values of the test specimens. The open porosity of the sample material was further derived from these values.

Results

Results of the dimensional analysis evaluation of dental structures

All mean deviations are plotted in Fig. 6. In the first group of specimens tested (Fig. 4), it was found that the specimen size in additively fabricated restorations did not have a significant effect on dimensional accuracy, specifically, the largest mean deviation found was for the three-unit bridges and was 0.36 μm greater than the eight-unit bridges. In contrast, milled eight-unit bridges had a mean deviation with respect to STL (Standard Triangle Language) model of 92.71 μm, which was 56.91 μm more than the average deviation for the milled crowns.
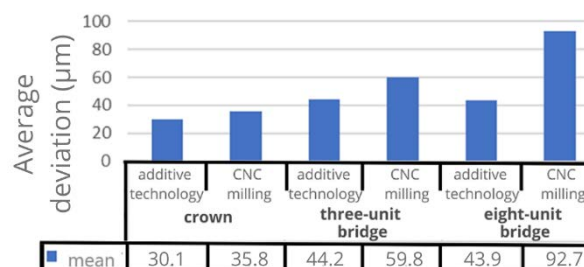

Fig. 6: Evaluation of dimensional accuracy for manufacturing technologies.

When comparing the three-unit bridges of the digital STL model against the 3D printed and milled ones, the resulting mean deviation value for the 3D printed work was 44.21 μm with a standard deviation of 3.52 μm and for the milled three-unit bridges it was a mean deviation of 35.80 μm with a standard deviation of 4.47 μm (Fig. 7).
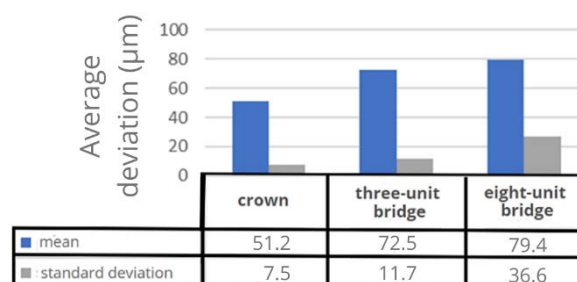

Fig. 7: Evaluation of the dimensional accuracy of dentures fabricated by additive manufacturing and milling.

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The research hypothesis assumes that additive manufacturing technology is more accurate than subtractive technology. By analysing the obtained values of deviations of dentures manufactured by additive technology and CNC milling, the hypothesis was verified using F-test and T-test statistical tests.

After subjecting the variances to T-tests, the resulting T-test value is <0.005 for all denture types compared (Table 1). This means that at the 0.05 level of significance, we reject the null hypothesis of equality of means. Thus, a statistically significant difference between the technologies was confirmed. Based on the available manufacturing technologies, materials and equipment used to produce the samples for this study, it can be concluded that dentures produced by 3D printing are more accurate than those produced by milling technology.

Table 1: Results of the T-test.

Type	p-value
Crown	0.003143 (<0.005)
Three-unit bridge	0.00007 (<0.005)
Eight-unit bridge	0.00017 (<0.005)

Overall, the table suggests that all three types of dental procedures (crown, three-unit bridge, and eight-unit bridge) exhibit statistically significant differences in outcomes compared to the control group, with increasingly lower p-values indicating stronger evidence against the null hypothesis.

Density results of fabricated dentures

By testing the samples with a pycnometric device, the density values of each sample were obtained. These values were compared with the theoretical density given by the manufacturer for each material. For the cast samples, the reported density is 8.9 g/cm³, for the material used for additive manufacturing it is 8.5 g/cm³, and for the material used for the subtractive manufacturing method, the reported density is 7.9 g/cm³. The average density values of the tested samples are shown in Fig. 8.

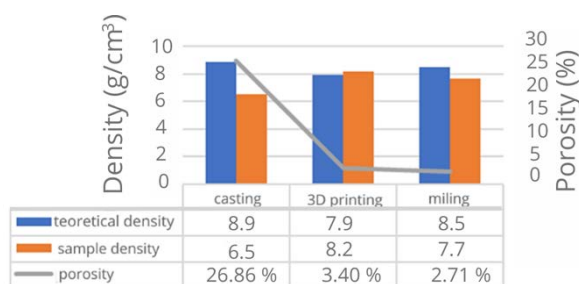|	casting	3D printing	miling
teoretical density	8.9	7.9	8.5
sample density	6.5	8.2	7.7
porosity	26.86 %	3.40 %	2.71 %

Fig. 8: Evaluation of the density and porosity of dentures fabricated by casting, additive manufacturing, and milling.

In the case of samples produced by the conventional casting method, the density of the samples reached significantly lower values, with an average deviation of 26.86%, which is significantly higher than in the 3D printing and milling processes, where the values of the so-called average deviation reached 2.71% for milled samples and 3.40% for samples produced by additive technology.

Discussion and Conclusion

From the data collected and evaluated, it can be concluded that fixed dentures fabricated using SLM 3D printing technology are more accurately CNC milled. Moreover, the data suggest that the structures produced by 3D printing and CNC milling have final densities that are essentially consistent with the ideal alloy density specified by the manufacturer. Therefore, it is reasonable to argue that the use of both technologies during the manufacturing process produces dental structures that are equally mechanically satisfactory.

After reviewing the data regarding specimens that have been created by casting, it is evident that using this method to create fixed restorations provides structures that are less robust and morphologically acceptable. It is important to note that these results only apply to the structures fabricated from the materials and devices reported in this study.

After analysing the data obtained from this study and synthesizing the findings from the literature, it is evident that the use of current technology to fabricate permanent dentures is a much more efficient method than the use of the casting method. Significantly, additive technology stood better than subtractive technology, with traditional casting being the least effective [7]. This supports a well-established research hypothesis, which was also statistically verified and supported the view that additive technology is more accurate than the milling technology.

Acknowledgement

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Ing. Viktória Rajťúková, PhD.
Department of Biomedical Engineering and Measurement
Faculty of Mechanical Engineering
Technical University of Košice
Letná 1/9, 04200, Košice

E-mail: viktoria.rajtukova@tuke.sk
Phone: +421 556 022 651