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Dimensional Accuracy and Final Density Measurement of One-, Three-, and Eight-Unit Fixed Dental Frameworks Based on Co-Cr, Manufactured by Using Conventional, Additive and Subtractive Technologies

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Abstract

For the aim of this study, 90 fixed metal frameworks based on Co-Cr were made by using conventional lost vax technique, additive 3D printing done by Selective Laser melting (SLM) technique and subtractive manufacturing using CNC milling. Constructions were produced by the Ceramill Motion 2 milling machine (Amann Girrbach) and Mlab Cusing R 3D printer (GE Additive). Samples were made as one-, three- and eight-unit frameworks based on existing clinical cases. Initial stl. model was built up on a scanned plaster model of three clinical cases by ZirconZahn Modellier software. Evaluation of dimensional accuracy was made by comparison of initial stl. model with a scan of manufactured framework and analyzed by measurement software. Density measurements were made by helium (He) based gas pycnometry. Gained data was statistically analyzed by using T-test and F-test for technologies comparison and non-parametric form of ANOVA: Kruskal Wallis was applied in density evaluation of all samples.

Keywords: 3D printing; additive technologies; fixed dental prosthetics; 3D printed dental prosthetic; additive technologies in dentistry; subtraction techniques; CNC milling in dentistry; pycnometry; Co-Cr alloy density.

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1. Introduction

Development of new technologies affects all of the spheres of human activities; it also impacts medicine, stomatology not excluded. Innovative technologies facilitate, for example, more accurate processing of input data (processing of imprints and models) using the scanning systems, as well as more efficient manufacturing technologies that improve production planning and automatization. A great advantage of digital technologies is the visualisation of the planned product so the patient can see the planned treatment even before starting the process of manufacturing.

Despite the fact that new materials are being developed, chrome-cobalt materials still rank among the key materials used in the production of dental replacements. Cobalt- and chrome-based alloys (Co-Cr) are largely used for metal bases for fixed dental prostheses due to their excellent mechanical properties, such as high resistance to corrosion and wear resistance and also good properties of biocompatibility.

In the past, CoCr materials were used for manufacturing metal frameworks by traditional method of casting (lost wax method). This process requires several manual steps to be carried out in the manufacturing process and no computer guided systems are used. Co-Cr based materials can be also used by subtractive (CNC milling) and additive (3D printing) technologies. During casting, a big amount of waste material is created. Novel method of CNC milling requires a metal block. Although this method exhibits high accuracy, its disadvantage is a significant amount of waste or unused material. The latest, albeit the least used technology, is the manufacturing using the Selective Laser Melting (SLM) from metal powder. Layers of metal powder are melted into a 3D model using a computer-controlled laser. Advantages of the SLM, when compared to conventional methods, include the possibility of manufacturing customised complex models and parts with a dense structure and predefined surface roughness. This facilitates the fabrication of robust as well as very fine elements, while the quantities of waste materials are negligible as the powder is recyclable [1,2].

One of the most important features of fabricated fixed dental frameworks is marginal fit of the crowns made. Another important property are dimensional accuracy and final mechanical properties of processed metal used in manufacturing which is highly dependent on a production method. The final metal properties after they have gone through the manufacturing process, marginal gaps, and dimensional accuracy of framework (which is related with internal fit of the crowns) are the mostly observed properties when evaluation of accuracy of manufacturing method is done, as they belong to the most important aspects that determine the expected lifespan and function of dental replacements. By creating as accurate construction as possible, microfractures, cement dissolving, bacteria infiltration, accumulation of plaque, formation of caries and gingivitis [3,4]. Also, the inner space between the replacement and the prepped tooth affects the retention and occlusion. If the internal gap is too wide or narrow, the work may become displaced, or it may lead to malocclusion or imperfect insertion of the replacement [5]. Therefore, marginal, and internal gaps are the critical factors that determine the success of fabrication of dental replacements [6,7].

The purpose of this submitted study was to apply conventional casting, 3D printing SLM method and CNC milling technique in order to manufacture samples of fixed metal frameworks of three clinical types (single crown, three-unit bridge and eight-unit bridge) made of the CoCr material. After manufacturing all 90 samples, they were backwards scanned and compared throw GOM INSPECT software (GOM, Germany). In addition to dimensional accuracy a testing of density by using gas pycnometry (AccuPyc II 1345, MICorp.), was performed to estimate a qualitative aspect of materials used in manufacturing.

The goal of this study was to evaluate all gained data and identify the most precise method of manufacturing a fixed metal framework with the most suitable mechanical and dimensional properties in the range of used technologies and materials.

1.1. Designing and modelling of fixed dental frameworks

After selecting three clinical cases (prosthetic treatment by single-crown, three-unit bridge and eight-unit framework), with convergency of preparation about 3–10°, cervico-occlusal reduction 3-4 mm and chamfer design preparation, plaster models were scanned by ARTI S 900 intraoral scanner and transformed into ZIRCONZAHN Modellier software (Figure 1). ased on the obtained data, the models of frameworks were subsequently designed. A created stl. model of each clinical situation vas than used for sample producing by STL technologies and CNC milling, but not for classical method of casting. By this method, frameworks were modelled by hand using wax done by dental technician. Totally ninety samples were made, thirty for each technology and from those ten for each clinical case.

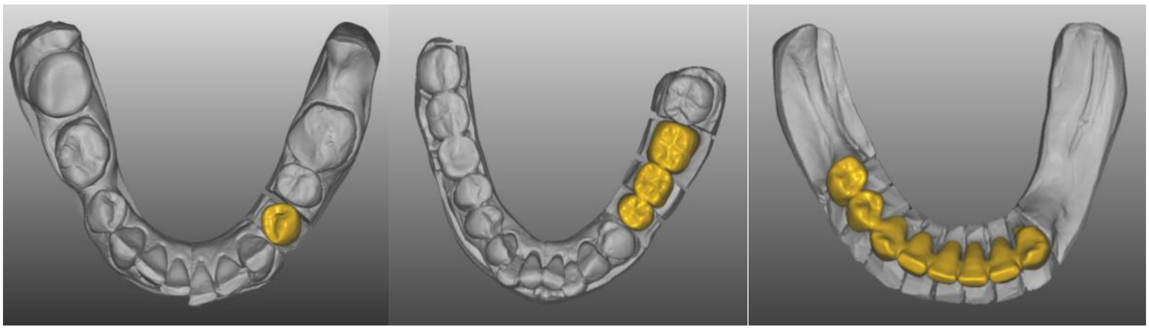

Figure 1: Dental frameworks modeled in ZirconZahn modellier software

a) Single crown b) 3-unit bridge c) 8-unit bridge

Afterwards all manufactured frameworks were backwards scanned and saved in ZirconZahn Archive and further transferred as stl. input files into GOMInspect software (Zeiss) and data sets for dimensional accuracy comparison were made.

1.2. Technologies and materials used

As first was created a group of samples made by casting using lost wax technique. All of these samples were made by dental technician, without creating wax preforms of frameworks. Material selected for this technique was Co-Cr based, commonly used Heraenium Pw (Kulzer). The initial phase of reproduction of the situation was carried out in the classic way by pouring the impression by stone plaster and creating split models with guide pins and repositioning rings and wax preforms of final frameworks included pouring channels and metal stack. Poured construction was afterwards mechanically processed and prepared for back scanning.

Another group of samples was made by Selective Laser Melting (SLM) technology using Mlab Cusing R 3D printer (GE Additive, USA) and selected material was Co-Cr based powder Star Bond Easy Powder 30 (Scheftner). Process started by recording an initial stl. model to CAMBridge software of 3D printer. After positioning the object on construction plate so the occlusal parts are facing the construction plate, designing a support structure, designation of objects and their positioning on a construction plate transformed to cls. format and by sending the file to Mlab Cusing R printer and launch the manufacturing process. Afterwards the samples were mechanically processed and annealed, so the manufacturing process will be identical with the real procedure done in manufacturing a fixed dental prosthetics.

Last method used for sample creation was CNC milling technology done by Ceramill Motion 2 (Amann Girbach) by using pressed powder plate Ceramill Sintron (Amann Girbach) based on Co-Cr as the most alike to previously used materials. After transporting initial .stl file to Ceramill Match program, selecting a material and its shape, positioning the objects in plane so there is no overlap of any construction part and designing the length, thickness, and position of attachments. After all initial necessary steps, the .stl file is uploaded to the CNC milling machine software Ceramill Match and the process is initiated. After milling, the process of annealing and mechanical processing is done.

1.3. Method of dimensional accuracy evaluation

In evaluation of dimensional accuracy, three groups were defined. In the first group was compared initial stl. model with all 3D printed samples, in the second group was compared initial stl. model with all CNC milled samples. Data gained from these two groups was used for evaluation of accuracy of each method itself. The third group was generated from comparison of referential 3D sample for each clinical case (sample was selected on a criterion of smallest deviation from initial stl. model) with all CNC milled samples. By this comparison was gained data used for this two-method comparison. Samples made by casting, was not incorporated in the final evaluation, as the deviation from initial stl. models (which was not used to generate these samples) or 3D printed, and milled samples was by the software non-evaluable, or the value of deviation differed in repeated comparison for the same sample.

The comparison itself was done by GOMInspect software (Figure 2). In each pair of compared samples, one was designated as nominal CAD Body and the compared sample as Mash Body. In groups where stl. model was compared with 3D printed or CNC milled samples, stl. was determined as CAD body. In the group where 3D sample was compared by all CNC milled samples, 3D sample was estimated as initial CAD body. For back-scanning Arti S900 extraoral scanner from ZirconZahn was used, calibrated after every set of samples. Reducing a blunder scan, mattifying spray (IP Sken Spray) was applied over the whole surface of frameworks, so the reflection of metal will be minimalized. After the process of scanning is completed, a scan needs to be cut, saved in stl. format and used for any CAD/ CAM device.

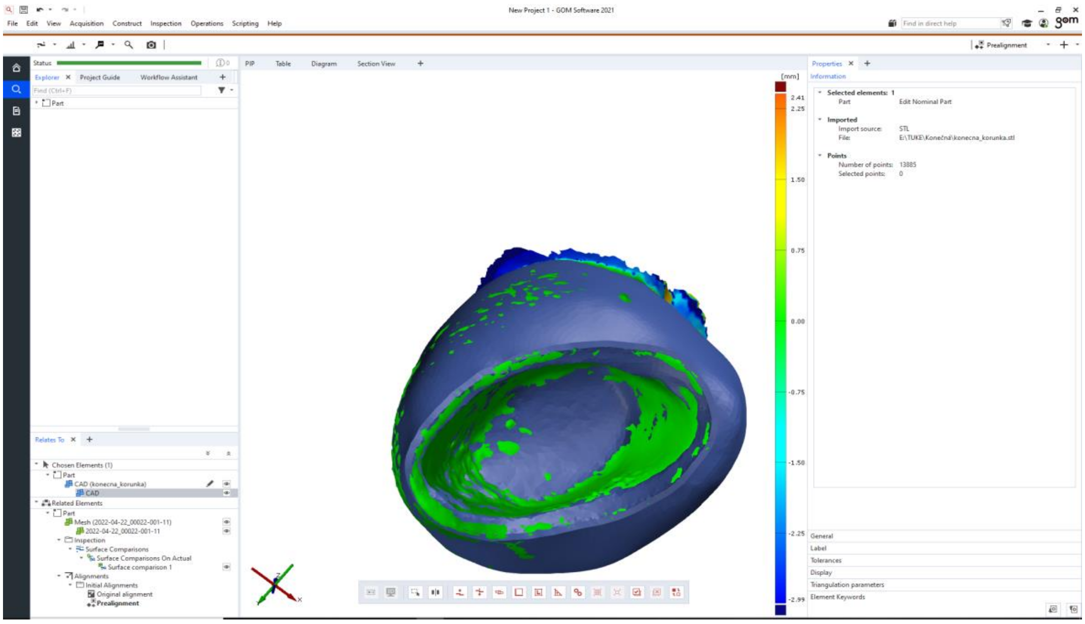

Figure 2: Visualization of deviation between stl. and CNC milled single crown sample made in GOMInspect software

1.4. Method of density measurement

Furthermore, an evaluation of final density of produced dental frameworks was made by using Gas Pycnometry device AccuPyc II 1345 (MICorp.), using helium (He) as the detecting medium. There were five samples chosen from each manufacturing method, and for each sample ten separate measuring was made and open porosity was estimated. Measured amount of density of each sample for each material was compared with optimal density given by manufacturer. Measurement was done by ASTM B923 a USP 699 norms.

2. Results

After comparison of all selected samples by software and gaining the complete data sheets of pycnometry analysis, statistical evaluation and analysis was performed. For a better orientation through analyzed data, samples were distributed and labeled (Table 1).

Table 1: Samples distribution

	Casting	CNC milling	3D printing	Nominal stl. model
Single crown	10 (**A1-10**)	10 (**B1-10**)	10 (**C1-10**)	**X1**
3-unit bridge	10 (**A11-20**)	10 (**B11-20**)	10 (**C11-20**)	**X2**
8-unit bridge	10 (**A21-30**)	10 (**B21-30**)	10 (**C21-30**)	**X3**

2.1. Comparison of stl. files with 3D printed and CNC milled samples

The comparison was made in several groups. In the initial comparison, nominal samples (marked X1, X2, X3) and samples produced by 3D printing (marked C1-C30) and CNC milling (marked B1-B30) were compared. The resulting values are shown in Table 2, 3 and 4. The nominal sample was a stl. model that was created as a production model in the "ZirconZahn Modellier" software for each situation, and samples were produced based on it.

Table 2: Comparison of stl. file with 3D printed and CNC milled samples for single crown

stl. - 3D print	Deviation [μm]	stl. - CNC milling	Deviation [μm]
X1-C1	30,3	X1 -B1	34,7
X1-C2	31,3	X1-B2	32
X1-C3	26,8	X1-B3	31,2
X1-C4	29,9	X1-B4	30,6
X1-C5	32	X1-B5	34,7
X1-C6	27,7	X1-B6	35
X1-C7	36,2	X1-B7	38,6
X1-C8	24,7	X1-B8	41,5
X1-C9	28	X1-B9	40,6
X1-C10	34,3	X1-B10	39,1
Average	30,12	**Average**	35,8
Variance	0,0122	**Variance**	0,02
Decisive deviation	3,492	**Decisive deviation**	4,472

Table 3: Comparison of stl. file with 3D printed and CNC milled samples for 3-unit framework

stl. - 3D print	Deviation [μm]	stl. - CNC milling	Deviation [μm]
X2-C11	45,5	X2-B11	58,2
X2-C12	47	X2-B12	68,2
X2-C13	46,3	X2-B13	65,8
X2-C14	47,5	X2-B14	51,4
X2-C15	46,4	X2-B15	55,7
X2-C16	40,4	X2-B16	56,4
X2-C17	37,7	X2-B17	52
X2-C18	45,1	X2-B18	63,9
X2-C19	46,4	X2-B19	49,4
X2-C20	39,8	X2-B20	69,9
Average	44,21	**Average**	35,8
Variance	0,0124	**Variance**	0,02
Decisive deviation	3,521	**Decisive deviation**	4,472

Table 4: Comparison of stl. file with 3D printed and CNC milled samples for 8-unit framework

stl. - 3D print	Deviation [µm]	stl. - CNC milling	Deviation [µm]
X3-C21	46,6	X3 -B21	86,8
X3-C22	48,4	X3-B22	81,4
X3-C23	35,9	X3-B23	81
X3-C24	45,9	X3-B24	67,1
X3-C25	42,6	X3-B25	137
X3-C26	36,6	X3-B26	83,9
X3-C27	37,8	X3-B27	70,6
X3-C28	47,9	X3-B28	86,5
X3-C29	49,2	X3-B29	88,9
X3-C30	47,6	X3-B30	143,9
Average	43,85	**Average**	92,71
Variance	0,0273	**Variance**	0,684
Decisive deviation	5,224	**Decisive deviation**	26,15

When comparing samples produced by 3D printing and milling with the initial stl. model used as their template, it turned out that the size of work does not have such a significant effect on the increasing tendency of deviation in 3D printed frameworks as expected (Figure 3). In the compared group of stl. and 3D printed three-unit bridge and stl. and 3D printed eight-unit bridge, the average deviation is greater for three-unit works (44.21µm) than for eight-unit works (43.85µm). It was also manifested in the compared group of stl. and milled single crowns, where the average deviation was 35.8 µm, and the group of stl. and milled three-unit bridges with the same average deviation of 35.8 µm. The group with the smallest decisive deviation is the compared group of 3D printed single crowns against the .stl file with a standard deviation of 3.4µm, and the group with the largest standard deviation is the compared group of stl. against the milled eight-unit works with a standard deviation of 26.1µm.

When comparing single crown samples produced by 3D printing and milling against the stl. model, the average deviation was 30.12 µm and decisive deviation was 3.492 µm for crowns produced by 3D printing. For milled single crowns, the average deviation was 35.8 µm with a standard deviation of 4.472 µm.

When comparing three-unit restorations in the stl. group against 3D printed and milled ones, the resulting value of the average deviation for 3D printed works was 44.21 µm with a decisive deviation of 3.521 µm, and for milling three-unit bridges it was an average deviation of 35.8 µm with a decisive deviation of 4.472 µm.

In the compared group of stl. with 3D printing and milling of eight-unit frameworks, the average deviation was 43.85 µm with a decisive deviation of 5.224 µm for 3D printing works, for milling eight-unit works the average deviation is 92.71 µm with a decisive deviation of 26.15 µm.   Standard deviation data is more clearly shown in the histogram below.

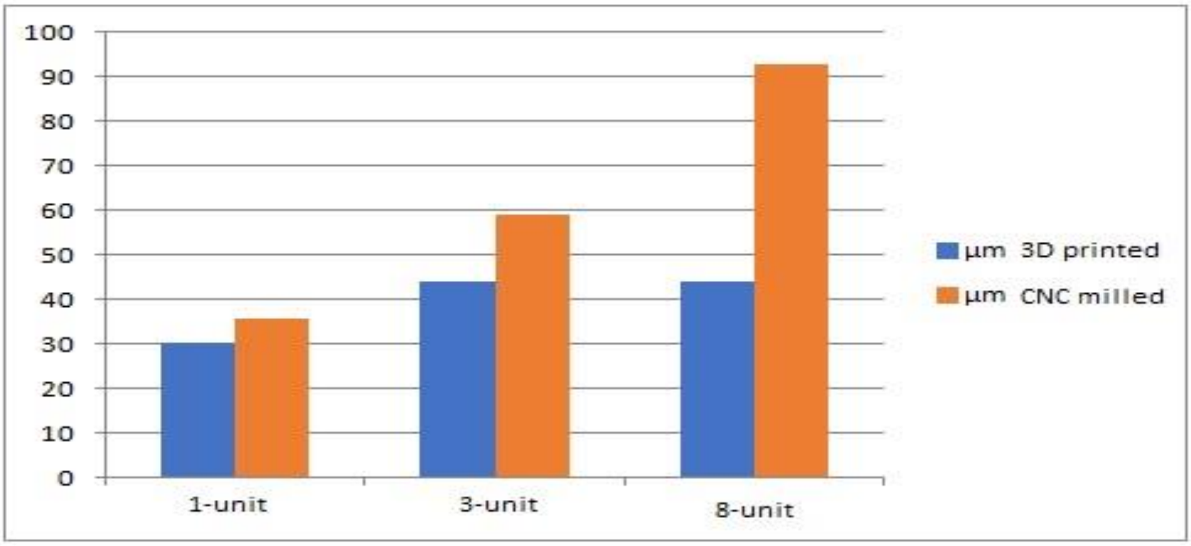

Figure 3: Average deviation considering the size and method of production

2.2. Comparison of reference 3D sample and CNC milled samples

In this evaluation, one sample from each clinical case produced by 3D printing was selected that had the smallest deviation from the original .stl file and was compared in the GOM Inspect software against all samples of the given group produced by the subtraction method - CNC milling (Table 5, 6, 7). From the samples of single crowns, sample C8 was selected, which showed the smallest deviation from the original stl. file - 24.7 µm and was determined in this comparison as the reference - "CAD Body". For the three-unit bridge, it was sample C17, whose deviation from the stl. file was 37.7 µm, and for the comparison of the eight-unit bridge, sample C23 was selected witch has a deviation of 35.9 µm.

Table 5: Difference between 3D printed sample and CNC milled samples of single crown

Referential sample of 3D printed – CNC milled samples	Deviation [µm]
C8-B1	54,2
C8-B2	47,3
C8-B3	52,2
C8-B4	42,1
C8-B5	55,8
C8-B6	38,8
C8-B7	58,6
C8-B8	55
C8-B9	45,9
C8- B10	62,2
Average deviation	51,21
Variance	0,056
Decisive deviation	7,483

Table 6: Difference between 3D printed sample and CNC milled samples of 3-unit bridge

Referential sample of 3D printed – CNC milled sample	Deviation [µm]
C17-B11	87
C17-B12	66,1
C17-B13	69,3
C17-B14	79,9
C17-B15	56,2
C17-B16	63,9
C17-B17	90,3
C17-B18	64,5
C17-B19	83,7
C17-B20	63,6
Average deviation	**72,45**
Variance	**0,138**
Decisive deviation	**11,74**

Table 7: Difference between 3D printed sample and CNC milled samples of 8-unit bridge

Referential sample of 3D printed – CNC milled samples	Deviation [µm]
C23-B21	74,2
C23-B22	65,8
C23-B23	70,3
C23-B24	55,8
C23-B25	123,3
C23-B26	68,2
C23-B27	55,6
C23-B28	73,3
C23-B29	74,6
C23-B30	132,8
Average deviation	79,39
Variance	0,709
Decisive deviation	26,63

When comparing the selected sample produced by 3D printing and all samples produced by CNC milling technology, the value of the average deviation had an increasing tendency due to the size of the work. A more significant difference appeared only when comparing the standard deviations of individual groups of samples, where the difference between three-unit and eight-unit works shows a greater value of the standard deviation than when comparing the decisive deviation of single crown and three-unit works. When comparing the reference 3D sample and milled samples of one-piece work, the average deviation was 51.21µm with a decisive deviation of 7.483µm. When comparing three-unit works, the value of the average deviation was 72.45 µm with a decisive deviation of 11.74 µm. In the compared group of eight-unit works produced by 3D printing and milling, the average deviation was 79.39 µm with decisive deviation of 26.63 µm. For better presentation, the dependence of the deviation of the 3D printed sample to the milled samples with respect to the size of work is shown in the graph below (Figure 4).

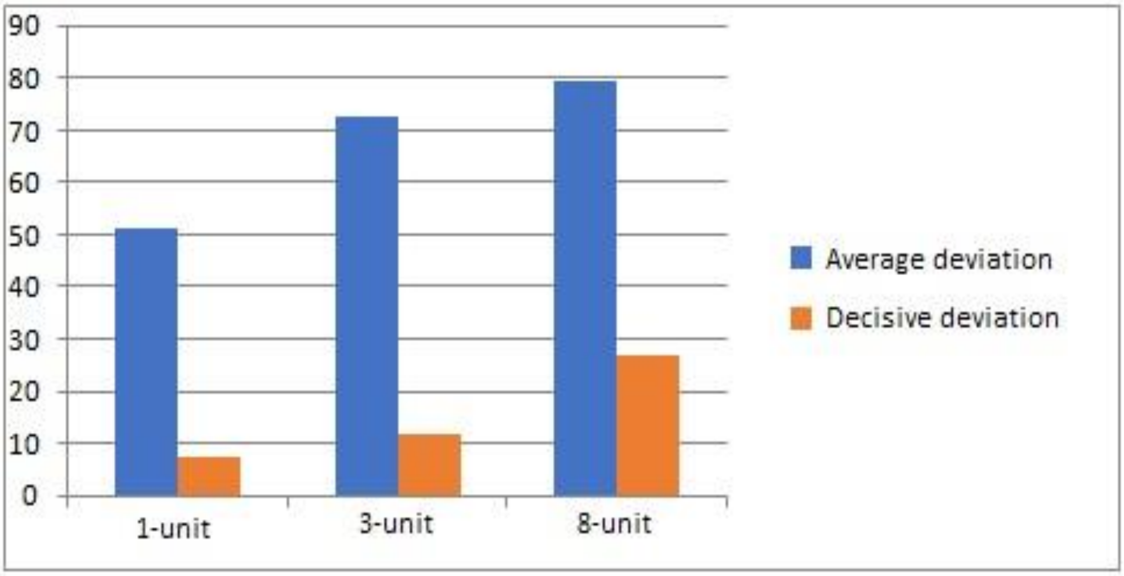

Figure 4: Graphic representation of the deviation of 3D and milled samples with aspect to the size of work in [µm]

The research hypothesis assumes that 3D printing technology is more accurate than milling technology. The hypothesis was verified using F-test and T-test statistical tests. Initial stl. files were compared to works produced by 3D printing and CNC milling technology.

When comparing the deviations of single crowns, the resulting T-test value is $p=0.003143$ (<0.005). When comparing the deviations in the set of three-unit bridges, $p=0.00007$ (<0.005) and for eight-unit works, $p=0.00017$ (<0.005). This means that at the significance level of 0.05 we reject the zero hypothesis about the equality of mean values. Thus, a statistically significant difference was confirmed between the technologies. Based on the available production technologies, materials and devices used to produce samples for the purposes of this study, it can be concluded that structures made by 3D printing are more accurate than works made by milling technology.

2.3. Evaluation of sample density

By pycnometry testing sample, we obtained real density values of the individual samples. These values were compared with the theoretical density that each material has given by the manufacturer. For cast samples from the material "Heraenium PW" the density is 8.9 g/cm³, for the material "Starbond Easy Powder 30" used for 3D printing it is 8.5 g/cm³ and for the milling material "Ceramill Sintron" it is given density 7.9g/cm³. The resulting densities of the tested samples are clearly presented in Table 8.

Table 8: Overlook of density values of tested samples

Casting	Theoretical density	Sample density	Open porosity
Sample 1	8,9 g/cm³	6,4473 g/cm³	28%
Sample 2	8,9 g/cm³	6,2305 g/cm³	30%
Sample 3	8,9 g/cm³	6,3602 g/cm³	28,6%
Sample 4	8,9 g/cm³	6,8898 g/cm³	22,59%
Sample 5	8,9 g/cm³	6,6645 g/cm³	25,12%
Average	8,9 g/cm³	6,51846 g/cm³	26,862%
CNC milling	Theoretical density	Sample density	Open porosity
Sample 1	7,9g/cm³	7,6321 g/cm³	3,4%
Sample 2	7,9g/cm³	7,7613 g/cm³	1,6%
Sample 3	7,9 g/cm³	7,607 g/cm³	3,71%
Sample 4	7,9 g/cm³	7,6969 g/cm³	2,58%
Sample 5	7,9 g/cm³	7,7209 g/cm³	2,27%
Average	7,9 g/cm³	7,6836 g/cm³	2,712%
3D printing	Theoretical density	Sample density	Open porosity
Sample 1	8,5 g/cm³	8,2345 g/cm³	3,13%
Sample 2	8,5 g/cm³	8,1835 g/cm³	3,37%
Sample 3	8,5 g/cm³	8,1837 g/cm³	3,37%
Sample 4	8,5 g/cm³	8,2014 g/cm³	3,22%
Sample 5	8,5 g/cm³	8,1669 g/cm³	3,92%
Average	8,5 g/cm³	8,1940 g/cm³	3,402%

Differences between sample densities were verified using statistical tests. In order to use the parametric test (ANOVA), the assumption that the random samples come from a population with a normal distribution must be met. This condition was verified by the Shapiro-Wilks test, at a significance level of 0.05 it was confirmed for all three technologies. The second condition, the homogeneity condition, was verified by the Hartley test, but it is not fulfilled at the 0.05 significance level.

A non-parametric form of ANOVA was used to compare the 3 technologies: Kruskal Wallis test. The result of the test is p=0.0374, which means that at the significance level of 0.05 we reject the null hypothesis about the equality of mean values. Thus, a statistically significant difference was confirmed between the technologies. Subsequently, post-hoc. the analysis revealed pairs between which there is a statistically significant difference. A statistically significant difference in sample density was not confirmed when comparing milling and 3D printing technology, p=0.72674 (<0.005). Samples produced by classic technology show the highest value of porosity, i.e., have the lowest density. This fact can significantly affect the lifetime of prosthetic work from a mechanical point of view (Figure 5).

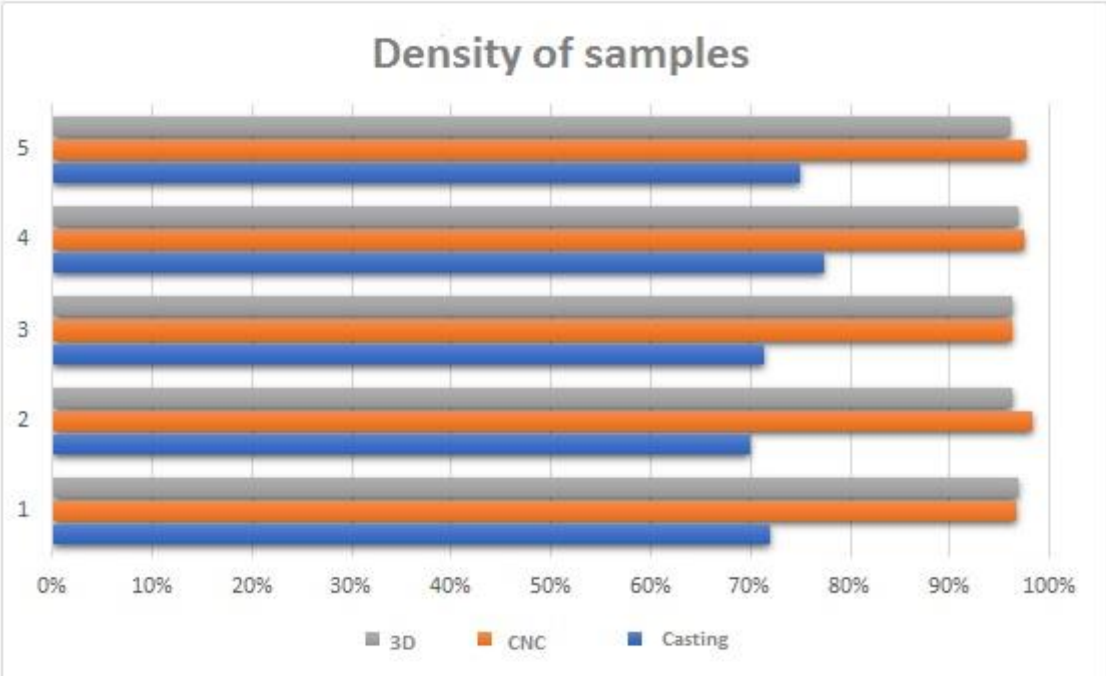

Figure 5: Graphic representation of density of dental restorations made by different technologies

The histogram shows the percentage distribution of the samples with respect to their measured density. It is evident that when using technological procedures using digital technologies, the density of manufactured dental replacements is almost identical to the density indicated in the technical parameters of the materials used in production. This also indicates the achievement of the properties of the prosthetic work, which are determined and optimal for the given material, such as e.g., surface hardness - resistance to abrasion, compressive and tensile strength, release of material molecules in the DÚ environment, etc.

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 26.862%, which is significantly more than in the technological procedures of 3D printing and milling, where the values of the average deviation reached 2.712% for milled samples and 3.402% for samples produced by 3D printing.

The assumed reason for such a significant difference between conventional method and the modern ones can lay in the very process of melting and cooling the alloy in the working process. The human factor can also have a significant impact on the quality of alloy, i.e., non-compliance or alteration of the work procedure.

3. Discussion

There are countless methods to determine the accuracy of prosthetic work. The basic factor in comparison study is processing the data under the same conditions and the creation of a sufficiently large set of data obtained under the same conditions that can be used for evaluation purposes.

For the purposes of this work, we used initially and in a back scan for all samples the same scanner and this created a sufficiently extensive database of scans that could be relevant to compare. Work procedures were strictly followed. In the production of metal structures by casting method, it is not possible to achieve complete accuracy and completely identical repetition in the creation of the same structure (each modeled individually by hand), therefore the samples produced by this method were used only as a reference for mutual comparison and were not further included in the evaluation of dimensional accuracy done by software. Despite the fact that with the additive and subtractive method the production process is digitalized and fully automatic, and the samples were made on the basis of one common stl. model, several factors could influence the data obtained.

The first could be the deviation in accuracy of the scanner used in initial scanning and also back scanning of the manufactured structures. Our Scanner: Arti S900 from ZirconZahn has a 10 µm deviation given by manufacturer. Another factor may be the way the software transforms the scanned data into a 3D model, but also the accuracy of the machines used to produce samples from CAD data. The accuracy specified by the manufacturer for the Mlab Cusing R device is 20 µm, for the Ceramill Motion 2 device used for the subtraction method, it is approximately 20-60 µm, but it also depends on the diameter of the manufactured object or the thickness of its walls and the diameter of the selected machining tool. In the production of samples, a new tool was used for each process in order to exclude the occurrence of inaccuracy caused by tool wear and the inability of the instrument to compensate for this phenomenon. In order to exclude differences in the produced samples during milling, the same shape and length of the tool were always used.

Initial data was gained by scanning a plaster working model of intraoral situation. In order to exclude the inaccuracy of the obtained data, plaster with a low reflection was used, and a layer of matting spray intended for dental scanners was applied to all scanned metal objects [8-10].

When determining the density of the material, samples made by all three technologies were evaluated, i.e., also samples made by casting, where the individual shape of the samples was not a factor for which they could not be included in testing and compared with other technologies. Each measurement was automatically repeated 10 timesfor each sample to confirm the correctness of the measurement.

Currently, any source is not providing an exact number of data determining the size of the marginal gap, which would be considered optimal for specific technology. For constructions made with additive SLM technology, more data are given in the literature, from 40- 120 µm, the value of 40 µm is most often found for single-member work [11-18]. Also, the value of the size of the marginal gap for restorations made by the subtraction method varies in the literature, we can meet values from 50 µm up to 200 µm in larger works, the most often given value as 60 µm is acceptable for a marginal gap with a one- to three-unit restoration [11][13][15-18]. All technologies are moving forward through development, and we can assume that the accuracy of replacements can even now approach the lower limits stated in the literature, thus enabling the production of long-lasting dental replacements.

4. Conclusion

Based on the obtained data and their analysis, it can be concluded that fixed dental restorations produced by SLM 3D printing technology are more accurate compared to the same restorations produced by CNC milling. It also follows from the obtained data that structures produced by 3D printing and CNC milling have a final density very close to the optimal density of the alloy provided by the manufacturer. It is therefore possible to state that by using both of these technologies in the production process, we can achieve equally mechanically satisfying dental structures.

From the obtained data for samples produced by casting, it can be concluded that the use of this technology in the production of fixed dental restorations results in less durable and less morphologically satisfactory fixed dental structures. All these conclusions apply only to fixed frameworks made by materials and device used in this study.

By summarizing the available literary sources and analyzing the data obtained from this work, the use of modern technologies in the production of dental fixed replacements appears to be a much more effective method compared to the conventional casting method. Additive technology achieved the best results, followed by subtractive technology, and the conventional casting method finished in last place. And this confirms the established research hypothesis of this study, which assumed that 3D printing technology is more accurate than milling technology. The hypothesis was also confirmed statistically.

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