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Study the precision of fixed partial dentures of Co-Cr alloys cast over 3D printed prototypes

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ABSTRACT

Purpose: of this paper is to investigate the accuracy of Co-Cr dental bridges, manufactured using 3D printed cast patterns.

Design/methodology/approach: Four-unit dental bridges are fabricated from the alloys *i-Alloy* and *Biosil-f* by lost-wax process. The polymeric cast patterns are 3D printed with different layer's thickness (13 µm, 35 µm and 50 µm). Two 3D printers are used: stereolithographic "*Rapidshape D30*" and ink-jet "*Solidscape 66+*". The geometrical and fitting accuracy as well as the surface roughness are investigated.

Findings: It is established that Co-Cr bridges, casted from 3D printed patterns with 50 µm layer thickness, characterize with the largest dimensions – 3.30%-9.14% larger than those of the base model. Decreasing the layer thickness leads to dimensional reduction. The dimensions of the bridges, casted on patterns with 13 µm layer thickness, are 0.17%-2.86% smaller compared to the primary model. The average roughness deviation *Ra* of the surface of Co-Cr bridges, manufactured using 3D printed patterns, is 3-4 times higher in comparison to the bridge-base model. The greater the layer thickness of the patterns, the higher *Ra* of the bridges. The silicone replica test shows 0.1-0.2 mm irregular gap between the bridge retainers and abutments of the cast patterns and Co-Cr bridges.

Research limitations/implications: Highly precise prosthetic constructions, casted from 3D printed patterns, can be produced only if the specific features of the 3D printed objects are taken in consideration.

Practical implications: Present research has shown that the lower the thickness of the printed layer of cast patterns, the higher the dimensional accuracy and the lower the surface roughness.

Originality/value: The findings in this study will help specialist in dental clinics and laboratories to choose the right equipment and optimal technological regimes for production of cast patterns with high accuracy and low surface roughness for casting of precise dental constructions.

Keywords: Materials, Biomaterials, 3D printing, Cast patterns, Co-Cr dental bridges

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BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

1. Introduction

Since the beginning of the last century prosthetic constructions of Co-Cr alloys are being fabricated through casting of wax patterns. However, the lost-wax technique is laborious and does not guarantee high quality of the final restoration because of the multiple handmade manipulations. During the 70's of the 20th century the CAD-CAM systems are being implemented in the dental offices and laboratories. The CAD unit generates virtual model of the object, upon which the CAM unit manufactures the construction itself [1,2]. According to the machine, included into the CAM unit, there are different possibilities for production of the objects: via subtraction of material (milling, ultrasound milling and laser "milling") or via addition of material (Selective Electron Beam Melting (SEBM), Selective Laser Sintering (SLS), Selective Laser Melting (SLM) [2,3]. The CAD-CAM systems present high efficiency of the process and provide high accuracy of the dental constructions. The enclosure of additive process to the CAM unit guarantees production of objects with complex shape from various materials with minimum waste material. The most frequently implemented additive technologies in the field of dental medicine are Stereolithography (SLA), Fused Deposition Modelling (FDM), Selective Electron Beam Melting (SEBM), Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and Ink-Jet Printing (IJP) [1,2,4-6].

Using the additive technologies wax/polymeric patterns for casting can be produced from generated 3D virtual models by laser assisted or Digital Light Projection (DLP) SLA, FDP and IJP. The type of the additive manufacturing process, the parameters of the technological regimes and the properties of the materials used influence mainly the geometrical and adjustment accuracy of the cast patterns as well as its surface roughness [7-9], which defines the accuracy and surface quality of the cast dental constructions. As with any additive manufacturing process, the layer's thickness, the position of the object towards the print direction and the optical properties of the polymers (in SLA) have a decisive effect on the object's accuracy. The thinner the layer and the lower the angle to the print direction, the lower the surface roughness, the higher the resolution and the dimensional accuracy, but the longer the production time [8,10].

The technology for production of prosthetic constructions by casting of 3D printed patterns is pretty new. The work of the 3D printing machines is based upon different technological processes and huge variety of materials. The peculiarities of the technological process and the material, which is used, influence the quality of the cast pattern and thus the casting process itself and the quality of the final object also. The data about the accuracy and the quality of the objects, manufactured with 3D printer, is contradictory and insufficient. The purpose of the present article is to study the accuracy of dental bridges from Co-Cr alloys, casted from 3D printed patterns, by evaluating their accuracy of dimensions, adjustment and roughness.

2. Experimental methods

2.1. Materials and samples manufacturing

Three groups of samples – four-unit dental bridges are fabricated through centrifugal casting from Co-Cr alloys. The bridges of the first group are cast from the alloy *Biosil-f* (Co-64.8, Cr-28.5, Mo-5.3, Si-0.5, Mn-0.5, C-0.4 mass %) by using cast patterns, manufactured with 3D printer *Solidscape 66+*, working on the principle "drop on demand jetting", a variety of IJP. The objects are printed with 13 µm layer thickness. The bridges from the second and third group are cast from *i-Alloy* (Co-64, Cr-30, Mo-5, C-0.5 mass %) and patterns, printed on *Rapidshape D30.* This printing machine is based on the process of DLP SLA. The constructions from the 2nd group are printed with 35 µm layer's thickness, and those from the 3rd group with 50 µm. The cast patterns are fabricated from specific materials according to the type of the 3D printer: wax-like polymer *Indura Cast* for *Solidscape 66+* and polymeric material *NextDent Cast* for *Rapidshape D30*. The cast patterns are produced upon 3D virtual model, generated by scanning of four-unit bridge. This base model is cast from the Co-Cr alloy *Biosil-f*, using a conventional wax pattern. The casting mold is made of *Sherafina rapid* investing material. The casting process of the samples is maintained according to the instructions of the producers of Co-Cr alloys and materials for 3D printed cast patterns. The base model and all the samples after the casting undergo mechanical cleaning and blasting for 8 s with corundum (Al_2O_3) with size of the particles 250 µm.

2.2. Dimensional accuracy measurements

The geometrical accuracy of the external dimensions of the bridges is studied through measurements of the connections between the bridge retainers and the pontics (*a1, a2, a3*), width of the pontics (*b1, b2*) and length – *L* of all manufactured bridges [11]. Three samples of each group are measured. The average values of the dimensions *a, b, L* as well as their maximum deviations are calculated via *Excell* software.

2.3. Fitting accuracy test

The fitting accuracy is investigated by replica test with silicone wash impression material. The fitting of the margin of the prosthetic constructions over the gypsum model is measured. The gap between the bridge retainers of the abutment teeth on the working cast is relative to the thickness of the silicone impression layer between them [11]. The space is measured in 6 points which are in the middle of: the medial/distal (Ap, A_M), the vestibular (Bp, B_M) and the lingual (Cp, C_M) surface of the bridge retainers. At first, the thickness of the wall of the metal framework together with the silicone layer is measured, and then the thickness of the metal wall only. The thickness of the silicone layer itself, i.e. the distance between the gypsum model and the bridge, is calculated by subtraction between the values of the above measurements.

2.4. Surface roughness measurements

The surface roughness is studied out by profile meter *Taylor Hobson Surtronik 3*. The average arithmetic deviation *Ra* of the surface roughness is measured on the vestibular surface of the second premolar of the bridge constructions because there the longest straight area is found [11]. The surface roughness is studied in 10 points in three bridges of each group and the average value of *Ra* is calculated. The surface morphology is investigated by optical microscopy *Olympos SZ51*.

3. Results and discussion

3.1. Dimensional accuracy

The average values of the dimensions of the polymeric cast patterns and the bridge constructions, fabricated of them, are shown in Fig. 1. The dimensions of the patterns are less than those of the bridges, casted from Co-Cr alloys. The smallest dimensions are presented by the patterns, printed with 35 µm thickness of layer, followed by those with 50 µm. Their values are greater than those of the bridge-base model. The same tendency is observed among the bridge constructions. It is clearly visible in Fig. 2 that the dimensions of the Co-Cr bridges raise with the enlargement of the thickness of the layer of the patterns, no matter of the type of the 3D printer and the alloy. The most accurate are the bridge samples, manufactured of patterns, printed with layers of 13 µm. The deviation of their dimensions from those of the bridge-base model varies between 2.86% and 0.55% (Fig. 3). The bridge samples, casted from patterns with thickness of the layer 50 µm, show the greatest dimensions. They are bigger than the dimensions of the bridge-base model with 3.30% up to 9.14%. No matter of the layer's thickness of the patterns, the type of the 3D printer and the alloy, the length *L* of the cast patterns and of the Co-Cr bridges is less than the length of the bridge-base model with 0.17%-0.38%.

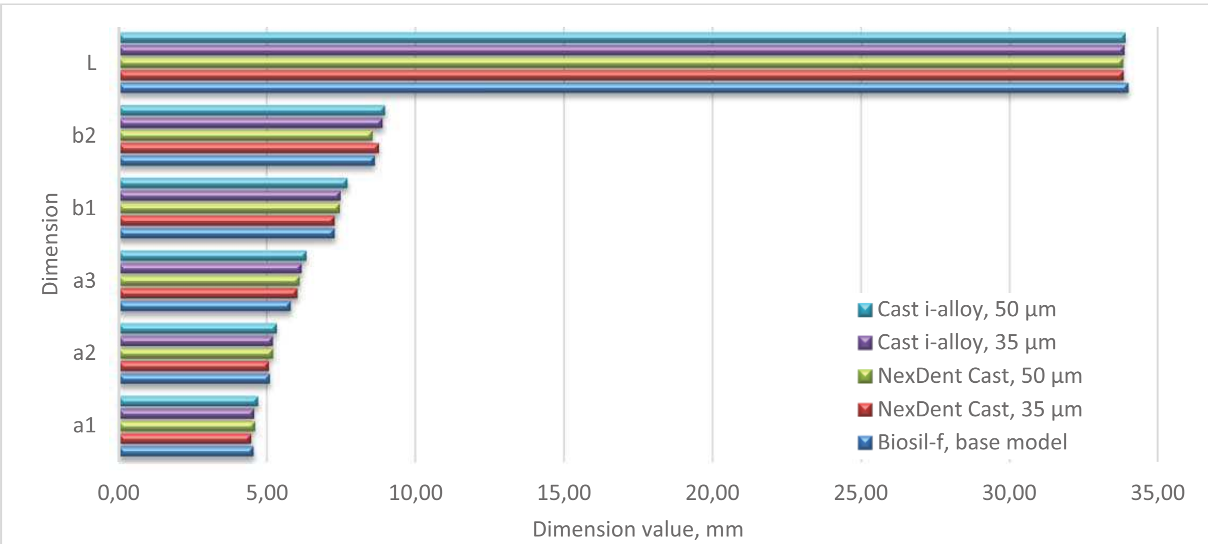


Fig. 1. Dimensions of cast bridges and polymeric cast patterns, printed with different layer thickness

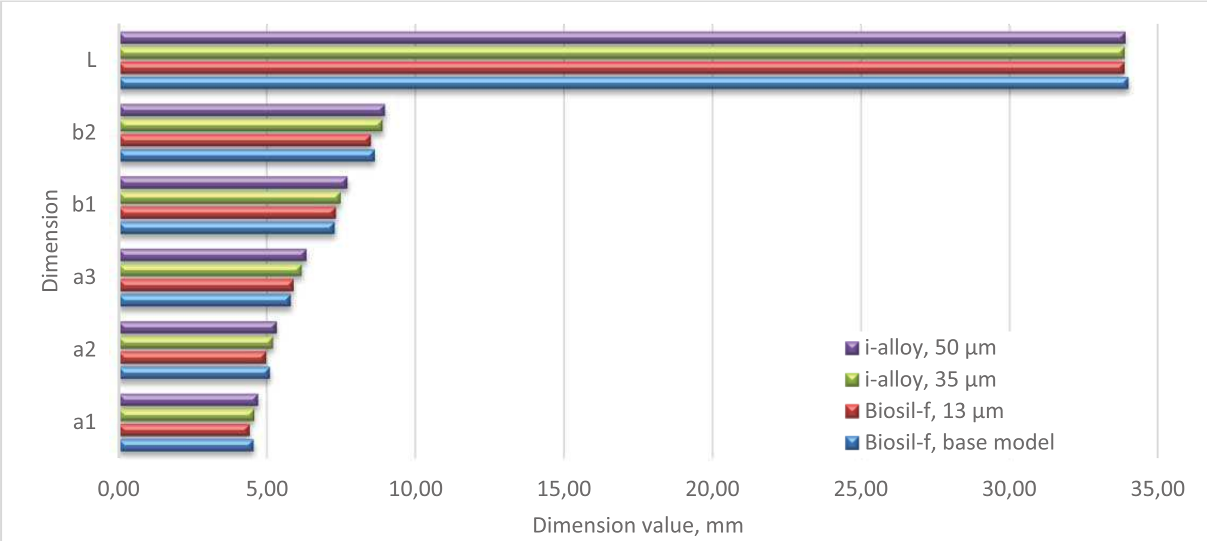
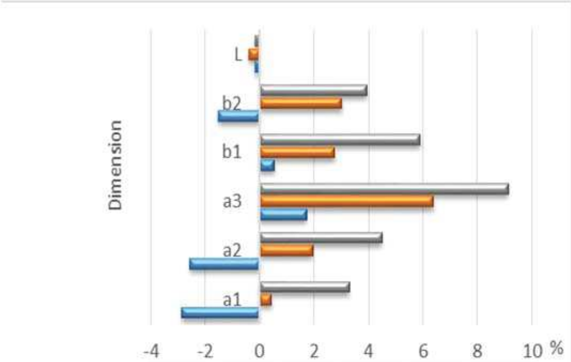


Fig. 2. Dimensions of cast bridges, manufactured using 3D printed cast patterns with different layer thickness



	a1	a2	a3	b1	b2	L
i-alloy, 50 µm	3,30	4,50	9,14	5,90	3,94	-0,17
i-alloy, 35 µm	0,44	1,96	6,38	2,75	3,01	-0,38
Biosil-f, 13 µm	-2,86	-2,55	1,72	0,55	-1,51	-0,17

Fig. 3. Difference of the dimensions of dental bridges with that of the base model

The enlargement of the dimensions of the 3D printed patterns, compared to those of the bridge-base model, proves the results of our earlier researches [11]. The dimensional increase among the cast patterns, printed with recommended by the producer 50 µm thickness of the layer, is 1.51%-3.45%. It concerns the dimensions in the building direction of the object – *Z*. Having in mind that a resin material is applied, most likely, it is a result of incomplete polymerization within the depth of the layer during the process of DLP SLA [11]. Many authors prove that the horizontal axis *X* and *Y* and the vertical axis *Z* have influence upon the dimensions during the SLA process [12,13]. Deformations mainly occur along the axis of building *Z*, causing shrinkage and step effect, which decreases the accuracy along axis *Z* or along directions, inclined towards *X, Y* and *Z* axis [14,15]. Therefore, the features of the 3D printing process should be taken in consideration in manufacturing of cast patterns and the virtual model should be designed such way that its dimensions has to compensate the dimensions of final construction.

3.2. Fitting accuracy

The silicone layer's thickness in different points of the marginal area of the premolar and molar retainers of the cast patterns, made of *NextDent Cast*, is shown in Fig. 4. No matter of the thickness of the printing layer of the pattern, a gap of 0.1-0.2 mm is observed between the retainers and the dies on the gypsum model. It is irregularly distributed - mainly in the molar retainer in the lingual, oral, as well as in the distal area along the length of the bridge. The distance between the premolar retainer and the gypsum die is observed only in the oral area. The irregularity and the value of the gap remains 0.1-0.2 mm even after casting of the bridges (Fig. 5). The gap along the bridges, among 3 of the samples, in the point A_P is 0.1 mm, and in the point A_M is 0. The rest 2 samples show no distance in these points which means that they are in contact with the surface of the gypsum model. In most of the samples, when studied in direction, perpendicular to the length of the bridge, if a vestibular gap is found in the points B_P and B_M, then no lingual gap is present in the points C_P and C_M and vice versa.

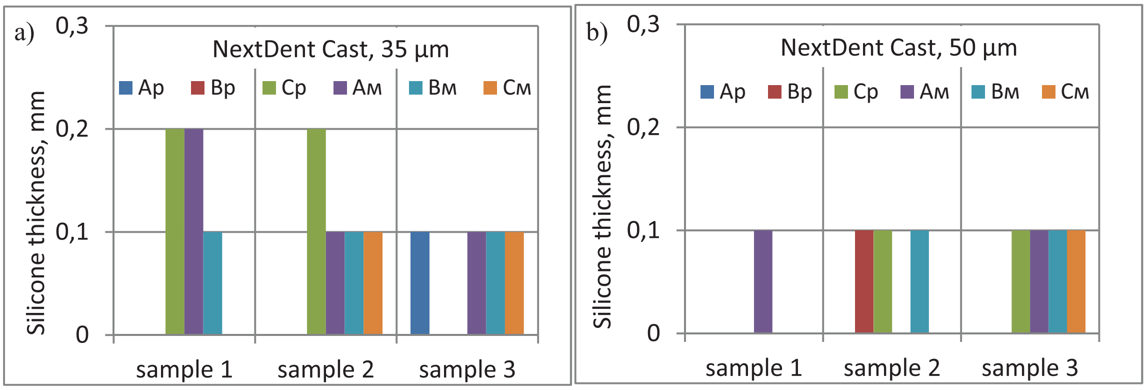


Fig. 4. Thickness of the silicone layer during measuring the adjustment accuracy of the polymeric cast patterns

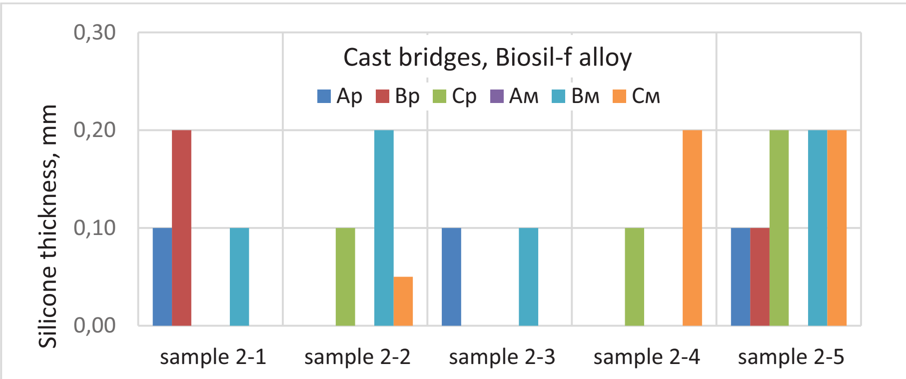


Fig. 5. Thickness of the silicone layer during measuring the adjustment accuracy of the cast bridges of *Biosil-f* alloy

The uneven gap between the retainers of the Co-Cr bridges and the gypsum dies is most likely a result of deformations of the cast patterns and deformations, obtained during the casting process. The deformations of the cast patterns are determined by the specific features of their production process – DLP SLA and drop on demand jetting. Main factors, influencing the quality of the objects, fabricated via SLA, are the amount of heat in the polymerization process, the shrinkage and the inner tensions [12,16,17]. They can cause deformations of the object, which are transferred to the Co-Cr cast construction. A new technology of printing is implemented in the machine *Solidscape 66+*: Smooth Curvature Printing (SCP), which provides high accuracy and smooth surface of the objects [18]. The producer's data show that the material, which is used, is thermoplastic and does not shrink. It is very appropriate for casting because it has low melting temperature – 105-115°C, zero thermal enlargement and burns out completely [19]. Contrary to the expectations, the distance between the retainers of the casted bridges and the dies is still uneven, which is probably a result of the specific features of the casting process and following cooling down.

3.3. Surface roughness

The data about mean arithmetic deviation *Ra* of the roughness of the polymeric patterns and the Co-Cr bridges, fabricated from them, are shown in Fig. 6. The values of *Ra* of the patterns are within the interval of 2.18-3.24 µm (Fig. 6-a). They are 2-3 times higher than *Ra* of the bridge-base model (Fig. 6-b). The greater the thickness of the layer of 3D printing, the greater the surface roughness of the final objects. The roughness of the bridges, cast from the 3D printed patterns, is 3-4 times higher compared to the bridge-base model (Fig. 6-b) which is cast from conventional wax pattern. Raising of the layer's thickness of the 3D printed patterns raises the roughness of the Co-Cr bridges. When a pattern, printed with 13 µm layer, is used, *Ra* of the bridge construction is 3.39 µm. When patterns are printed with 35 µm and 50 µm layer's thickness, the roughness of the bridges is greater: *Ra*=3.69 µm and 4.03 µm respectively.

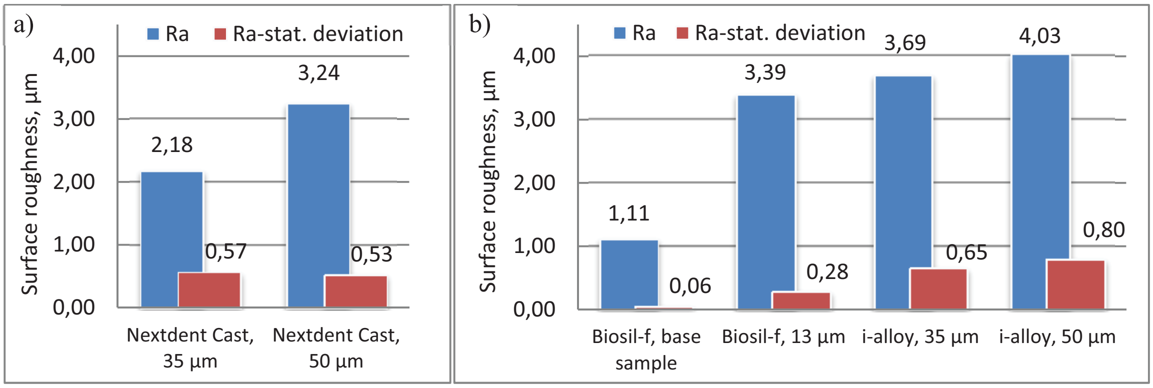


Fig. 6. Average arithmetic deviation *Ra* of the surface roughness of polymeric cast patterns – a) and cast dental bridges – b)

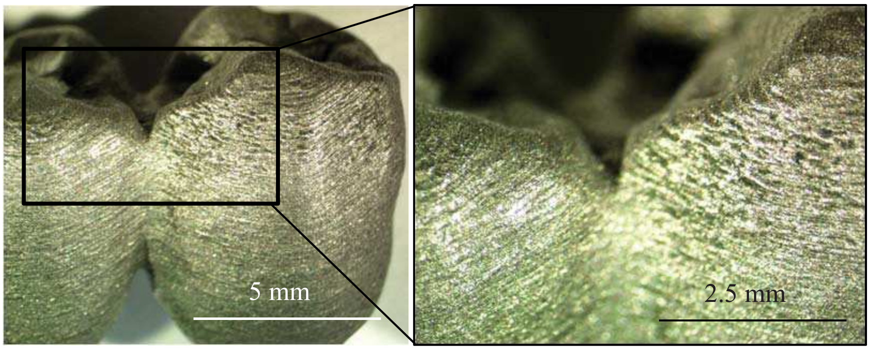


Fig. 7. Surface morphology of Co-Cr bridges, cast on patterns, 3D printed with 13 µm layer thickness

The surface morphology of Co-Cr bridges, cast using patterns, 3D printed with 13 µm layer thickness is shown in Fig. 7. It is clearly seen that the single layers of the polymeric patterns, 3D printed even with the lowest layer thickness, remain on the metal surface after the casting, cleaning and sandblasting.

One of the main disadvantages of the additive technologies is the high roughness of the objects, as well as the visibility of the building layers on the surface [2,3,7,8]. The mentioned disadvantages are directly connected to the layer's thickness and to the angle of inclination towards the building direction [8,10,14,15]. Respectively, increasing of the roughness of the cast with the increasing of the layer's thickness of the 3D printed pattern is relevant. The greater roughness of the cast constructions, in comparison to the patterns, is determined not only by the size of the investment particles and the specific features of the casting process, but also by the following sand blasting. Despite the mechanical treatment after casting, the building layers remain visible in some areas of the bridges even when minimum thickness of 13 µm or 35 µm is used.

4. Conclusions

The present article concerns study of accuracy of dimensions, adjustment and surface roughness of 4-unit Co-Cr bridges, fabricated with 3D printed patterns.

It is established that Co-Cr bridges, casted from 3D printed patterns with 50 µm layer thickness, characterize with the largest dimensions – 3.30%-9.14% larger than those of the base model. Decreasing the layer thickness leads to dimensional reduction. The dimensions of the bridges, casted on patterns with 13 µm layer thickness, are 0.17%-2.86% smaller compared to the primary model. The average roughness deviation *Ra* of the surface of Co-Cr bridges, manufactured using 3D printed patterns, is 3-4 times higher in comparison to the bridge-base model. The greater the layer thickness of the cast patterns, the higher *Ra* of the bridges. The silicone replica test shows 0.1-0.2 mm irregular gap between the bridge retainers and abutments of the cast patterns and Co-Cr bridges.

Highly precise prosthetic constructions, casted from 3D printed patterns, can be produced only if the specific features of the 3D printed objects are taken in consideration.

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Additional information

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