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Accuracy of polymeric dental bridges manufactured by stereolythography

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ABSTRACT

Purpose: Purpose of this paper is to investigate the accuracy of dental bridges produced via digital light projection stereolithography process.

Design/methodology/approach: 3D printer Rapidshape D30 was used for manufacturing of two groups of samples – temporary four-part bridges and cast patterns for permanent bridges. The temporary bridges were made of NextDent C+B polymer, while the cast patterns - of NextDent Cast. The samples were manufactured with different layer's thickness (0.035 mm and 0.050 mm). The geometrical and adjusting accuracy were investigated by measuring of the samples' dimensions and silicone probe, while the surface roughness was studied out by profile meter and optical microscopy.

Findings: It was established that the dimensions of the temporary bridges and the cast patterns, printed with layer thickness 50 μm, are larger than that of the virtual 3D model with 0.1-0.3 mm. Decreasing the layer thickness to 35 μm leads to 0.29%-1.10% smaller sizes of dental bridges and cast patterns in comparison to that of the virtual 3D model. The average roughness deviation Ra of the 3D printed temporary bridges and cast patterns is larger than that of the initial model. As the surface roughness depends on the layer's thickness, the samples with 0.035 mm layer characterize with lower Ra values. The silicone probe shows that the temporary bridges as well as the cast patterns need additional adjusting in the dental office or corrections during design of the virtual 3D model and 3D printing process in the dental laboratory.

Practical implications: The stereolithography as part of CAD/CAM manufacturing process characterizes with high accuracy as a whole. But present study reveals that additional adjusting or preliminary corrections of the design of 3D printing process are needed for dental constructions produced by SLA.

Originality/value: The geometrical and fitting accuracy as well as the surface roughness of dental bridges, produced by stereolithography were evaluated. The data, shown in the present study, will help dentists and dental technicians to precise the manufacturing regimes for production of dental constructions with high accuracy.

Keywords: Biomaterials; Additive technologies; Stereolithography; Dental bridges

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The use of additive technologies begins in the 80's of the past century when C.W. Hull develops the process of stereolithography-the first 3D printing technology [1]. The earliest implementations of these technologies are mainly for production of prototypes and cast patterns. During the process of stereolithography a concentrated beam of UV light focuses over the surface of a reservoir full of liquid photopolymer. As the light beam draws the object over the surface of the liquid, a layer of the monomer polymerises or cures at each determinate time period. Thus the product is being built up layer by layer until the final shape is obtained [2-4].

In the very beginning the stereolithography is implemented in the medicine and dentistry for fabrication of physical models of the human anatomy [5], for planning of surgery procedures and construction of custom implants. In the present time this process is being applied for manufacturing of denture bases, custom trays, models, including orthodontic models, surgical guides in implantology, provisional crowns and bridges, resin patterns for casting of metals and alloys [2,3]. The latest generation printing machines possess high accuracy 25 μm-29 μm. This parameter depends mainly on the optical properties of the applied resin, the thickness of the polymerisation layer and the type of the light source [4-7].

Ishida Y. and Miyasaka, T. [8] investigate the dimensional accuracy of full coverage crown prototypes for casting, manufactured on four different printers based upon the principle of: stereolithography via laser beam and concentrated UV beam, fused deposition modelling and inkjet printing. The authors establish that in all types of printing machines the internal and the external diameters of the full crowns are smaller than those of the 3D models which is possible to compensate by 3-5% enlarging of the dimensions of the virtual object. The surface roughness is highest in the crowns fabricated by fused deposition modelling, and lowest-when stereolithography with laser beam is used. This statement is proved also by the researches of Bliznakova Kr. [5] and Braian M. [9].

Dikova T. et al. [6] study the accuracy of standard cubic samples with dimension of the wall 5 mm, manufactured from different polymers by the printing machine Rapidshape D30, working on the principle of digital light projection stereolithography. The samples are printed into two dimensional orientations towards the basis - a wall, parallel to the basis and edge, parallel to the basis. They establish that in both printing positions the dimensions of the printed objects are bigger than those of the models but the least diversion is found among the cubic samples, made of the polymer NextDent SG, indicated for production of surgical guides. The material has the layer's thickness of 0.050 mm, but for its transparency the polymerisation process goes entirely. Among almost all of the polymers the surface roughness is smaller when the cubs are printed horizontally in comparison to those, printed in tilted position (average values of Ra=0.46-2.69 μm and Ra=1.74-2.77 μm respectively). The roughness of the samples, printed with inclination of 45o, depends on the thickness of the polymerisation layer.

As the 3D printers, working on the principle of digital light projection stereolithography, such as Rapidshape D30, are of the newest generation, the information about their application for manufacturing of dental constructions is still insufficient. The aim of the present paper is to evaluate the geometrical and adjustment accuracy as well as the surface roughness of temporary dental bridges and cast patterns for permanent dental bridges made of different polymers and to give practical advices for improvement the accuracy of 3D printed objects.

2. Experimental methods

2.1. Materials and samples manufacturing

Two groups of samples-temporary four-unit bridges and cast patterns for permanent bridges (Fig. 1) are manufactured by digital light projection stereolithography process using 3D printer Rapidshape D30. Two polymers with different colour and optical properties, delivered by the producer, are used. The temporary bridges are printed of polymer NextDent C+B with white-yellowish colour A3.5 according to VITA shade guide. The cast patterns are made of polymer NextDent Cast which has dark-red colour. The bridges of each polymer are manufactured with different layer's thickness (0.035 mm – 5 samples and 0.050 mm – 5 samples). After 3D printing the samples are being inserted in the chamber with light source for final fotopolymerization for 30 min (NextDent C+B) and 10 min (NextDent Cast).

2.2. Dimensional accuracy measurements

The geometrical accuracy of the external dimensions of the bridge constructions is studied through measurements of the connection between the bridge retainers and the pontic, width of the pontics and length of all manufactured bridges (Fig. 2a). The maximum deviation of the dimensions as well as their average values are calculated via Excell software - a, b, L.

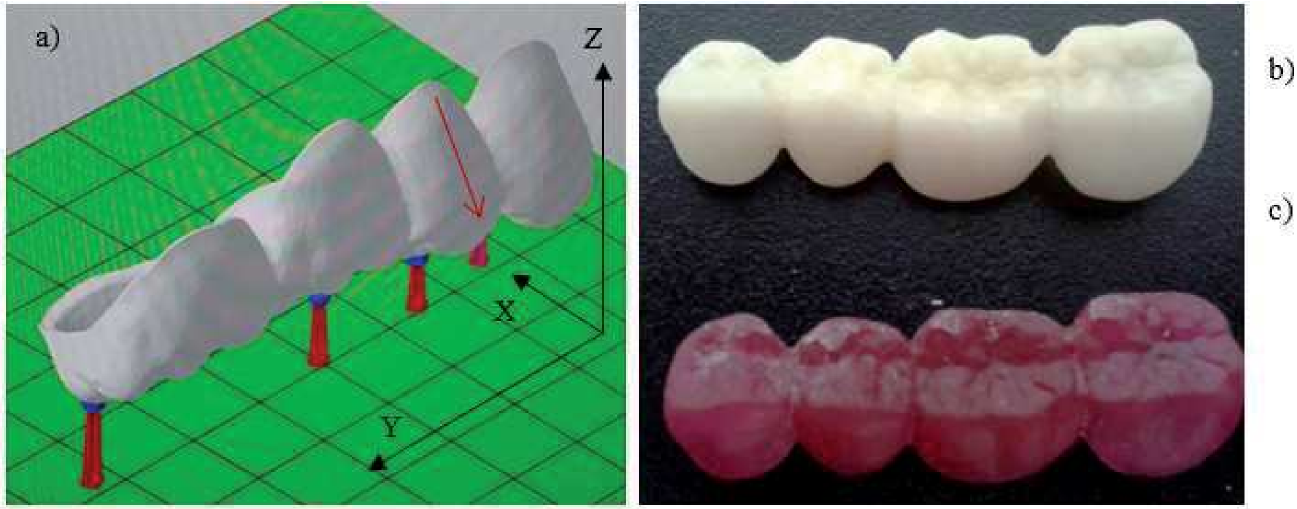


Fig. 1. Virtual 3D model – a), temporary dental bridge, – b) and cast pattern of dental bridge, – c) produced by 3D printing of polymers NextDent C+B and NextDent Cast accordingly

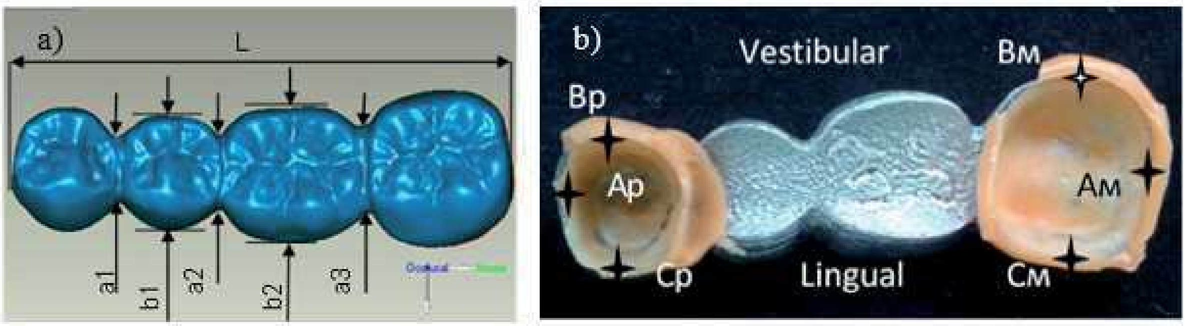


Fig. 2. Scheme of measuring the external dimensions – a) and thickness of the silicone layer, – b) in adjusting of the dental bridges

2.3. Adjustment accuracy test

The fitting accuracy is investigated by test with silicone wash impression material. The exact fitting of the prosthetic constructions over the gypsum model is measured. The distance between the bridge retainers the abutment teeth on the working cast is relative to the thickness of the silicone impression layer between them. The space is measured in 6 points (Fig. 2b) which are in the middle of: the medial/distal, the vestibular and the lingual 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. The surface roughness is studied in 10 points in 3 bridges of each group and the average value of Ra is thus found out. The surface morphology is investigated by optical microscopy Olympos SZ51.

3. Results obtained

3.1. Dimensional accuracy

The average dimensions of 4-unit bridge constructions, manufactured by stereolithography of two types of polymers, which differ in their layer thickness, are shown in Fig. 3. The samples, fabricated with lower thickness of the layer-35 µm, are smaller in sizes, compared to their virtual model. The decrease of the dimensions is within 0.29%-1.10% (Fig. 4). On the other hand, the dimensions a1-a3, b1 and b2 of the experimental objects with thickness of the layer 50 µm are higher than the virtual ones with 1.51%-3.45% (Fig. 4). The length of the bridges L is less than the virtual with 0.49%-0.53% regardless the layer's thickness and the type of the polymer. The maximum deviations of the dimensions of the samples with layer of 50 µm are higher than that of bridges with thickness of layer 35 µm (Fig. 5). A tendency of decreasing the maximum deviation of the dimensions a1, a2, b1 and b2 with the decrease of the thickness of the layer is established in both of applied polymers. The maximum deviation of the length of the bridges, which is in perpendicular direction, remains almost constant no matter of the change of the layer's thickness for both types of polymers (-0.15/ -0.20 mm).

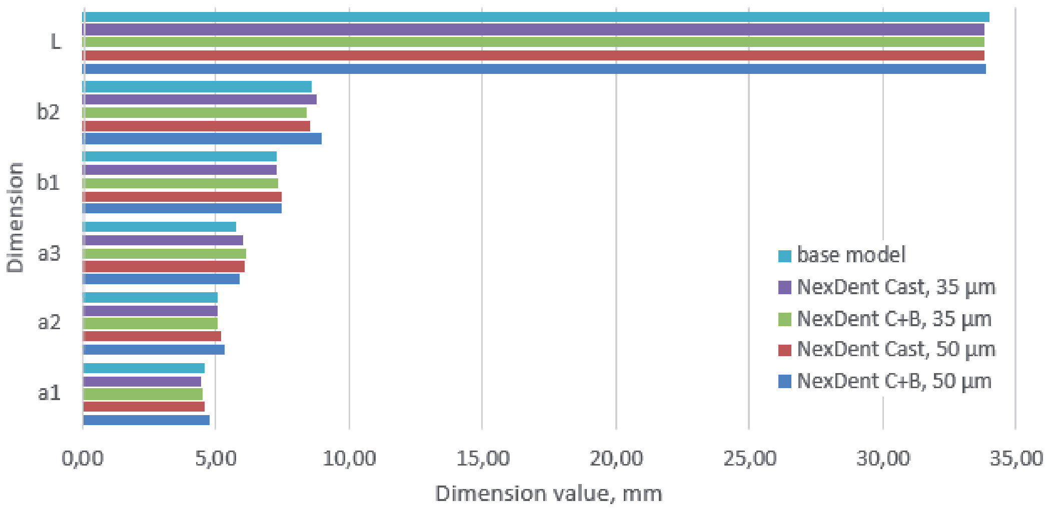
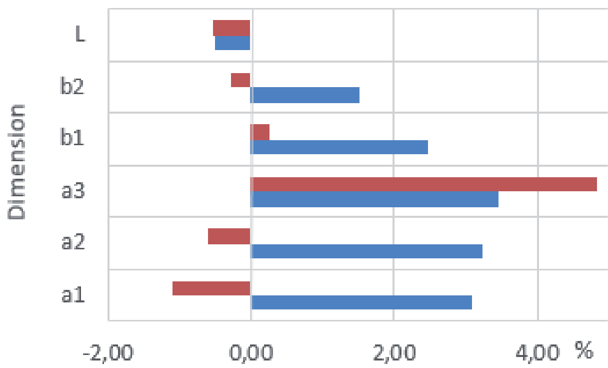


Fig. 3. Dimensions of polymeric dental bridges, produced by 3D printing



	a1	a2	a3	b1	b2	L
polymer layer 35 µm	-1,10	-0,59	4,83	0,27	-0,29	-0,53
polymer layer 50 µm	3,08	3,24	3,45	2,47	1,51	-0,49

Fig. 4. Difference of the dimensions of 3D printed polymeric dental bridges with that of the base model

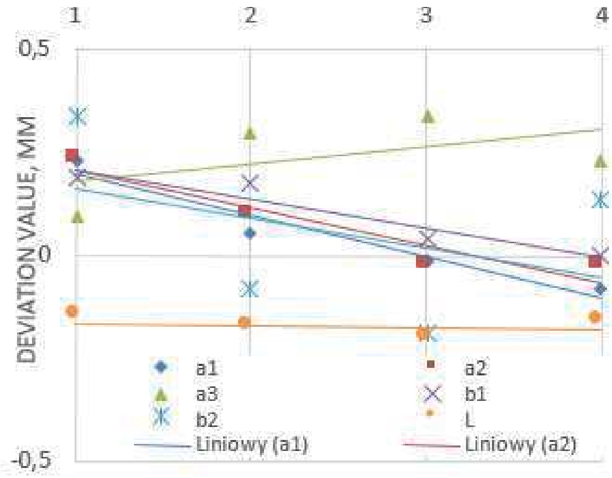


Fig. 5. Dimensions' deviations of polymeric dental bridges, produced by DLP stereolithography: 1 – NexDent C+B, 50 µm; 2 – NexDent Cast, 50 µm; 3 – NexDent C+B, 35 µm; 4 – NexDent Cast, 35 µm

3.2. Adjustment accuracy

The silicone layer thickness in different points of the premolar and molar retainers of the bridge constructions is shown in Fig. 6. It is clearly visible the different way in which the gap between the abutment and the retainer is changing regarding the type of the polymer and the thickness of the printed layer. A distance of 0.1-0.2 mm in vestibular and lingual area is found in two among the three samples, made of NextDent C+B with 50 µm thickness (Fig. 6a). However, along the bridge constructions, in the points AP and AM, the distance is 0, i.e. the three samples are fitting firmly over the gypsum model. The decreasing of the thickness of the printing layer up to 35 µm shrinks the distance between the abutments and the retainers in all points to 0. The same distance in the group of bridges, made of NextDent Cast, is 0.1-0.2 mm for both values of the layer's thickness. It is noticeably that the gap is distributed irregularly in this group of samples-mostly in the molar retainer in the lingual, vestibular and distal area along the bridge. A gap between the premolar retainer and the gypsum model is found only from the lingual side.

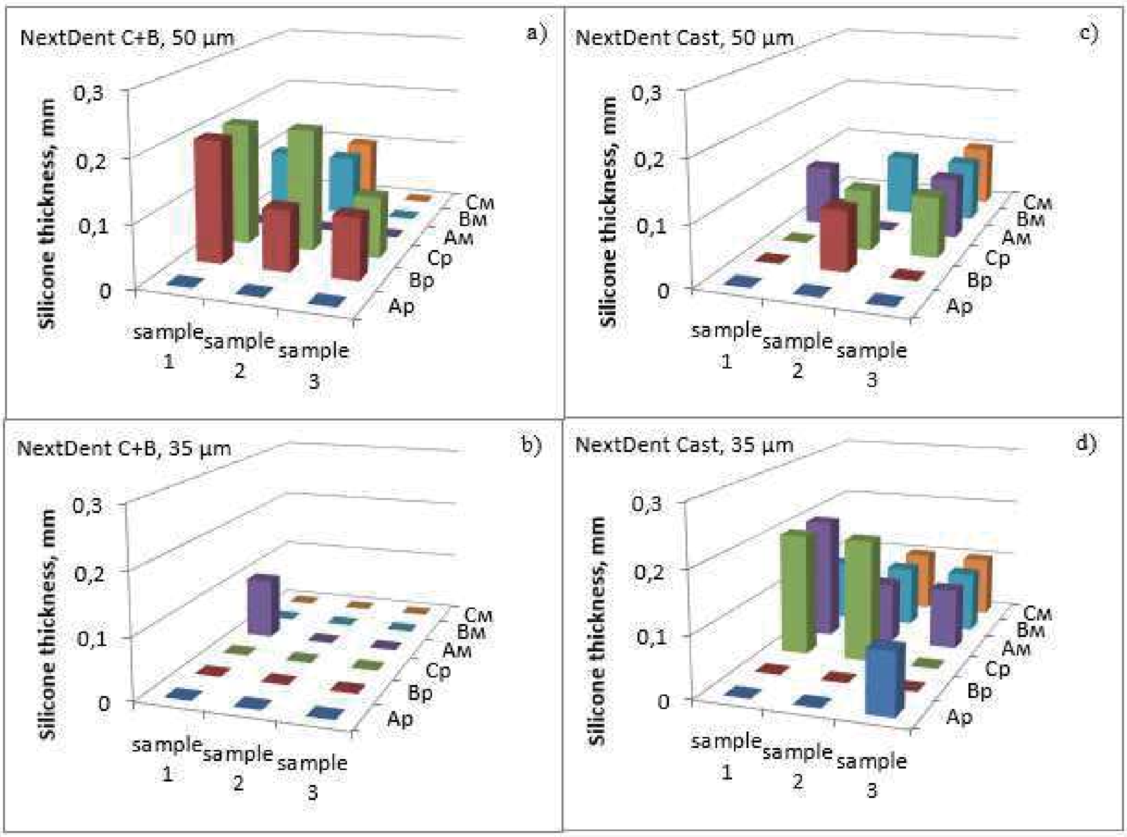


Fig. 6. Thickness of the silicone layer during measuring the adjusting accuracy of the bridges

3.3. Surface roughness

The average arithmetic deviation Ra of the surface roughness among the provisional bridges of NextDent C+B is one and the same for both values of thickness of the layer – 1.78 μm (Fig. 7). Only the statistical deviation of Ra increases from 0.42 μm up to 0.53 μm with the increase of the thickness of the printing layer. Among the cast patterns, made of NextDent Cast with thinner layer, the roughness is slightly greater than that of the temporary bridges – Ra=2.18 μm. The thicker the layer is the greater the roughness up to Ra=3.24 μm. The above statements are proved by the optical microscopy investigation of the samples' surface (Fig. 8a). A layered structure, which is specific feature of the objects built up via stereo-lithography, is well seen on the pictures.

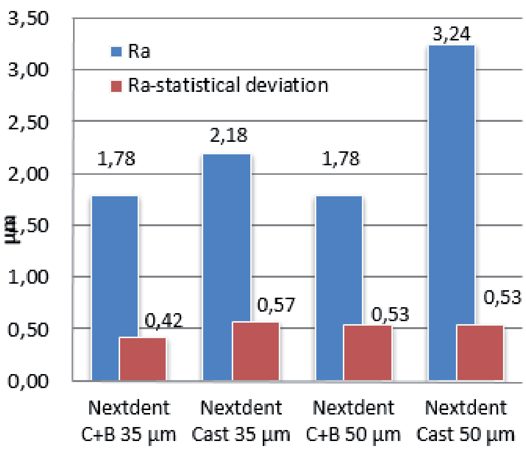


Fig. 7. Average arithmetic deviation Ra of the surface roughness

4. Discussion

The quality of the prosthetic construction is in a relation with the material and technology it is being manufactured. During the light curing process two factors mainly influence the entire polymerization-the thickness of the single layer and the optical properties of the material [10,11]. It is well known fact that the thicker the layer is and the darker the colour is the longer light exposure is needed for entire polymerization of the layer.

4.1. Dimensional accuracy

The studied samples are made of two types of polymers which differ in colour, optical properties and thickness of the structuring layer. As the dimensions in both directions of the bridges, fabricated with lower thickness of the layer (35 μm) from both polymers, are smaller with 0.29%-1.10%, compared to those of the virtual model (Fig. 3 and Fig. 4), probably the polymerization process is taking place throughout the entire thickness of the layer. The full process of polymerization explains the greater shrinkage of the dimensions of the samples which increases during the final light curing.

Among the group of bridges with larger thickness of the layer (50 μm) probably the polymerization process does not flow within the whole layer. The shrinkage is less and respectively the dimensions larger – 1.51%-3.45% more than the virtual model (Fig. 3, Fig. 4). The greater values of dimensions are in X-Z direction (Fig. 1a), where Z is the direction of the object's building up. The length of the bridges, which is the Y direction, is less than the virtual length with 0.49%-0.53% for both thicknesses of fabrication.

Therefore, the orientation of the prosthetic construction during the printing process also influences the accuracy of dimensions, which confirms our earlier researches [6]. In the Y direction, which is not the direction of printing of the samples, the constructions have almost equal shrinkage regardless the material and the thickness of layer. At the same time, in X-Z direction, which is the direction of building up of the object, the deviation of the dimensions is influenced by the layer's thickness. When the structuring is done with thinner layers the dimensions are smaller, and when the printed layers are thicker – 50 μm (thickness recommended by the producer of the investigated polymers), the dimensions are bigger than those of the virtual model. This disparity can be compensated by setting of the virtual 3D model and printing process with appropriate percentage, relevant to the shrinkage. The type of the construction should also be taken into consideration when setting the virtual object. If provisional bridges are going to be manufactured, the enlargement of the dimensions is not recommended and the 3D model should be corrected. While in cast patterns production, enlargement of the dimensions within 1.51%-3.45% is favourable, as it can compensate the shrinkage of the alloys during casting of the final constructions.

4.2. Adjustment accuracy

The smaller dimensions of the temporary bridges, made of NextDent C+B with less thickness of the layer, lead to absence of distance between the retainers and the gypsum model, which is necessary for the luting cement (Figs. 6a,b).

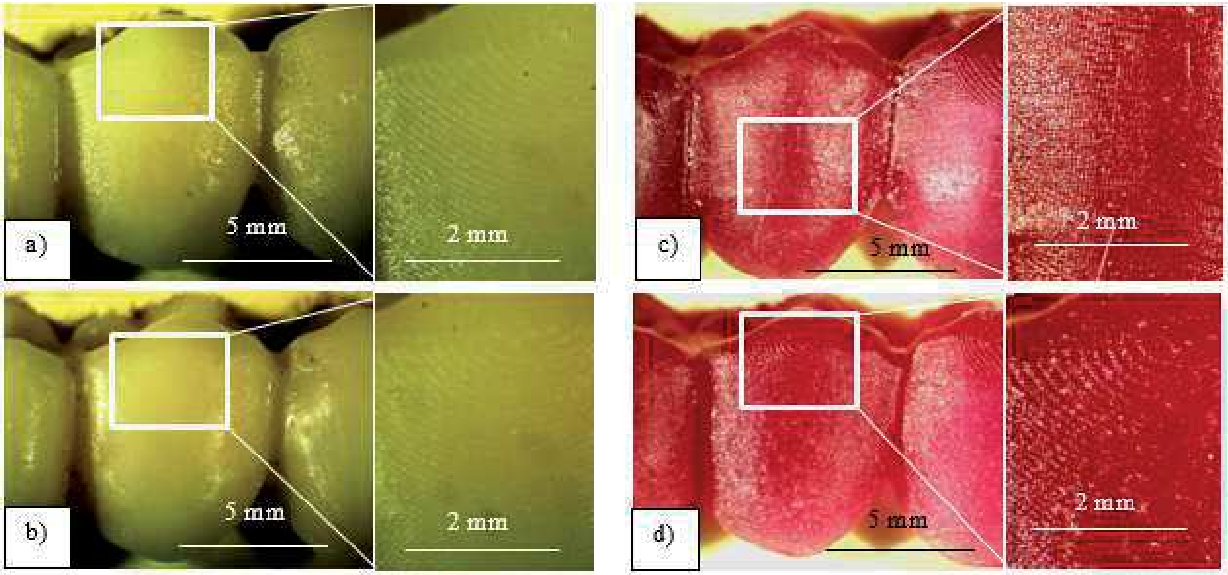


Fig. 8. Surface morphology of temporary bridges – a), b) and polymeric cast patterns – c) and d), produced with different layer thickness 35 µm – a), c) and 50 µm – b) and d)

The presence of gap mainly in the molar retainers in cast patterns, made of NextDent Cast (Fig. 6c and Fig. 6d) is a result not only of the shorter length of the bridges but also of the torsion of the constructions. As in the both thicknesses of layer a similar location of the gap is observed, it is possible to be caused by the incomplete polymerization during printing because of the dark colour of the polymer. The torsion of the construction may occur during the final polymerization due to the higher level of residual monomer in the volume, which causes higher internal stresses, as well as due to the small number of supports (Fig. 1), which cannot resist enough to these stresses.

In order to increase the fitting accuracy some measures should be taken on the process of 3D printing and on final polymerization. Adjusting of the virtual dimensions of the 3D model, way of disposition and number of supports can prevent deformations and inaccuracies. Avoiding the torsion is possible by inserting the construction over the gypsum cast during the final polymerization.

4.3. Surface roughness

The surface roughness of 3D printed constructions depends on the thickness of their layer and the angle of the surface orientation to the printing direction [4,6]. Different defects, caused by specific features of polymerization process, can also influence the surface roughness.

There are no variations in the values of average arithmetical deviation Ra of surface roughness of the bridges, made of polymer NextDent C+B, because the difference in the layers' thickness is small – only 15 µm and the angle of the measured surface towards the axis Z is not big. While Ra of the cast patterns, made of NextDent Cast, is slightly higher than those of the temporary bridges and raises with increasing of the layer's thickness. The difference in the roughness of the constructions from both polymers is probably a result of the particularities of the polymerization process regarding the different colour and optical properties of both materials.

The higher surface roughness of the cast patterns can complicate the cast process, resulting in increased roughness of the cast dental object. That is why the surface of the polymer model should be polished or treated with dissolvent before investing to decrease the roughness.

5. Conclusions

The accuracy of the dimensions, adjustment accuracy and surface roughness of 4-unit bridges, made of polymers via stereolithography technique, are studied in the present research. It is established that the orientation of the construction towards the direction of printing influences the accuracy. Dimensions, situated in the direction of layering, are bigger with 1.51%-3.45%, and those, which are not in the direction of printing, are 0.49%-0.53% smaller than those of the virtual 3D model. These disparities can be compensated during designing of the digital 3D model and the 3D printing process, taking into consideration the construction's indication-temporary bridges or cast patterns.

The inaccuracy in the geometrical dimension's cause inaccuracy of adjustment and absence of gap between the bridge constructions ant the gypsum model. Correction of the dimensions of the virtual 3D model way of disposition and number of supports will prevent from inaccuracy and deformations.

The surface roughness of the cast patterns, manufactured with regime, recommended by the producer, is relatively high Ra=3.24 μm, which can complicate the cast process and cause higher roughness of the cast itself. Pretreatment of the polymer model is necessary before the fabrication of the mould in order to decrease the level of roughness.

If no corrections are undertaken during design of the virtual 3D model and 3D printing process, the dental specialist should make additional adjusting of the ready temporary bridges and the cast dental constructions.

Acknowledgements

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