Original article

INVESTIGATION THE FITTING ACCURACY OF CAST AND SLM CO-CR DENTAL BRIDGES USING CAD SOFTWARE

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ABSTRACT:

The aim of the present paper is to investigate the fitting accuracy of Co-Cr dental bridges, manufactured by three technologies, with the newly developed method using CAD software. The four-part dental bridges of Co-Cr alloys were produced by conventional casting of wax models, casting with 3D printed patterns and selective laser melting. The marginal and internal fit of dental bridges was studied out by two methods – silicone replica test and CAD software. As the silicone replica test characterizes with comparatively low accuracy, a new methodology for investigating the fitting accuracy of dental bridges was developed based on the *SolidWorks* CAD software. The newly developed method allows the study of the marginal and internal adaptation in unlimited directions and high accuracy. Investigation the marginal fit and internal adaptation of Co-Cr four-part dental bridges by the two methods show that the technological process strongly influences the fitting accuracy of dental restorations. The fitting accuracy of the bridges, cast with 3D printed patterns, is the highest, followed by the SLM and conventionally cast bridges. The marginal fit of the three groups of bridges is in the clinically acceptable range. The internal gap values vary in different regions – it is highest on the occlusal surfaces, followed by that in the marginal and axial areas. The higher fitting accuracy of the bridges, manufactured by casting with 3D printed patterns and SLM, compared to the conventionally cast bridges is a good precondition for their successful implementation in the dental offices and laboratories.

Keywords: dental bridges, fitting accuracy, silicone replica; CAD software, 3D printing, selective laser melting

1. INTRODUCTION

The precise marginal and internal fit are one of the main criteria for the clinical success of dental restorations. [1–3] Insufficient adaptation at the crown margin results in cement solubility and plaque retention, which can cause secondary caries of the tooth structure and inflammation of periodontal tissues. [4–6] Internal adaptation is also an

important issue because the uniform luting space between the internal surface of the crown and the prepared abutment tooth will facilitate placement without compromising retention and resistance. [7] According to Specification No.8 of the American Dental Association the thickness of the luting cement film for a crown restoration should be less than 25 μm in using Type I, or 40 μm in Type II luting agents. [8] However, in the studies, examining the marginal adaptation, it was shown that the clinical fit in this range of dimensions is rarely achieved. The marginal fit of the restoration is determined by the Marginal Discrepancy (MD) of a coping [9], defined as the distance from the abutment margin to the metal coping in a straight line. [10] There is no consensus regarding the clinically acceptable limits of marginal fit of dental restorations. Most researchers agree on an acceptable, marginal discrepancy below 100 μm - 120 μm [7, 10], as values, greater than 120 μm are considered not clinically acceptable. [7, 11, 12]

The accuracy of fit of dental restorations can be evaluated *in vivo* as well as *in vitro*. The *in vivo* investigations can directly reflect the clinical results, but because of differences in the restorations geometry, environmental factors and the mastication dynamics, it is difficult to be standardized. [11] The *in vitro* studies have to imitate clinical conditions as much as possible, and the results should be easily reproduced with minimum variables, thus helping the clinical research. Two groups of methods – destructive and non-destructive are mainly used for estimation of the adjustment accuracy of dental restorations. In the only destructive method, the cemented specimens are cross-sectioned, and the marginal area is examined under a microscope. [13] The non-destructive methods include direct microscopic examination of the marginal area, silicone replica technique, laser videography, profilometry and x-ray computed microtomography. The direct microscopic method is easier, faster, and can be easily repeated, that is why it is one of the most widely used. However, the precision of the measurements is lower, because of the projection errors and difficult identifying the reference points to measure. [11, 13] As a variation of the two methods, mentioned above, an epoxy resin replica of the marginal area

instead of the area itself can be measured, which does not provide accurate results.

The nondestructive replica technique is an accurate and reliable method, which can be used as *in vivo* and *in vitro* studies for evaluating the fit of the restorations. [4, 14] This technique models the marginal and internal discrepancy between the restoration and prepared teeth with elastomeric impression materials - silicone, polyether. [1, 6, 10, 13-15] The silicone replica technique can be used for *in vivo* measurement the adaptation of the indirect restorations just before luting. [4] In clinical conditions, the force, applied on the crown, lined with light viscosity silicone, cannot be standardized. [16] The finger pressure, which any clinician can apply while cementing a crown, varies from 20 to 67 N [3, 17]. That is why in the investigation the adjustment accuracy the most researchers used the seating force in that range – 20N [6], 50N [10], 60 N [3]. It should be noticed that the differences of the applied force do not significantly affect the thickness of the silicone layer. [1, 18] After manufacturing, the silicone replica is sectioned (which provides only a limited number of gap measurements), observed and measured with microscopy. [13, 15] Different types of microscopes are used to examine the marginal discrepancies - light microscopes, stereo microscopes, digital microscopes. [11] But these devices have limitations in the presence of over-contouring margins. Most authors consider that precise results may be obtained by using scanning electron microscopy (SEM). [11, 14]

In laser videography, the light-bodied silicone replica is digitized along with the die. This method is mostly used to measure the internal gap, while it is not too reliable for identification the reference points, necessary to measure the marginal fit. [13, 19] The measuring of the marginal fit by profilometer - tool, used for surface roughness investigations, ensures only indirect measurements of the absolute marginal discrepancy [13] - the distance from the edge of the metal structure to the abutment margin [10]. The x-ray micro-tomography is considered as the most innovative technique because it provides nondestructive visualization and measurement of an object's internal structure by making multiple projections of the object and reconstructing the projections with specialized software. [10, 13, 20] The disadvantage of this technique is the low capacity of discrimination (1.8 mm) compared with optical or scanning electron microscopy. [10]

The accuracy of the measurement refers to how close the average is to the exact value. Currently, there is no standard for the optimal number of the sites, measured per crown [11]. Most of the authors accept that approximately 50 measurements for marginal discrepancy values yield clinically relevant information. [11, 14, 21]

The marginal fit values of the Co-Cr dental restorations greatly depend on the fabrication methods and, occasionally, on the alloy systems [10]. The most common technology for production of Co-Cr dental constructions is a lost-wax process, in which the metal framework is cast using hand-made wax pattern. The technological process characterizes with a lot of manual work, which is a precondition for generating of errors and lowering the denture's quality.

The implementation of the modern CAD/CAM systems and the new additive technologies in the dental offices and laboratories can extremely improve the quality of dental restorations [22-24]. Two approaches can be applied for fabrication of Co-Cr dental constructions using additive technologies. During the first one, the Co-Cr dental alloy is cast with 3D printed polymeric patterns, while during the second the metal framework is produced directly from the virtual model by selective electron beam melting (SEBM), direct metal laser sintering (DMLS) or selective laser melting (SLM).

Huang Z, et al. [1] established that the SLM Co-Cr metal-ceramic crowns were better in marginal fit, not significantly different in axial fit and less accurate in occlusal fit than that of the cast samples. Sundar MK, et al. [3] concluded that the copings of Metal Laser Sintered (MLS) Co-Cr alloy had a better marginal fit and a decrease in micro-leakage compared to the copings of Ni-Cr alloy, manufactured by conventional lost wax technique. Concerning to the gap distribution Tamac E, et al. [4] compared the clinical marginal and internal adaptations of metal-ceramic crowns, fabricated by CAD/CAM milling, DMLS and traditional casting. They established that mean marginal gap values were 86.64 μm for milling, 96.23 μm for DMLS, and 75.92 μm for casting. The gap values in the axial wall region where the higher for the three groups of samples, followed by the gap values of axio-occlusal and occlusal surface regions. The cement film thickness at the occlusal region and axio-occlusal region was higher for the DMLS crowns. Kim EH, et al. [10] found out that the marginal discrepancy of the SLM crowns (98.7 μm for 20 μm thick layer and 128.8 μm for 30 μm thick layer) is larger than the cast crowns (65.3 μm – 70.4 μm), as the marginal discrepancy increases with the increase the layer's thickness in SLM samples. Kaleli N, et al. [11] compared the marginal adaptation after fabrication of the framework, porcelain application, and cementation of metal-ceramic restorations prepared by conventional lost-wax technique, milling, DMLS and a direct powder-bed process. They observed lowest marginal discrepancy values in the crowns, prepared by the direct process powder-bed method, followed by the DMLS, milling and casting. Pompa G, et al. [12] established that the fixed dental prostheses, manufactured by SLM have a better marginal adaptation in the acceptable range. However, the cement gap characterized by irregular distribution – wider in the region of the shoulder than at the point of closure. The marginal discrepancy increased after porcelain application and cementation. As a whole, the fully digital fabrication method provided better margin fit than the conventional method. [24]

The production technology strongly influences on the accuracy of dental constructions. Because of the great variety of dental restorations as well as a lot of investigation techniques, there is not a standardized method for estimation the fitting accuracy until now. The existing methods for evaluation of dentures adaptation characterize with different accuracy. The aim of the present paper is to investigate the fitting accuracy of Co-Cr dental bridges, manufactured by three technologies, with the newly developed method using CAD software. The Co-Cr samples were

produced by conventional casting of wax patterns, casting using 3D printed patterns and selective laser melting.

2. EXPERIMENTAL METHODS

2.1. Materials and methods of samples preparation

In order to obtain samples with sufficiently good repeatability at first a master model of 4-part dental bridge was made of Co-Cr alloy „Biosil f” by the conventional casting of the hand-made wax pattern. Before manufacturing the wax pattern, the prepared teeth of the gypsum model were covered with two layers of distance lacquer, ensuring 120 µm gap for cementation of the dental construction. The bridge-master model was used for manufacturing of silicone mould for production of wax models and for generating of the virtual 3D model. Five samples of four-part dental bridges were manufactured by each of the three different technologies. The first technology was a conventional lost-wax process, in which the wax patterns were produced in a silicone mould. After that the bridges were cast by centrifugal casting of Co-Cr alloy „Biosil f” with chemical composition, given by the producer: 64,8% Co; 28,5% Cr; 5,3% Mo; 0,5% Si; 0,5% Mn; 0,4% C (wt.%). During the second technological process the bridges were cast of the same alloy, but the patterns were 3D printed of the polymer using „Solidshape 66+” system. In order to obtain maximum accuracy, the thickness of the printed layers was 0,0127mm. In the third technology, the bridges were produced directly from the virtual 3D model by selective laser melting using a SLM125 machine of the “SLM Solutions” company, Germany. The base material - metal powder of Co-Cr alloy (Co212-f ASTM F75) with the same chemical composition as that of „Biosil f” alloy was melted in layers with 0,03 mm thickness unless the desired construction was obtained. The technological regime, recommended by the manufacturer, was used.

2.2. Fitting accuracy investigation

The fitting accuracy of dental bridges, produced by the three technologies, was studied out by two methods – silicone replica test and CAD software. Before investigations, the master bridge and the Co-Cr bridges of the three groups were fitted on the plaster model. Adjustments were made with abrasive bur by an experienced dental technician to mimic clinically acceptable conditions.

2.2.1. Silicone replica test

The fitting accuracy of the bridges to the plaster model was evaluated using silicone replica of the marginal and internal areas. The replicas of all samples were manufactured with crème silicone impression material *Oran Wash* by the same dentist using the technique, similar to clinical cementation of the bridge. During the procedure, only finger pressure was applied. The thickness of the silicone replica defines the distance between the prepared abutment teeth of the plaster model and bridge retainers. The silicone thickness in 6 points (Fig. 1) of the marginal region of the bridge retainers was measured: in the middle of medial-distal, vestibular and lingual surfaces. The measurements were done by the same researcher with a calliper for metal and wax constructions with 0.1 mm accuracy. As the

thickness is too small (0.1-0.2 mm) and the silicone impression material is elastic, at first the total thickness of the metal and silicone and then only the thickness of the metal was measured. The thickness of the silicone, i.e. the distance between the bridge and the plaster model, was calculated by formula 1:

$$\delta_S = \delta_{M+S} - \delta_M \quad (1)$$

Where: δ_S is the silicone thickness, mm; δ_{M+S} is the total thickness of the silicone and metal, mm; δ_M is the metal thickness, mm.

The maximum, minimum and average values of the gap, as well as the standard deviations, were calculated.

Fig. 1. Scheme of the silicone thickness measurement.

2.2.2. CAD software method

The measurement of the gap between the abutment teeth of the plaster model and the bridge retainers in the silicone replica test was done by an indirect method, which is a precondition for generating of errors. [13] In order to provide better accuracy, a new methodology for investigating the fitting accuracy of dental bridges was developed based on the *SolidWorks* CAD software. The plaster model and the bridges, produced by the three technologies, were scanned with scanner *Tizian Smart-Scan* and software *Exocad*. The as received information was used for generating of virtual 3D models, which then were converted in *stl*-format. This file format is compatible with the *SolidWorks* software and was used to create virtual 3D models of the plaster model and the real bridges for the relevant software environment. Using the various *SolidWorks* features, each of the bridges was placed and fixed on the virtual plaster model. Three sections were made (Fig. 2) – in the medial-distal direction of the bridge (*plane 1*) and vestibular-lingual of both crowns-retainers (*plane 2* and *plane 3*). The distances between the abutment teeth and the bridge retainers were measured at the points where the measurements were made during the silicone replica test. This method gives the opportunity to investigate not only the marginal but also the internal adaptation of dental restorations. The Internal Gap (IG) is defined as the perpendicular distance between the inner surface of the crown and the outer surface of the abutment tooth. [5, 6] To study the changes of the distance between the surfaces of the abutments and the bridge retainers in different directions, measurement of the internal gap in 28 points of each bridge was done (Fig. 3). The data were statistically processed with *Excell* software.

Fig. 2. Scheme of sections of the virtual 4-part dental bridge, fixed on the plaster model.

Fig. 3. Scheme of measurement of the distances between the abutments and the bridge retainers using CAD software.

3. RESULTS

3.1. Silicone replica test results

Figure 4 shows the fitting accuracy of four-part bridges, manufactured by different technologies. The thickness of the MD silicone replica of the master bridge is too uneven. It varies between 0.05mm – 0.40mm. The bridges, cast with wax models, made in a silicone mould, has higher adjustment accuracy. The thickness of their MD silicone replicas is in the range 0.09mm – 0.18mm. Most uniform silicon thickness of 0.10 mm is measured in the bridges, cast with 3D printed patterns. The fitting accuracy of the SLM bridges is comparable with that of the samples, cast with wax models, made in a silicone mould. The thickness of the silicone replica is in the range 0.10mm – 0.20mm.

Fig. 4. The marginal fit of bridges, manufactured by different technologies. Master bridge – 1); Casting with wax models, made in silicone mould – 2); Casting with 3D printed patterns – 3); Selective laser melting – 4).

3.2. CAD software method results

The results of the silicone replica test are confirmed when examining the MD between the abutments of the plaster model and bridge retainers using specialized CAD software. The distances' values are measured at the points, at which the measurements were made during the silicon replica test (Fig. 5). The results obtained (Fig. 6) show that

the most even is the distance of the bridge, cast with 3D printed pattern, followed by the SLM bridge. The most uneven is the gap of the sample, fabricated by conventional casting. In both investigation methods, the standard deviation of the distance's values is the least for the bridges, cast with 3D printed pattern (Fig. 7).

Fig. 5. Distances between abutments and bridge retainers in the marginal region of a virtual model of SLM dental bridge. Medial-distal section - a) and b); vestibular-lingual section of premolar – c) and d); vestibular-lingual section of molar – e) and f)).

Fig. 6. The marginal gap between abutments and bridge retainers of dental bridges, measured by silicone replica test and CAD software. (Sample 1-5 – conventionally cast with wax pattern, sample 2-5 – cast with 3D printed pattern and sample 3-5 –manufactured by SLM).

Fig. 7. Average values and standard deviations (St Dev) of the marginal gap between the abutments and bridge retainers, measured by silicone replica test and CAD software.

This type of study allows tracking the change of the IG between the surfaces of the abutments of the plaster model and bridge retainers in different directions. The measurements at various points show its uneven distribution in medial-distal and vestibular-lingual directions in the both crowns-retainers (Fig. 8). Almost in all cases, the distances between the lingual, vestibular, medial and distal walls of the bridge retainers and the abutments (axial gaps) are the smallest (point 2 and 6 on the graphs). They vary between 0.00 – 0.14 mm for the premolar and 0.00 – 0.31 mm for the molar in the different technologies. The marginal gaps between the abutment tooth and the bridge re-

tainer are within 0.08 – 0.21 mm for the premolar and 0.06 – 0.28 mm for the molar (point 1 and 7 on the graphs). The largest are the distances in the occlusal surface (occlusal gaps) 0.11 – 0.64 mm for the premolar and 0.11 – 0.37 mm for the molar. These data confirm the results of the silicone replica test (Fig. 9), in which there is the absence of gaps in the axial regions and a greater amount of silicone in the corresponding regions of the occlusal surfaces. The graphs in Fig. 8 clearly indicate that the bridge, cast with 3D printed model, has the most uniform internal gap, followed by the SLM bridge and the bridge, manufactured by conventional casting technology.

Fig. 8. The internal gap between abutments and bridge retainers of virtual models of dental bridges in medial-distal – a) and b) and vestibular-lingual directions – c) and d). (Sample 1-5 – conventionally cast with wax pattern, sample 2-5 – cast with 3D printed pattern and sample 3-5 –manufactured by SLM).

Fig. 9. Silicone replica of the gap between the abutments and bridge retainers of SLM dental bridges.

4. DISCUSSION

The gap between the abutment teeth of the plaster model and the crowns-retainers of 4-part dental bridges, produced of Co-Cr alloys by three different technologies, was investigated using two methods – silicone replica and CAD software. During the silicone replica test, the MD was calculated by an indirect method, which can affect the accuracy. Moreover, the accuracy of the measuring tools was comparatively low - 0.1 mm. The features of the *SolidWorks* software give opportunity not only the MD and IG but also the distances along the X, Y and Z-axes between the surfaces of the metal infrastructure and the abutment tooth to be measured with accuracy 0.01 mm and higher. The higher accuracy of the second method was proved by the results of this study.

As the fabrication method influence on the fit of dental restorations [10, 15], the fitting accuracy of the master bridge is lowest due to the conventional casting of the hand-made wax model (Fig. 4). The accuracy of adjustment of bridges, cast with wax patterns, made in a silicone mould, is higher than the master bridge because the manufacturing of the samples in mould ensures good repeatability and higher dimensional accuracy. The highest is the fitting accuracy of the bridges, cast with 3D

printed patterns, which was confirmed by the investigation with CAD software (Fig. 6). The silicone replica test shows that the gap between the abutment and the retainers of the bridges, cast with 3D printed patterns, is lower than that of the SLM ones (Fig. 4), despite that the both groups of bridges were produced using the same virtual model. This is may be due to the dual shrinkage in the first technology – once of the 3D printed wax pattern and the second - of the Co-Cr alloy. While in the SLM, the bridges are fabricated directly from the virtual model, and only the shrinkage of the Co-Cr alloys occurs. Concerning to the adjustment accuracy of the SLM bridges, there is a discrepancy between the results of the two investigation methods. The silicone replica test shows that their fitting accuracy is close to that of the bridges, produced by conventional technology (Fig. 4). But the CAD software method indicates the higher fitting accuracy of SLM bridges, comparable to the bridges, cast with 3D printed patterns (Fig. 6). This is may be due to the high roughness of the SLM bridges [25], which can affect the measurements during the silicone replica test. The average MD, obtained by the two methods, have very small differences (Fig. 7). The values are around the upper limit for the clinical acceptance of the marginal discrepancy - 120 μ m [7, 10-12]: 0.100/0.125 mm for conventionally cast bridges, 0.133/0.132 mm for the bridges, cast with 3D patterns and 0.133/0.118 mm for the SLM samples. Considering almost twice smaller standard deviations in comparison with the silicon replica test, the study of MD with specialized CAD software gives more accurate results.

The features of the *Solid Works* software allow investigation the internal fit of dental bridges in unlimited directions. The study of the IG in medial-distal and vestibular-lingual directions shows that the axial gap is the smallest, followed by MD and the largest is the occlusal gap, independently of the tooth type or the technological process (Fig. 8). These results confirm the findings of [6, 14, 15]. The gaps values of the conventionally cast bridges have the highest variations, followed by the SLM bridges and samples, cast with 3D printed patterns. Concerning to the gap values in the marginal and occlusal regions of the SLM and conventionally cast bridges, they are in accord-

ance with the results of Huang Z, et al. [1], Tamac E, et al. [4] and Shamseddine L, et al. [14]. This study proves that the internal gap variations are strongly influenced by the technological processes. While the high values of the occlusal gap and the axial gap in some regions are most probably results of both the manufacturing process features and the manual adjustment of the bridges [14].

CONCLUSION

The fitting accuracy of Co-Cr dental bridges, manufactured by three technologies, was investigated by a newly developed method using CAD software, which allows study of the marginal and internal adaptation in unlimited directions and high accuracy.

Investigation the marginal fit and internal adaptation of Co-Cr four-part dental bridges by silicone replica test and CAD software show that the technological process strongly influences the fitting accuracy of dental restorations.

The fitting accuracy of the bridges, cast with 3D printed patterns, is the highest followed by the SLM and conventionally cast bridges. The marginal fit of the three groups of bridges is in the clinically acceptable range. The internal gap values vary in different regions—it is highest on the occlusal surfaces, followed by marginal and axial areas.

The higher fitting accuracy of the bridges, manufactured by casting with 3D printed patterns and SLM, compared to the conventionally cast bridges is a good precondition for their successful implementation in the dental offices and laboratories.

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