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Evaluation of the fit of 3D printed three-unit fixed dental prosthesis: an *in-vitro* study

Ocena dopasowania wydrukowanej w 3D trzyczłonowej stałej protezy dentystycznej: badanie *in vitro*

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KEY WORDS:
cobalt chromium, marginal gap, 3D printed pattern, internal gap, lost wax technique

Summary

Introduction. *A major factor that affects the success of a fixed prosthesis is its fit. A proper marginal fit would prevent future biological failures of the fixed dental prosthesis. These distortions begin at the wax pattern stage itself. One of the major reasons is the manual labour involved. With the advent of CAD/CAM and 3D printed technology these errors can be reduced or avoided completely.*

Aim of the study. *To evaluate marginal gap and internal gap of three-unit Co-Cr fixed dental prosthesis fabricated by patterns produced with conventional techniques and those produced by using 3D printed resins.*

Material and methods. *Typhodont teeth were prepared for a metal ceramic 3-unit prosthesis. Forty-two dental stone models were fabricated. They were divided into group A (handmade wax patterns) and B (3D printed resin pattern). These were cast into Co-Cr 3-unit fixed dental prosthesis framework using lost wax technique. All the specimens were sectioned and viewed under a stereomicroscope. The marginal and internal gap were noted. The results were subjected to Shapiro Wilks test.*

HASŁA INDEKSOWE:
stop kobaltowo-chromowy, szczelina brzeżna, wzór wydrukowany w 3D, szczelina wewnętrzna, technika wosku traconego

Streszczenie

Wprowadzenie. *Głównym czynnikiem wpływającym na jakość leczenia protezami stałymi jest ich dopasowanie. Prawidłowe dopasowanie brzeżne zapobiegnie przyszłym uszkodzeniom biologicznym stałej protezy dentystycznej. Zniekształcenia te zaczynają się już na etapie wzoru woskowego. Jednym z głównych powodów jest związana z tym praca manualna. Wraz z pojawieniem się technologii CAD/CAM i druku 3D błędy te można ograniczyć lub całkowicie uniknąć.*

Cel badania. *Ocena szczeliny brzeżnej i wewnętrznej trzyczłonowej stałej protezy dentystycznej Co-Cr, wykonanej według wzorów wytworzonych technikami konwencjonalnymi oraz wytworzonych przy użyciu żywic drukowanych w 3D.*

Materiał i metody. *Zęby typu Typhodont zostały przygotowane pod protezę metalowo-ceramiczną 3-punktową. Wykonano 42 modele, które podzielono na grupę A (ręcznie robione wzory woskowe) i B (wzór drukowany z żywicy 3D). Odlano podbudowę protezy ze stopu Co-Cr przy użyciu techniki traconego wosku. Wszystkie próbki podzielono na skrawki i oglądano pod mikroskopem stereoskopowym. Odnotowano szczelinę*

Results. *The results revealed that conventionally made wax patterns showed greater marginal and internal gap when compared to 3D printed pattern at both molar and premolar end.*

Conclusions. *Frameworks fabricated using a CAD-CAM and 3D printed workflow had significantly smaller marginal and internal discrepancies compared to those with a traditional workflow. Both groups demonstrated marginal discrepancies within the range of clinical acceptability.*

brzeżną i wewnętrzną. Wyniki poddano testowi Shapiro Wilksa.

Wyniki. *Wyniki pokazują, że konwencjonalnie wykonane wzory woskowe wykazały większą szczelinę brzeżną i wewnętrzną w porównaniu do wzoru wydrukowanego w 3D zarówno na końcu zębów trzonowych, jak i przedtrzonowych.*

Wnioski. *Prace wykonane przy użyciu CAD-CAM i drukowanego w 3D przepływu pracy charakteryzowały się znacznie mniejszymi rozbieżnościami krańcowymi i wewnętrznymi w porównaniu do tych z tradycyjnym przepływem pracy. Obie grupy wykazały marginalne rozbieżności w zakresie akceptowalności klinicznej.*

Introduction

One of the major criteria that governs success of a fixed prosthesis is its marginal fit and internal accuracy.[1] A proper marginal fit would prevent future biological failures like dissolution of cement, plaque accumulation, secondary caries and finally failure of the FDP.[2,3] However, literature states that a marginal gap between 10 and 160 μm and internal gap between 81 and 136 μm are acceptable.[1,4]

The most widely used material in fabrication of a fixed dental prosthesis is the porcelain fused to metal.[5] Base metal alloys are usually the material of choice for the fabrication of a fixed dental prosthesis. Nickel chromium has been used for the same purpose for many years. But due to the associated drawbacks like metal allergies currently cobalt chromium has been made available to us as a crown and bridge material.[1] Even in Co-Cr alloy a small percentage of nickel is added by some manufacturers (less than 1%) due to its ductility.[6] There are various compositions of Co-Cr available for crown and bridge currently, most of them nickel-free. Cobalt itself adds up to the ductility of the material, other components like cerium, gallium, neobium, silica are added in minor quantities that help to increase corrosion resistance and bonding of porcelain to the Co-Cr alloy.[6] They also provide controlled thermal expansion and fluidity.[6] Conventionally, the metal ceramic FPDs were fabricated through conventional lost wax technique, which is a gold standard procedure. But it involves manual skill, it is time consuming and requires labour. Apart from this any distortion of the wax pattern during removal, or any error during processing and finishing, can affect the marginal and internal fit of the prosthesis.[7] Reducing the marginal discrepancy and improving the fit of the prosthesis should be the ultimate goal to improve the success rates. With the evolution of dentistry, newer methods that are more digitally driven are replacing the traditional techniques. One such technique is the use of a 3D printed technology. The use of digitally driven dentistry can help reduce the errors of traditional methods in the fabrication of FDP. The patterns can be 3D printed and then lost wax technique can be incorporated for casting. CAD/CAM technology in dentistry is an attempt to replace the manual traditional laboratory steps. With advent and increasing popularity of

CAD/CAM technology in dentistry both time and cost can be effectively saved, compared to conventional casting technology. Also, multiple patterns can be prepared at the same time thus reducing the labour required. Having said that one cannot deny that there is a learning curve that is involved.

Therefore, success of a prosthodontic treatment is considered only if the prosthesis fits precisely. The fit of the prosthesis is of utmost importance when long-term prognosis of a fixed dental prosthesis treatment is needed.[7] Ill-fitting prosthesis with marginal gaps can eventually lead to failure. There is currently no data available which compares the marginal and internal fit of a 3D printed three-unit FDP made of Co-Cr metal. Therefore, the aim of this study is to evaluate marginal gap and internal gap of a three-unit Co-Cr fixed dental prosthesis fabricated by patterns produced with conventional techniques and those produced by using 3D printed resins.

Materials and methods

Model fabrication

On a typhodont two posterior abutment teeth were prepared: a premolar and a molar tooth with a shoulder margin, following which 42 silicone impressions were made and models were poured with type IV gypsum (die stone). A total of 42 models were fabricated. Each impression was poured only once. The models were then divided into two groups A and B, each group consisting of 21 models. On both groups a die hardener (Renfert) was applied. In group A models two layers of 13 micron thickness die spacer (Renfert die master gold, die master silver, GmbH) were applied 1 mm above the margin. The total cement space was equal to 26 microns. The group B models were scanned using a model scanner (Denstply Sirona inEos). A spacer thickness of 26 microns was then set in the software before designing the pattern.

Fabrication of frameworks

A total of 42 Cobalt chromium three-unit FPDs were fabricated using two different processing techniques.

Group A: Conventional wax pattern technique

The 21 models to which the die spacer was applied, a wax separating medium (picosep, Renfert) was applied to it. Next, wax patterns of 3unit FPDs were fabricated with a connector thickness of around 3.5 * 2.5 mm^2 using crown wax (Crowax, Renfert). The framework was then sprued using the gates technique. This was then invested in a phosphate-based investment material (Bellavest, Bego). The patterns were then cast in Co-Cr alloy (Wirobond C, Bego) in a vacuum casting machine (Cascom).

Group B: 3D printed patterns

The master cast was directly scanned and a spacer thickness of about 26 microns was selected following which the FPD framework was designed in the CAD software (Dentsply, Sirona). Next, 21 patterns were 3D printed from a castable resin using Ackuretta 3D printer (model: Free Shape 120). These patterns were then cast using the lost wax technique. The patterns were sprued using the gates technique and invested in a phosphate-based investment material (Bellavest, Bego), which was then cast in Co-Cr alloy (Wirobond C, Bego) as mentioned above.

Cementing and sectioning of the specimens

All the frameworks were then divested and sandblasted with aluminium oxide 50 microns at 2 bar pressure and then cemented on the master cast with luting GIC (Type 1, - Shofu Hy-BOND glassionomer CX). The models were kept under 50 N pressure during cementation with a loading device. The cemented frameworks were then sectioned after 24 hours. They were glued to a metal plate and sectioned with a low-speed carborundum disc mesiodistally along the centre of each framework (Fig 1, Fig 2).

Fig. 1. Sectioned molar part viewed under stereomicroscope.

Fig. 2. Sectioned premolar part viewed under stereomicroscope.

Analysing and measuring the specimen

All the measurements were made on the cemented framework on the master cast. A stereomicroscope (Lawrence and Mayo) was used for the analysis. Digital images were taken with a magnification of 8x and analysed in a measuring software (Motic version 2.0). For each abutment tooth eleven points of reference were measured. A total of 924 measurements were performed on 42 samples by one blinded observer.

Statistical analysis

Differences between the two-fabrication methods were subjected to Shapiro-Wilk test. Inter group comparison was done using t test. The level of significance was set at 5%. Keeping alpha error at 5% and Beta error at 20%, power at 80%, $p<0.05$ was to be considered statistically significant.

Results

The mean and SDs of marginal and internal gap of two different techniques are tabulated below.

Table 1. The mean values of marginal and internal gap of Group A and B at molars

The results revealed that conventionally made wax patterns showed greater marginal and internal gap of around 110.03 (microns) and 302.98 microns, respectively at the molar. However, 3D printed patterns showed lesser marginal and internal gap of around 97.40 (microns) and 107.65 microns, respectively.

Table 2. The mean values of marginal and internal gap of Group A and B at premolars

The results reveal that conventionally made wax patterns showed greater marginal and internal gap of around 122.25 (microns) and 254.65 microns, respectively at the premolar.

T a b l e 1. The mean value of marginal and internal gap of Group A and B at molar is tabulated above

Group	N	Mean microns	Std. Deviation	Std. Error Mean	T value	p value of t test
Marginal gap A (conventional patterns - molar) B (3D printed pattern - molar)	 21 21	 110.03095 97.40476	 19.411842 11.019697	 4.236011 2.404695	 2.592	 0.013*
Internal gap A (conventional patterns - molar) B (3D printed pattern - molar)	 21 21	 302.98707 107.65102	 84.726324 31.686310	 18.488800 6.914520	 9.896	 0.000**

Table 2. The mean value of marginal and internal gap of Group A and B at premolar is tabulated above

Group	N	Mean	Std. Deviation	Std. Error Mean	T value	p value of t test
Marginal fit						
A (conventional patterns - pre molar)	21	122.25000	25.481279	5.560471	2.305	0.026*
B (3D printed pattern - pre molar)	21	101.42500	32.632896	7.121082		
Internal fit						
A (conventional patterns - pre molar)	21	254.65476	56.049541	12.231013	6.472	0.000**
B (3D printed pattern - pre molar)	21	149.44150	49.074235	10.708876		

However, 3D printed patterns showed lesser marginal and internal gap of around 101.42 (microns) and 149.44 microns, respectively.

Discussion

Discrepancies with regard to marginal and internal fit can occur for several reasons and at multiple stages of fabricating the pattern,[8] beginning from impression making to cast pouring, die sectioning and ditching, standardizing the spacer thickness, wax pattern fabrication and casting procedures. Therefore, the technique used to fabricate the prosthesis plays a crucial role in providing accuracy.[8]

The traditional lost wax technique used to fabricate fixed prosthesis involves multiple manual steps and hence increases the possibility of errors.[8] Making handmade patterns out of crown wax for fabricating a three-unit fixed partial denture is the most tiresome, technique sensitive and laborious task. It relies on the skill of the technician. Apart from this, literature also states that wax has certain innate qualities like sensitivity to temperature, it can be distorted while removing the pattern from the cast as its fragile. Distortion can also occur due to release of internal stresses, elastic memory and high coefficient of thermal expansion. If overheated it loses its properties.[1,7] To overcome these errors newer techniques like the additive manufacturing techniques have been introduced in recent times.[8]

The additive manufacturing technique can be used to either 3D print the patterns or sinter the metal. 3D printing of the patterns can be done using wax or castable resin. This technique then follows casting with conventional lost wax technique. It is relatively cheap when compared to sintering technique. Apart from this, the quality of the copings can be controlled, its dimensional accuracy, higher production rate, reduced time and labour involved. These are several advantages of printing. It does have a certain disadvantage of added cost and the whole process has a learning curve.[7] In this study, a DLP (digital light processing) printing technology was used. The advantage of this technique is that the entire layer is cured at once, it is faster, multiple copings can be printed at once and each layer gets cured at a time.[9]

Base metal alloys have been the material of choice with respect to fixed prosthesis as they are resistant to permanent deformation and have excellent clinical performance. Cobalt chromium is now more frequently used than nickel chromium due to the associated allergies. Co-Cr is also less prone to corrosion than nickel chromium. With the advent of newer technologies, the associated casting difficulties have been reduced, hence making these base metal alloys a material of choice.

In this study the marginal and internal discrepancy was measured by a technique put forth by *Holmes* et al[10] (Fig 3). According to the results obtained in this *in vitro* test, the mean

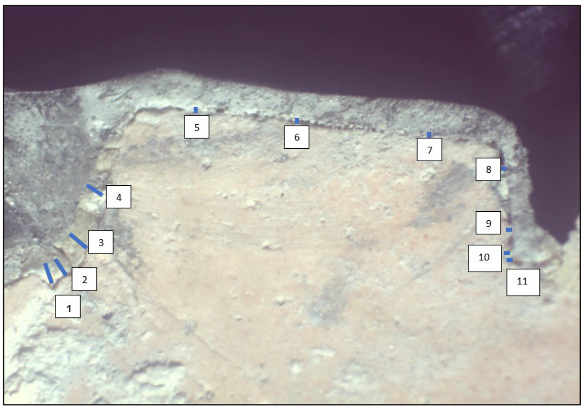

Fig. 3. Eleven points of examination under stereomicroscope.

marginal gap in a 3-unit FPD at molar was 110 microns and that at premolar was 122.25 microns when fabricated by using conventional crown wax and lost wax technique. A mean marginal gap of 97.40 microns at molar and 101.42 microns at premolar was noted in the patterns that were 3D printed and cast through traditional lost wax technique. According to the current study, the 3D printed patterns showed lesser marginal gap, which means they showed a better marginal fit and accuracy. *Farjood* et al. conducted a study and concluded that marginal discrepancy of single crown Ni-Cr copings fabricated with rapid prototyping patterns was 89.8 microns, and that of conventionally made patterns was 69.5 microns; here the cement space used was 30 microns for rapid prototyping models and 27 microns for handmade patterns.[7] However, *Fathi* et al. in their study in 2015 on single crown coping patterns made with conventional technique and 3D printed technique concluded that the marginal gap was 160±24µm and 63±6 for the conventional and 3D printed technique, respectively.[11] They also concluded that the accuracy of printed patterns was better than the conventionally handmade patterns. They used different cement space thickness of 0 microns, 30 microns and 50 micron and concluded that 30 microns spacer thickness gave the best results of around 111 microns marginal gap when conventionally made and 126 microns when digitally made. Their study also concluded that the more the cement space, the bigger would be the marginal gap, and that providing no cement space would result in the greatest marginal gap.[11] A study was conducted by *Arora* et al. in 2018 where they compared the single crown copings of Ni-Cr made conventionally and 3D printed and concluded that the marginal gap noted was 101.67 microns for 3D printed patterns and 107.84 microns in case of conventional patterns,[8] which is more or less close to the readings obtained in the current study. A study was conducted by *Bhaskaran* et al in 2018 who concluded that the marginal fit on 3D printed single crown copings of Co-Cr was better than conventional or laser sintered copings. They also concluded that the marginal gap was significantly lesser in the DMLS crowns around 10.52 microns.[1] Conversely, *Kim* et al. in 2013 checked the marginal fit and accuracy of a three-unit FPD made of Co-Cr and stated that the marginal gap was 79.9 microns with respect to copings fabricated by traditional technique and 113.3 microns in the case of DMLS copings.[12] Similarly, *Ortorp* et al. in 2010 studied the marginal fit of Co-Cr FPDs fabricated with four different techniques and they found that DLMS (84 microns) group showed the best fit followed by milled wax (117 microns), lost wax (133 microns) and milled Co-Cr (166 microns), here the spacer thickness used was 50 microns.[2] A study conducted by *Khaledi* et al. in 2019 to evaluate the marginal fit on Ni-Cr copings fabricated with three different techniques milling, stereolithography and 3D wax printing concluded that there was least marginal discrepancy noted in 3D polyjet printed patterns (41micrometer).[14] In a study conducted by *Addugala* et al. in 2022 wherein they evaluated the marginal fit of metal copings fabricated with additive (printed using DLP technique) and subtractive technique (PMMA milled). The printed patterns were made of two different resin materials: the acrylonitrile-butadiene-styrene and polylactic acid. They concluded that the marginal fit of milled patterns was better than the 3D printed patterns and those made of polylactic acid were better than acrylonitrile-butadiene-styrene among the printed patterns.[15] *Handal* et al. in 2022 conducted a study to evaluate the marginal fit of Co-Cr copings fabricated by milling and printed techniques and concluded that the milled castings had better marginal fit than the printed ones.[16] *McLean* et al. concluded that marginal gap ingequalling 120 microns was an acceptable value,[4] although in literature a clear clinically acceptable margin has not been defined. Studies have indicated clinically acceptable margin ranging between 39 and 120 microns and some state up to 50 microns.[5,10] These values are still quite debateable. According to ADA specification no.8 an acceptable marginal discrepancy for fixed restorations is around 25 to 40 micrometer.[5] The data from the current study reveals that both groups had a marginal gap within the acceptable aforamentioned range of values and the marginal gap of 3D printed patterns was lesser than the conventionally fabricated crown. The results proved a significant difference between the two groups.

The mean internal gap recorded in the current study along the axial and occlusal surface of molar and premolar that was fabricated conventionally was about 302.98 microns and 254.65 microns, while that of 3D printed copings was about 107.65 microns at molar and 149.44 microns at premolar. Therefore, we can see that the internal discrepancy was greater in conventional technique than in the 3D printed technique. Similar results were noted in a study conducted by *Fathi* et al. in 2015 on single crown copings and they concluded that the occlusal discrepancy occurred mostly in conventionally made patterns around 300 microns and the least in 3D printed wax patterns around 100 microns and the milled wax pattern the discrepancy was around 200-250 microns. The spacer thickness that gave the best result was 30 microns.[11] This is at variance with the study conducted by *Farjood* et al. in 2016 who concluded that the total internal discrepancy was 95.9 (±8.0) mm for the CAD/RP group and 76.9 (±10.2) mm for the conventional group (cement space was 30- and 27-microns resp.,). They concluded that the conventional method was better than the printed method with regard to single crown Ni-Cr copings.[7] *Quante* et al. in their study in 2008 checked the accuracy and marginal fit of a Co-Cr single crown metal ceramic prosthesis fabricated by laser melting technology with two different Co-Cr alloy brands. They concluded that the mean internal gaps ranged between 250-350 µm.[13] In 2018, *Arora* et al. conducted a study on Co-Cr single crown copings and they concluded that the internal discrepancy was the lowest for 3D printed patterns (133 microns) while that of DMLS was 169 microns.[8] A study was conducted by *Addugala* et al. in 2022 wherein they evaluated the internal fit of metal copings fabricated with additive (printed using DLP technique) and subtractive technique (PMMA milled). The printed patterns were made of two different resin materials: the acrylonitrile-butadiene-styrene and polylactic acid. They concluded that the internal fit of printed patterns was better than the milled patterns and those made of polylactic acid were better than acrylonitrile-butadiene-styrene among the printed patterns.[15] A study conducted by *Bhaskaran* et al. in 2013 on Co-Cr single crowns also revealed that the internal discrepancy was the smallest in 3D printed patterns around 36 microns, followed by conventional method which was around 40 microns and then DMLS crowns which was around 41 microns.[1] All these studies have shown variable results. Most of them have concluded that the least prominent discrepancy was seen in 3D printed patterns. This is because the prepared tooth can be directly scanned and then the pattern can be designed through CAD/CAM. By doing so the number of variables can be reduced and also the thickness of the die spacer and the thickness of patterns can be standardized. Therefore, less chances of errors and hence lesser discrepancy can be noted in printed patterns. Nevertheless, based on the existing literature, the clinically accepted values for internal gap ranges between 81 and 136 µm while certain studies mention it to be between 250-350microns.[13] The values for internal gap in the current study lies within the clinically acceptable limit. The greater the internal gap, the bigger will be the space occupied by the cement and the lesser will be the retentive nature of the restoration. Hence, it is necessary to use a method in which the internal gap is the least present, which would again ensure the longevity of the restoration.

Limitations of the study

It is an *in-vitro* study and cannot simulate exact oral environment. There could have been distortion of the metal or the cast during sectioning due to the heat generated although all the necessary precautions were taken. Further studies on effects of aging are recommended.

Conclusion

According to the results obtained in the current study we can conclude that the patterns made using 3D printed technology showed a significant difference and that the marginal gap and internal gap was the smallest when compared to handmade patterns.

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