Volume 9, Issue 3, 2019, 3919 - 3925 **ISSN 2069-5837**
Biointerface Research in Applied Chemistry
www.BiointerfaceResearch.com
https://doi.org/10.33263/BRIAC93.919925
Original Research Article **Open Access Journal**
Received: 13.03.2019 / Revised: 15.05.2019 / Accepted: 28.05.2019 / Published on-line: 15.06.2019

Comparison of reconstruction of cement space in resin copings fabricated with the use of a 3D printer in single- and three-unit restorations

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ABSTRACT
Marginal and internal gaps are very important factors in fixed prosthetic restorations. The marginal fit is affected by the cementing process of the restoration. One of the techniques used to create the required space between the prepared tooth and the crown is to use a die spacer. The aim of the current study was to assess the accuracy of reconstruction of the cement space in the resin copings of extracoronal restorations fabricated with the use of the 3D printing technique and compare it in single- and three-unit restorations. After taking impressions from the left maxillary first premolar and first molar teeth of a jaw model, a total of 20 models were prepared with the use of a 3D printer for single-unit and three-unit groups (a total of 120 samples) and cemented on their relevant dies. The samples were sectioned buccolingually. The images of the internal gaps were prepared under a light microscope and evaluated. The values in different groups were compared in relation to marginal and internal fit and analyzed with ANOVA (mixed models). Statistical significance was set at P<0.05. Comparison of the accuracy of reconstruction of the cement space in resin copings fabricated with the use of a 3D printer showed that in the single-unit premolar tooth with a presumptive cement space of 45 µm the cement space was 30.45±20.01 µm (P>0.001) at the margin and 36.01±13.52 µm (P>0.001) in the internal area; in the reconstruction of the three-unit molar tooth with a presumptive cement space of 25 µm, the cement space at the margin was 105.97±33.7 µm (P>0.964), with 120.09±63.15 µm (P>0.005) in the internal area. It was concluded from the results of the present study that the accuracy of reconstruction of the cement space in resin copings fabricated with the use of a 3D printer in samples with a larger presumptive cement space was higher than that in samples with a smaller presumptive cement space. The accuracy of the reconstruction of the cement space in resin copings fabricated using a 3D printer in single-unit restorations was higher than that in three-unit restorations.
Keywords: *Cement space, 3D printer, restoration.*

1. INTRODUCTION

The primary aim of each fixed prosthodontic restorative treatment is to provide a thoroughly fit crown and restoration for the patient [1,2]. In this context, marginal and internal gaps are very important factors for the long-term success of prosthetic restorations [3]. The importance of marginal integrity and its relationship with oral health and the longevity of the extracoronal restorations have been shown in previous studies. The marginal fit is affected by the cementation process of the restoration [4]. Marginal gaps are predominantly produced due to trapping of cement between the tooth and the extracoronal restoration due to the hydrodynamic pressures that are created during cementation [5].

One of the methods to create the necessary space between the prepared tooth and the crown in order to prevent the incidence of hydrodynamic pressures and incomplete seating of the crown is to use die spacers [6]. Use of a die spacer improves the marginal fit between the restoration and the tooth, decreasing the risk of dissolution of cement, recurrent caries and periodontal problems [7]. In addition, the thickness of the die spacer affects the retention and marginal gap [6].

Emes et al increased the thickness of die spacer from 0 to 25 µm and reported an increase of 25% in the retention of the extracoronal restoration [8]. The effect of die spacer thickness was also confirmed in a study by Wilson and Curter, in which when the thickness of die spacer changed from 0 to 8 layers, the retention of the crown enhanced from 250 N to 375 N [9]. These studies explain the relationship between the thickness of die spacer and marginal gap.

When a die spacer is not used, there is a marginal gap of 649 µm, which is greater than the acceptable level; however, the thickness of the die spacer increased from one layer to 8 layers, the marginal gap size of 479 µm decreased to 38 µm [10]. The marginal gap size might be affected by the margin design during tooth preparation and the convergence of the prepared tooth [11-15].

3D printing is used for copings, fixed prosthetic restorations, pressable patterns for anatomic contours and removable partial dentures that are made of wax or acrylic resin [16]. Although the designing software of many CAD systems makes it possible to determine the thickness of die spacer, the results achieved from a 3D printer might not be controlled as it is expected [17,18].

Based on a study by Hoang et al, in which the reconstruction of the cement space was evaluated in restorations manufactured with CAD/CAM system and a 3D printer, in the majority of cement spaces studied the 3D printer was not able to create a homogeneous space in all the crown areas [6]. In another study, Bhaskaran et al compared the marginal and internal gaps of Cr-Co copings fabricated with the use of conventional and 3D printed resin pattern techniques and reported that the marginal gaps of crowns fabricated with the use of a 3D printer were smaller than the conventional technique of wax elimination; however, their internal gaps were larger [19]. Considering the paucity of studies on the subject and discrepancies in the results of studies that are available, it appears it is necessary to carry out further studies on the fabrication of restorations with the use of 3D printers.

The thickness of the die spacer is adjusted depending on the clinical condition during designing of extracoronal restorations with the use of CAD software program and by considering the geometry of the prepared tooth for achieving proper retention, a favorable seal and good marginal adaptation of the restoration. The accuracy of the reconstruction of this designed space for the cement in wax and resin patterns resulting from a 3D printer is very important. It appears the curing process after fabrication of the initial pattern of resin copings might affect their dimensional changes and it is probable that the volume of the resin pattern can have a great role in increasing these changes, resulting in more pronounced changes in the space designed for the cement in restorations with a larger volume (i.e. multi-unit restorations).

Since adequate number of studies are not available in this field (evaluation of the accuracy of the use of 3D printers in the fabrication of restorations) and since all the available studies on the evaluation of cement space with both the CAD/CAM and 3D printer techniques have evaluated single-unit restorations and no study is available on multi-unit bridges in this respect, the present study was undertaken to evaluate the accuracy of reconstruction of cement space in resin copings of extracoronal restorations fabricated with the use of 3D printing technique and compare them in single-unit and multi-unit restorations.

2. MATERIALS AND METHODS

In this study, the maxillary left first premolar and molar teeth of a model were mounted in an acrylic resin block with the long axes of the teeth parallel to each other, with a mesiodistal distance of approximately 8 mm (i.e. the width of a typical premolar tooth) (Figure 1).

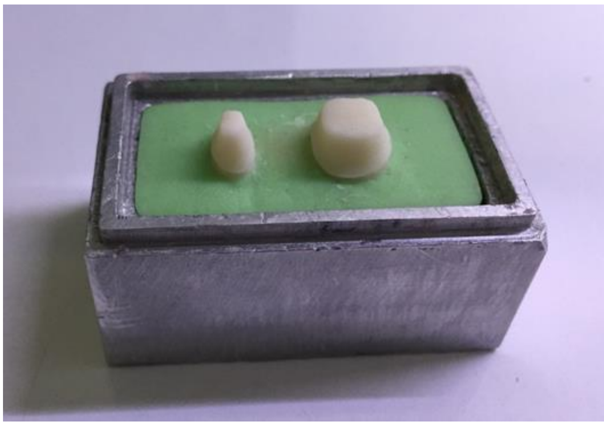

Figure 1. The teeth mounted in the acrylic resin block.

Then the space required for the impression material was prepared by placing wax around the teeth and the adjacent tissues (for 5 mm). Then an aluminum tray was fabricated. Designing and fabrication of the aluminum tray was carried out by creating a 5-mm space on the occlusal surface of the teeth. This special tray was cuboid in shape to prevent dimensional changes during the study. The aim of fabricating the aluminum tray was to make it possible to prepare a hard tray with no dimensional changes. The teeth were prepared to receive metal-ceramic restorations with the following: characteristics: an occlusal convergence of 12º, occlusal reduction of 2 mm, axial reduction of 1.5 mm, and a chamfer finish line.

In order to measure the divergence angle of the prepared tooth, the tooth was placed in front of a plate and photographed (Nikon, D3100). The images were evaluated with the use of Protractor software program on a monitor (Iconico Inc). The occlusal convergence on each image was calculated by combining the angles of the two opposing walls.

Then a surveyor was used to assess the parallelism of the prepared surface of the teeth and establish the necessary parallelism. The amount of tooth preparation was checked with a putty index. The test samples were reconstructed by taking impressions from this sample for homogeneity of all the samples.

In order to determine the samples size, by considering a mean difference of 25 and 45 µm in space for single-unit and multi-unit restorations based on a study by Hoang et al, the samples size was estimated at 20 samples in each subgroup at 50±11 and 30±10 µm, α=0.05 and a power of 80%. To compare the amount of cement space reconstruction in single-unit and multi-unit restorations, 20 samples were prepared for each group with 20 impression taking procedures from the prepared teeth. The samples underwent an impression taking procedure with simultaneous putty-wash technique using Panasail additional silicone (Fast Set Putty; Ketten Back LP) and X-light (wash) impression materials (Figure 2).

Figure 2. The putty-wash technique used simultaneously for impression taking procedure.

Type IV dental stone (Resin Rock, Whip Mix Corp.) was used for pouring the die. The prepared dies were divided into 2 groups with 2 different cement spaces of 25 and 45 µm in single-unit and three-unit restorations. The dies were sent to the laboratory for the fabrication of resin copings. Each die was scanned with the use of a 3D scanner (DS300 3D Scanner; Shining 3D) (Figure 3).

Figure 3. Placement of the samples in the 3D scanner.

Then the raw STL file prepared by the scanner was designed with CAD (EXO CAD) software program in a manner to create a cement space at a distance of 0.5 mm from the finish line with the designed size and a coping thickness of 5.0 mm (Figure 4).

Figure 4. The images designed in the EXO CAD software program.

Each resin coping was labeled digitally so that it could be matched with its corresponding die. The output file was printed by a printer (Digital DLP 3D Printer) with the use of castable UV-cured resin material (Dilax Resin) and placed in a Pro 4 UV oven (Aswna UV Lamp) (Figure 5).

Figure 5. The printed three-unit sample.

Each coping was cemented to its corresponding die with a self-adhesive resin cement (Relyx Unicem 2; 3M ESPE) and underwent a 50-N pressure in a UTM machine, followed by irradiation from the mesial, distal, buccal and lingual aspects, remaining under pressure for 6 minutes for complete setting (Figure 6). Each sample was dissected with the use of a diamond disk in a buccolingual direction (Figure 7).

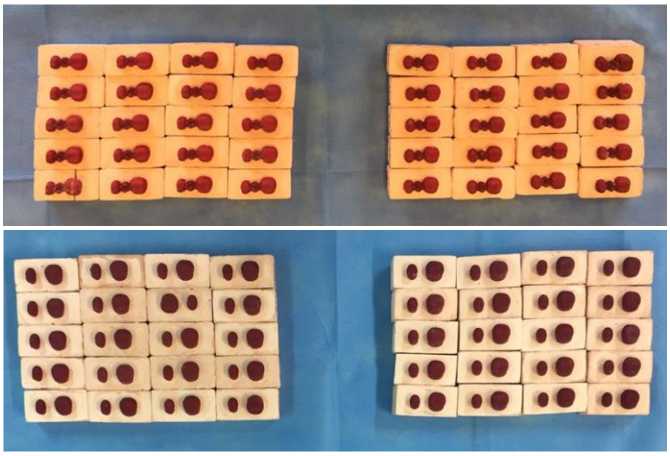

Figure 6. A total of 120 samples of copings cemented to dies.

Figure 7. The samples sectioned in the buccolingual direction.

The interval gap between the printed resin coping and the stone die was evaluated in each sample in 5 areas: A: facial chamfer; B: facial midaxial; C: occlusal; D: lingual midaxial; E: lingual chamfer. The image of the internal gap was prepared under a light microscope (stereomicroscope; Nikon WD 32.5) at ×100 magnification and evaluated (Figure 8).

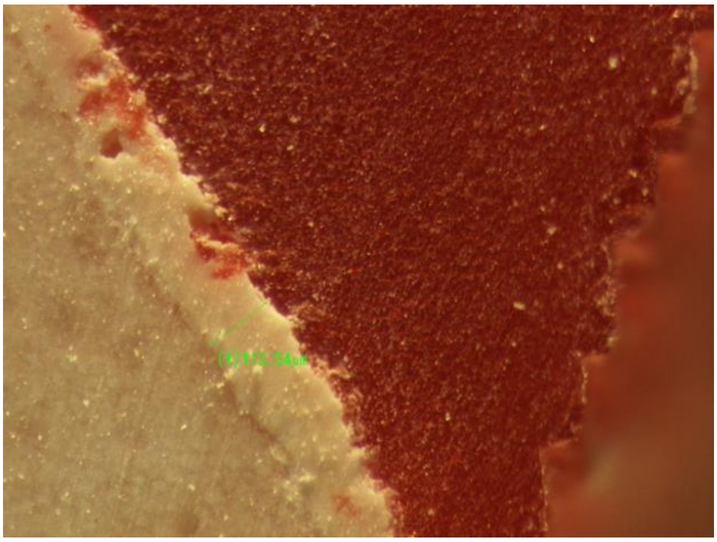

Figure 8. The microscopic view of the cement space.

Measurements were carried out 5 times at each point to achieve a mean value. This way, the marginal gap was calculated using the mean measurements in areas A and E and the internal gap was calculated using the mean measurements in areas B, C and D.

3. RESULTS

Results.

1. Comparison of the accuracy of reconstruction of the cement space in resin copings fabricated with the use of a 3D printer in the premolar tooth with presumptive cement spaces of 25 and 45 µm showed that the accuracy of cement space reconstruction of the marginal and internal gaps in single-unit copings was better than that in 3-unit copings (Figures 9-12).

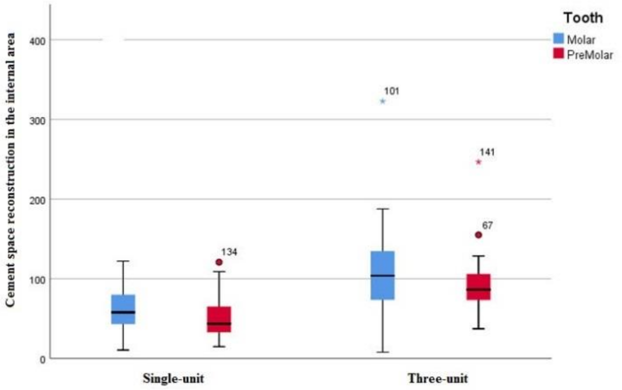

Figure 9. Comparison of the accuracy of cement space reconstruction in the internal area in single-unit and three-unit restorations in molar and premolar teeth.

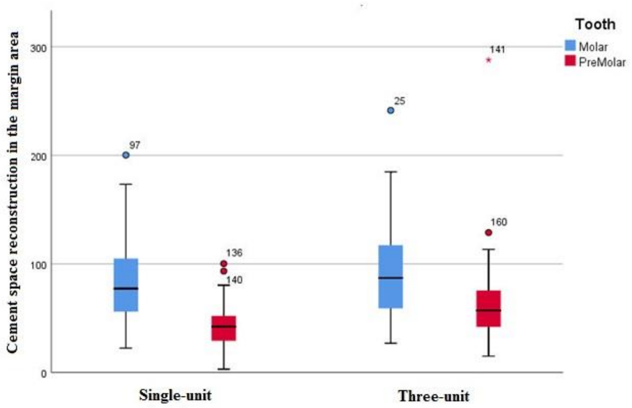

Figure 10. Comparison of the accuracy of cement space reconstruction in the margin area in single-unit and three-unit restorations in molar and premolar teeth.

2. Comparison of the accuracy of the cement space in resin copings fabricated with the use of a 3D printer in the molar tooth with presumptive cement spaces of 25 and 45 µm showed that the accuracy of cement space reconstruction in the internal area in single-unit copings was better than that in 3-unit copings, with no significant differences in the marginal area (Figures 9 and 10).

Generally, the accuracy of reconstruction of the cement space in the margin and internal areas of single-unit copings was better than that in 3-unit copings (Figures 11 and 12).

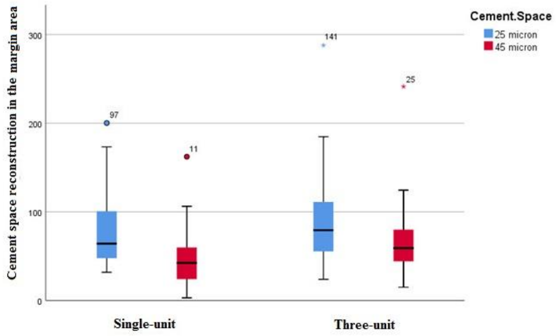

Figure 11. Comparison of the accuracy of cement space reconstruction in the margin area in single-unit and three-unit restorations with presumptive cement spaces of 25 µm and 45 µm.

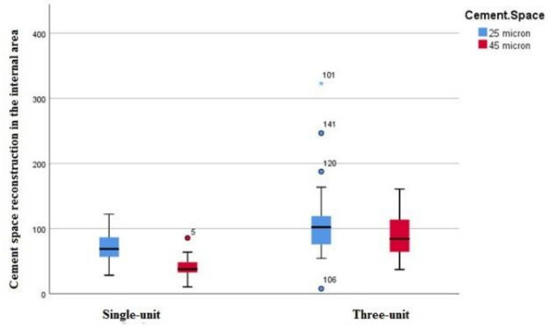

Figure 12. Comparison of the accuracy of cement space reconstruction in the internal area in single-unit and three-unit restorations with presumptive cement spaces of 25 µm and 45 µm.

Discussion.

Ideally, the crown margin should completely contact the margin of the prepared tooth. Therefore, a minimum of marginal gap is nominally and virtually acceptable. The terms “marginal gap” and “internal gap” are not synonymous [19]. An increase in the internal space compromises the retention of the crown. Therefore, measuring the gap at the margin shows the amount of fit [19].

The marginal gap after cementations is larger than the sum of cement thickness and marginal gap before cementation. Therefore, all the rational cautions that result in a decrease in cement thickness and marginal gap should be considered. The most important factor in decreasing marginal misfit is the determination of the cement space [4]. Pascoe et al showed that from a geometric viewpoint castings with larger sizes exhibited better fit compared to castings with smaller sizes during cementation because there is no adequate space for the cement (in the latter case) (20). Different techniques have been suggested for determining the cement space; in this context, placing a die spacer on the die results in the creation of proper space for the cement [4].

Considering technological advances, another technology which is currently used to determine the cement space is the use of a 3D printer, which yields a different form of output for the CAD software program and has made it possible to produce different designs and use different materials. Apart from the ability to produce complex and voluminous designs, such as surgical patterns, orthodontic plaque and dental casts, the 3D printing of a crown is carried out in appropriately 20 minutes. Therefore, production of copings and temporary crowns after tooth preparation and in the same session is possible with the use of a 3D printer. Currently, the technology for this procedure is available on the dental market; however, sufficient studies have not been undertaken to evaluate 3D printing and the materials that can be printed [21-24].

In the present study, the accuracy of reconstruction of the cement space by computer-assisted systems and fabrication by 3D printing technique was evaluated in single-unit and three-unit copings. To compare the accuracy of reconstruction of the cement space, 80 samples were fabricated and evaluated for 4 coping groups with two different cement spaces of 25 and 45 μm with the use of a 3D printer.

Comparison of the accuracy of cement space reconstruction in resin copings fabricated with a 3D printer showed that the reconstruction accuracy of the cement space in the premolar tooth in both groups with presumptive cement spaces of 25 and 45 μm at margins and the internal space was better in single-unit copings compared to three-unit copings. In the reconstruction of the cement space in molar teeth in both groups with presumptive cement spaces of 45 and 25 μm the accuracy of the cement space reconstruction in the internal area of single-unit copings was better than that in 3-unit copings, with no significant differences at the margins.

Based on a study by Hoang et al, the maximum acceptable marginal gap is 120 μm [6] and based on a study by Bhaskaran et al, the maximum acceptable marginal gap is 160 μm, with a maximum acceptable internal gap of 136 μm [19]. Based on previous studies, in all the single-unit and three-unit samples prepared with the use of a 3D printer, all the gaps at both the margin and the internal area are clinically acceptable. Therefore, 3D printing technique exhibits clinically acceptable accuracy in both single-unit and three-unit restorations.

Since sufficient studies are not available on the subject and since all the previous studies with the use of both CAD/CAM and 3D printing techniques have evaluated single-unit restorations and no study is available on this variable in multi-unit restorations the aim of the present study was to evaluate the accuracy of reconstruction of cement space in resin copings of extracoronal restorations fabricated with the use of 3D printing technique and compare them in single-unit and three-unit restorations.

Hang-Nga Mai et al evaluated the fit of temporary crowns fabricated with a 3D printer and reported that use of a 3D printer increased marginal adaptation and improved the fit of temporary crowns in the occlusal area [25]. In addition, based on a study by Pompa et al, 3D printing resulted in better initial marginal fit compared to the manual technique [26].

Campagni et al reported the coefficient percentages of changes in cement space when 2−6 layers of True-fit die spacer were applied. These change coefficients varied from 25.6% for 6 layers to 53.2% for 2 layers [27]. Based on the study by Hoang et al, the range of these changes were 14−33%, indicating a higher accuracy of the 3D printing technique compared to the manual technique [6]. On the other hand, based on a study by Munoz et al (2016), in which the marginal adaptation of crowns fabricated with the use of 3D printing, milling and the manual techniques were evaluated, the milling and manual techniques exhibited better adaptation compared to the 3D printing technique [28].

In a study by Grajower et al, when the thickness of the die spacer was increased from one layer to 8 layers the marginal gap clearly improved from 479 μm to 38 μm. Therefore, it was concluded that crowns with a thin cement space do not properly sit on the tooth [10]. In addition, based on the study by Hoang et al, copings with a cement space of 85 μm exhibited higher accuracy compared to copings with smaller cement space [6]. The effect of the thickness of die spacer was confirmed in a study by Wilson and Curter, too, in which when the thickness of the die spacer increased from 0 to 8 layers the retention of the crown increased from 250 N to 375 N [9]. The results of the present study are consistent with those of the studies above, indicating that copings with a presumptive cement space of 45 μm exhibited better reconstruction accuracy compared to those with a presumptive cement space of 25 μm, which according to a study by Psillakis might be attributed to the inadequate space for the escape of excess cement during cementation of copings with a smaller cement space, resulting in incomplete seating or separation of coping from the tooth surface due to the hydrostatic pressure of the cement [7].

Rapid and automated methods in dental materials and restorations area has shown a significant impact in the field of restorative dentistry in recent years [29-35]. Since no similar studies are available, the results of the present study were predominantly compared with those of a study by Tahayeri et al, who evaluated the crowns fabricated with the use of a 3D printer. The study above evaluated the parameters affecting the accuracy of crowns fabricated using the 3D printing technique. The samples printed with a degree of 90 with white resin exhibited the best accuracy compared to other groups. No significant relationship was detected between the thickness of the printed layers and modulus of elasticity and peak stress [29].

In the current study, the overall statistical analyses carried out ruled out the hypothesis that there are no differences in the accuracy of reconstruction of cement space in resin copings between single-unit and three-unit restorations with the use of a 3D printer. The results showed that copings exhibited greater reconstruction accuracy compared to three-unit copings. It appears the curing process after printing of initial patterns of resin copings can affect their dimensional changes and the volume of the resin pattern might play an important role in increasing these changes; in this context, the cement space designed in the restorations with larger volumes (multi-unit restorations) exhibit more significant changes.

The results of the present study showed a higher accuracy of reconstruction of the cement space in copings with a larger presumptive cement space. It is recommended that during the designing process of restorations, larger cement spaces be used so that the accuracy of the reconstruction of cement space would not be affected.

4. CONCLUSIONS

The results of our study revealed that the accuracy of cement space reconstruction in resin copings fabricated with the use of a 3D printer in samples with smaller volume of the resin pattern (single-unit restorations) was higher than that in samples with larger volume of the resin pattern (three-unit restorations). In addition, the accuracy of cement space reconstruction in resin copings fabricated with the use of a 3D printer was lower in samples with larger presumptive cement space compared to samples with a smaller presumptive cement space.

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6. ACKNOWLEDGEMENTS

The authors would like to thank the Research Vice Chancellor of Tabriz University of Medical Sciences, for financial support of the study. This article is a part of a thesis (No. 58094) submitted for the MD degree in the Faculty of Dentistry, Tabriz University of Medical Sciences.