

Evaluation of Cement Space Reproduction in Copings Fabricated by 3d Printing Technology Using Computer Aided Designing: An Invitro Study

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Abstract

Statement of Problem: Cement space has an important contribution in enhancing the fit of indirect restorations, and although Computer Aided Designing allows precise control of spacer thickness, variations between the design parameters and the actual fit especially in 3D printed copings may influence both clinical performance and casting accuracy. Analysis regarding the fit of 3D printed resin copings and their casted counterparts are lacking, and data on accuracy is needed. **Purpose:** The purpose of this study was to assess how accurately the programmed cement space values were reproduced by comparing the internal gap measurements of 3D-printed resin copings with those of cast resin copings. **Material and Methods:** A typodont maxillary canine was prepared and scanned to design three groups of resin copings with cement spacers of 25µm, 40µm, and 55µm using CAD software. All the copings were 3D printed and half of them were cast into metal using the lost-wax technique. All samples were cemented, sectioned, and evaluated for internal gaps using a scanning electron microscope. Data were analyzed using t-tests, ANOVA, and Tukey's post hoc test ($p < 0.05$). **Results:** The mean values of the internal gaps were within permissible clinical limits ($<120\mu\text{m}$) for all the groups. The measured internal gap values were close to the programmed values (25µm, 40µm, 55µm) in resin copings ($p > 0.05$), but not after casting ($p < 0.01$). The printer consistently maintained uniform cement thickness, demonstrating reliable internal gap reproduction within each group ($\text{CV} < 10\%$). **Conclusions:** Within the limitations of the study, 3D printing showed accurate reproduction of cement space thickness in resin copings, while significant discrepancies were found after casting.

Key Words: 3D printed resin copings, cement space thickness reproduction, casted 3D printed resin copings, programmed cement space thickness.

Introduction

The dental field is undergoing a significant paradigm shift, and the primary reason is digitalization. There are two types of digital manufacturing techniques: additive and subtractive. 3D Printing (Micro-stereo lithography) 3D Printing is an example of additive manufacturing technique that needs data from CAD software to work.¹ 3DPT can be used to manufacture copings, anatomic crowns, and partial denture frameworks.¹ Cement space provides space for the luting cement between the intaglio surface of the crown and the tooth surface, thereby, reducing the stress, increasing retention, and providing a better fit for the final prosthesis.² Cement space also enhance the marginal adaptation between the prepared tooth and the restoration, reducing the probability of cement dissolution, secondary caries, accumulation of plaque, and periodontal problems.²

There have always been different schools of thought where some researchers feel that providing less cement space improves retention.³ In contrast, others agree that increased cement space thickness improves retention.^{4,5} A marginal gap as high as 649µm was observed when no die spacer was given.⁶ When the cement space thickness was raised from one to eight layers, the marginal adaptation was substantially enhanced from 479µm to 38µm.^{4,5,6} An ideal cement space thickness of 25µm has been suggested.⁷ However, inconsistent results have been reported in the research involving paint-on die spacers available commercially.^{4,8,9}

Computer-aided design (CAD) technology facilitates the design of restorations on a virtual platform and the cement space can be programmed based on individual cases. Literature reveals studies that examine the accuracy of cement space using CAD for subtractive manufacturing. The milling technique involves the use of a specific milling bur of fixed diameter imposing problems like movement constraints which makes accurate reproduction of intricate shapes becomes challenging, limiting the precision of the final restoration.¹⁰ However, studies on accuracy of reproduction of die spacer thickness using CAD for 3DPT (additive manufacturing) is sparse.^{2,10,11,12}

The clinical fit of the definitive restoration may be compromised if the cement space parameters set in the computer-aided design program do not correspond with the internal fit of the 3D-printed resin copings.² Therefore, the purpose of this study was to assess how accurately the programmed cement space values of 25µm, 40µm and 55µm were reproduced in 3D printed resin copings and the cast copings. The null hypothesis is that the programmed cement space would be accurately reproduced in 3D printed resin and the cast copings.

Methodology

A typodont right maxillary canine was prepared to be provided with a porcelain fused to metal crown using the standard protocol. Care was taken that the entire procedure was done using a high-speed air-rotor hand piece with a continuous supply of water coolant.

The typhodont model was scanned using an extra oral scanner (Medit T310-MEDIT corp. 8, Yangpyeong-ro 25-gil, Yeongdeungpo-gu, Seoul, Republic of Korea). The scanned image was then imported to the Exocad software version 2.4-7290. Here, the scanned image was modified, and a die was designed. The die was digitized and saved as a Standard Tessellation Language (STL) file and then printed using a 3D printer (Ackuretta Dentiq 120-Taiwan).

Using the scanned data, three different copings of 0.5mm overall thickness was designed in the Exocad software (Dental CAD 2.4 Plovidiv, Exocad GmbH, Germany)

- Group 1: A cement space gap of 25µm was given.
- Group 2: A cement space gap of 40µm was given.
- Group 3: A cement space gap of 55µm was given.

12 resin copings were printed in each group making a total of 36 copings. Out of the 12 resin copings in each group, six were casted to Chromium-Cobalt (Cr-Co) alloy using the lost wax casting technique, further dividing the groups into group A (pre-cast) and B (post-cast).

All the copings were converted to STL format and then imported into the printing software (*Alpha3D*. Version 1.5, Alpha3D, 2021, Taiwan) and arranged on the virtual platform. A total of 36 resin samples (12 per group), were printed using the 3DPT.

Six samples from each group were invested in casting rings with a phosphate-bonded investment material (Varseo Vest C&B, BEGO, Germany), carried out by a single experienced technician in accordance with the manufacturer's instructions. Induction casting technique was employed for casting. The copings were then finished under standard protocol. The copings were finally abraded with 50-micron Al₂O₃ at a pressure of 325kPa.

The 18 resin samples and the 18 Cr-Co copings were luted on the dies using a resin cement (3M™ RelyX™ U200 Automix Self-Adhesive Resin Cement, Minnesota, U.S.). After loading the copings with the resin, it was placed on the die with a rocking motion and was kept under a constant deadweight load of 6.1kg for 7min till the setting process to complete.¹³ Residual cement was removed using a fine microbrush. Specimens were cut in the bucco-lingual plane using a low-speed diamond disc under wet conditions.

The internal gap, as defined by Holmes et al., refers to the perpendicular measurement extending from the intaglio surface of the casting to the axial wall of the preparation.^{14,15} The internal gap of the pre-cast and post-cast specimens were analyzed at five locations per section using a scanning electron microscope (Ultra55 FE-SEM Carl Zeiss EDS, FELMI ZFE, Austria). This gives a total of 10 points per die. Overall, 360 measurements were acquired for the entire study. The internal gap images were gathered from a Scanning electron microscope at 200x magnification.

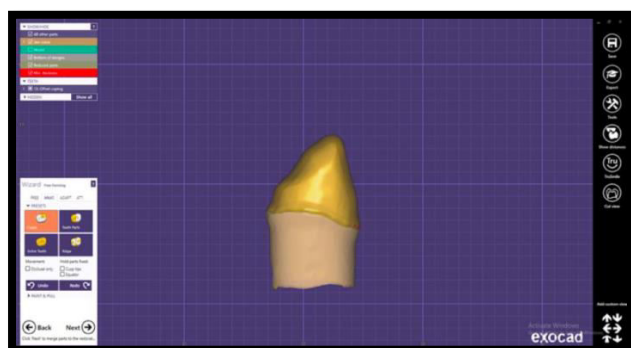


Figure 1: Coping design in Exocad software



Figure 2: Cemented resin coping

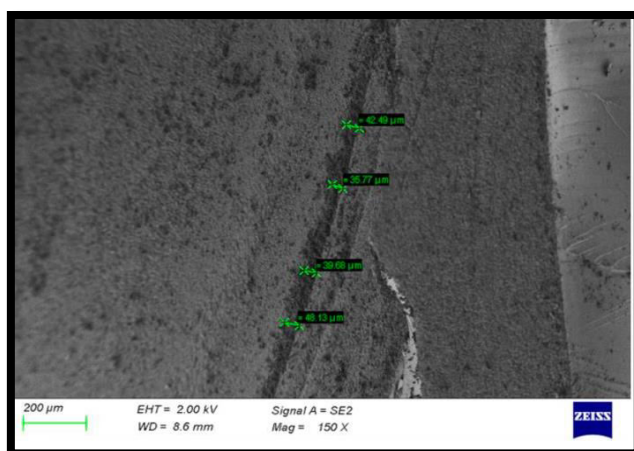


Figure 3: SEM image of group 2A copings

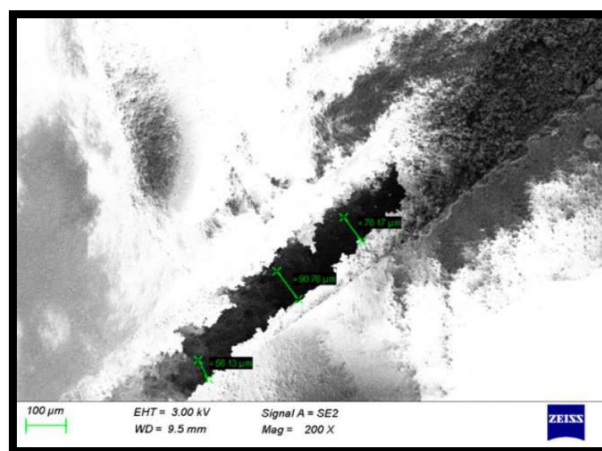


Figure 4: SEM image of group 3B copings

Statistical Analysis:

The data analysis was performed using a statistical software (IBM SPSS Statistics Version 30.0.0.0, NY). Descriptive statistics in the form of frequency distribution and percentage was used to describe the data. The programmed values were compared with the mean internal gap using a one-sample t-test. One way ANOVA test was applied for the mean measured cement thickness comparisons across six groups. Tukey's post hoc test was done to determine which comparison group is statistically significant. Paired t-tests were done for intergroup comparisons. Results were presented using tables and graphs. The level of significance was set at $P < 0.05$.

Results

The average internal gap measurements of the pre-cast (group 1A, 2A and 3B) and the post-cast groups (group 1B, 2B and 3B) is represented in Table1 and Graph 1.

Measurement precision within each group was assessed using the coefficient of variation (Table-1). A lower CV signifies higher precision. Conventionally, a CV of 10% or less is considered indicative of high precision.² According to Table-1 group 3B has shown highest precision and group 2A is the least precise. However, all the groups fall well under the 10% CV with group 2A going slightly above the margin. The finding reflects the printer's ability to maintain uniform internal gaps across specimens in the group. Table-2 presents the results of the one-sample t-test. Within the pre-cast group, p-values greater than 0.05 denotes the absence of a statistically significant difference between the sample mean and the programmed mean. Conversely, post-cast group shows p-values < 0.001, indicating a statistically significant difference.

Intra group and inter group comparisons using ANOVA test (Table-3) concluded that there are significant differences ($p < 0.001$) in cement thickness between the groups. This indicates that there is a statistically significant difference in mean cement thickness in at least few of the six groups. Among all groups, 3D printed resin copings (1A, 2A, 3A) demonstrated cement thickness closest to their programmed values. In contrast, metal copings (especially 25 μ m, 40 μ m, and 55 μ m) exhibited notably higher values, suggesting deviation from the intended cement spacer thickness. Based on mean values alone, the resin groups outperformed the metal groups in replicating the programmed spacer thickness.

Pairwise comparisons of all the groups done using the Tukey HSD post-hoc test (Table-4) indicates significant differences in cement thickness among most groups, except for 1B vs 2A ($p = 0.963$) and 2B vs 3B ($p = 0.007$), which are not statistically different. Group 1A (Resin at 25 μ m) demonstrates the smallest deviation from the programmed thickness and is significantly thinner than all other groups. In contrast, Group 3B (Metal at 55 μ m) shows the greatest deviation, reflecting a larger cement space compared to the resin groups.

Table-5 indicates that there is a very weak negative correlation (-.192) between the two variables belonging to groups 1A and 1B, strong positive correlation (.873) between groups 2A and 2B and moderate positive correlation (.680) between groups 3A and 3B. Two-sided p value for group 2A vs 2B is 0.023 which is < 0.05. Hence this is statistically significant. The correlation for groups 1A vs 1B and 3A vs 3B is not statistically significant, as the p-value is much higher than 0.05.

In all comparative groups, the confidence intervals lie entirely above or below zero, indicating a statistically significant difference (Table-6). Consistently low p-values ($p < 0.05$) across all comparisons further confirm that the variables in each group differ significantly.

Tables

Table 1: Group-wise Means, Standard deviations, Standard errors and Coefficient of Variation

Groups	Mean in μm	SD	SE	Coefficient of variation (%)
1A- 25 μm precast	26.8500	2.3	0.94190	8.59
1B- 25 μm postcast	43.2000	2.77	1.13284	5.86
2A- 40 μm precast	45.0000	4.84	2.16564	10.76
2B- 40 μm postcast	72.7667	4.77	1.94862	6.56
3A- 55 μm precast	56.3500	3.09	1.26141	5.48
3B- 55 μm postcast	81.3333	3.9	1.59346	4.80
TOTAL = 36	54.2500	19.03297	3.17216	

SD = Standard deviation, SE= Standard error, μm = micrometre, % = Percentage

Table 2: Comparison of measured internal gap values to the programmed cement space values in the resin and metal copings

		Significance		95% CI of the Difference	
Groups	t	Two-sided p	Mean Difference	Lower	Upper
Group 1A	1.964	.107	1.85000	-.5712	4.2712
Group 2A	2.309	.069	5.00000	-.5670	10.5670
Group 3A	1.070	.333	1.35000	-1.8926	4.5926
Group 1B	16.066	<.001	18.20000	15.2879	21.1121
Group 2B	16.815	<.001	32.76667	27.7576	37.7757
Group 3B	16.526	<.001	26.33333	22.2372	30.4294

CI = Confidence Interval; t = t-statistic; % = percentage

Table 3: Intergroup and Intragroup comparison with ANOVA

	Sum of Squares	Mean Square	F	Sig.
Between Groups	12235.253	2447.051	165.677	<.001
Within Groups	443.637	14.788		
Total	12678.890			

Table 4: Tukey HSD Post-hoc pairwise comparisons

Group Pair	Mean Difference (I-J)	Std. Error	p-value (Sig.)
1A vs 1B	-16.3500	2.22020	<.001
1A vs 2A	-18.1500	2.22020	<.001
1A vs 2B	-45.9167	2.22020	<.001
1A vs 3A	-29.5000	2.22020	<.001
1A vs 3B	-54.4833	2.22020	<.001
1B vs 2A	-1.80000	2.22020	.963
1B vs 2B	-29.56667	2.22020	<.001
1B vs 3A	-13.15000	2.22020	<.001
1B vs 3B	-38.33333	2.22020	<.001
2A vs 2B	-27.76667	2.22020	<.001
2A vs 3A	-11.35000	2.22020	<.001
2A vs 3B	-36.33333	2.22020	<.001
2B vs 3A	-16.41667	2.22020	<.001
2B vs 3B	-8.56667	2.22020	.007
3A vs 3B	-24.98333	2.22020	<.001

Std. Error = Standard error of mean; Sig. = significance level

Table 5: Pearson's Correlation of pre-cast and post-cast groups

Groups	Corelation	Significance Two-Sided p-value
1A and 1B	-.192	.718
2A and 2B	.873	.023
3A and 3B	.680	.137

Table 6: Paired t-test results for intergroup comparisons

Groups	Mean	Std. Deviation	Std. Error Mean	95% CI of the Difference		t	Significance
				Lower	Upper		Two-Sided p
1A and 1B	-16.35000	3.93434	1.60619	-20.47883	-12.22117	-10.179	<.001
2A and 2B	-27.76667	2.59281	1.05851	-30.48765	-25.04568	-26.232	<.001
3A and 3B	-24.98333	2.89511	1.18192	-28.02157	-21.94510	-21.138	<.001

CI = Confidence Interval; t = t-statistic; Std. Error = Standard Error of the Mean; Std. Deviation = Standard Deviation; % = percentage

Discussion

Null hypothesis was accepted in the case of resin copings manufactured by 3D printing, as the measured internal gaps closely resembled the programmed cement space thickness. Conversely, the null hypothesis was rejected for the casted resin copings, since their measured internal gaps did not correspond to the programmed cement space thickness.

Previous studies evaluating the internal gaps of 3DPT resin copings in relation to the programmed spacer thickness are sparse, thereby limiting the direct comparison with the findings of the current study challenging. Nevertheless, the outcomes of this study may be compared with prior studies focusing on alternative techniques, materials, and the marginal/internal fit of 3D-printed resin crowns.^{2,10,11,12,16}

Accuracy describes the closeness of a measurement to the true value, while precision refers to how consistently the same measurement is obtained under unchanged conditions, regardless of whether it's close to the true value. This precision is calculated with the help of coefficient of variation and CV values of <10% was considered acceptable.² In the present study, the consistent performance in maintaining cement thickness uniformity highlights the printer's capacity to reproduce internal gaps effectively within each group.

Previous investigations have evaluated the internal gaps associated with CAD/milling technologies. Kokubo et al. reported that In-Ceram crowns with a programmed spacer of 50 µm exhibited internal gaps of 165.9–200.3 µm, about three to four times the intended

value.¹⁷ Similarly, Moldovan et al. found internal gaps of 100–130 μm for CAD/Cercon (10–20 μm spacer) and 60–70 μm for CAD/Cerec (–100 μm), indicating system-dependent variations in fit.¹⁸ Shin et al. investigated how different cement space parameters influence the marginal and internal adaptation of 3D-printed definitive resin crowns and suggested a 70 μm cement space as the most suitable value for achieving optimal adaptation.¹⁰ While opinions differ regarding whether thinner or thicker spacers enhance retention, there is general consensus that increasing the cement space thickness leads to better marginal adaptation.^{2,4,5} Additionally, ceramic crowns showed enhanced fracture resistance when the average internal gap at the axial wall was around 73 μm .¹⁹

Direct comparison of resin and metal copings showed that casted copings had greater cement thickness, indicating poor correspondence between programmed and reproduced values. Bhaskaran et al. found Co-Cr copings from 3D-printed resin had smaller marginal (27.22 μm) and internal gaps (36.15 μm) than conventional castings, though slightly higher than DMLS copings (10.52 μm and 41.22 μm).¹¹ Arora et al. reported better marginal fit for resin copings than PMMA copings after casting.¹⁶ Kale et al. demonstrated that increasing the cement space from 30 to 50 μm reduced marginal discrepancy, improving fit.¹⁴ In the present study, a direct relation couldn't be established between the programmed value and the internal fit as the mean internal gap with the 25 μm and 55 μm were closer to the programmed value than the 45 μm group. However, it was not statistically significant.

Various techniques measure internal gaps, including Micro-CT, optical or digital microscopy, and the replica technique (silicone impression).^{2,10,20} In this study, a scanning electron microscope was used for its high resolution, magnification, depth of field, accuracy, reliability, and accessibility.

The limitations of this include the small sample size and the inability to fully replicate clinical conditions. This study variables like the point of measurement, material and technology used might affect the results. Potential inaccuracies might have occurred during the scanning and printing stages. Additionally, the study was limited to only 10 measurements per specimen, and the findings are specific to the particular CAD and 3D printing system used. Therefore, the outcomes may not necessarily extend to alternative software or hardware setups. Routine dimensional changes caused by lost wax technique of casting were also not considered.

Further research is needed to assess the accuracy of additive technologies, which exhibit shrinkage errors and resolution limits. In digital dentistry, subtractive methods are considered more accurate and have stronger literature support due to longer market

presence. Studies should focus on addressing additive manufacturing shortcomings to improve clinical performance.

Conclusion

Taking into consideration the limitations of this in vitro investigation, the following conclusions were reached:

1. There was no significant difference between the programmed cement space thickness values and the acquired internal gap means in the 3D printed resin copings.
2. There was a significant difference between the programmed cement space thickness values and the acquired internal gap means in the post cast copings.
3. There was a significant difference when comparing the pre-cast and post-cast cement space thickness values.
4. The printer consistently maintained uniform cement thickness, demonstrating reliable internal gap reproduction within each group.

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