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RESEARCH AND EDUCATION

Effect of cement space settings on the marginal and internal fit of 3D-printed definitive resin crowns

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ABSTRACT

Statement of problem. The cement gap setting affects the marginal and internal fits depending on the crown material and manufacturing method (subtractive or additive manufacturing). However, information on the effects of cement space settings in the computer-aided design (CAD) software program, which is used to aid the manufacturing with 3-dimensional (3D) printing-type resin material, is lacking, and recommendations for optimal marginal and internal fit are needed.

Purpose. The purpose of this in vitro study was to evaluate how cement gap settings affect the marginal and internal fit of a 3D-printed definitive resin crown.

Material and methods. After scanning a prepared typodont left maxillary first molar, a crown was designed with cement spaces of 35, 50, 70, and 100 μm by using a CAD software program. A total of 14 specimens per group were 3D printed from definitive 3D-printing resin. By using the replica technique, the intaglio surface of the crown was duplicated, and the duplicated specimen was sectioned in the buccolingual and mesiodistal directions. Statistical analyses were performed using the Kruskal−Wallis and the Mann−Whitney post hoc tests (α=.05).

Results. Although the median values of the marginal gaps were within the clinically acceptable limit (<120 μm) for all the groups, the smallest marginal gaps were obtained with the 70-μm setting. For the axial gaps, there was no observed difference in the 35-, 50-, and 70-μm groups, and the 100-μm group showed the largest gap. The smallest axio-occlusal and occlusal gaps were obtained with the 70-μm setting.

Conclusions. Based on the findings of this in vitro study, a 70-μm cement gap setting is recommended for optimal marginal and internal fit of 3D-printed resin crowns. (J Prosthet Dent 2023;■:■-■)

With improvements in computer-aided design and computer-aided manufacturing (CAD-CAM) techniques, dental prostheses are being increasingly manufactured using this technology.[1] CAM methods include subtractive and additive manufacturing techniques. The milling method, the most popular in dentistry,[2] requires a dedicated milling bur applied to each block when cutting a prosthesis. However, because of limitations of the milling bur and its fixed thickness, the movement of the milling bur axis limits the reproducibility of complex shapes and prevents precise machining.[3] In addition, milling generates considerable noise, requires a long time, and the debris from the blocks is not reusable.

Additive manufacturing produces less noise, is economical, and faster by eliminating the impression-making step and various drilling processes.[4] In addition, complex shapes can be easily reproduced with this technique with high precision.[5] Three-dimensional (3D) printing methods are recent developments in digital technology that have become popular in dentistry6[6,7]; for example, for interim prostheses. Efforts have been made to clinically introduce 3D-printing materials and fabricate definitive prostheses. The physical properties of these materials have been improved[8,9] to reach the strength

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Clinical Implications

A 70-µm cement gap setting is recommended for optimal marginal and internal fit of 3D-printed resin crowns.

required for definitive prostheses according to the International Organization for Standardization (ISO) standard 10 477.[10] To facilitate the clinical usage of 3D-printed prostheses, they must have stable internal fit, physical characteristics, and color. The accuracy of the marginal and internal fits, along with improvements in the physical properties, contributes to the clinical success of a prosthesis.[11-13] Excessive incongruity in the crown margin can increase the rate of cement dissolution, which can induce microleakage and plaque deposition associated with secondary caries, pulpitis, and pathological periodontal conditions.[14-20] Although what is considered an acceptable marginal gap size has varied,[21-25] 120 µm has been considered the clinically acceptable limit of marginal gap,[26-28] a value based on the criteria proposed by McLean and von Fraunhofer.[29]

Fusayama et al[30] reported that die spacing is the most widely used method to achieve consistent spacing for luting cement. Using a uniform space reduced the marginal discrepancy of the crown and facilitated complete setting.[31,32] In digital dentistry, the cement gap setting in the CAD software plays the same role as the die spacer. One CAD software program (exocad DentalCAD 2.2; exocad GmbH) allows setting the cement gap in the crown intaglio surface design process, and setting no cement gap at a desired distance from the margin. Moreover, an additional cement gap can be included in the axial and radial directions. Currently, rules for setting the optimal values are lacking.[33]

The direct-view, cross-sectioning, and replica techniques have been used for measuring marginal adaptation.[34-36] Laurent et al[37] reported that predictable measurement of the thickness of the cement film layer is possible with the replica technique, regardless of the region of the intaglio surface of the crown (marginal, axial, or occlusal), if an appropriate silicone material is used.

Depending on the manufacturing method (subtractive or additive) and the type of material, the cement space setting impacts the marginal and internal fits differently.[38-42] Although increasing the cement space can benefit the marginal fit of the restoration,[43,44] an internal space greater than 120 µm can increase the risk of fracture of ceramic restorations.[45] Research on the cement space setting value of prostheses made of 3D printing-type resin material is lacking. Therefore, this in vitro study aimed to evaluate how cement gap settings affect the marginal and internal fits of 3D-printed definitive resin crowns. The null hypothesis was that there would be no difference in the marginal and internal gaps of 3D-printed resin prostheses fabricated using the various cement gap settings in the CAD-CAM software system used.

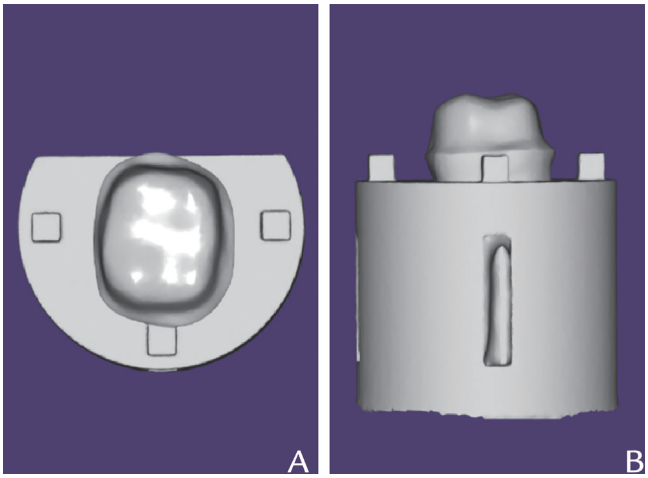

Figure 1. Computer-aided design software program rendering of scanned prepared teeth. A, Occlusal view. B, Buccal view.

MATERIAL AND METHODS

A typodont tooth (ANA-4 ZP; frasaco GmbH) was prepared by an operator (J-H.K.) with more than 20 years of experience in tooth preparation. The prepared tooth was scanned by a dental laboratory scanner (T500; Medit), and a CAD software program (Rhinoceros 5.0; Robert McNeel & Associates) was used to design a die for a replica. The designed die was printed by a metal 3D printer (rainbow Metal Printer; Dentium Co) and 3D printing materials (Ti64 Grade 23; GE Additive) from the standard tessellation language (STL) file (Fig. 1).

The printed metal die was sprayed with a powder (Easy scan; Dmax) to prepare the surface and was scanned with an intraoral scanner (TRIOS3; 3Shape A/S). Subsequently, the STL file of the metal die was imported into a CAD software program (exocad DentalCAD 2.2; exocad GmbH) to design 3D-printed definitive resin crowns.

The thickness of all crowns was set at approximately 1.0 mm, and the cement space was set at 35, 50, 70, and 100 µm. An experienced operator (Y-J.K.) designed the crowns, and the design was imported into a 3D printer (UNIZ Maker; UniZ Technology). Fourteen crowns were arranged on the platform of the 3D printer, and a support was attached perpendicular to the occlusal plane. All crowns were printed with 100-µm layer thickness with a liquid definitive 3D-printing resin (TC-80DP; Graphy Inc) with a DLP-type 3D printer (Sprint Ray Pro 95; SprintRay). After fabrication, each crown was rinsed with 95% isopropyl alcohol for 5 minutes in an ultrasonic cleaner (Shinhan 200H 3 L; Shinhan-sonic). Subsequently, the outer and intaglio surfaces were

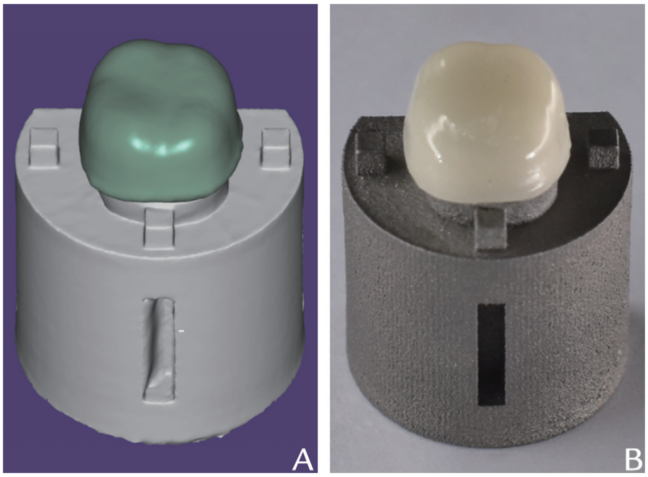

Figure 2. A, Virtual crown design. B, 3D-printed resin crown with metal die.

postpolymerized for 30 minutes with a polymerizing unit (Cure-M 102H; Sona Global Co Ltd) (Fig. 2).

After drying the intaglio surface of the crown, a white silicone impression material (FIT CHECKER; GC America Inc) was inserted to which an operator (H.S.) applied constant pressure for 2 minutes until the silicone completely polymerized. After which, the crown was carefully separated from the metal die, and the silicone film was examined to ensure complete attachment to the intaglio surface. This step was repeated if tearing or air bubbles were present. The silicone film-lined intaglio surface of the crown was filled with a low viscosity silicone impression material (Aquasil Ultra XLV; Dentsply Sirona) and the lower part was reinforced with putty (Aquasil Putty; Dentsply Sirona). Reinforcement with a light body and putty silicone enabled accurate sectioning, and yielded a film that can be used to evaluate internal fit.[37] After polymerization of the light body and putty, the crown was removed.

This process was repeated twice to obtain 2 casts. After segmenting with a sharp scalpel blade (Stainless Sterile blade #11; Paragon) at the center for the buccolingual and mesiodistal directions, measurements were obtained at 7 points on each plane, resulting in 14 reference points per crown (Fig. 3). To standardize the location of the measuring spots on the whole sample, the marginal gap was measured at a position approximately 100-µm apart from the margin, the axial gap was measured at the center of the axial plane, the axio-occlusal gap was measured at the line angle where the axial plane and the occlusal plane meet, and the occlusal gap was measured at the center of the occlusal plane. A microscope with a ×0.5 lens at ×10 magnification (SMZ-171; Motic) was used to measure the thickness of the silicone film at 3 points for the marginal, axial, and axio-occlusal planes and the occlusal areas. A cross-section of the replica was made using the Motic Live Imaging Module with a software program (Motic Images Plus 3.0 ML; Motic) provided by the microscope manufacturer, and the measurement was performed using the "Measure" tool menu in the program. Overall, 42 measurements were obtained for each replica (12 marginal points, 12 axial points, 12 axio-occlusal points, and 6 occlusal points). Each point was measured by 1 author (H.S.) and the average values of 3 measurements made at each point was recorded (Fig. 4).

All data were analyzed with a statistical software program (IBM SPSS Statistics, v23.0; IBM Corp). Mean and standard deviation values were calculated from the data measured from the replica specimen. The Shapiro–Wilk test was used to analyze normal distributions. Since it represented content of partial normality, the data of the internal gap in each reference point according to the cement gap setting were conducted using nonparametric analysis with the Kruskal–Wallis test. The Mann–Whitney U post hoc test was used to determine differences between groups (α=.05).

RESULTS

The result of the Kruskal–Wallis test indicated that the cement space values significantly affected the marginal, axial, axial-occlusal, and occlusal gaps (P<.05). The median and interquartile range for marginal, axial, axio-occlusal, and occlusal gaps for all 14 crowns with cement space at 35, 50, 70, and 100 µm are shown in Figure 5. The 70-µm cement space group with the smallest marginal gap (81.0 ±35.7 µm) was significantly different compared with the other groups (P=.002). The 100-µm group with the largest axial gap (127.1 ±63.1 µm) was significantly different compared with the other groups (P<.001). The 70-µm group with the smallest axio-occlusal gap (78.0 ±27.6 µm) was significantly different compared with the other groups (P<.001). The 70-µm group had the smallest occlusal gap (103.5 ±41.7 µm), which was not significantly different from that of the 100-µm group (P=.084); the 35- and 50-µm groups showed a significantly larger occlusal gap from that observed in the 70-µm group (P<.001 and P=.002).

DISCUSSION

This study evaluated the effect of cement gap settings on marginal fit and internal gap of 3D-printed definitive resin crowns. The 70-µm cement gap setting group had a significantly better fit in the marginal, axio-occlusal, and occlusal areas. Therefore, the null hypothesis was rejected.

The occlusal gap was generally larger than the marginal and axial wall gaps. However, even with a large gap, the occlusal area can be completely filled with cement during crown seating. However, the retention may decrease if the gap is large, and microleakage and cement washout may occur at the margin and axial wall.[20] In the 35- and 50-µm groups, interference at the axial wall is expected, likely inhibiting complete seating and increasing the marginal gap.

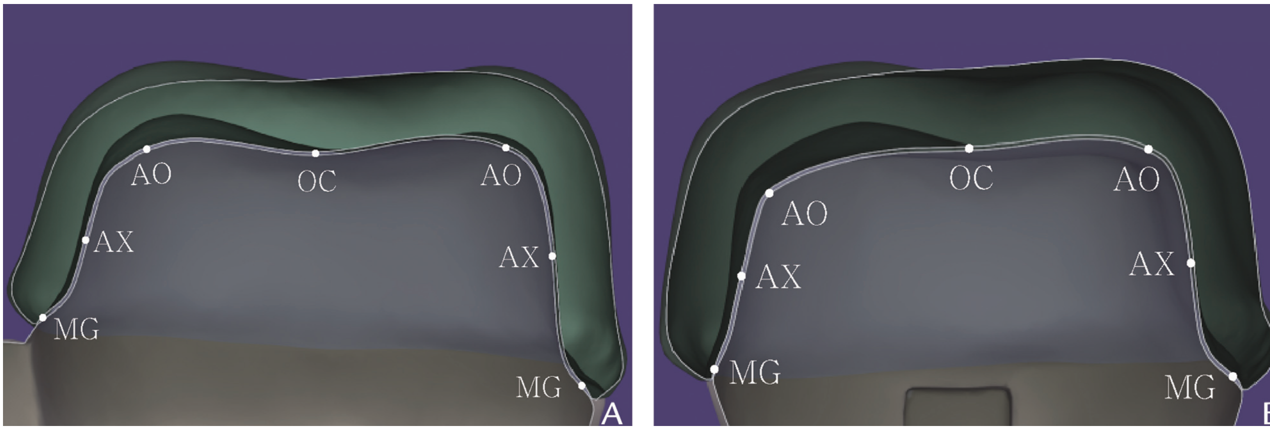

Figure 3. Representative sectional view of simulated cement space with 70-µm cement gap setting. A, Buccolingual section. B, Mesiodistal section. AO, axio-occlusal gap; AX, axial gap; MG, marginal gap; OC, occlusal gap.

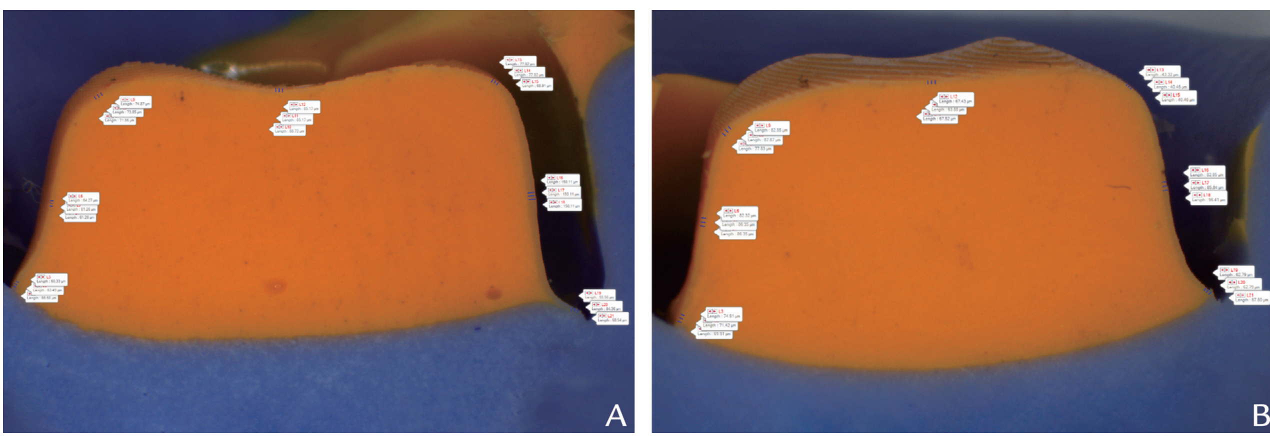

Figure 4. Cross-sectional view of replica specimens with 70-µm cement gap settings. A, Buccolingual section. B, Mesiodistal section.

Previous studies that evaluated the marginal and internal gaps of 3D-printed resin crowns based on the cement space setting are sparse.[33] Therefore, a direct comparison of the results of the present with previous studies is not feasible. Nevertheless, the findings can be compared with the results of previous studies on different cement space settings for crowns of other materials. Grajower and Lewinsteine[38] determined that the optimal cement space was 50 µm: 30 µm for the cement material and a decrease in friction due to surface roughness and 20 µm to provide for potential distortion in the manufacturing process. Kale et al[39] examined the effect of the cement gap setting value on the marginal gap of zirconia crowns and concluded that the marginal discrepancy decreased when the cement space is increased from 30 to 50 µm. Nakamura et al[40] measured the marginal gap of CEREC 3 standardized crowns according to 3 different cement space settings and reported that, with the luting space set at 10 µm, the mean value of the marginal gap is significantly larger than that with the luting space set at 30 µm or 50 µm. Sultan et al[41] concluded that the smallest mean marginal gap of resin-ceramic implant prostheses was when the luting space was set at 60 µm. According to Özçelik et al,[42] the marginal gap is smallest for polymethyl methacrylate interim CAD-CAM crowns when the digital cement gap value is set at 20 µm at the margins and 60 µm at the other intaglio surfaces. Depending on the material, the cement space should vary according to the processing method. For 3D-printed resin crowns, the intaglio surface is manufactured in a stepwise manner, owing to the nature of the additive manufacturing process, requiring a larger cement space. When printing, the stacking height also has an effect, and in the present study, the layer thickness was set at 50 µm. At the corresponding lamination height, a cement gap of 70 µm resulted in a uniform fit.

The marginal gap size in all the cement gap settings (35, 50, 70, and 100 µm) was lower than 120 µm, which has been considered to be the maximum clinically acceptable marginal gap size.[29] However, the clinically acceptable size for the marginal gap depending on the crown material and manufacturing techniques has not

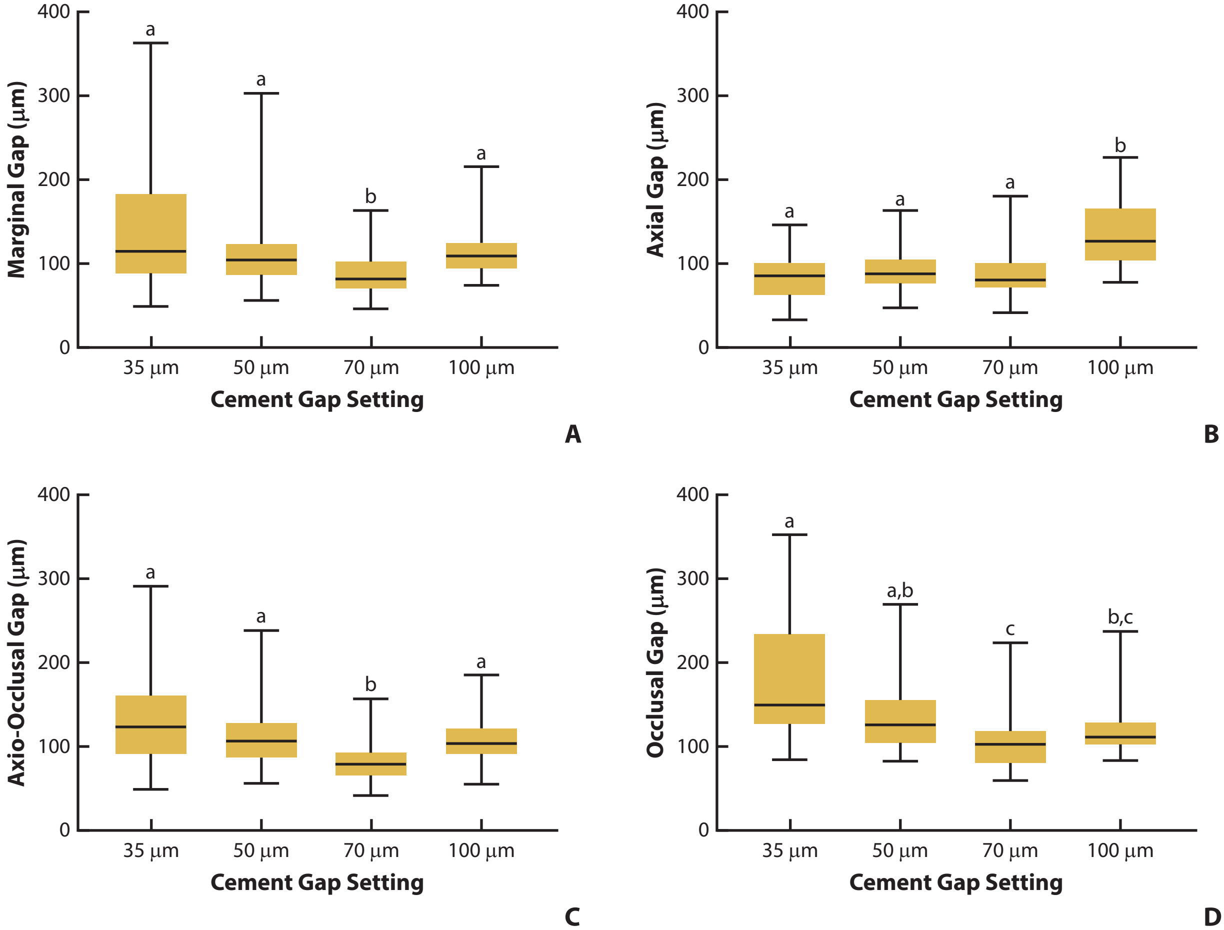

Figure 5. Median values of margin, axial, axio-occlusal, and occlusal gaps in 4 different cement space settings (35, 50, 70, and 100 μm). A, Marginal gap; B, Axial gap; C, Axio-occlusal gap; D, Occlusal gap. Different subscript letters indicate significant difference between groups according to Mann–Whitney U test (*P*<.05).

been established. An acceptable discrepancy in the marginal gap size of the crown is 50 to 200 μm.[21-23] A recent study[24] determined that the best fit for ceramic prosthesis was between 7.5 and 206.3 μm; however, a consensus remains to be established. It is unclear whether the criteria of a 120-μm marginal gap size are applicable in the 3D printing of the resin crown that is manufactured differently from previous methods.[21-25] A direct comparison between various studies is difficult because of the diversity of the crown materials, CAD-CAM environment, lack of consistency in defining a marginal fit, and use of different methods to measure the marginal fit.[25]

The replica technique is a nondestructive, accurate, and reliable evaluation method. Rahme et al[34] reported that the sectioning and silicone replica techniques produce similar measurements of the marginal gap of Procera ceramic crowns. However, in the replica technique, the crown margin is difficult to distinguish from the finishing line, and the silicone film might tear when the crown is removed.[35] In addition, incorrect plane sectioning can result in the overestimation or underestimation of measurements.[36]

Limitations of the present study included the small sample size and the in vitro design being different from those in actual clinical practice. The clinical environment may induce thermomechanical fatigue, and the effects on the marginal and internal gaps depend on the abutment condition and type of preparation.[46,47] Additional research regarding the crown thickness, printing method and materials, thickness of printing layers, surface roughness, and adhesive method is required for sustainable application in clinical practice.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Although the median values of the marginal gaps were within the clinically acceptable limit (<120 μm) for all groups, the smallest marginal gaps were observed in the 70-μm setting.
2. For the axial gaps, there was no observed difference among the 35-, 50-, and 70-μm groups, and the

100-µm group showed the largest gap. The smallest axio-occlusal and occlusal gaps were obtained with the 70-µm setting, not the 35-, 50-, and 100-µm settings.

3. A 70-µm cement gap setting is recommended as the optimal marginal and internal fit for 3D-printed definitive resin crowns.

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Heedo Shin: Software, Investigation, Data curation, Writing – original draft, Validation, Visualization. **You-Jung Kang:** Formal analysis, Resources, Writing – original draft, Project administration, Validation, Visualization. **Hoon Kim:** Software, Investigation, Data curation. **Jee-Hwan Kim:** Conceptualization, Methodology, Supervision, Writing – review & editing, Funding acquisition.

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