Dental Research Journal

Original Article

Evaluation of internal fit of press ceramic and porous structured cobalt–chromium crown fabricated by additive manufacturing

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ABSTRACT

Background: The purpose of this *in vitro* study is to fabricate a novel metal–ceramic prosthesis with a porous structure, to compensate for the disadvantages associated with the design of existing prostheses, and to measure the internal fit of this prosthesis.

Materials and Methods: In this *in vitro* study, the mandibular first molar was scanned from the dental computer-aided-design to design a 3 mm porous structure frame. The frame was produced using the lamination method and fired in a pressed ceramic. For comparison, pore-free specimens were fabricated by selective laser sintering (SLS) as described above, and porous specimens were fabricated by casting (total n = 30). The internal fit was then measured using a digital microscope (at 100× magnification), and the data were analyzed using one-way ANOVA (α = 0.05).

Results: The total mean internal discrepancies for each group were 42.32 ± 22.50 μm for the porous structure SLS group (PS-group), 107.54 ± 38.75 μm for no-porous casting group (group), and 121.36 ± 50.19 μm for the no-porous SLS group (group), with significant differences (P < 0.05) among all groups.

Conclusion: The internal discrepancies of porous structure crown fabricated by SLS were smaller than that of no-porous crown fabricated by casting and SLS. Based on these laboratory findings, further studies should be conducted to evaluate the feasibility of the newly designed porous structure and press ceramic prosthesis to determine whether they can be applied in clinical practice.

Key words: Dental crown; internal fit, metal–ceramic restorations, porosity, prosthesis design

Received: 04-Sep-2019
Revised: 19-Jun-2021
Accepted: 06-Sep-2021
Published: 16-Aug-2022

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INTRODUCTION

Computer-aided-design/computer-aided-manufacturing (CAD/CAM) systems have been widely applied in the dental field. In the case of implants, CAD can be used prior to surgery to develop a plan for reducing patient inconvenience by reducing the time of operation spent discussing the prosthesis that is to be applied.[1] A study carried out by Sanna reported a cumulative survival rate of 91.5% over 5 years with a prosthesis using CAD/CAM, suggesting that the proportion of prostheses produced using CAD/CAM is only expected to grow.[2] In addition, the introduction of a lamination system into the medical and dental industries has greatly contributed to the digitization of the dental

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How to cite this article: Bae EJ, Kim JH, Lim JY. Evaluation of internal fit of press ceramic and porous structured cobalt–chromium crown fabricated by additive manufacturing. Dent Res J 2022;19:65.

industry. For example, dental crowns,[3] implants,[4] dentures,[5] orthodontic appliances,[6] and surgical guides[7] are designed by CAD and manufactured in a laminated manner. This digital system is advantageous in terms of shortening the working time, simplifying the process, and allowing for the production of a precise, customized prosthesis. The lamination method involves stacking layers from slice data and is superior to the lost wax technique or the cutting method in that it can implement complicated shapes while producing less waste.[8] The popularity of the lamination method is growing substantially in the field of customized prosthetics, as it allows for the production of any type of desired design.[9] It also presents opportunities for new designs, as it can create highly complex geometries.[10]

Cobalt–chromium, in particular, is one of the most commonly used materials in metal–ceramic restorations, due to its corrosion resistance and biocompatibility.[11] Further, in selective laser sintering (SLS), the lamination method which has been introduced in recent years, cobalt–chromium is used as the main material to form the metal–ceramic substructure.[12] However, as the color of the metal affects the final esthetics, patients who care about esthetics tend to avoid metal–ceramic prostheses, due to reports of discoloration of the gums.[13] If the advantages of the existing prosthesis are maintained while additionally solving the problem of low esthetics, which is a limitation of any metal–ceramic prosthesis, patients can achieve the desired results.

For decades, efforts toward overcoming the limitations of conventional prostheses have been made through improving the materials and manufacturing methods used.[14,15] Furthermore, the introduction of digital systems has led to expected effects that can even change the fundamental design of the prosthesis. Studies that have changed the designs of prostheses include marginal fit studies of two different margin designs, such as that by Handal,[16] the study of a zirconia-based ceramic with a stable design applied to a stress concentration area,[17] a design improvement study of dental restorations with a composite interlayer added,[18] and an evaluation of prosthesis quality according to the preparation design;[19] however, few studies have altered the design of the prosthesis itself. Parthasarathy proposed a patient-specific porous titanium craniofacial implant design that considered both esthetic and functional requirements while having ideal porosity and desired density through porosity, but there were differences between this study and the prostheses applied.[20]

In this study, a new prosthesis design is proposed using CAD and the lamination method and evaluated as to whether or not it is clinically applicable. Evaluation of the various parts is crucial for applying the newly developed prosthesis in clinical practice. In general, metal–ceramic restorations are evaluated for biocompatibility, esthetics, fracture resistance, and marginal fit.[21,22] Among them, the internal fit affects the maintenance and support of the prosthesis, such that if the space of the inner adhesive is excessive, problems such as fracture or drop may occur, and if it is too small, the mounting of the prosthesis may be incomplete. Such incompatibility leads to marginal leakage, and as the marginal leakage increases, complex problems occur, leading to failure of the restoration. Methods for measuring the marginal fit have also been studied extensively. Sorensen[23] suggested the direct observation, cutting observation, evaluation method involving impression and visual observation by probe, and Molin and Karlsson[24] used the silicone replica technique, which allows for repeated measurements without needing to cut the prosthesis. In this study, the silicone duplication method was used to measure the fit of various parts of the inner surface of the prosthesis.

Various evaluations are needed to apply the newly developed prosthesis to clinical settings in a stable manner; evaluation of features such as the bond strength and esthetics should be conducted in the future as well. This *in vitro* study evaluated the internal fit by fabricating porous metal–ceramic prostheses newly developed for the purpose of complementing the design of existing prostheses in a laminated manner.

MATERIALS AND METHODS

In this *in vitro* study, the prepped mandibular right first molar was chosen as the master die (A50-Assortment; Nissin Dental Products Inc., Kyoto, Japan). The artificial tooth was prepared with a tooth reduction of 1 mm occlusal/proximal/axial wall and chamfer margin of 0.8.

To replicate the master die, a cylindrical mold (diameter 3 cm) was made with paraffin wax. The master die was fixed in the center of the cylinder and the silicone (Deguform; Degudent GmbH, Rosbach, Germany) was slowly poured into the cylinder. After the silicone was cured, the paraffin wax and master die were removed to complete the silicone mold. A total of 30 stone dies were fabricated with dental hard stone (GC Fujirock EP, GC Corporation, Tokyo, Japan) in a silicone mold.

The design of the frame was based on a scan of the stone die performed with a dental scanner (3shape E1; 3shape A/S, Copenhagen, Denmark). The cement gap was set to 10 μm (1), the extra cement gap to 30 μm (2), the distance to the margin line to 1000 μm (3), the smooth distance to 200 μm (4), and the thickness of the frame to 500 μm (sky blue color) [Figure 1].

For the frame design, the attachment-hole function was used in the engraving tool embedded in the 3Shape software (Dental system 2017; 3Shape A/S, Copenhagen, Denmark). Each of the three buccal and lingual places formed holes with diameters of 3 mm (surface direction), and the distance between these holes was approximately 4 mm. Scale marking was used to set the same position. The occlusal surface formed four holes, each of 3 mm diameter, in the insertion direction located approximately 2 mm diagonally from the center of the scale marking [Figure 2].

The designed frame was extracted with stereolithography (STL), then laminated with cobalt–chromium (SP2; EOS Gmbh, Krailling, Germany). SLS specimen production followed the standard method recommended by the manufacturer as follows. The scan speed was 7 m/s, the lamination thickness was 100 μm, the laser standard Yb (Ytterbium)-fiber was 200 W, and the manufacturing speed was 20 m^3/s.

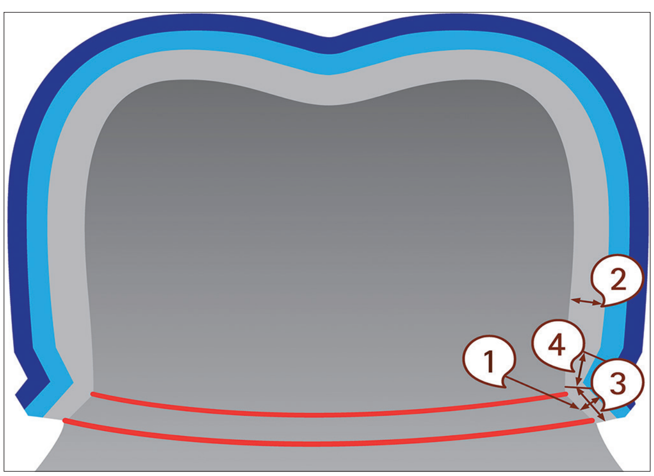

Figure 1: Set cement gap values. 1: Margin cement gap (10 μm); 2: Extra cement gap (30 μm); 3: Distance to margin line (1000 μm); 4: Smooth distance (200 μm) and thickness of the metal frame was set to 500 μm (sky blue color).

The surface to which the support was attached was polished using a polishing tool and a handpiece. Next, in accordance with the manufacturers' instructions, a thin opaque lining was applied on the cobalt–chromium surfaces. The crown was then completed using a press-type ceramic (Amber POM Ingot; Hass, Gyeonggi-do, Korea) [Figure 3].

For comparison, 10 specimens without porosity were prepared by the above lamination method. Ten cobalt chrome specimens without porosity were prepared using the casting method and fired in the same manner as above.

To measure the internal fit, the inner surface of the crown was filled with light body silicone (Aquasil Ultra XLV; Dentsply Sirona, York, PA) and immediately placed in the abutment, following which a press machine was used to apply a pressure of 50 N for the fit.[25] After the fully hardened light body silicone was carefully separated from the crown, it was covered with regular body silicone (Aquasil Ultra Rigid; Dentsply Sirona, York, PA) and stabilized. The separated light body silicone was then used for measuring the distance between the crown and main abutment. However, it was thin, had a low resistance to tearing, and was difficult to maintain its shape; therefore, regular body silicone was used.

Silicone was cut with a sharp knife and used to measure the same area based on the part marked on the master abutment. The internal fit was measured using a digital microscope (at 100× magnification) (BH 41; Olympus Microscopes, Shinjuku, Japan) in a total of nine places, including the margins of buccal, lingual, mesial, distal margin, axial wall regions,

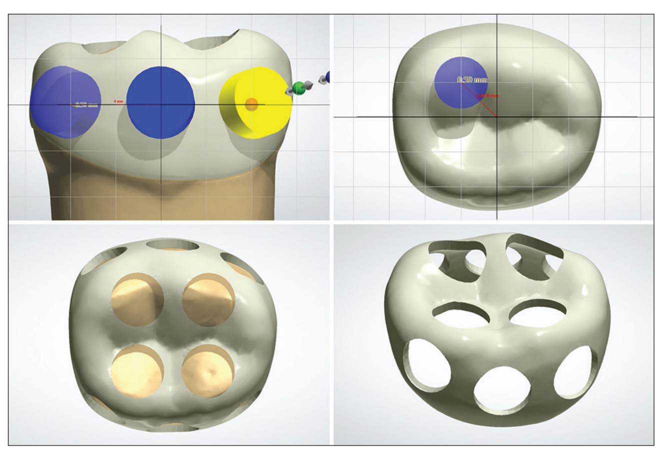

Figure 2: Porous frame design process. Three holes in each of the buccal and lingual sides and four holes in the occlusal surface (diameter: 3 mm).

and the occlusal surface [Figure 4]. To analyze the measurement results, descriptive statistics were used to compare the means and standard deviations.

Comparisons among groups were performed using ANOVA analyses with Tukey *post hoc* analyses for pairwise comparison (IBM SPSS statistics 23; IBM Corp., Armonk, NY). The results for each group were tested at a significance level of $\alpha = 0.05$.

RESULTS

Table 1 shows the internal fit results of the porous structure SLS group (PS-group), no-porous casting group (NPC-group), and no-porous SLS group (NPS-group). The total mean internal discrepancies for each group were 42.32 ± 22.50 μm for the PS-group, 107.54 ± 38.75 μm for the NPC-group, and 121.36 ± 50.19 μm for PR, with significant differences ($P < 0.05$) among all groups. Comparing the averages of the measurement points in the PS-group, the mesial margin was the smallest at 28.19 ± 20.76 μm and the occlusal was the largest at 76.78 ± 19.74 μm. In the NPC-group, the distal axis was the smallest at 62.07 ± 22.36 μm, and the occlusal was the largest at 227.46 ± 56.83 μm. In the NPS-group, the lingual margin was the smallest at

Figure 3: (a) Cobalt–chromium porous structure frame; (b) completed crown specimen; (c) porous inside crown; (d) laminating inside crown; (e) casting inside crown.

Table 1: Mean and standard deviation descriptive statistics of internal fit (μm) for all groups (*n*=30)

Discrepancy	Mean±SD			*P*
	PS	NPC	NPS	
BA	$42.68^{a, b}$±22.77	84.98^{a}±31.56	76.30^{b}±33.21	0.008
BM	$34.85^{a, b}$±24.26	148.74^{a}±50.12	124.48^{b}±65.00	0.000
DA	36.27^{a}±34.45	62.07^{b}±22.36	$105.67^{a, b}$±48.26	0.001
DM	$43.47^{a, b}$±25.72	95.55^{a}±47.25	104.73^{b}±51.74	0.008
LA	$29.62^{a, b}$±17.26	80.29^{a}±32.74	97.59^{b}±40.44	0.000
LM	46.51^{a}±14.74	$105.06^{a, b}$±49.34	58.41^{b}±24.74	0.001
MA	42.51^{a}±22.79	66.90^{b}±23.09	$104.78^{a, b}$±38.19	0.000
MM	$28.19^{a, b}$±20.76	96.83^{a}±35.45	98.26^{b}±62.76	0.001
OD	$76.78^{a, b}$±19.74	227.46^{a}±56.83	276.92^{b}±87.41	0.000
Total	42.32±22.50	107.54±38.75	121.36±50.19	

$^{a, b}$Statistical significance between groups in rows followed by the same letters, Multiple comparisons, Tukey's–Honest Significant Difference. BA: Buccal axial wall discrepancy; BM: Buccal margin discrepancy; DA: Distal axial wall discrepancy; DM: Distal margin discrepancy; LA: Lingual axial wall discrepancy; LM: Lingual margin discrepancy; MA: Mesial axial wall discrepancy; MM: Mesial margin discrepancy; OD: Occlusal discrepancy; PS-group: Porous structure selective laser sintering group; NPC-group: No-porous casting group; NPS-group: No-porous selective laser sintering group

58.41 ± 24.74 μm and the occlusal was the largest at 276.92 ± 87.41 μm [Table 1]. Table 2 shows the mean values of the margin and axial wall for each group. The PS-group had a measured margin discrepancy of 38.26 ± 21.37 μm and axial wall discrepancy of 37.77 ± 24.32 μm; those of NPC-group were 111.55 ± 45.54 μm and 73.56 ± 27.44 μm, respectively; and those of NPS-group were 96.47 ± 51.06 μm and 96.06 ± 40.03 μm, respectively. The margin, axial, and occlusal surface measurement methods are shown in Figure 5.

DISCUSSION

The porous structure is often selected and used in various forms such as circle, rectangle, square, and rhombus. In the medical implant industry, a porous structure is applied for strong osseointegration.[26] Specifically, it is manufactured for fine structure reproduction and bone growth in additive manufacturing.[27] This study aimed to reproduce the ideal porous structure via a lamination method and proposed a patient-specific porous crown design considering the esthetic and functional requirements for stable adaptation as a dental prosthesis.

Parthasarathy reported that different mechanical properties may be obtained due to the different sizes and densities of porous structures, and higher porosity leads to better predictability.[22] Cosma *et al.* also stated that the stability of bone ingrowth varies with the pore size.[28] In this study, a dedicated program embedded in dental CAD software was used to design pores with the same size of 3 mm. As there may be differences in the results depending on the sizes and shapes of the pores, further studies should be conducted considering the pore size and density.

Table 2: Mean and standard deviation of margin and axial wall discrepancies (μm) for all groups

Discrepancy	PS	NPC	NPS
Margin	38.26±21.37	111.55±45.54	96.47±51.06
Axial wall	37.77±24.32	73.56±27.44	96.09±40.03

PS-group: Porous structure selective laser sintering group; NPC-group: No-porous casting group; NPS-group: No-porous selective laser sintering group

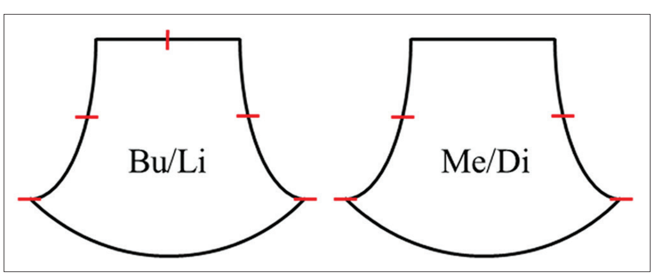

Figure 4: Measurement of internal fit by region (four margins, four axial walls, one occlusal).

Ucar *et al.*[29] reported that a laser-sintered cobalt–chromium crown had a mean internal fit of 62.6 ± 21.6 μm greater than that in this study. Schaefer *et al.*[30] conducted a three-dimensional analysis in pressed lithium disilicate partial crowns, and reported that the marginal and internal accuracies were 78 and 34 μm, respectively. They also highlighted the advantages of the ceramic press method, stating that a dental ceramic has poor elasticity, whereas press materials have improved mechanical and optical properties. Complementing the disadvantages of the existing porcelain fused to metal (PFM), the crown prepared by firing ceramics on metal using the press method is believed to have excellent bonding strength and esthetics.

The results of this study indicate that the crown with the press ceramic applied to the porous structure has less internal gap than the crowns manufactured by the conventional casting and additive manufacturing methods. In this study, the press ceramic was applied on the frame, and the ceramic was considered to have infiltrated into the adhesive space, causing the inner surface value to decrease. A study by Mously *et al.* found the internal gap to be 74.03 μm in the press method and 90.04 μm in the CAD/CAM method for an axial space of 30 μm, as in this study, indicating that the internal gap by the press method is smaller. The gap in the press method was also found to be smaller than the marginal gap. Mously

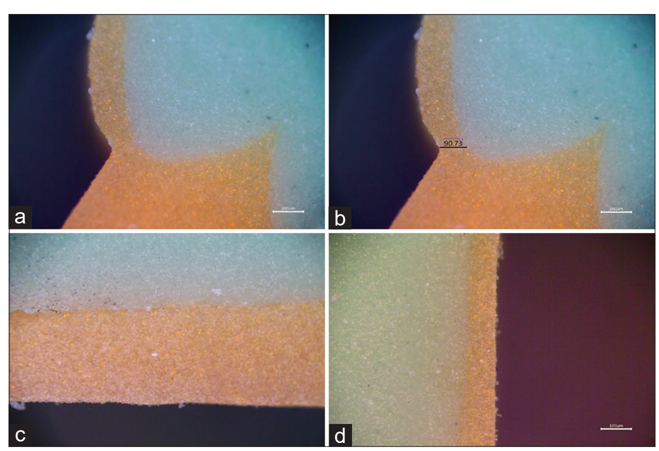

Figure 5: Internal fit as measured using a digital microscope (100×). (a) Margin; (b) margin discrepancy measurement; (c) axial wall; (d) occlusal.

et al. reported that this difference may arise from the fabrication technique used and the die spacer thickness.[31] However, the mean discrepancy was found to be 76.78 ± 19.74 μm on the occlusal surface, and additional research is needed to determine the reason for it being higher than that on axial wall and margin. Nesses[32] reported that the occlusal gap was large because cement accumulates on the occlusal surface during insertion.

By contrast, Nesses that the selective laser melting gap (156 μm) was the largest in marginal fit studies of milling (95 μm), casting (116 μm), and selective laser melting, which was not consistent with the results of this study. However, Nesses study was not completely reproduced in the form of a clinical crown, and there may be a discrepancy in the result because Nesses study was a bridge crown. Further, the production equipment used was different.

This study used CAD to set the inner space and fired the ceramic using a press. Therefore, for future clinical applications, it is necessary to consider that the inner space set by CAD can be changed by the press method. The internal fit of the prosthesis affects the success and failure of the prosthesis, and hence is a very important factor for the prevention of secondary caries. Many studies have reported that the internal fits of prostheses fabricated by digital means, such as CAD/CAM or 3D printers, are clinically acceptable within 120 μm.[33,34] This study showed clinically acceptable ranges of internal fit with averages of 38.26 and 37.77 μm in the margin and axial wall, respectively. Various evaluations are needed to apply the newly developed prosthesis to clinical practice in a stable manner. As the evaluation in this study was carried out based on internal fit, evaluations of the bond strength and esthetics should also be conducted in the future.

CONCLUSION

The following conclusions were obtained from the limited research findings of this *in vitro* study:

1. The total mean internal discrepancies for each group were 42.32 ± 22.50 μm for the PS-group, 107.54 ± 38.75 μm for the NPC-group, and 121.36 ± 50.19 μm for the NPS-group, with significant differences ($P < 0.05$) among all groups
2. Regarding the measurement points, in the PS-group, the mesial margin was the smallest at 28.19 ± 20.76 μm and the occlusal was the largest at 76.78 ± 19.74 μm. In the NPC-group, the distal axis was the smallest at 62.07 ± 22.36 μm, and the occlusal was the largest at 227.46 ± 56.83 μm. In the NPS-group, the lingual margin was the smallest at 58.41 ± 24.74 μm and the occlusal was the largest at 276.92 ± 87.41 μm
3. Based on these laboratory findings, it is concluded that further studies should be conducted to evaluate the feasibility of the newly designed porous structure and press ceramic prosthesis to determine their application potential in clinical practice.

Financial support and sponsorship

- This research was supported by the Basic Science Research Program through the National Research Foundation (NRF) of Korea, funded by the Ministry of Education (Grant No. 2017R1D1A1B03035688).
- This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. 2018R1A5A7023490).
- This work was also supported by a grant from the Daedeok Korea Innovation Cluster funded by the Korean government (MSIT) (No. 2021-DD-RD-0189).

Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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