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Original Article

The influence of pontic distribution on the marginal and internal gaps of CAD/CAM five-unit anterior zirconia framework

Min-Chieh Chang [a,b], Lu-Wen Cheng [c], Shu-Fen Chuang [c,d], Yung-Chung Chen [b,c*]

[a] *Department of Biomedical Engineering, National Cheng Kung University, Tainan, Taiwan*
[b] *Division of Prosthodontics, Department of Stomatology, National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University, Tainan, Taiwan*
[c] *School of Dentistry & Institute of Oral Medicine, College of Medicine, National Cheng Kung University, Tainan, Taiwan*
[d] *Division of Operative Dentistry, Department of Stomatology, National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University, Tainan, Taiwan*

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Marginal gap

Abstract *Background/purpose:* Nowadays, zirconia-based framework has been used for long-span or full-arch fixed dental prostheses (FDPs). This study aimed to evaluate the effect of pontic distribution on marginal and internal gaps of five-unit anterior zirconiabased DPs.
Materials and methods: Right maxillary central incisor and second premolar were selected as terminal abutments and three different edentulous conditions with one nonterminal abutment were simulated. Marginal and internal gaps in each zirconia-based samples(n = 10) were examined by computer-aided replica technique. Five regions, including marginal gaps at mesial or distal finishing line, internal gaps at the mesial or distal axial wall, and occlusal surface, were statistically analyzed ($\alpha = .05$).
Results: Most of marginal gaps and internal gaps at axial wall were clinically acceptable, but larger at occlusal surface. For the three experimental groups, clinically accepted percentage with qualified gaps were less than 30%.There were statistical differences at axial wall over pontic side and marginal gaps over non-pontic side between groups ($P<0.05$). For sum of gaps of all abutments in each group, statistical differences were found at marginal and axial wall ($P < 0.05$). As for those on terminal and non-terminal abutments, statistical differences were found on second premolar ($P < 0.05$).
Conclusion: Except for occlusal surface, the overall marginal gaps and internal gaps at axial wall of five-unit anterior zirconia-based FDPs with different pontic distribution were clinically

* Corresponding author. School of Dentistry & Institute of Oral Medicine, College of Medicine, National Cheng Kung University, No.1, University Road, Tainan City, 701, Taiwan.
E-mail address: yc_chen@mail.ncku.edu.tw (Y.-C. Chen).

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acceptable. However, the percentage with qualified gaps were low (<30%). Greater gaps were noted when adjacent pontic existed. Different pontic size and distribution with curvature had an influence on the gaps.

Introduction

Clinically, one of the most important all-ceramic materials is zirconia, which is composed of densely arranged crystals and has excellent mechanical properties.[1–3] Computer-aided design/Computer-aided manufacturing (CAD/CAM) technology has been widely applied for fabricating zirconia-based fixed dental prostheses (FDPs) and the manufacturing process can be categorized into soft-machining (SM) and hard-machining (HM).[2,4] The marginal fit of zirconia FDPs is significantly dependent on the fabricating system.[5] For the SM process, a pre-sintered zirconia block is cut into shape and sintered to reach its final state of desired mechanical properties. As for the HM process, a fully sintered zirconia block is directly carved to form the final product. Kohorst showed that marginal misfit of four-unit FDPs processed from fully sintered zirconia blocks was less than that processed from presintered blocks,[5] because the complex geometry of zirconia FDPs can cause inconsistent volume shrinkage from post-sintering of SM process.[5] However, unfavorable cracking could occur during HM process and further weaken the mechanical performance. Therefore, the SM process has been widely used nowadays.[6,7]

Prospective clinical cohort studies reported that the incidence of secondary caries on three-to five-unit zirconia-based posterior FDPs were 21.7 % at five-year follow-up,[8] and 27 % at 10-year follow-up.[9] The life table analysis in Le 's review study revealed five-year survival rate of tooth-supported FDPs was 93.5 %.[10] However, cumulative five-year complication rate was 27.6 % and the top causes of failure were veneering fractures, framework fractures and caries. It stated the SM process was responsible for 75 % of caries incidence, and 92 % of which resulted in an unusual high occurrence of marginal gaps.[10] In addition, the highest rate of marginal discoloration was also found in zirconia-based FDPs, which may be resulted from the marginal inaccuracy of zirconia frameworks.[11] And Pjetursson's review study also mentioned that in the discussion section.[12] Ideal marginal and internal adaptation play an important role in the longevity of FDPs.[13,14] A marginal gap less than 120 μm is clinically accepted.[15,16] Increased marginal gap may result in plaque accumulation, secondary caries, microleakage, marginal discoloration,[11] and loosening of FDPs.[14,17,18] And increased internal cement space would induce tensile stresses, reduce fracture toughness, and raise the risk of veneering porcelain cracking and framework distortion.[19–21]

Various factors, including substructural design, margin configuration, span length, veneering procedures, CAD/CAM systems, composition and homogeneity of material blocks, cement space, and manual adjustment of the intaglio surface, can affect the marginal and internal gaps.[13,17,20,22–28] For better seating clinically, adequate cement space should be set for compensating potential distortion during the CAM process, accommodating cement film thickness, and reducing friction.[29] Generally, the sintering shrinkage of zirconia material is about 20–25%.[2,13,30]

The zirconia-based FDPs fabricated from pre-sintered blocks need to be enlarged to compensate for the volumetric change.[5] If the shrinkage is not well controlled, distortion and misfit should be expected.[7,30] Most studies regarding marginal and internal gaps for zirconia-based FDPs were limited to four or less units.[6,8,31–34] For those less than three units, their gaps ranged from 100 to 200 μm.[6,31,32] However, when the pontic span becomes longer, greater sintering shrinkage may deteriorate the adaptation between FDPs and abutments.[5,26,35] Kunii reported that although marginal and internal gaps of three- and four-unit zirconia-based FDPs were both within clinical acceptance, the marginal gap and thickness of the cement layer on the axial surface of the pontic side were slightly greater than those of the non-pontic side [[26]]. For five-unit FDPs, if there is a pier abutment that can support, marginal gap became smaller. Lee found that increased span length could decrease the fit when anterior zirconia-based FDPs was six-unit or longer.[36] Larger gaps existed at the junction of margin and axial wall and the incisal region. Kim concluded that the number of pontics significantly influenced the marginal and internal gaps of monolithic four-unit posterior FDPs, and the marginal and axial gaps with an adjacent pontic were significantly larger than those without an adjacent pontic.[37] Most studies only focused on one certain type of edentulous condition and the alignment of zirconia substructures were linear.[5,26,35,37] For longer span anterior zirconia-based FDPs with curvature, the investigation regarding the influence of sintering shrinkage on marginal and internal gaps is still limited.

The aim of this study was to evaluate the effect of different pontic distribution on marginal and internal gaps of five-unit anterior zirconia-based FDPs. The null hypothesis was that the distribution of edentulous area would not cause any difference in terms of the marginal and internal gaps.

Materials and methods

Model fabrication of experimental groups

The right maxillary central incisor (CI) and second premolar (P2) were selected as terminal abutments of five-unit zirconia-based FDPs on a typodont model (KaVo, Biberach, Germany). Two out of three interjacent abutments, the right maxillary lateral incisor (LI), canine (C), and first premolar

(P1), were removed to form the following three edentulous conditions (Fig. 1). Occlusal reduction of 2 mm was performed for each abutment and its margin was 0.5 mm in width with 360-degree chamfer design. The experimental typodont models were scanned with a tabletop scanner (AutoScan-DS200+ Dental 3D Scanner, SHINING 3D, Hangzhou, China), and exported to a CAD software (Solidworks 2017, Dassault Systèmes SolidWorks Corporation, Waltham, MA, USA) for constructing a 40 × 20 × 8 mm rectangular base. Subsequently, those were fabricated from polymethyl methacrylate (PMMA) disks (Ceramill *M*-Plast, Amann Girrbach AG, Charlotte, NC, USA) using a dental milling machine (IDC MIKRO 4×, Amann Girrbach AG) instead of 3D-printed model, to avoid dimensional errors during the polymerization process. The entire workflow is depicted in Fig. 2.

Fabrication of zirconia frameworks for each experimental group

The PMMA models were scanned again for designing the zirconia framework. For the area beyond 1.5 mm above the finish line, the cement space was set as 50 μm, and the rest was set as 40 μm (Fig. 3A).[18,20] The thickness of the zirconia coping of terminal abutments was set at 0.5 mm and the cross-sectional area of the connectors was set at 12 mm^2 (Fig. 3B).[38] To reduce the morphological discrepancy of each group, the pontic contour of the three experimental models was cut back from the same full-contoured model (Fig. 3C).

A total of thirty zirconia frameworks (10 samples for each group) were milled from pre-sintered zirconia disks (Ceramill Zolid FX White, Amann Girrbach AG) as the

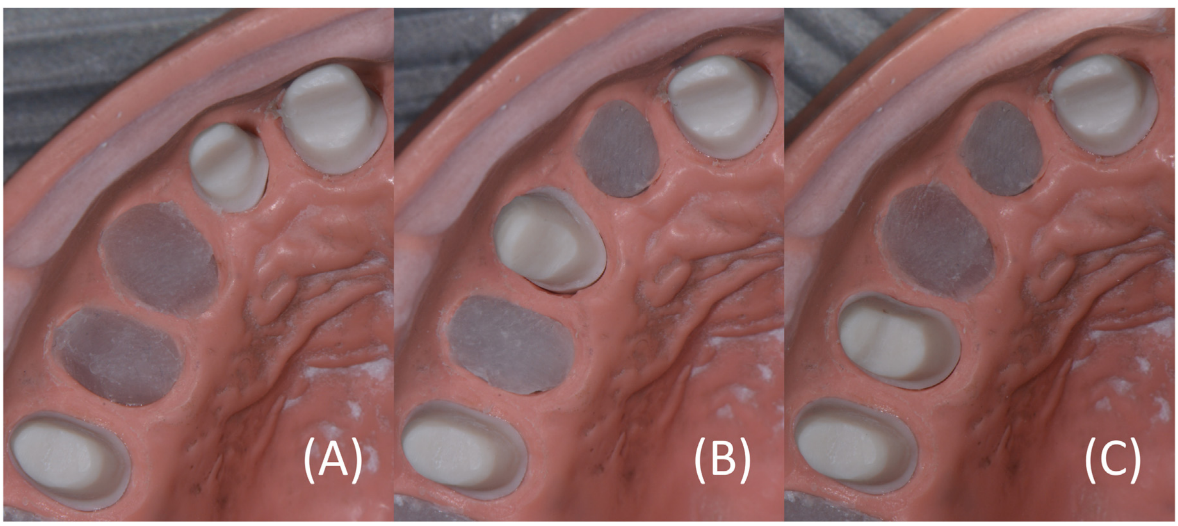

Fig. 1 Three experimental groups with different edentulous conditions. They are (A) missing the right maxillary canine and first premolar (CI-LI-X-X-P2), (B) missing the right maxillary lateral incisor and first premolar (CI-X-*C*-X-P2) and (C) missing the right maxillary lateral incisor and canine (CI-X-X-P1-P2), respectively. (Abbreviations: C: canine, CI: central incisor, LI: lateral incisor, P1: first premolar, P2: second premolar, X: missing tooth.)

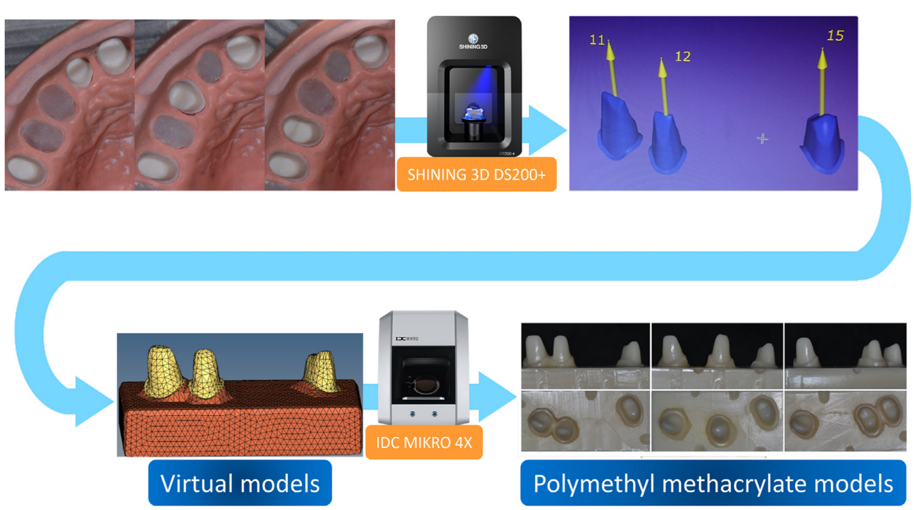

Fig. 2 Workflow of fabricating experimental models.

designed pattern, leaving the cement space, and sintered to the final state in a furnace (Muffle Furnace 3 M, Sinosteel Corporation, Beijing, China). Samples were gradually heated to 900 °C for 90 min, raised to 1540 °C for 210 min, and kept at 1540 °C for another 2 h. After sintering, they were gradually cooled down to room temperature. Finally, all samples were examined for deformation. The intaglio surface of the zirconia frameworks was steam-cleaned, and no additional manual adjustment was performed.

Measurement of marginal and internal gaps for each experimental group

Polyvinyl siloxane impression material (Aquasil Ultra XLV, Dentsply Sirona, Charlotte, NC, USA) was injected into the inner side of zirconia frameworks and seated on the experimental models. Then, an object of 1 kg was placed on them for 7 min which is the setting time of the impression material. Subsequently, zirconia frameworks were carefully removed, and a thin layer of impression material, or the "replica", remained on the abutments. If the replica is found broken, the whole process must be repeated. The thickness of this replica was considered the gap between frameworks and abutments (Fig. 4). Finally, digital scans of the experimental models with the relevant replica were conducted, and the stereolithography (STL) files were imported into an image processing software (Geomagic Studio 12, DEVELOP3D, London, UK). Image superimposition of digital scans within each group was achieved by using the functions of multiple registration points and algorithm alignment correction until the discrepancy was below 75 μm at the registration notches of the bases

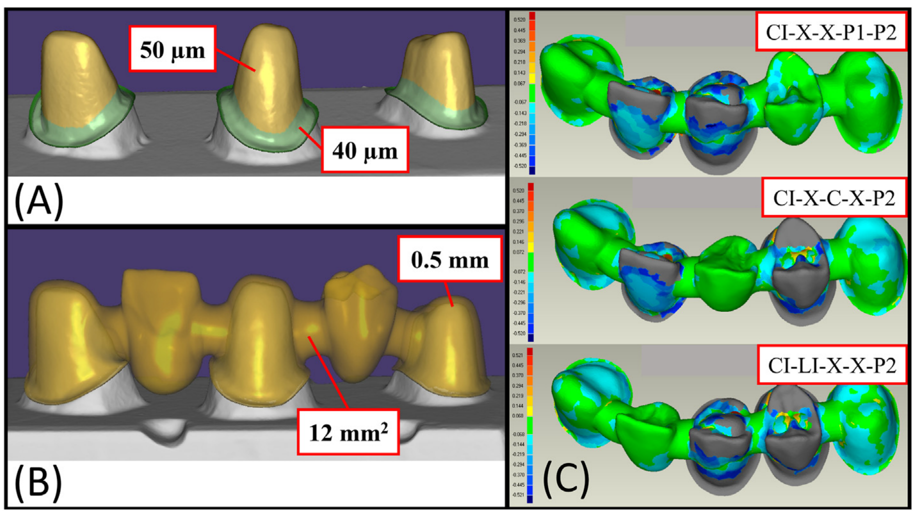

Fig. 3 (A) The cement space setting. (B) Zirconia framework design. (C) The pontic contour was cut back from the same model of full contour. (Abbreviations: C: canine, CI: central incisor, LI: lateral incisor, P1: first premolar, P2: second premolar, X: missing tooth.)

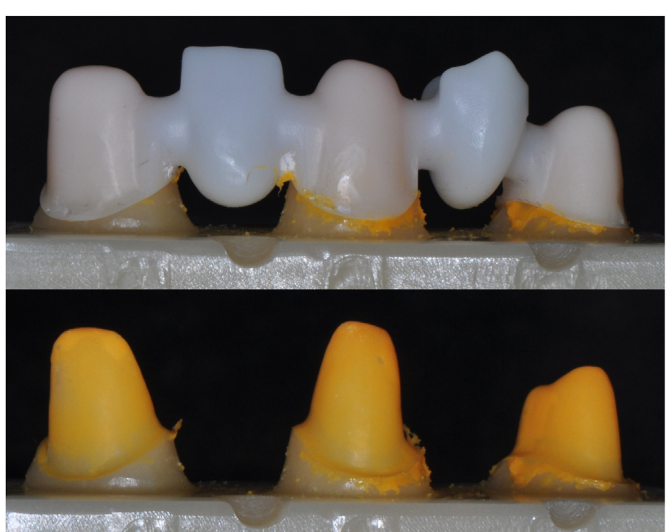

Fig. 4 Adequate amount of polyvinyl siloxane impression material was applied before sintered zirconia frameworks were seated onto the models. A thin layer of material was remained on the abutments after frameworks were removed.

among all scans (Fig. 5). The superimposed images of three groups were imported into an image measuring tool (3Shape 3D Viewer 1.3, 3Shape, Copenhagen, Denmark), and the gaps were measured at a mesiodistal cross-section along the long axis (Fig. 6A). 10 superimposed STL models were simultaneously loaded to ensure the measurement was done at the same cross-section (Fig. 6B). Five measurement locations on each abutment were marginal gaps at the mesial (MMG) or distal finishing line (DMG), internal gaps between the abutment and the middle points of mesial (MIG) or distal axial wall (DIG), and internal gap at the central point of the occlusal surface (OIG) (Fig. 7).

Data calculation and statistical analysis

The data array was composed of five measurements on three abutments from 10 samples among three groups. The obtained data were calculated and analyzed using a spreadsheet software (SAS 9.4 statistical software, SAS Institute, Cary, NC, USA). To study the influence of arch curvature and

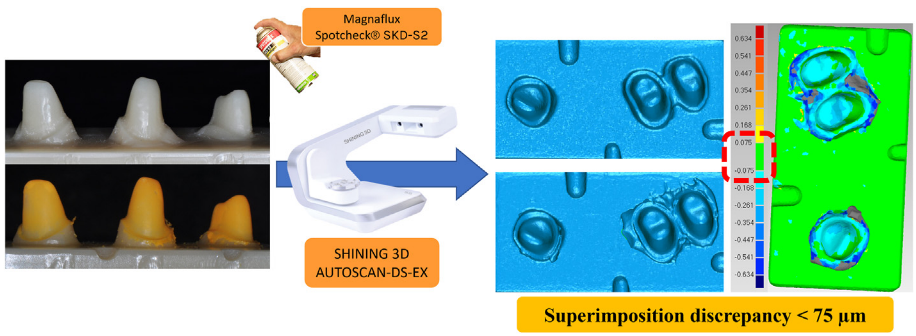

Fig. 5 Digital scans for the experimental model with the relevant replicas and image superimposition within each experimental group.

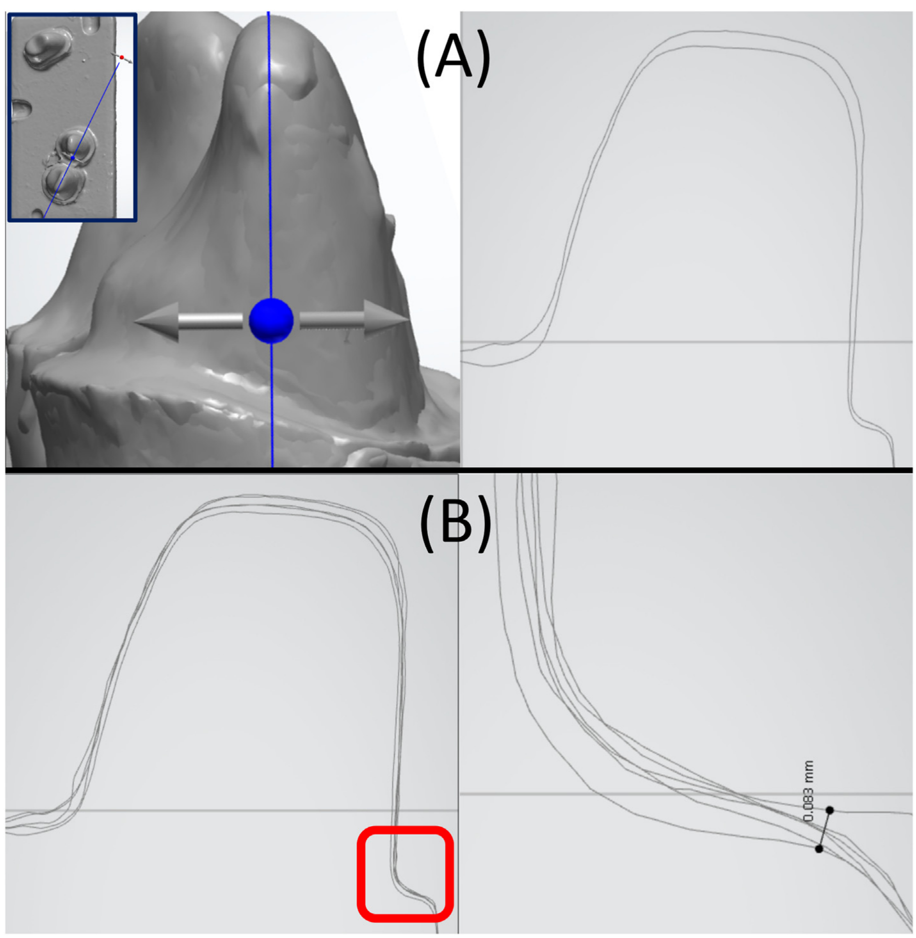

Fig. 6 Superimposed models. (A)The gaps between frameworks and abutments were measured at a cross-section along the long axis. (B)The measuring points of the 10 superimposed STL models were at the same site.

sintering shrinkage of pontics, the data array was reorganized as the groups of pontic and non-pontic sides (Fig. 8). In addition, the mean values and standard deviations of marginal gaps and internal gaps at the axial wall area were recalculated and analyzed with one-way ANOVA. Pairwise comparison was conducted within each experimental group using two-sample *t*-test. Furthermore, the marginal gap, the internal gaps at the axial wall and occlusal surface area were pooled together for all abutments and assessed among three experimental groups using one-way ANOVA. Finally, the sum of marginal and internal gaps on terminal and non-terminal abutments were also compared between each experimental group, respectively. A value of 0.05 was used for determining statistical significance and the Scheffe's test was used for post-hoc analysis.

Results

Descriptive statistics

Table 1 demonstrated the mean values and standard deviations of gaps at the five measurement locations of each abutment. All mean values of gaps from three experimental groups were greater than the cement space that was set. With the exception of DMG of CI, MMG of LI, MMG and MIG of P2 in group CI-LI-X-X-P2, MMG of P2 in group CI-X-*C*-X-P2, and DMG of P2 in group CI-X-X-P1-P2, the overall marginal gaps and internal gaps at the axial wall were within the threshold of clinical acceptance (<120 μm).[15,16] In addition, the internal gaps at the occlusal surface were greater on most abutments, except for those on LI in group CI-LI-X-X-P2, P2 in group CI-X-*C*-X-P2 and CI-X-X-P1-P2.

The percentage of clinically accepted marginal gap

Table 2 showed the clinical acceptance (<120 μm) percentage for three experimental groups. The difference between those was not statistically significant, but the percentage was low (10—30 %). In addition, there were also no statistically significant differences on both of terminal abutments between groups, but the difference on non-terminal abutment was statistically significant. The percentage of clinically accepted marginal gap on non-terminal abutment in group CI-LI-X-X-P2 was significantly lower than those in the other two groups.

Marginal and internal gaps over the pontic and non-pontic side between each experimental group

The mean values and standard deviations of marginal gaps and internal gaps at the axial wall area adjacent to the pontics were reorganized as data of the pontic side and the rest as data of the non-pontic side (Table 3). According to the results from one-way ANOVA, there was a significant difference at the axial wall area over the pontic side among experimental groups, and the post-hoc comparison showed the internal gap in group CI-X-X-P1-P2 was the smallest. On the other hand, there was a significant difference at the margin area over the non-pontic side among experimental groups. The mean of marginal gap in group CI-LI-X-X-P2 was greater than those in groups CI-X-*C*-X-P2 and CI-X-X-P1-P2.

As for the results from two-sample *t*-test within each experimental group, there were statistically significant differences at the axial wall area for group CI-LI-X-X-P2, and the margin area for group CI-X-*C*-X-P2. Furthermore, two-way ANOVA showed an interaction between measurement location and pontic distribution in axial wall area.

Sum of marginal and internal gaps of all abutments between each experimental group

Table 4 showed the sum of marginal gaps, internal gaps at axial wall and occlusal surface area from each experimental group. There were statistically significant differences for the sum of marginal gaps and internal gaps at

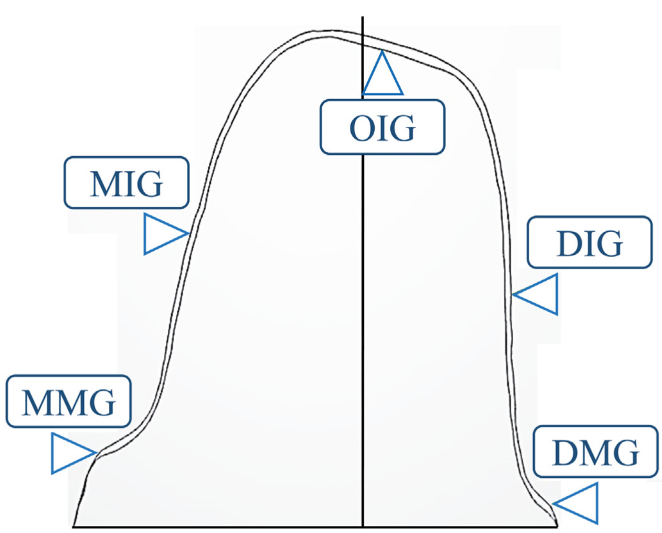

Fig. 7 Five measurement locations for each abutment. They are marginal gaps at the mesial or distal finishing line, internal gaps between the abutment and the middle points of mesial or distal axial wall, and internal gap at the central point of the occlusal surface. (Abbreviations: DIG: internal gap at distal axial wall, DMG: distal marginal gap, MIG: internal gap at mesial axial wall, MMG: mesial marginal gap, OIG: internal gap at occlusal surface.)

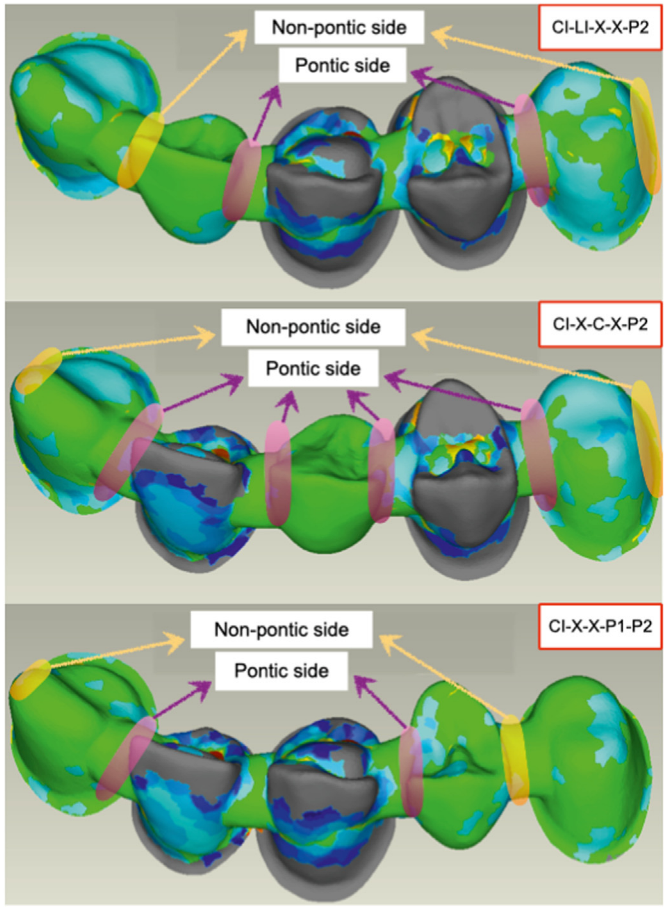

Fig. 8 Data was reorganized as pontic and non-pontic sides for each group. For CI-LI-X-X-P2, DMG & DIG of LI and MMG & MIG of P2 were reorganized as pontic side. MMG & MIG of LI and DMG & DIG of P2 were reorganized as non-pontic side. For CI-X-*C*-X-P2, DMG & DIG of CI, MMG & MIG & DMG & DIG of C, and MMG & MIG of P2 were reorganized as pontic side. MMG & MIG of CI and DMG & DIG of P2 were reorganized as non-pontic side. For CI-X-X-P1-P2, DMG & DIG of CI and MMG & MIG of P1 were reorganized as pontic side. MMG & MIG of CI and DMG & DIG of P1 were reorganized as non-pontic side. (Abbreviations: C: canine, CI: central incisor, DIG: internal gap at distal axial wall, DMG: distal marginal gap, LI: lateral incisor, MIG: internal gap at mesial axial wall, MMG: mesial marginal gap, OIG: internal gap at occlusal surface, P1: first premolar, P2: second premolar, X: missing tooth.)

axial wall of all abutments among the three experimental groups. The post-hoc comparison showed that the sum of marginal gaps in group CI-LI-X-X-P2 was greater than the other groups. And the sum of internal gaps at axial wall area in groups CI-LI-X-X-P2 and CI-X-*C*-X-P2 were greater than that in group CI-X-X-P1-P2. No significant difference could be found for the sum of internal gaps at occlusal surface area of all abutments among groups, but the value was greater than those of marginal gaps and internal gaps at axial wall area.

Sum of marginal and internal gaps on terminal and non-terminal abutments between each experimental group

Table 5 showed the sum of marginal and internal gaps on terminal and non-terminal abutments from each group. There was a statistically significant difference on P2 terminal abutment among the three experimental groups. And the post-hoc comparison showed that the gaps in groups CI-LI-X-X-P2 and CI-X-*C*-X-P2 was greater than that in group CI-X-X-P1-P2. In addition, there were no statistically significant differences on CI terminal abutment and non-terminal abutments between the experimental groups.

Discussion

The present study evaluated the effect of different pontic distribution on marginal and internal gaps of five-unit anterior zirconia-based FDPs via computer-aided replica technique, which utilized digital image superimposition for measurement,[38] and prevent some drawbacks resulted from conventional replica technique,[36,37] such as measurement in only one cross-section for each specimen, deviation during cutting the replica, and the magnified image for measurement can be too blurred to define.[38] Based on the above findings, the null hypotheses were rejected.

The overall marginal gaps and internal gaps at the axial wall area of five-unit anterior zirconia-based FDPs with different pontic distribution were almost within the threshold of clinical acceptance (<120 μm),[15,16] although the internal gaps at DMG of CI, MMG of LI, MMG and MIG of

Table 1 Mean values and standard deviation of gap widths at each measurement location for experimental groups (μm) (n = 10).

Measurement location	Experimental groups		
	CI-LI-X-X-P2	CI-X-*C*-X-P2	CI-X-X-P1-P2
	Mean ± SD	Mean ± SD	Mean ± SD
CI			
MMG	60.5 ± 23.7	58.6 ± 20.8	85.5 ± 40.8
MIG	103.0 ± 31.4	98.5 ± 34.8	49.7 ± 29.3
OIG	164.3 ± 68.7	115.2 ± 35.7	155.1 ± 22.9
DIG	107.1 ± 20.9	90.2 ± 24.2	69.3 ± 25.9
DMG	141.7 ± 94.1	105.6 ± 56.9	105.0 ± 49.1
LI			
MMG	153.1 ± 46.7	–	–
MIG	73.8 ± 33.2	–	–
OIG	117.4 ± 45.1	–	–
DIG	77.9 ± 25.4	–	–
DMG	96.7 ± 57.9	–	–
C			
MMG	–	64.2 ± 27.1	–
MIG	–	107.3 ± 22.1	–
OIG	–	168.6 ± 46.8	–
DIG	–	92.4 ± 12.4	–
DMG	–	100.7 ± 60.9	–
P1			
MMG	–	–	75.8 ± 28.8
MIG	–	–	50.8 ± 22.9
OIG	–	–	175.4 ± 30.3
DIG	–	–	96.6 ± 35.0
DMG	–	–	82.2 ± 18.7
P2			
MMG	139.5 ± 87.6	162.4 ± 119.9	52.8 ± 26.9
MIG	139.8 ± 29.6	118.1 ± 35.7	68.9 ± 19.8
OIG	142.5 ± 63.7	142.0 ± 59.7	120.9 ± 28.7
DIG	69.2 ± 19.5	77.5 ± 16.6	67.6 ± 34.3
DMG	110.0 ± 52.7	64.0 ± 59.4	132.8 ± 47.6

Abbreviations: C: canine, CI: central incisor, DIG: internal gap at distal axial wall, DMG: distal marginal gap, LI: lateral incisor, MIG: internal gap at mesial axial wall, MMG: mesial marginal gap, OIG: internal gap at occlusal surface, P1: first premolar, P2: second premolar, X: missing tooth.

Table 2 The rate of clinically accepted marginal gap (n = 10).

Clinically accepted rate	CI-LI-X-X-P2	CI-X-*C*-X-P2	CI-X-X-P1-P2	*P*-value
	N (%)	N (%)	N (%)	
	1/10 (10.0)	3/10 (30.0)	2/10 (20.0)	0.847
Terminal abutments				
CI	6/10 (60.0)	8/10 (80.0)	4/10 (40.0)	0.248
P2	8/10 (80.0)	5/10 (50.0)	6/10 (60.0)	0.510
Non-terminal abutment	LI: 1/10 (10.0)	C: 8/10 (80.0)	P1: 9/10 (90.0)	<0.001*

*Groups with the same letter do not significantly differ at $P < 0.05$.
Abbreviations: C: canine, CI: central incisor, LI: lateral incisor, P1: first premolar, P2: second premolar, X: missing tooth.

P2 in group CI-LI-X-X-P2, MMG of P2 in group CI-X-*C*-X-P2, and DMG of P2 in group CI-X-X-P1-P2 were not clinically acceptable. Some data from this present study were greater than the previous studies on prostheses with shorter spans.[6,31,32] It could be attributed to the anisotropic volume contraction during the sintering process.[13] The longer spans of FDPs were, the greater sintering shrinkage and the larger gaps can be found.[35]

Furthermore, the percentage of clinically accepted marginal gap were low (10–30 %). We must pay attention to

Table 3 Comparison of marginal gaps and internal gaps at the axial wall over the pontic and non-pontic side between each experimental group (μm). Identical superscripted lowercase letters in each horizontal row indicated no statistically significant differences ($P > 0.05$), while non-identical letters indicated statistically significant differences ($P < 0.05$).

Measurement location	Experimental groups			*P*-value of one-way ANOVA	*P*-value of two-way ANOVA for interaction
	CI-LI-X-X-P2	CI-X-*C*-X-P2	CI-X-X-P1-P2		
	N/Mean ± SD	N/Mean ± SD	N/Mean ± SD		
Margin: pontic side	20/118.1 ± 75.5	40/108.2 ± 79.7	20/90.4 ± 42.0	0.458	0.053
Margin: non-pontic side	20/131.6 ± 53.3^{a}	20/61.3 ± 43.4^{b}	20/83.9 ± 31.0^{b}	<0.001*	
P-value of *t*-test	0.519	0.005*	0.578		
Axial wall: pontic side	20/108.9 ± 41.6^{a}	40/102.0 ± 26.7^{a}	20/60.1 ± 25.6^{b}	<0.001*	0.002*
Axial wall: non-pontic side	20/71.5 ± 26.6	20/88.0 ± 28.6	20/73.2 ± 39.6	0.211	
P-value of *t*-test	0.002*	0.066	0.221		

Post hoc test (Scheffe's test).
*Groups with the same letter do not significantly differ at $P < 0.05$.
Abbreviations: C: canine, CI: central incisor, LI: lateral incisor, P1: first premolar, P2: second premolar, X: missing tooth.

Table 4 Comparison of sum of the marginal gaps, the internal gaps at axial wall and occlusal surface area of all abutments between each experimental group (μm). Identical superscripted lowercase letters in each horizontal row indicated no statistically significant differences ($P > 0.05$), while non-identical letters indicated statistically significant differences ($P < 0.05$).

Sum of gaps	Experimental groups			*P*-value of one-way ANOVA
	CI-LI-X-X-P2	CI-X-*C*-X-P2	CI-X-X-P1-P2	
	N/Sum, Mean ± SD	N/Sum, Mean ± SD	N/Sum, Mean ± SD	
Marginal gaps	60/7015.0, 116.9 ± 70.0^{a}	60/5555.0, 92.6 ± 72.8^{b}	60/5341.0, 89.0 ± 43.5^{b}	0.035*
Internal gaps at occlusal surface	30/4242.0, 141.4 ± 61.1	30/4258.0, 141.9 ± 51.7	30/4514.0, 150.5 ± 35.0	0.738
Internal gaps at axial wall	60/5708.0, 95.1 ± 35.9^{a}	60/5840.0, 97.3 ± 27.9^{a}	60/4029.0, 67.2 ± 31.4^{b}	<0.001*

Post hoc test (Scheffe's test).
*Groups with the same letter do not significantly differ at $P < 0.05$.
Abbreviations: C: canine, CI: central incisor, LI: lateral incisor, P1: first premolar, P2: second premolar, X: missing tooth.

that because increased marginal gap would affect the longevity of zirconia-based FDPs,[13,14] and might be the reason for the high incidence of secondary caries and marginal discoloration.[8–11] On the other hand, most of the gaps at the occlusal surface area was greater and beyond the clinically acceptable range (<120 μm).[15,16] Table 4 showed that the mean value of the sum of occlusal surface area was greater than those of marginal gaps and internal gaps at axial wall area. Abduo's study also demonstrated the same trend.[13] The increased internal cement space would raise the risk of veneering porcelain cracking and framework distortion.[19–21]

As shown in Table 2, the clinically accepted percentage on non-terminal abutment in group CI-LI-X-X-P2 was significantly lower than those in the other two groups. In addition, marginal gaps and internal gaps at the axial wall were significantly greater when the abutment had an adjacent pontic (Table 3). The number and volume of pontics had a significant effect on the fit of five-unit anterior zirconia-based FDPs. The greater pontic volume was, the greater distortion may be introduced. Greater marginal gap was found over the abutments away from the pontics. Similar trends can be found from the previous studies.[26,36,37] It can be explained by the linear shrinkage of the zirconia framework that occurred during the sintering process and the horizontal warping directed toward the pontic.[39] Furthermore, although there was no significant difference between groups CI-X-*C*-X-P2 and CI-X-X-P1-P2, the amounts of marginal gaps over non-pontic side in group CI-LI-X-X-P2 and CI-X-X-P1-P2 were greater than those in group CI-X-*C*-X-P2. It implied that larger amount of sintering shrinkage occurred next to an adjacent zirconia coping than an adjacent zirconia pontic; however, further investigation is needed to verify that.

The results in Table 4 demonstrated that the mean value of the sum of marginal gaps in group CI-LI-X-X-P2 was greater than those in groups CI-X-*C*-X-P2 and CI-X-X-P1-P2. The amount of the sum of internal gaps at axial wall area in group CI-LI-X-X-P2 and CI-X-*C*-X-P2 were greater than those in group CI-X-X-P1-P2. Table 5 also showed that the mean values of the sum of marginal and internal gaps on P2 terminal abutment in groups CI-LI-X-X-P2 and CI-X-*C*-X-P2 was

Table 5 Comparison of sum of marginal and internal gaps on terminal and non-terminal abutments between each experimental group (μm). Identical superscripted lowercase letters in each horizontal row indicated no statistically significant differences ($P > 0.05$), while non-identical letters indicated statistically significant differences ($P < 0.05$).

	CI-LI-X-X-P2	CI-X-*C*-X-P2	CI-X-X-P1-P2	*P*-value
	N/Sum, Mean ± SD	N/Sum, Mean ± SD	N/Sum, Mean ± SD	
Terminal abutments				
CI	50/5766.0, 115.3 ± 64.4	50/4681.0, 93.6 ± 40.3	50/4646.0, 92.9 ± 49.5	0.055
P2	50/6010.0, 120.2 ± 60.8[a]	50/5640.0, 112.8 ± 75.2[a]	50/4430.0, 88.6 ± 45.1 [b]	0.030*
Non-terminal abutment	LI: 50/5189.0, 103.8 ± 50.8	C: 50/5332.0, 106.6 ± 50.4	P1: 50/4808.0, 96.2 ± 50.3	0.564

Post hoc test (Scheffe's test).
*Groups with the same letter do not significantly differ at $P < 0.05$.
Abbreviations: C: canine, CI: central incisor, LI: lateral incisor, P1: first premolar, P2: second premolar, X: missing tooth.

greater than that in group CI-X-X-P1-P2. It might be because different pontic size and distribution in the five-unit anterior zirconia-based FDPs with curvature cause anisotropic contraction and distortion during the sintering process.[13] The framework configuration and curvature would influence the marginal gap of anterior zirconia frameworks independent of CAD/CAM system.[23] Further study is needed to verify the effect of curvature on the marginal and internal gaps of FDPs.

Nowadays, zirconia is often used clinically for frameworks of long-span or full-arch FDPs. For five-unit anterior zirconia-based FDPs with different pontic distribution, the results from this study showed the percentage with qualified gaps were low, the gaps were larger when adjacent pontic existed, and the gaps at occlusal surface were not clinically acceptable. The clinical implication is that the fit of long-span or full-arch zirconia-based FDPs might be problematic when the number of consecutive pontic increases and further larger cement space would result in even poorer mechanical performance. Owing to the limitations of this study, the marginal and internal gaps were measured at five measurement points in only one cross-section for each abutment. These measurements might not be a true representation of the overall adaptation. In addition, repeated firing cycles and veneering could aggravate distortion and have an adverse effect on the marginal and internal gaps of zirconia-based FDPs. If the gaps of five-unit anterior zirconia-based FDPs had been measured after veneering, the study would have been closer to clinical setting. Finally, although PVS material was used in the present study, a realistic cementation procedure was not evaluated. Increased discrepancy, especially in marginal regions, may occur during the cementation procedure.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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