Effect of vertical preparation on fit of heat pressed zirconia reinforced lithium disilicate and monolithic zirconia three-unit fixed partial dentures: A comparative study

Mohammed Elsherbini
The University of Tokyo
Walid Al-Zordk
Mansoura University
Mohamed Diaa
Mansoura University
Rahma A Amin
Mansoura University
Amal Abdelsamad Sakrana (asakrana@mans.edu.eg)
Mansoura University

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Abstract

Background: The aim of this study was to evaluate the effect of horizontal and vertical tooth preparation on the internal and marginal fit of zirconia reinforced lithium silicate and monolithic zirconia fixed partial dentures.

Methods: Forty ceramic fixed partial dentures were divided into four groups (n=10) according to ceramic type and finish line design. Group HL: Horizontal tooth preparation with heat pressed zirconia reinforced lithium disilicate. Group HZ: Horizontal tooth preparation with zirconia fixed partial denture. Group VL: Vertical tooth preparation with heat pressed zirconia reinforced lithium disilicate fixed partial denture. Group: VZ: Vertical tooth preparation with zirconia fixed partial denture. Micro-CT was used to evaluate the fit of each fixed partial denture. Data were collected and statistically analyzed.

Results: Horizontal preparation showed a significant better fit than that of vertical preparation for both abutments (*P*[illegible].001). Zirconia showed significant better fit than heat pressed zirconia reinforced lithium disilicate for the posterior abutment. All the results were within internal and marginal fit requirements.

Conclusions: Nevertheless, being within the clinically acceptable fit values, the vertical preparation can negatively affect the marginal gap and internal fit of fixed partial dentures at certain points. The marginal gap and internal fit of the ceramic fixed partial dentures can be affected by ceramic type and finish line design.

Background

The conventional tooth preparation for anterior or posterior crowns necessitates reduction that can reach between 40% and 70% of tooth structure [1]. Multiple efforts were done to reach the appropriate tooth preparation technique that can ensure adequate marginal fit and emergency profile with the least loss of enamel and dentin in the process [2]. With minimally invasive dentistry, less tooth reduction means better adhesion and improved clinical durability [3].

The success of minimally invasive restorations depends on the strength of the restoration and its bond strength to the tooth structure [4]. Tooth reduction without a definite finish line provides a more conservative alternative to the typical horizontal margins with different terms used to describe this technique such as edgeless, shoulder-less or vertical tooth preparation [5]. The vertical preparation technique was originally indicated for periodontal-prosthetic rehabilitations and metal-ceramic restorations, however the introduction of high-strength ceramic materials allowed the use of vertical preparation as an alternative to the more extensive horizontal one [6]. Reducing the margin thickness of the restorations appears to be the most technically challenging issue with minimal invasive finish lines as cracks may be induced from the occlusal surface to the thin margin causing failure of the restoration [7, 8].

Monolithic zirconia restorations were introduced to solve the problem of porcelain veneer chipping and showed promising clinical performance with adequate esthetics [9–12]. Minimally invasive vertical finish lines has been already tested in multiple studies using monolithic zirconia crowns due to their high flexural strength values [2, 13, 14]. However, the combination of lithium disilicate ceramic restorations with vertical preparations can present an attractive approach because these glass-ceramics offer high-strength with superior optical properties, and well-documented bonding quality [15, 16].

The pressable lithium disilicate material has become a popular restorative material due to its good mechanical properties, and optical characteristics [17–19]. Zirconia-reinforced lithium silicate glass ceramics were introduced with 10% zirconium dioxide particles homogeneously incorporated inside lithium silicate glass ceramic matrix improving its mechanical and esthetic properties [20]. Recently, pressable zirconia-reinforced lithium silicate glass ceramic (Vita Ambria, Vita Zahnfabrik, Bad Säckingen, Germany) was introduced to the dental market with an average biaxial strength of 550 MPa that can be used for fabrication of laminate veneers, full crowns and three-unit fixed partial dentures up to the second premolars [21].

The fit of indirect restorations is crucial for their long term clinical performance and success [22–25]. Marginal adaptation is determined by measuring the perpendicular distance between the prepared tooth and the internal surface of the restoration at the margin [26–28]. Poor fit can cause luting cement dissolution, plaque retention with increased risk of secondary caries, loss of retention, periodontal and pulpal inflammation [29–31]. Moreover, discrepancies between restoration and the prepared tooth may influence durability of the restoration. Resin cements performance can be optimized when the internal gap of a restoration is 50 to 100 µm [32–34]. Different methods have been used to evaluate internal and marginal fit of indirect restorations with no standardized methodology; these mainly include direct measurement, cross-sectional measurement, and the impression replica technique [35]. The micro-computed tomography (micro-CT) was proposed as a reliable and non-destructive technique to evaluate the internal and marginal adaptation of dental restorations. This technique allows 2D and 3D investigation of the marginal and internal gaps within the range of a few micrometers at multiples sites and directions [36].

The aim of this study was to evaluate the effect of vertical tooth preparation on the internal and marginal fit of heat pressed zirconia reinforced lithium disilicate and monolithic zirconia fixed partial dentures. The first null hypothesis was that the vertical preparation would not affect the fit of ceramic fixed partial denture. The second null hypothesis was that the ceramic type would not affect the fit of the fixed partial denture.

Methods

The study groups for this study are presented in Table 1. Two typodont mandibular casts (Pro 2001-UL-SPFEM-32 typodont model, Nissin Dental Products Inc., Kyoto, Japan) with missing right first premolars were used to receive tooth preparation on the canine and second premolar teeth. For one of the typodont casts, the abutment preparation was performed with 6-dgree taper, 4.5 mm wall height, and 1 mm circumferential chamfer finish line. For the second typodont model, the abutment teeth were prepared with the same characteristics except having feather-edge (vertical) margin configuration [37]. The abutment preparation was performed by a single operator using a paralleling device (Dentalfarm A3006 B, Turin, Italy) and a straight hand-piece (Traus AT-II, Saeshin Precision Co., Daegu, Korea). Both prepared typodont casts were scanned (Ceramill Map 400, Amann Girrbach GmbH, Koblach, Austria). Based on the scan data, both preparation segments were printed (Phrozen shuffle, phrozen Technology, Hsinchu, Taiwan) using a printer resin (FTD Dentifix-3D LR, 3D printing resin, Lumi industries, Montebelluna, Italy). Then, the printed patterns were invested and casted to obtain two metal casts.

Forty impressions were made (Presigum, President Dental GmbH, Germany) and poured in type IV stone (Elite Master, Zhermack SpA, Italy) according to manufacturer's instructions. After setting, each stone working cast was evaluated for any defects. All working casts were scanned (Ceramill Map 400, Amann Girrbach GmbH, Koblach, Austria). Then, all fixed partial dentures were designed using the CAD software (Ceramill Mind, Amann Girrbach GmbH, Koblach, Austria). A cement layer of 40 µm starting 0.5 mm from the margin, and connectors with 9 mm^2 dimensions were chosen [38].

Fabrication of the restoration: For heat pressed zirconia-reinforced lithium disilicate fixed partial dentures (HL and VL groups), a pattern was printed (Phrozen shuffle, phrozen Technology, Hsinchu, Taiwan) using a printer resin (FTD Dentifix-3D LR, 3D printing resin, Lumi industries, Montebelluna, Italy) for each fixed partial denture. The resin patterns were sprued and invested, and then the pressing procedures were performed following the instructions of the manufacture using a heat pressed zirconia-reinforced lithium disilicate ingots (Vita Ambria, Vita Zahnfabrik, Bad Säckingen, Germany). Finally, each fixed partial denture was finished and cleaned before being subjected to glaze firing following the instructions of the manufacture. For zirconia fixed partial dentures (HZ and VZ groups), the restorations were dry milled from a zirconia disc (Zolid fx, Amann Girrbach GmbH, Austria) using the CAD-CAM milling machine (Ceramill motion II, Amann Girrbach GmbH). The milled zirconia restorations were sintered (Ceramill Therm 3, Amann Girrbach, Austria), then glazed based on the recommendations of the manufacturer.

Micro-CT scanning: Each fixed partial denture was seated on its respective metal model with finger pressure. To prevent movement of the restoration, utility wax was placed on the facial and lingual margins of each restoration. To evaluate the fit, each fixed partial denture was scanned by micro-CT equipment (SkyScan 1173 micro-CT scanner, Bruker, Kontich, Belgium). The scanning parameters were: x-ray source voltage of 40-130kV, source current of 61 µA, x-ray detector distortion-free flat panel sensor of 2240 x 2240 pixels and scan duration of 21 minutes per specimen. Projected images were reconstructed using special software (NRecon, SkyScan, NV, Belgium). The cross-sectional micro-CT images and the region of interest were obtained using the machine software (SkyScan Data Viewer 1.5.0.0, SkyScan, NV, Belgium). To evaluate the fit of each fixed partial denture, ten measurement sits were used: marginal gap (perpendicular measurement from the internal surface of the retainer to the margin of the die), chamfer area (800 µm occlusal to the margin of the die), axial wall (internal fit at the midpoint of the axial wall), axio-occlusal transition area (transition from the occlusal surface to the axial wall), occlusal area (500 µm from the axio-occlusal angle). Additionally, the horizontal marginal discrepancy was analyzed from cross-sectional images taken at the horizontal plane (Fig. 1).

Statistical analysis: Analysis of data was carried out with SPSS version 26. Testing the normality of data was done with Kolmogorov-Smirnov test and Levene test. Continuous variables were described as mean, standard deviation, minimum, median and maximum. Student t-test was used to compare two groups when data were parametric, while non-parametric data were compared by Mann-Whitney U median for non-parametric data. Two-way analysis of variance (ANOVA) was used to examine the influence of two different categorical variables (preparation and material) on dependent variables.

Results

For the single abutment teeth, an overview of the fit in canine and premolar for both materials (heat pressed zirconia-reinforced lithium disilicate and zirconia) regarding horizontal preparation and vertical preparation (Table 2). The canine of horizontal preparation showed a significant better fit than that of vertical preparation for the marginal gap area ($P < .001$), finish line area ($P < .001$), and incisal area ($P = .008$). Also, the premolar of the horizontal preparation showed a significant better fit than vertical preparation for the marginal gap area ($P < .001$). Regarding the material type, canine of heat pressed zirconia-reinforced lithium disilicate showed no significant differences in the fit for the different measurement areas compared to canine of zirconia. However, the premolar of zirconia showed significant better fit than that the premolar of heat pressed zirconia-reinforced lithium disilicate for marginal gap area ($P = .004$), axial wall area ($P < .001$), and axio-incisal transitional area ($P = .032$). Regarding the interaction between preparation type and material type, there were only a statistical significant effect for horizontal marginal discrepancy at canine ($P < .001$) and premolar ($P < .001$) abutments and for finish line area at canine abutment ($P = .007$).

An overview of the fit for the fixed partial denture for both materials (heat pressed zirconia-reinforced lithium silicate and zirconia) regarding horizontal preparation and vertical preparation (Table 3). For fit of the fixed partial denture at margin, the interaction between preparation type and material type had a statistical significant effect for horizontal marginal discrepancy ($P < .001$) as shown in Table 4, whereas, there was no significant interaction for marginal gap area (Table 5). Regarding internal fit of the fixed partial denture, there were no significant interaction for axial wall area ($P = .941$), axio-incisal transitional area ($P = .722$), and incisal area ($P = .800$), whereas, there was a significant interaction for finish line area ($P = .011$) (Figs. 2 and 3).

Discussion

The first null hypothesis that the vertical preparation would not affect the fit of ceramic fixed partial denture was partially accepted as the vertical finish line design negatively affected the marginal gap and internal fit at certain points. Also, the second null hypothesis that the ceramic type would not affect the fit of the fixed partial denture was partially accepted.

Heat pressed zirconia reinforced lithium disilicate and zirconia ceramics were selected for the current study. Monolithic zirconia restorations provide good mechanical properties, biocompatibility and adequate esthetics [9, 10], while the pressable zirconia reinforced lithium disilicate material has become popular due to its precision, superior bonding ability, and superior esthetics [15, 18]. In this study micro-CT was used as a non-destructive technique to assess marginal and internal fit at selected points. It allows 2D and 3D investigation of the marginal and internal gaps within the range of a few micrometers [35]. The micro-CT scanning procedure was done without cementation in order to improve the contrast between the metal die, the ceramic restoration and the internal gap. In addition, cementation of each fixed partial denture could cause some damage to the cement gap and interfere with the measurement results [36]. In this study, mandibular canine and second premolar teeth were used as abutments. The effect of abutment tooth type on the fit of the restoration is controversial. Huang et al [25] and Kokubo et al [27] found that no difference in the fit between anterior, premolar and molar abutments. In the current study, only one cast model was used for all the examined restorations of each preparation design to offer standardized experimental set-up and optimized conditions [10].

In the present study, different levels of adaptation were observed for the ceramic fixed partial dentures at the different measuring points for both ceramic systems even though a uniform 40 μm cement spacer setting was used. These finding are in agreement with other studies [35, 36], which could be attributed to accumulation of errors including error in the design and milling process, fatigue of milling machine and manufacturer differences in the milling burs and blocs [34]. Although there was a statistically significant difference between the groups, all the results are within fit requirements. McLean and von Fraunhofer [30] stated that a marginal gap less than 120 μm is considered clinically acceptable, so the amount of marginal discrepancy present in this study was within the clinically acceptable values.

The fit of a three-unit fixed partial denture is dependent on the internal fit of both retainers on each abutment [33]. Regarding the fit of the single abutments in this study concerning the material type, the premolar of zirconia showed significant better fit than that the premolar of zirconia reinforced lithium silicate for marginal gap area ($P = .004$), axial wall area (P[illegible].001), and axio-incisal transitional area ($P = .032$). This finding can be explained that CAD-CAM technology can produce restorations with improved adaptation due to the fewer production steps compared to the heat pressing technique.[28] These findings are in accordance with Nejatidanesh et al [31] who found that CAD/CAM restorations provided better internal adaptation. On the other side, Raafattammam [19] reported that CAD-CAM lithium disilicate group recorded statistically significant higher internal gap mean value than press group which may be attributed to the cementation technique. However, canine of zirconia showed no significant differences in the fit compared to canine of heat pressed zirconia reinforced lithium silicate, the decrease in canine fit measurements with the CAD/CAM restorations may be related to the anatomical transmission of the dental arch from the linear posterior region to the curved anterior region, distortion of the framework is likely to occur after the final sintering and will have a negative impact on the marginal adaptation [11, 12].

Regarding the finish line design, multiple studies evaluated the effect of finish-line design on the marginal and internal adaptations of ceramic crowns mostly covering chamfer and rounded shoulder finish lines with diverse results [13, 18, 22]. This in vitro study evaluated the marginal adaptation of the fixed partial dentures with two different finish line designs; chamfer and feather-edge. Historically, vertical margins showed procedural advantages of easier impression making and improved marginal adaptation after cementation [17], with little information in the literature covering the effect of feather-edge finish line on the marginal and internal adaptations of ceramic crowns. Comlekoglu et al [14] evaluated the marginal integrity of veneered zirconia crowns with four different finish lines including feather-edge and revealed that the feather-edge type of finish line design exhibited the least marginal discrepancy. However, in the current study horizontal preparation showed a significant better fit than that of vertical preparation at the marginal gap area for both abutments which could be attributed to the used of different materials and measuring methods [35, 36].

Clinical studies are needed to assess the clinical performance of the vertical preparation with newly developed ceramic materials. Complications such as caries, periodontal disease, loss of vitality, marginal gap, marginal chipping, fracture and loss of retention of ceramic restoration employing vertical preparation need to be evaluated in clinical setting.

Conclusions

Within the limitations of this in vitro study, it was concluded that;

1. Nevertheless, being within the clinically acceptable fit values, the vertical preparation can negatively affect the marginal gap and internal fit of fixed partial dentures at certain points.
2. The marginal gap and internal fit of the ceramic fixed partial dentures can be affected by ceramic type and finish line design.

Abbreviations

micro-CT: micro-computed tomography; μm: micrometer; 2D: two dimensional; 3D: three dimensional; CAD-CAM: computer aided design-computer aided manufacturing.

Declarations

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Authors’ contributions

Study design: ME, W.-Z, AS. Experiments and data analyses: ME, W.-Z, RA, AS. Drafted the manuscript: MD, W.-Z. Reviewed the manuscript: AS. All authors have read and approved the final manuscript.

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Not applicable.

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Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1. Study groups used in the study.

Code	Group
HL	Horizontal tooth preparation with heat pressed zirconia reinforced lithium disilicate fixed partial denture
HZ	Horizontal tooth preparation with monolithic zirconia fixed partial denture
VL	Vertical tooth preparation with heat pressed zirconia-reinforced lithium disilicate fixed partial denture
VZ	Vertical tooth preparation with monolithic zirconia fixed partial denture

Table 2. Means, standard deviations (SD), minimum (Min.), median, and maximum (Max.) in micrometers for the fit at canine and premolar abutments with heat pressed zirconia reinforced lithium disilicate and monolithic zirconia regarding horizontal and vertical preparation

Measurement area	Horizontal preparation				Vertical preparation			
	Zirconia reinforced lithium disilicate		Monolithic zirconia		Zirconia reinforced lithium disilicate		Monolithic zirconia	
	Canine	premolar	Canine	premolar	Canine	premolar	Canine	premolar
Marginal gap								
Mean (SD)	59.7 (10.8)	71.1 (6.9)	60 (2.5)	60.5 (4.1)	72.7 (9.7)	80.1 (7.6)a	85.9 (16.6)	73.6 (15.9)
Min.	44	62	56	56	64	72	72	59
Median	61.5^{A}	70	$59.5^{B,C}$	$59.5^{a,b}$	67.5^{B}	80^{a}	$79^{A,C}$	68^{b}
Max.	72	81	64	67	87	93	115	93
Finish-line area								
Mean (SD)	60.5 (7.6)	69.5 (6.5)	57.6 (3)	60.7 (5.5)	65.9 (7.4)	71.2 (6.4)	79.6 (14.6)	67.7 (16.1)
Min.	52	58	53	50	59	60	55	53
Median	57.5^{A}	70^{b}	57.5^{B}	61^{a}	63.5	69	$85^{A,B}$	$62^{a,b}$
Max.	73	79	62	68	80	81	93	90
Axial wall								
Mean (SD)	74 (3.8)	92.2 (6.1)	75 (11.4)	72.5 (17.5)	73 (8.3)	91.3 (10.9)	75.3 (13.6)	74.9 (13.7)
Min.	64	86	66	52	64	81	55	55
Median	75	91.5	70.5	74.5	71	88	75	81
Max.	78	106	97	95	86	109	95	87
Axio-incisal transitional area								
Mean (SD)	111.6 (11.2)	106.5 (7.9)	101.9 (15.4)	100.1 (18.6)	118.1 (7.5)	116 (13.4)	109.7 (15.7)	102.9 (12.7)
Min.	100	99	87	83	99	99	91	89
Median	106.5	104	96.5	94	120.5	112.5	108	101.5
Max.	130	122	124	126	123	141	133	126
Incisal area								
Mean	105.4	108.9	103.9	102.5	116.2	112.4	112	106

(SD)	(15.3)	(12.3)	(10)	(9.8)	(8.1)	(11.2)	(7.8)	(12)
Min.	93	93	92	92	106	97	99	94
Median	98	103.5	103.5	100.5	117	114	111	101
Max.	131	124	121	122	127	128	125	125
Horizontal marginal discrepancy								
Mean (SD)	76.9 (6.33)	78 (10)	64 (9.6)E	61.3 (11.7)	79.2 (5.6)	83.4 (5.5)a	90.9 (6.4)	89.2 (4.9)
Min.	69	61	54	51	75	75	81	82
Median	$75.5^{A,C}$	78.5	$62^{B,C}$	$57^{a,b}$	$76^{D,E}$	83^{a}	$90^{A,B,D}$	89^{b}
Max.	86	90	80	83	89	91	99	97
Similar uppercase letters indicate significant differences between fit of canine; similar lowercase letters indicate significant differences between fit of premolar (P<.05).								

Table 3. Means, standard deviations (SD), minimum (Min.), median, and maximum (Max.) in micrometers for the fit of the fixed partial denture with heat pressed zirconia-reinforced lithium disilicate and monolithic zirconia regarding horizontal and vertical preparation

Measurement area	Horizontal preparation		Vertical preparation	
	Zirconia-reinforced lithium disilicate	Monolithic zirconia	Zirconia-reinforced lithium disilicate	Monolithic zirconia
Marginal gap				
Mean (SD)	65.4 (6.3)	60.3 (2.5)	76.4 (7.8)	79.8 (13.9)
Min.	53.5	57	68.5	65.5
Median	66	60.5^{A,B}	74.3^{A}	77^{B}
Max.	76	64.5	89.5	104
Finish-line area				
Mean (SD)	65 (4.3)	59.2 (2.7)	68.5 (2.7)	73.6 (11.2)
Min.	58	54.5	63	56.5
Median	64.5^{A}	59.8^{B,C}	69.3^{B}	71.5^{A,C}
Max.	72	62.5	74	91.5
Axial wall				
Mean (SD)	83.1 (4)	73.8 (13)	84.9 (9.6)	75.1 (9.3)
Min.	75	61	73	56
Median	82.3	71.5	84	76
Max.	90	96	102	88
Axio-incisal transitional area				
Mean (SD)	109 (7.8)	101 (17)	117 (8.5)	106.3 (12)
Min.	100.5	85	99	92.5
Median	106.8	95^{A}	117.3^{A}	102.8
Max.	122	124	132.5	127
Incisal area				
Mean (SD)	107.2 (11.8)	103.2 (5.7)	114.3 (6.8)	109 (7.9)
Min.	93.5	97	104	98
Median	105.3	102^{A}	115.8^{A}	110.3

Max.	125.5	113.5	126	122
Horizontal marginal discrepancy				
Mean (SD)	77.5 (6.9)	62.6 (10.6)	81.3 (3.4)	90 (2.9)
Min.	66	52.5	75	86
Median	77.3^{A}	59.8^{B}	82.5	90^{A,B}
Max.	87.5	81.5	86	95.5
Similar uppercase letters indicate significant differences between fit of fixed partial denture (P<.05).				

Table 4. Two-way ANOVA test for effect of material and preparation on fit of the fixed partial denture at horizontal marginal discrepancy area

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3919.419	3	1306.473	29.058	.000
Intercept	242502.756	1	242502.756	5393.695	.000
Material	2441.406	1	2441.406	54.301	.000
Preparation	91.506	1	91.506	2.035	.162
Material * Preparation	1386.506	1	1386.506	30.838	< .001
Error	1618.575	36	44.960	-	-
Total	248040.750	40	-	-	-
Corrected Total	5537.994	39	-	-	-

Table 5. Two-way ANOVA test for effect of material and preparation on fit of the fixed partial denture at marginal gap area

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2514.350	3	838.117	11.125	.000
Intercept	198528.100	1	198528.100	2635.280	.000
Material	2325.625	1	2325.625	30.871	.000
Preparation	8.100	1	8.100	.108	.745
Material * Preparation	180.625	1	180.625	2.398	.130
Error	2712.050	36	75.335	-	-
Total	203754.500	40	-	-	-
Corrected Total	5226.400	39	-	-	-

Figures

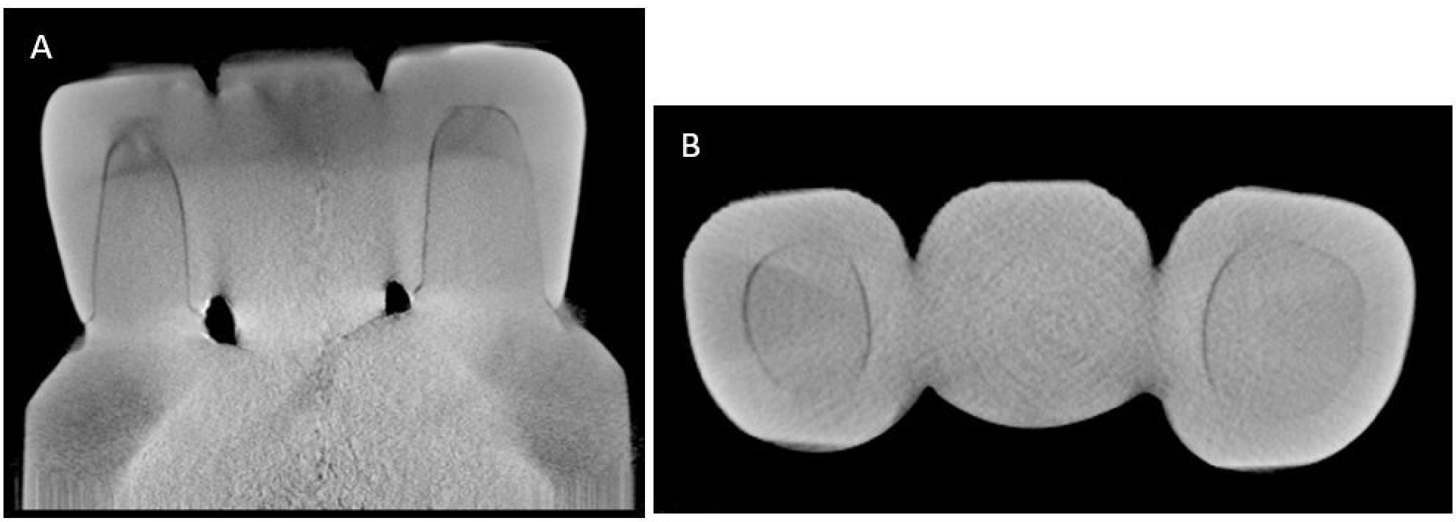

Figure 1

Cross-section images of the fixed partial denture; A: the mesio-distal direction, and B: horizontal plane at marginal area for horizontal marginal discrepancy.

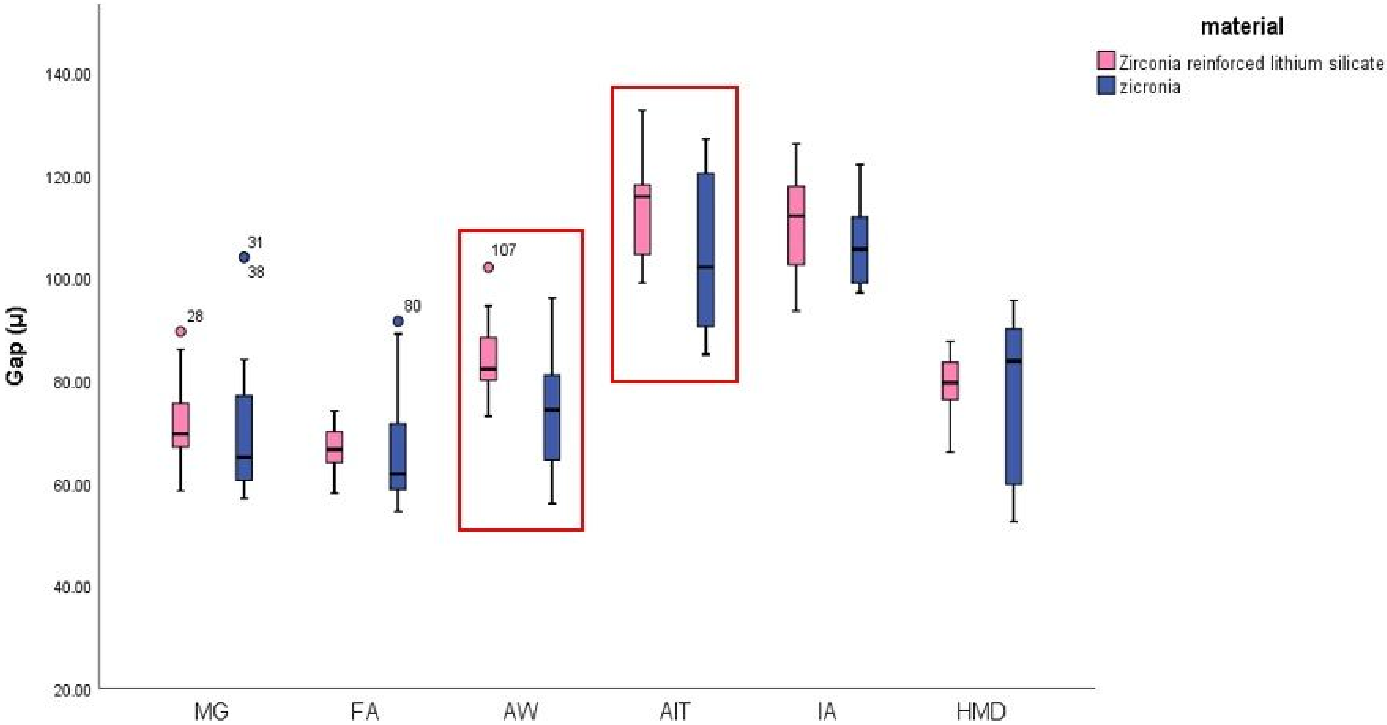

Figure 2

Fit of heat pressed zirconia-reinforced lithium silicate and monolithic zirconia fixed partial dentures. Red frame indicates significantly different groups (P<.05). MG, Marginal gap; FA, Finish-line area; AW, Axial wall; AIT, Axio-incisal transitional area; IA, Incisal area; and HMD, Horizontal marginal discrepancy.

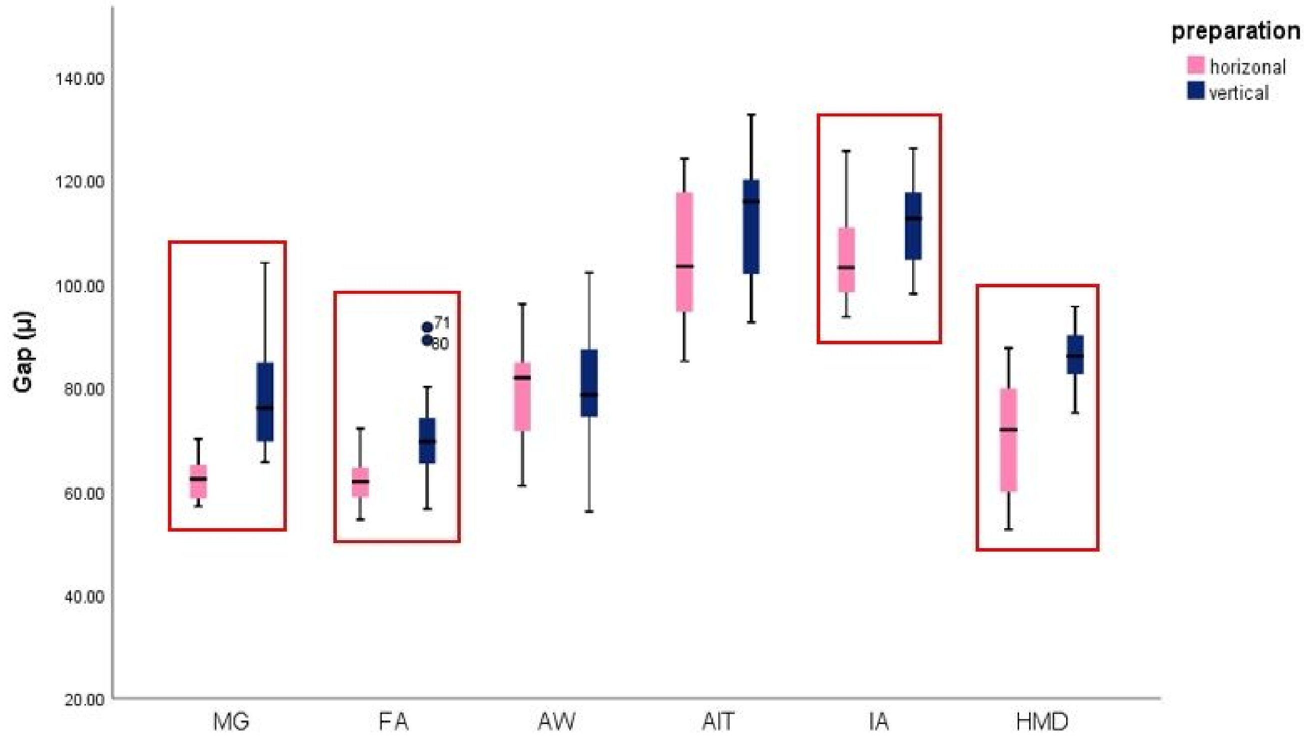

Figure 3

Fit of horizontal and vertical prepared fixed partial dentures. Red frame indicates significantly different groups (P<.05). MG, Marginal gap; FA, Finish-line area; AW, Axial wall; AIT, Axio-incisal transitional area; IA, Incisal area; and HMD, Horizontal marginal discrepancy.