Effect of the number of abutment teeth on the marginal and internal accuracy of four-unit monolithic zirconia fixed dental prostheses

Woong-Gi Kim

The Graduate School

Yonsei University

Department of Dentistry

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Directed by Professor Sun-Jai Kim

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Woong-Gi Kim

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This certifies that the master's Thesis

of Woong-Gi Kim is approved

Thesis Supervisor: Sun-Jai Kim

Thesis committee: June-Sung Shim

Thesis committee: Jee-Hwan Kim

The Graduate School

Yonsei University

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2016년 12월

김웅기 드림

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Abstract

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Woong-gi Kim

Department of Dentistry
The Graduate School
Yonsei University

Directed by Professor Sun-Jai Kim, DDS, MS, PhD

Purpose. The purpose of the current study was to evaluate the accuracy of four-unit monolithic zirconia fixed dental prostheses with different number of abutment teeth and impression techniques.

Material and methods. Right premolars and molars of mandibular acrylic model were prepared to receive four-unit zirconia fixed dental prostheses. Acrylic models were categorized in three groups according to the number of abutment teeth: Group NP: 4 abutment teeth and no pontic, Group 1P: 3 abutment teeth and one pontic, and Group 2P: 2 abutment teeth and two pontics. Each model was duplicated with the epoxy resin and each epoxy resin model was duplicated with type IV dental stone for ten times per each group. Each epoxy resin model was scanned for ten times per each group with the intraoral scanner, and all dental stone models were scanned with dental lab scanner. According to the method of digitalization, the models were categorized in two groups: Group DD: direct digitalization and group ID: indirect digitalization. Four-unit zirconia monolithic FDPs were designed, milled, and sintered to the full density in the furnace. Silicone replica technique was used to measure the discrepancies. The discrepancies of margin, axial-wall, and occlusal center areas were measured.

Results. The mean values of Group NP, 1P, and 2P were 67.99.± 12.68 μm, 69.38 ± 12.03 μm, and 72.09 ± 13.93 μm at the margin area, 119.46 ± 18.49 μm, 121.08 ± 18.29 μm, and 125.58 ± 21.51 μm at the axial-wall area, and 175.69 ± 23.83 μm, 178.02 ± 22.06 μm, and 187.03 ± 26.76 μm at the occlusal center area, respectively. The mean values of Group DD and ID were 65.77 ± 12.59 μm and 72.95 ± 12.53 μm at the margin area, 114.80 ± 20.01 μm, 122.10 ± 20.91 μm at the axial-wall area, 175.40 ± 27.74 μm, and 185.10 ± 20.03 μm at the occlusal center area, respectively. There was significant difference among the group NP, 1P, and 2P at the marginal and axial area (p<.05). For all measurement areas, there was significant difference between group DD and group ID (p<.05). There was no interaction between the method of digitalization and the number of abutment teeth for all measurement areas (p>.05).

Conclusion. The number of abutment teeth had a significant effect on the marginal and internal fit of four-unit monolithic zirconia FDPs (p<.05). Improved marginal and internal fit with a direct digitalization was obtained comparing with those with the aid of an indirect digitalization (p<.05).

Key words: zirconia; the number of abutment teeth; direct and indirect digitalization; marginal and internal accuracy

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I. INTRODUCTION

The computer aided design and computer aided manufacturing (CAD/CAM) technique has been used widely to fabricate ceramic restorations.[1] For acquisitioning digital images of teeth, some methods have been introduced: Digitalization of the dental stone cast, digitalization of impressions, and intraoral digital impression.[2] Indirect digitalization starts from the conventional impression method. Restorations generated by this method have proved successful both functionally and esthetically[3], however factors such as three-dimensional change of impression materials and gypsum casts, variation in the length of time between impression making and pouring the dental stone, the temperature of dental office or laboratory, surface wettability of gypsum products, and disinfection procedures can have an effect on the material distortion and the accuracy of the overall scan data.[4] The intraoral scanner, on the contrary, uses a variety of optical technologies to obtain the data of teeth directly. Acquired data are sent to co-relating software and used directly to design restorations.[5] It is a desirable technology in terms of reducing procedures which might have a chance of errors, thus a number of digital intraoral impression systems have been widely developed.[3]

Intraoral scanner fabricates the virtual image of casts using the working principle of active triangulation, confocal microscopy, or wave front sampling, etc. Also, the data capturing methods are divided into camera image impression or video image impression.[5] Even though the intraoral scanners can reduce the errors made from conventional methods, there are possibilities of inaccuracy resulting from the inherent disadvantage of direct digitalization, such as patient's movement and dentist's movement while obtaining scan data, reflection of light off the tooth surface, saliva and humidity of patient's mouth.[5]

Appropriate marginal and internal adaptation are critical factors for the longevity of fixed dental prostheses.[6] There is consensus among various authors that marginal discrepancy under 120μm is clinically acceptable.[7] An inadequate marginal adaptation may negatively affect the longevity of the dental restoration. If a wide cement layer is exposed to the oral environment, dissolution of the cement by the action of oral fluids and chemical–mechanical forces will be promoted.[8] Wide marginal discrepancy also contribute to plaque accumulation, leading micro-leakage, secondary caries, endodontic inflammation, and periodontal diseases.[6] It has been demonstrated that an excessive internal cement layer may induce residual tensile stresses, which leads to initiate cracks on the veneering ceramics.[9] As opposed to this, too small internal space may cause unstable seating of prostheses.[10] Comparing with other ceramic materials, yttriastabilized zirconia restoration is accepted as an appropriate material that has proven its suitability and fracture toughness in posterior region.[12] If the semi-sintered zirconia block is used for fabricating FDPs, it has to be sintered to the full density according to a certain sintering procedure. In this procedure, an inevitable linear shrinkage (approximately 15-30%) occurs and a following increased density is obtained.[13] For compensating the linear shrinkage of zirconia during the sintering, the optimization of software calculating the degree of shrinkage is required. Even if the calculating procedure is optimized, factors such s the homogeneity and the composition of pre-sintered zirconia block may have an effect on the final restorations.[14]

In a systematic review by Contrepois *et al.*[15], an overall review of the data retrieved for marginal gap of zirconia FDPs showed 94.9% were less than 120 μm, but a clinical study reported inferior marginal adaptation and a 22% rate of secondary caries after 5 years with zirconia substructures.[16] Pjeutursson *et al.*[17] also reported that when comparing metal-ceramic FDPs and zirconia FDPs, a significantly higher incidence of caries in abutment teeth was observed for densely sintered zirconia FDPs, and also reported that the incidence of ceramic fracture and the loss of retention was significantly higher for densely sintered zirconia FDPs compared to metal-ceramic FDPs, reinforced glass ceramic FDPs, glass-infiltrated alumina FDPs. Abduo *et al.*[11] demonstrated that contributing factors which affect the fit of the prostheses were fabrication system of zirconia, veneering, configuration, span length of zirconia, etc.

Because of the growing need for long-span FDPs, evidence-based scientific studies considering the fit of fixed dental prostheses rather than a single crown are required. However available previous *in-vitro* studies considering the adaptation of zirconia FDPs have been limited in small restorations such as single crowns or three-unit FDPs with one pontic. Particularly, in an author's knowledge, there were no studies which consider the effect of the number of abutment teeth in the same span length on the marginal and internal adaptation of more than four-unit zirconia FDP.

The purpose of the current study was to evaluate the effect of the number of abutment teeth on the marginal and internal adaptation of CAD/CAM-generated four-unit zirconia fixed dental prostheses by means of direct or indirect digitalization. Null hypothesis tested were 1) the number of abutment teeth did not affect the accuracy of four-unit zirconia fixed dental prostheses, and 2) the method of digitalization did not affect the accuracy of four-unit zirconia fixed dental prostheses.

II. Material and Methods

1. Preparation of artificial teeth

A mandibular acrylic model (D85DP-500B.1, Nissin dental, Japan) was used in this study. A 1.2-mm, 360° deep chamfer preparation was made on the right first, second premolars (pm1 and pm2) and the right first, second molars (m1 and m2). The preparation was performed with a surveyor using a carbide bur (Komet H 356 RGE 103.031, Gebr. Brasseler, Lemgo, Germany) to ensure that the artificial teeth had a total occlusal convergence of 25° (Fig. 1). A 1.5mm occlusal reduction was made. The preparation was finished with high-speed handpiece and extra-fine diamond chamfer bur (856, Brasseler, SS White, Axis).

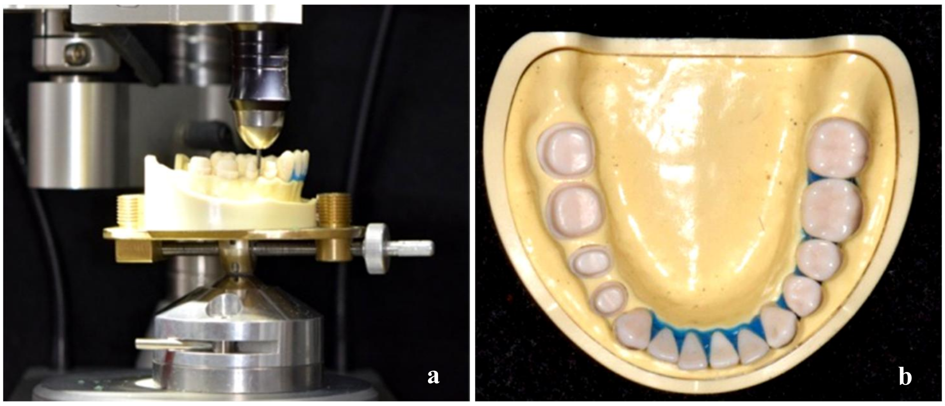

Fig. 1 Preparation of artificial teeth. (a) The preparation using a surveyor (b) Acrylic model after preparation. All undercuts in sulcus and inter-proximal area were blocked out with light-cure resin.

2. Fabrication of the epoxy resin master model

After the preparation of artificial teeth, impressions of maxillary and mandibular acrylic model were made with polyvinyl siloxane impression material using a stock tray. Impressions were poured with vacuum-mixed epoxy resin (Polyurock, Metalor technolocies, Stuttgart, Swiss) and removed after 12 hours. Subsequently, artificial tooth m1 was separated from the acrylic model and impression was made and poured in the same way. Artificial tooth pm2 was then separated and impression was made and poured. In this way, three epoxy resin models were fabricated. According to the number of abutment teeth, epoxy resin models were categorized in three groups: Group NP: no pontic and four abutment teeth (pm1, pm2, m1, m2), group 1P: one pontic and three abutment teeth (pm1, pm2, m2), and group 2P: two pontics and two abutment teeth (pm1, m2).

Duplicating of maxillary acrylic model was also performed in the same way. For group 1P and 2P, partially edentulous regions were trimmed with carbide bur and polished for mimicking the alveolar ridge after the tooth extraction. All deformities and nodules were checked and adjusted with carbide bur, manually (Fig. 2).

Fig. 2 Master model. (a) Group NP (b) Group 1P (c) Group 2P. The length of edentulous area was 15mm for group 1P and 24mm for group 2P.

3. Digital impression by direct and indirect method

Digitalization of master models was performed by two different methods: Direct and indirect digitalization.

For direct digitalization, each master model was scanned with an intraoral scanner (Cerec Omnicam, Sirona). Scanning procedure was performed by one operator, who followed the procedure recommended by the manufacturer. Each master model was scanned for ten times respectively, and data were saved. The complementary scanning of maxillary acrylic model was performed on the full-arch in order that the software could perform a buccal bite scan. All virtual models obtained from the intraoral scanner were sent to a design PC via CEREC Connect version 4.3.

For indirect digitalization, in comparison, master models were duplicated with light-bodied polyvinyl siloxane impression material (ImprintⅡ Light body, 3M ESPE, USA) with a custom acrylic resin tray for ten times per each group (Fig. 3). A custom acrylic resin tray was made separately for all impression procedures. Each impression was poured with vacuum-mixed type IV dental stone (Fuji Rock, GC America, Chicago, Ill.) and removed after 24 hours. Consequently, ten dental stone models per each group, in total thirty stone models, were made. Maxillary master model was also duplicated in the same way. Each stone model was scanned with a dental laboratory scanner (inEos X5, Sirona), and data were saved. According to the method of digitalization, all models were categorized in two groups: Group DD: Direct digitalization, and Group ID: Indirect digitalization.

Considering both the number of abutment teeth and the method of digitalization together, total 6 subgroups were categorized in this study (Table 1). Workflow in the current study represents in Fig. 4.

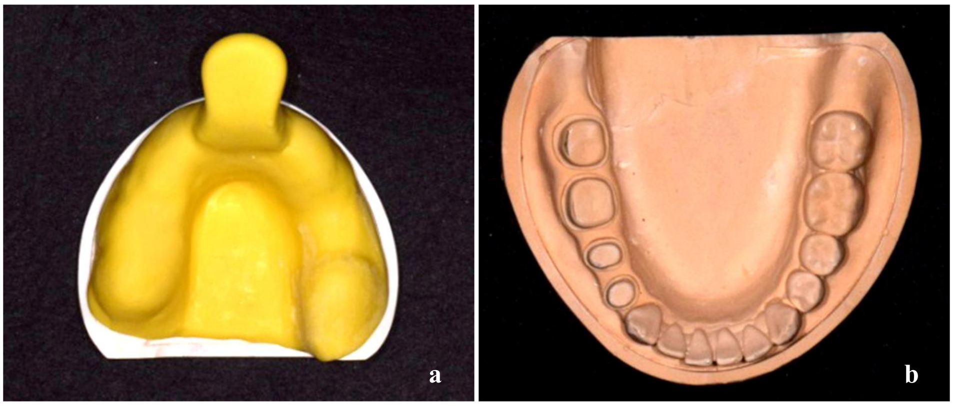

Fig. 3 The example of fabricating the stone model on group NP. (a) A custom acrylic resin tray used for duplication, (b) One of dental stone casts of group NP.

Table 1. Experimental groups and subgroups in this study

	Group NP	Group 1P	Group 2P
Direct digitalization (Group DD)	Subgroup NP-DD	Subgroup 1P-DD	Subgroup 2P-DD
Indirect digitalization (Group ID)	Subgroup NP-ID	Subgroup 1P-ID	Subgroup 2p-ID

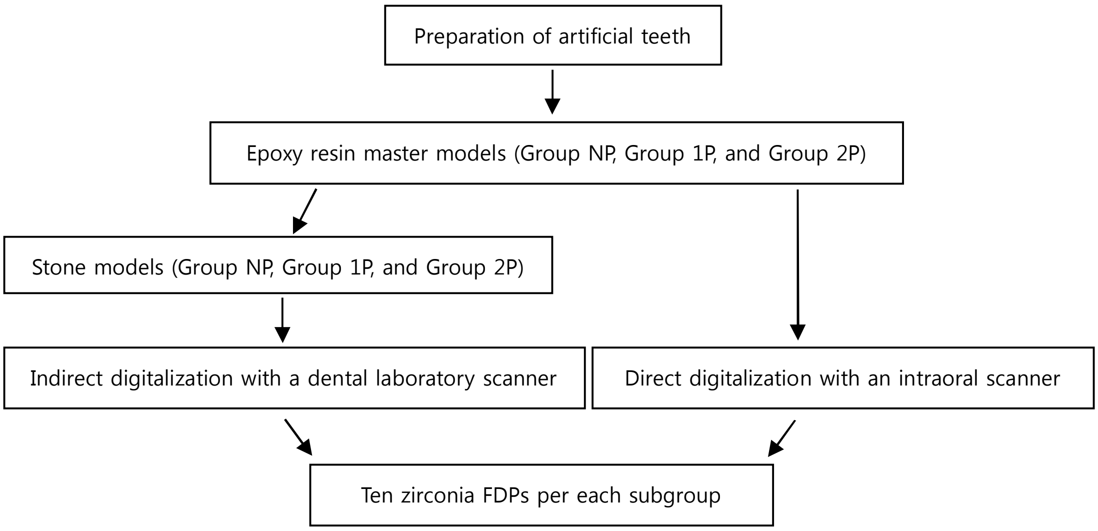

Fig. 4 Workflow of fabricating zirconia FDP.

4. Fabrication of four-unit monolithic zirconia fixed dental prostheses

In each subgroup, ten monolithic zirconia FDPs were designed using a CAD (CEREC inLab software version 15.1, Sirona) and milled from pre-sintered zirconia disks (ZirPremium, Acucera, Korea) by a five-axis dental milling machine (inLab MC X5, Sirona). After the milling process, the framework was sintered to full density in a special furnace (inFire HTC, Sirona) at a temperature of 1,500°C for 12 hours. After the sintering procedure, all restorations were examined for deformity and debris and steam-cleaned. Any manual adjustment was not performed so that only the efficiency of scanners, software, and milling and sintering procedure could be evaluated.

5. Fabricating replicas of the marginal and internal discrepancy

For measuring marginal and internal discrepancies, the replica technique described by Molin and Karlsson *et al.*[20] was used. The intaglio surface of restorations was filled with low-viscosity light-bodied polyvinyl siloxane (Aquasil Ultra XLV, Dentsply DeTrey GmbH, Konstanz, Germany), then was placed onto the underlying abutment teeth of epoxy resin master models. Maximum finger pressure for 7 minutes was loaded on pm1 and m2 until the material firmly set. After the light-bodied silicone had set, the FDPs were removed from the master model carefully, while the thin silicone layer remained on the underlying epoxy resin abutment teeth. The silicone layer, representing the discrepancy between the abutment teeth and the restorations, was subsequently stabilized by the application of a contrasting regular-bodied silicone (Aquasil Monophase, Dentsply DeTrey GmbH, Konstanz, Germany) with a customized resin tray. All replicas were segmented axially with a sharp lancet along mesio-distal and bucco-lingual direction guided from cutting slots of the customized tray so that each replica could be sectioned at the same location (Fig. 5).

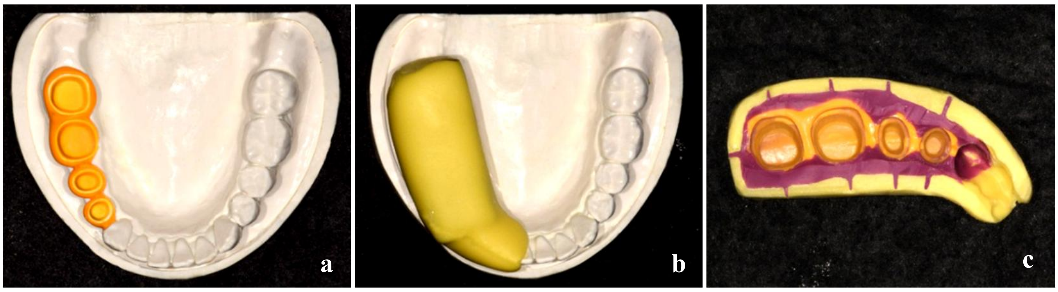

Fig. 5 Replica technique used in this study. (a) Orange-colored silicone represents the gap between the restoration and abutment. (b) Customized tray with tissue stops on incisors and buccal, lingual and distal side of abutment teeth. (c) Bucco-lingual and mesio-distal sectioning is guided from slots marked in the tray, so that the same position of each replica would be sectioned.

6. Marginal and internal gap measurement

The following areas were used to determine the marginal and internal discrepancy: Margin (area MG): The closest distance between the FDP and the abutment. Axial wall (area AG): The internal adaptation of the crown walls up to the transition to the occlusal surface. Occlusal center (area OG): The internal adaptation of the occlusal surface of the FDP to the abutment. The mesio-distally sectioned plane was divided into five locations: A. Mesial-margin, B. Mesial-axial, C. Occlusal center, D. Distal-axial, E. Distal-margin. Likewise, the bucco-lingually sectioned plane was divided into five locations: a. Buccal-margin, b. Buccal-axial, c. Occlusal center, d. Lingual-axial, e. Lingual-margin. Therefore, ten measurements were performed per each abutment. Marginal and internal gap demonstrated by Holmes *et al.*[24] was used. The perpendicular measurement from the internal surface of the restoration to the margin of the preparation was defined as a marginal gap, and the same measurement at the axial wall was defined as an axial gap (Fig. 6).

The discrepancies of each location were measured using a reflected light microscope (Axioscope 2; Zeiss, Oberkochen, Germany) at 50X magnification. All locations were pictured by a digital single lens reflex camera (Nikon D100;

Tokyo, Japan) through the microscope and the captured data were directly transferred to a desktop computer. The discrepancy measurement was made using the special analysis software (i-Solution version 7.3, Innerview, Korea). An accuracy of 1 μm was used to measure the thickness of replicas. Distinct contrast of the specimens was established as the critical criterion for reliable measurement.

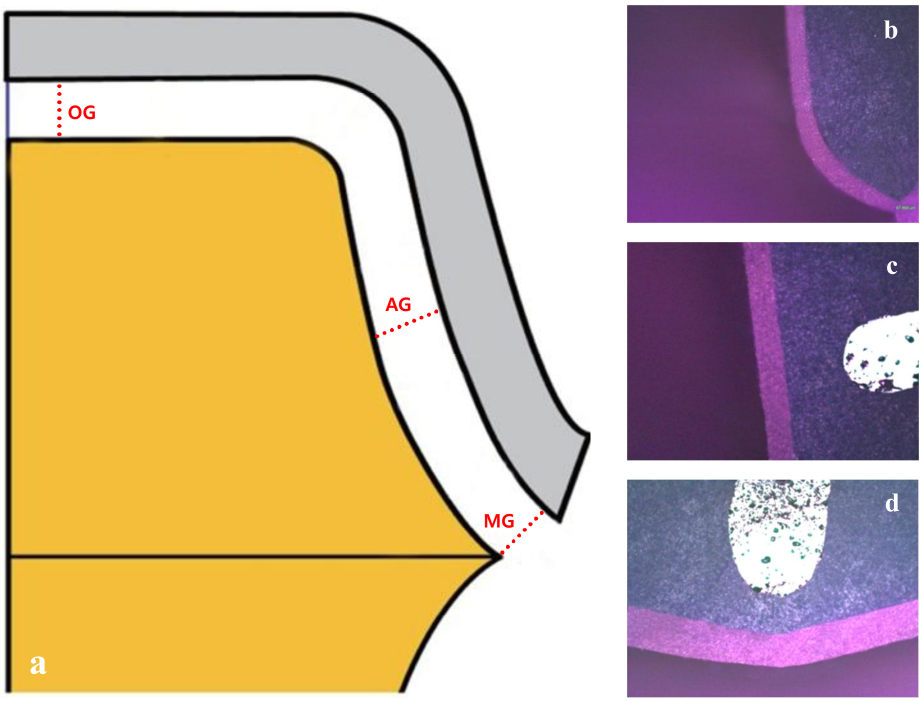

Fig. 6 Schematics of gap measurement locations of 50X magnification. (a) Example of sectioned replica of molar. (b) Marginal (MG) area, (c) Axial-wall (AG) area, (d) occlusal center (OG) area.

7. Statistical analysis

Data were imported into a statistical program (SPSS 18.0, SPSS Germany, Munich, Germany). The normality of involved groups was estimated using Kolmocorov-Smirnov test. One-way ANOVA was used to compare the effect of the number of abutment teeth and independent t-test was used to compare the effect of the digitizing method. Two-way ANOVA was used to verify the interaction between two variances. Post hoc Tukey HSD tests were conducted. The results of $p<.05$ were accepted statistically significant.

III. Results

The mean values and standard deviation (SD) by measurement areas for each 6 subgroups are given in Table 2 and Fig. 7.

Table 2. Overall mean value (SD) for each experimental condition (μm)

Measurement area	Method of digitalization	Group NP	Group 1P	Group 2P	p value
		The number of abutment teeth			
MG	Group DD	63.54 (12.06)	65.00 (10.94)	69.16 (13.32)	.013
AG		108.11 (18.54)	111.24 (17.50)	124.38 (20.47)	.001
OG		167.94 (28.97)	173.35 (22.11)	184.90 (30.07)	.142
MG	Group ID	71.06 (11.68)	73.14 (11.74)	76.40 (14.915)	.027
AG		117.66 (17.50)	121.86 (20.37)	126.78 (22.57)	.022
OG		181.45 (14.15)	182.69 (21.54)	189.16 (23.58)	.545

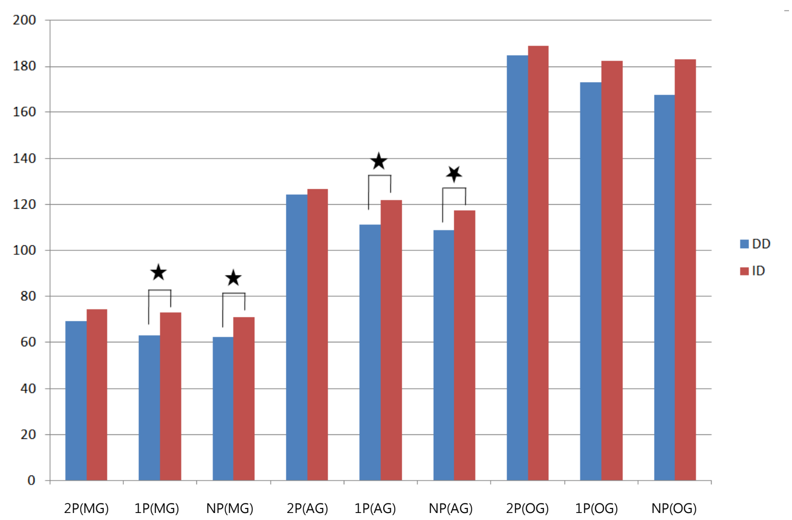

Fig. 7 Comparison of mean values of group DD and group ID. Asterisks (★) indicate the values that are significantly different among groups (p<.05).

1. Effect of the number of abutment teeth

The effect of the number of abutment teeth is shown in Table 3. There was significant difference between the group NP and 2P at the MG area (Group 2P: 72.09 ± 13.93 μm, Group NP : 67.99 ± 12.68 μm, $p<0.05$) and the AG area (Group 2P: 125.58 ± 21.51 μm, Group NP: 119.46 ± 18.49 μm, $p<.05$). Also there was significant difference between the group 2P and group 1P at the MG area (Group 2P: 72.09 ± 13.93 μm, Group 1P: 69.38 ± 12.03 μm, $p<.05$) and the AG area (Group 2P: 125.58 ± 21.51 μm, Group 1P: 121.08 ± 18.29 μm, $p<.05$). There was no significant difference among groups at the OG area.

Table 3. Results of one-way ANOVA according to the number of abutment teeth factors

Measurement area	Group	Mean (μm)	SD	p value
MG	Group NP	67.99	12.68	.016
	Group 1P	69.38	12.03	
	Group 2P	72.09	13.93	
AG	Group NP	119.46	18.49	.015
	Group 1P	121.08	18.29	
	Group 2P	125.58	21.51	
OG	Group NP	175.69	23.83	.093
	Group 1P	178.02	22.06	
	Group 2P	187.03	26.76	

2. Effect of the method of digitalization

The effect of the method of digitalization is shown in Table 4. The direct digitalization shows significantly lower mean values compared with the indirect digitalization at the MG area (DD: 65.77 ± 12.59 μm, ID : 72.95± 12.53 μm, $p<.01$), the AG area (DD: 114.80± 20.01 μm, ID: 122.10± 20.91 μm, $p<.01$), and the OG area (DD: 175.40 ± 27.74 μm, ID: 185.10± 20.03 μm, $p<.05$).

Table 4. Results of independent t-test according to the method of digitalization factors

Measurement area	Group	Mean (SD)	SD	p value
MG	**Group DD**	65.77	12.36	.000
	Group ID	72.95	12.53	
AG	**Group DD**	114.80	20.01	.000
	Group ID	122.10	20.91	
OG	**Group DD**	175.40	27.74	.035
	Group ID	185.10	20.03	

3. Interaction between the number of abutment teeth and the method of digitalization

The results of two-way ANOVA at all areas are presented in Table 5. There was no interaction between the number of abutment teeth and the method of digitalization and for all areas.

Table 5. Results of two-way ANOVA. Method is comprised of levels direct and indirect digitalization, while number of teeth is comprised of levels the number of abutment teeth NP, 1P and 2P.

Measurement area	Source	Type III SS	df	Mean squares	f value	p value
MG	Method	7377.189	1	7377.189	48.182	.000
	number of teeth	2404.761	2	1201.880	7.850	.024
	Total	480.917	2	240.458	1.570	.209
AG	Method	7377.189	1	6401.861	16.334	.000
	number of teeth	2404.761	2	6543.214	16.750	.000
	Total	480.917	2	752.061	1.920	.148
OG	Method	7377.189	1	2824.058	4.906	.029
	number of teeth	2404.761	2	1433.794	2.491	.087
	Total	480.917	2	317.723	.552	.577

IV. Discussion

In this *in-vitro* study, the effect of the number of abutment teeth and the method of digitalization on the marginal and internal adaptation of four-unit monolithic zirconia fixed partial prostheses was evaluated.

For clinical evaluation of the marginal and internal fit, the replica technique collaborating with the light microscopy is accepted as a reliable method.[15,21-25] Because of its non-invasive, effective, and non-destructive procedure, this method was suitable for present study, which requires numerous measurements per each abutment.

In present study, all marginal and internal gaps of each abutment teeth were measured and recorded. The values related with the location in an abutment – mesial, distal, buccal, and lingual – and the location of abutment teeth - pm1 and m2 - were not considered separately. All areas were categorized in 3 areas: margin (MG), axial wall (AG), and occlusal center (OG).

The number of abutment teeth affects the marginal and internal fit of monolithic four-unit zirconia FDPs, as group 2P shows more discrepancy compared with group NP or group 1P in MG and AG areas. Therefore, the first null hypothesis was rejected. In OG area, there was no significant difference among the group NP, 1P, and 2P. Regardless of the method of digitalization, however, the mean marginal, axial, and occlusal discrepancy shows a tendency to become numerically lesser as the number of abutment teeth increases. So to speak, as the number of pontics becomes larger, mean marginal and internal discrepancy of the restoration become larger. As direct and indirect digitalization groups were fabricated under the same condition, it can be assumed that there would be a distortion related to the number of pontics. According to the result of this study, it seems that the shrinkage of the pontic during sintering procedure has an influence on the marginal and internal fit of the final restoration. It is known that as the number of teeth becomes larger, the fit of the restoration will be inferiorly affected. In this study, somewhat large convergence angle (25˚) and complete removal of undercuts make it feasible for final restorations to be completely seated. In pilot study prior to present study, each abutment tooth was prepared with four convergence angles – 12˚, 15˚, 20˚, and 25˚ – in order to verify which convergence angle assures the complete seating of final restoration in all subgroups. The complete seating of four-unit zirconia restoration was not able to be obtained with the convergence angle 12˚, 15˚ and 20˚, especially in subgroup DD-4 and ID-4. When checking the fit of the restoration with silicone indicator (Fit Checker, GC, Japan), the mesial wall of pm1 and distal wall of m2 were the most common disruptive areas. Convergence angle 25˚ guaranteed the repeated complete seating of 4 unit zirconia FDPs in all 6 subgroups without needs of any manual adjustment. As the optimum convergence angle in fabricating four-unit zirconia FDPs was not considered in this study, further study is needed in this regard.

Analysis of the results of this study suggests that the mean marginal and internal discrepancy of 4-unit zirconia FDPs with the aid of direct digitalization was significantly smaller than those fabricated with indirect digitalization at all areas ($p<.05$). Therefore, the second null hypothesis was rejected. As demonstrated by previous studies, indirect digitalization starts from the conventional impression taking procedure. The long chain of working process includes possibility of not practitioner-related errors, such as impression material shrinkage, a separation of the impression material from the impression tray, and dimensional changes of dental stone.[26-29] Several literatures reported that there is approximately 10μm dimensional change during the procedure of impression taking and fabricating the dental stone cast.[30] On the contrary, digital work flow eliminates the needs of creating the stone. The better results made by direct digitizing method may be attributed to the improved efficiency of the intraoral scanner and the software.

Some authors reported that there are some handicaps for direct digitizing method due to the inaccessibility to proximal areas and invisibility of sub-gingival margins in natural teeth. In this study, whereas, whole margins were obvious for gap measurement procedure and undercuts were completely and carefully removed for eliminating the factors which might be acted as an unintended variance. Omnicam uses a working principle called active triangulation. Emitted light with multiple wavelengths in stripe patterns is reflected back from the surface and the data from reflected light are recorded and calculated by applying triangulation to obtain three-dimensional image of the subject. In this *in-vitro* study, we used an epoxy resin as a master model, and its low translucency parameter, well-dried surface condition and consequent the better degree of reflection might affect the results of the intraoral scanner, positively. In *in-vivo* situation, the glossy state and translucency of the teeth have an effect on the way of reflection of lights.

According to the results of two-way ANOVA, there is no significant interaction between the method of digitalization and the number of abutment teeth. As shown in Fig. 5, subgroup DD-1P and DD-NP shows significant better results than those of ID-1P and ID-NP at MG and AG areas, whereas the results from subgroup DD-2P shows no significant difference compared to those with ID-2P at all measurement areas. From this, it seemed that somewhat inferior effect with direct digitalization is suspicious when the edentulous region is wider. As direct digitalization lacks stable reference landmarks, the first image from the scanner is used as a reference when continuous images are stitched. In the previous study considering the accuracy between the intraoral and extraoral scanner, Flugee *et al.*[31] reported that the precision of intraoral scanner decreased with an increasing distance between the implant scanbodies, whereas the precision of the dental lab scanner was independent of the distance between the scanbodies. In this study, the scan field was smaller in an intraoral scanner (a tip size of Omnicam: 16 x 16 mm) than a dental laboratory scanner. Somewhat small tip size of the intraoral scanner used in current study has a possibility of making more errors during superimposition. As scanning procedure processes, the errors related to superimposition gradually pile up. In this regard, the deviation of the final image of intraoral scanner might be influenced by the length of edentulous area, where there is no reference to stitch images continuously. Moreover, in vivo situation makes it more difficult to stitch images accurately.

There are a few studies considering the marginal fit of CAD/CAM generated four-unit zirconia FDPs, with a variety of measured results. Almeida *et al*.[32] reported that mean marginal gap of four-unit zirconia FDPs by means of direct and indirect digitalization was 63.96 and 65.33 μm, respectively. Kulnaree *et al*.[33] reported that mean marginal discrepancy of 4-unit zirconia substructures were 112 μm, and Emre et al. reported that the mean marginal discrepancy of four-unit zirconia substructures was 98.3 μm. In present estimation, the mean value of marginal discrepancy was 65.11 μm in Group DD and 72.95 μm in Group ID, respectively. The values were somewhat smaller than those of previous studies. This might be attributed to the large convergence angle of axial wall, which leads a better seating of the restoration.

Further comparison and evaluation were performed to confirm the effect of the pontic on marginal and internal fit. When observing second molar alone, the mean marginal and axial discrepancy was significantly different between mesial and distal location for both group DD and ID (Table 6). When comparing according to the number of abutment teeth, both mesial and distal MG area, there was no significant difference among group NP, 1P, and 2P. However, at each mesial and distal AG area, there was significant difference among group NP, 1P and 2P (Table 7). As the number of pontics increases, the mean axial discrepancy becomes larger, especially on the group 2P. Axial areas, rather than marginal areas, seem to be affected more by the number the pontics.

Table 6. Results of independent t-test comparing the mesial and distal discrepancy of second molar at MG and AG area according to the method of digitalization (μm)

Measurement area		Group DD		Group ID	
		Mean (SD)	P value	Mean (SD)	p value
MG	mesial	76.50(10.25)	.030	84.98(10.65)	.020
	distal	70.03(12.21)		78.95(78.82)	
AG	mesial	134.13(17.75)	.000	143.70(20.95)	.003
	Distal	103.96(17.07)		115.33(13.25)	

Table 7. Results of one-way ANOVA comparing the mesial and distal discrepancy of second molar at MG and AG area according to the number of abutment teeth (μm)

Measurement area		The number of abutment teeth			
		Group NP	Group 1P	Group 2P	p value
MG	mesial	76.55(10.94)	78.09(9.21)	82.58(11.95)	.300
	distal	66.79(14.13)	69.62(10.56)	71.78(9.21)	.394
AG	mesial	131.71(22.86)	134.90(18.05)	147.13(14.40)	.029
	distal	102.11(13.14)	105.82(11.67)	113.75(14.04)	.020

When comparing group NP and group 2P in mesio-distal direction, the mean marginal and axial discrepancy on the pontic side (distal side of pm1 and mesial side of m2) is significant greater than that of non-pontic side (Table 8). This result might be explained by the horizontal warpage directed toward the pontic. The bending stress during the sintering procedure makes the axes of the abutment portion of frameworks inclined, resulting to make an inaccuracy between the non-pontic and pontic-sides. Based on the result of this study, the presence of pontic had an adverse effect on the fit of zirconia FDPs, though mean marginal discrepancy were clinically acceptable. Although there was no linear relationship among the group NP, 1P, and 2P, there were numerically higher values on group 2P than group 1P, and group 1P than group NP.

Table 8. Results of independent t-test comparing pontic and non-pontic side of pm1 and m2. Pontic side is comprised of levels pm1 distal and m2 mesial area, while non-pontic side is comprised of levels pm1 mesial and m2 distal area (μm)

Measurement area		Mean (SD)	SD	p value
MG	pontic side	77.61	13.18	.006
	non-pontic side	65.44	11.26	
AG	pontic side	133.33	19.46	.001
	non-pontic side	104.40	15.21	

Several authors indicate that the shrinkage of the pontic affects on the fit of final restoration. Beuer *et al.*[12] reported that the post-milling sintering of pre-sintered zirconia can lead not only just linear shrinkage but also the distortion of the framework. Inhomogeneous density of the semi-sintered zirconia block might affect the distortion of restorations. In previous studies considering the marginal and internal fit of more than four-unit zirconia FDPs, the coping or substructure, not fully-contoured prostheses, was evaluated.[13,33,34] In present study, four-unit monolithic zirconia restorations were evaluated for clinical assessment of the marginal and internal discrepancy for eliminating the possibility of any changes during the veneering procedure.[35,36] The volume of fully-contoured pontic, especially on group 2P, might contribute to the shrinkage during sintering procedure more strongly.

Larger marginal and internal discrepancy for m2 than pm1 was observed. This phenomenon was also able to observe from previous studies. This results correspond with other studies by Reich *et al.*[6] using Lava™ four-unit frameworks, by Boening et al.[19], who examined the marginal gap of Procera™ crowns, and by Moldovan et al.[37], who evaluated the internal gap of zirconia substructures. This might be attributed to the volume of molar, which is larger than that of premolar. When calculating the proportional shrinkage by the software, calculating errors might affect the geometry of molar more than that of premolar.

Previous studies evaluated the marginal discrepancy of zirconia FDPs which presents mixed vector values of horizontal and vertical marginal discrepancies, defined as absolute marginal discrepancy by Holmes et al.[24,38,39] Between two of those values, which of values affecting more on the absolute marginal discrepancy is not evident. As demonstrated in the literature[40,41], the horizontally over-extended restoration is able to be improved by adjusting marginal areas of the restoration prior to the cementation, while vertically under-extended restoration should be re-fabricated to obtain better fit. In this regard, the present study focused on the vertical marginal gap of restorations.

There are limitations regarding the material and method in present study. The simulated situation is different from the intraoral circumstance. Direct digitalization using intraoral scanner system can be affected by numerous factors, such as the humidity, saliva, undercuts between teeth, and translucency parameter of abutment teeth. Marginal and internal fit were measured at five points per each two cross-sectional abutment, which might not be true representative values of whole marginal and internal adaptation. The cementation procedure was not involved. Increase of discrepancy, especially at the marginal area, might be occurred during cementation.

V. Conclusion

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

1. The number of abutment teeth had a significant effect on the marginal and internal fit of CAD-CAM fabricated monolithic four-unit zirconia FDP, especially comparing group NP and group 2P ($p<.05$).
2. Improved marginal and internal fit of CAD-CAM fabricated monolithic four-unit zirconia FDP with a direct digitalization was obtained comparing with those with the aid of an indirect digitalization ($p<.05$).
3. The pontic side of the framework shows larger mean marginal and internal discrepancy than those of non-pontic side of the framework ($p<.01$).

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국문요약

지대치 개수에 따른 4-unit 단일 지르코니아 보철물의 변연 및 내면 적합도 비교

(지도교수 김 선 재)

연세대학교 대학원 치의학과

김 웅 기

이 실험의 목적은 4-unit 단일 지르코니아 보철물 제작 시 지대치 개수가 변연 및 내면 적합도에 미치는 영향을 조사하는 것이었다. 하악 아크릴 모델의 우측 제 1,2 소구치 및 제 1,2 대구치를 단일 지르코니아 보철물을 위한 치아 삭제를 시행한 후 기성 트레이와 실리콘 인상재를 이용하여 에폭시 레진 모델로 복제하였다. 이 후 제 1 대구치를 아크릴 모델에서 분리해 내고 에폭시 레진 모델로 복제하였고, 이어서 제 2 소구치를 아크릴 모델에서 분리 후 에폭시 레진 모델로 복제하였다. 각 에폭시 레진 모델을 열 번 씩 구강스캐너로 디지털 인상 채득하였다. 이 후 에폭시 레진 모델을 개인 트레이 및 실리콘 인상재를 이용하여 모델 당 열 번 씩 초경석고 모델로 복제한 후, 초경석고 모델을 탁상형 스캐너로 인상 채득하였다. CAD/CAM 과정을 통한 디자인, 밀링이 완료 된 후 최종 소결 과정을 통하여 총 60개의 단일 지르코니아 보철물이 제작되었다. 변연 및 내면 간극은 replica technique을 이용하여 측정하였으며 모든 지대치의 변연, 축면, 그리고 교합면 간극을 측정하였다. 지대치 개수가 미치는 영향과 인상 채득 방법의 영향을 각각 1-way anova를 이용해 비교하였고 두 변수의 교호작용은 2-way anova를 이용하여 분석하였다.

실험결과 지대치 개수가 감소함에 따라 변연 및 축면의 간극이 유의하게 증가하였다 ($p<.05$). 탁상형 스캐너보다 구강 스캐너를 이용하였을 때 변연, 축면, 교합면 간극이 유의하게 작은 값을 보였다 ($p<.05$). 두 변수간 교호작용은 없었다. Pontic과 인접한 부위인 제 1 소구치 원심면과 제 2 대구치 근심면의 변연 및 축면 간극은 pontic과 인접해 있지 않은 제 1 소구치 근심면과 제 2 대구치 원심면의 변연 및 축면 간극보다 유의하게 큰 값을 나타내었다 ($p<.01$).

핵심되는 말 : 지르코니아; 지대치 개수; 디지털 인상 채득 방법; 변연 및 내면 적합도