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In-vitro evaluation of marginal and internal fit of 3-unit monolithic zirconia restorations fabricated using digital scanning technologies

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PURPOSE. This study aimed to compare the marginal and internal fit of 3-unit monolithic zirconia restorations that were designed by using the data obtained with the aid of intraoral and laboratory scanners. **MATERIALS AND METHODS.** For the fabrication of 3-unit monolithic zirconia restorations using impressions taken from the maxillary master cast, plaster cast was created and scanned in laboratory scanners (InEos X5 and D900L). The main cast was also scanned with different intraoral scanners (Omnicam [OMNI], Primescan [PS], Trios 3 [T3], Trios 4 [T4]) (n = 12 per group). Zirconia fixed partial dentures were virtually designed, produced from presintered block, and subsequently sintered. Marginal and internal discrepancy values (in μm) were measured by using silicone replica method under stereomicroscope. Data were statistically analyzed by using 1-way ANOVA and Kruskal Wallis tests (P<.05). **RESULTS.** In terms of marginal adaptation, the measurements on the canine tooth indicated better performance with intraoral scanners than those in laboratory scanners, but there was no difference among intraoral scanners (P<.05). In the premolar tooth, PS had the lowest marginal (86.9 ± 19.2 μm) and axial (92.4 ± 14.8 μm), and T4 had the lowest axio-occlusal (89.4 ± 15.6 μm) and occlusal (89.1 ± 13.9 μm) discrepancy value. In both canine and premolar teeth, the D900L was found to be the most marginally and internally inconsistent scanner. **CONCLUSION.** Within the limits of the study, marginal and internal discrepancy values were generally lower in intraoral scanners than in laboratory scanners. Marginal discrepancy values of scanners were clinically acceptable (< 120 μm), except D900L. [J Adv Prosthodont 2021;13:373-84]

KEYWORDS
Dental marginal adaptation; Dental internal adaptation; Computer-aided design; Zirconia; Dental impression techniques

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INTRODUCTION

Advancements in computer-aided design and computer-aided manufacturing (CAD-CAM) technology have led to the emergence of different pre-processed prosthetic materials with drastically improved mechanical and optical properties. Zirconia restorations can be traditionally obtained with the aid of bi-layered approach in which a zirconia coping is fabricated and subsequently veneered with feldspathic ceramic. Although this type of restoration provides superior aesthetic appearance as the veneering ceramic camouflages the opaque appearance of zirconia, it suffers from catastrophic failures and delamination in veneer porcelain. To circumvent all these drawbacks, monolithic restorations that do not require veneering have been introduced to dental market.[1,2]

The first attempts to map the intraoral tissues have been made in the 1970s. With the rapid progress in this technology, various intraoral and laboratory type digital impression systems that offer results comparable to conventional impression techniques in terms of accuracy and precision have been developed.[3,4] A previous study showed that digital scanners used in direct digital technique are effective in obtaining more compatible indirect restorations.[5] With this technique, the clinicians apply the necessary corrections in the same session with no need for another impression taking as done in the conventional impression method.[6] On the other hand, digital scanning systems have disadvantageous properties including difficulties in acquiring data in gingival margins[4] and low success rate of intraoral scanners in full arch scans than traditional methods.[7,8]

Each manufacturer provides individualized or multiple techniques for data collection. Active wave-front sampling (Lava COS and True Definition scanner), active triangular, optical microscopy or videos (CEREC AC Bluecam and Omnicam), and parallel confocal method (iTero and TRIOS) are the most common techniques.[9] Scanners provide a digital copy of the region in STL (standard tessellation language), OBJ (Wavefront Object File), and PLY (Stanford Triangle Format) format or in the format language specially released by the developer company.[10] Accurate capture of critical areas is essential with the scanners and a number of parameters may influence the accuracy of the digital impressions.[8] Chen *et al*.[11] reported that the use of different optical systems affects scanning accuracy. A study by Erozan and Ozan[12] highlighted that the file type used in the design phase either in a special format or STL format affects the accuracy of the impression. Oh *et al*.[13] found that scanning strategy affects accuracy. According to Son and Lee's study,[14] the margin level (being equigingival or subgingival) can affect accuracy. Whether the scanned tooth is wet, moist or dry,[11] the lighting conditions of the environment,[15] whether the scanned area is at anterior or posterior, and the type of tooth scanned[15,16] and its location[8] affect accuracy. In addition, software design and data processing and image triangulation method can affect the resolution and surface topography of the final digital impression produced.[17]

Marginal fit is considered as one of the most important criteria in the evaluation of fixed prostheses.[18] The greater marginal mismatch, the higher plaque index and loss of retention, and the greater the exposure of the cement material to the oral environment.[19] The internal fit of a ceramic crown is another critical factor. Inadequate internal fit can cause low resistance of the restoration and decrease fracture resistance.[20,21] According to the study by McLean and von Fraunhofer,[22] it is stated that 120 µm marginal discrepancy is clinically acceptable. However, different marginal discrepancy values including 100 µm[23,24] and 75 µm[25] were also stated. Still, there is no consensus on the clinically acceptable marginal discrepancy value.

When the marginal and internal fit studies are examined, monolithic zirconia restorations are not frequently encountered. In most studies, bi-layered zirconia restorations[26,27] and metal-supported restorations[21] were considered. In addition, single unit crowns[20,28] were commonly studied. The scientific data regarding the influence of different scanner types on the fit of monolithic zirconia restorations are limited. Therefore, in this *in vitro* study, it was aimed to compare the internal (axial, axio-occlusal, occlusal) and marginal fit of 3-unit monolithic zirconia fixed partial dentures (FPDs), which were designed on the data obtained with 4 intraoral and 2 laboratory scanners. Our study is important in terms of determining which of today's popular digital scanners provides more compatible restorations as marginal and internal adaptation are critical parameters in terms of longevity of the prosthetic restorations. The first null hypothesis was that there would be no difference in terms of marginal and internal (axial, axio-occlusal, occlusal) fit between the laboratory scanner InEosX5 (control group) and its corresponding test groups (Omnicam and Primescan intraoral scanners) and between the laboratory scanner D900L and its corresponding test groups (Trios 3 and Trios 4 intraoral scanners). The second null hypothesis was that there would be no difference in terms of marginal and internal fit between the Omnicam, Primescan, Trios 3, and Trios 4 intraoral scanners.

MATERIALS AND METHODS

The clinical scenario was simulated in the frasaco phantom cast of the maxillary typodont (AG-3 WOK, Frasaco, Tettnang, Germany). Three-unit FPD would be produced by preparing the maxillary left canine and second premolar teeth by the following principles: 1.5 mm occlusal reduction, 1 mm axial reduction, 1 mm deep shoulder marginal edge, and round internal angle. Subsequently, the preparations were checked by using an intraoral scanner.

Four different scanners were used as intraoral scanners in this study: 3Shape Trios 3 (T3) (3Shape, Copenhagen, Denmark), 3Shape Trios 4 (T4) (3Shape, Copenhagen, Denmark), CEREC AC Omnicam (OMNI) (Sirona Dental System, Bensheim, Germany), and CEREC Primescan AC (PS) (Sirona Dental System, Bensheim, Germany). Cerec InEos X5 (Sirona Dental System, Bensheim, Germany) and 3Shape D900L (3Shape, Copenhagen, Denmark) laboratory scanners were assigned as control groups. InEos X5 laboratory scanner was determined as the control group for the OMNI and PS intraoral scanner groups, and the D900L laboratory scanner was determined as the control group for the T3 and T4 intraoral scanner groups. The sample size utilized was calculated for 80% power.

Conventional impression was taken using 2-step putty/wash polyvinyl siloxane material (Hydrorise Maxi Heavy Body and Hydrorise Light Body, Zhermack, Badia Polesine, Italy) and pre-fabricated metal tray. Before that, adhesive of the impression material (Universal Tray Adhesive, Zhermack, Badia Polesine, Italy) was applied into the tray. Plaster casts were obtained by pouring scannable Type IV hard plaster (Elite Rock, Zhermack, Badia Polesine, Italy) into the impressions made. The resulting casts were scanned 12 times in the InEos X5 and D900L laboratory scanners. As a result of the scans, the digital data files in the special format (InEos X5: .cam / D900L: .dcm) of each scanner created from the plaster cast were obtained to form the control groups.

During scanning, according to the scanning path strategy recommended by the companies, full arc scanning was performed 12 times for each intraoral scanner on master cast. Data files of each system obtained from digital impressions in their own special formats (Omnicam, Primescan: .cam / Trios 3, Trios 4: .dcm) were sent to the laboratory. In order to ensure standardization in the designs, wax modelling was done on the master cast and this cast was scanned in InEos X5, and STL file of the wax modelling was obtained. Subsequently, it was overlapped with STL file obtained while the designs were being made. The designs were made by the same researcher using the scanners' own design programs, CEREC InLab SW and 3Shape Dental System (Fig. 1). Design was virtually made by the same researcher. The cement gap was determined as 50 µm.

Then, monolithic zirconia FPDs were fabricated by using zirconia blocks (Whitepeaks CopraSupreme Zr-I HT-S; Whitepeaks Dental Solutions GmbH, Essen, Ger-

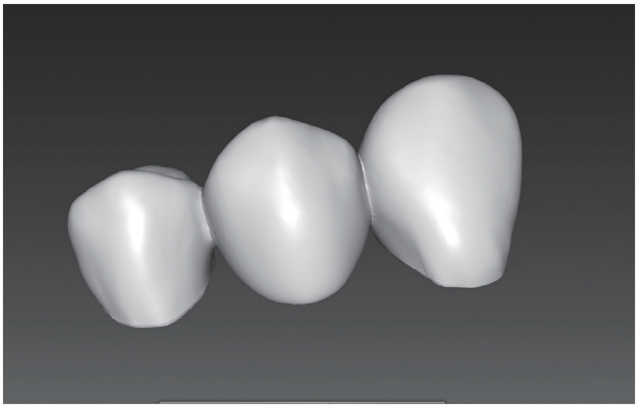

Fig. 1. Virtual design of 3-unit zirconia restoration.

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many) and an InLab MC (Dentsply Sirona, Charlotte, NC, USA) milling device (milling axes). Subsequently, the zirconia FPDs were sintered in Sirona inFire HTC speed (Sirona Dental System, Bensheim, Germany) for 90 minutes at 1500°C. After sintering, glazing was applied in a Programat P300 (Ivoclar Vivadent, Schaan, Liechtenstein) glazing oven. No additional adjustment has been done for the FPDs.

After all restorations were steam cleaned and dried, measurements were made with the silicone replica method. In order to duplicate the cement gap between the restoration and the preparation surface, the light-body silicone impression material (Elite HD + Light body Fast Setting; Zhermack, Polesine, Italy) was applied into the restoration and the restoration was placed onto the master cast. An occlusal force of 50 Newtons (≈ 5 kg) was applied to each FPD by using a specially-designed load mechanism. After polymerization of the light-body silicone impression material, the zirconia restorations were carefully separated from master cast. However, since the replica obtained at this stage was very thin, it was reinforced with a heavy-viscous silicone impression material (Elite HD + Putty Soft Fast Setting; Zhermack, Polesine, Italy) in order to provide adequate stabilization during sectioning. Obtained replicas were divided into mesio-distal and bucco-palatal cross-sections.

In order to measure and evaluate marginal, axial, axio-occlusal, and occlusal discrepancy values, measurement points were determined according to the literature to ensure the comparability with previous studies[27,29-31] (Fig. 2). A total of 17 standard measurement points for the canine tooth, 8 in the bucco-palatal direction and 9 in the mesio-distal direction, and a total of 22 points for the second premolar tooth, 11 in the mesio-distal direction and 11 in the bucco-palatal direction were assigned. The standard measuring point was measured with a stereomicroscope (Olympus SZ61TR; Olympus Corporation, Shinjuku, Tokyo, Japan) at ×40 magnification. After acquiring digital images (CMEX-10 Pro; Euromex, Arnhem, Netherlands), the discrepancy values (in µm) were recorded. A total of 2,808 points were measured (Fig. 3).

Data were statistically analyzed with IBM SPSS V23. Conformity to the normal distribution was evaluated by using the Shapiro-Wilk test. One-way analysis of variance and Welch test were conducted to compare normally distributed discrepancy values according to the groups, and multiple comparisons among groups were performed with Tukey HSD and Tamhane's T2 test. Kruskal Wallis test was used to compare the non-normally distributed discrepancy values, and multiple comparisons were analyzed with Dunn's test. Significance level was taken as $P < .05$.

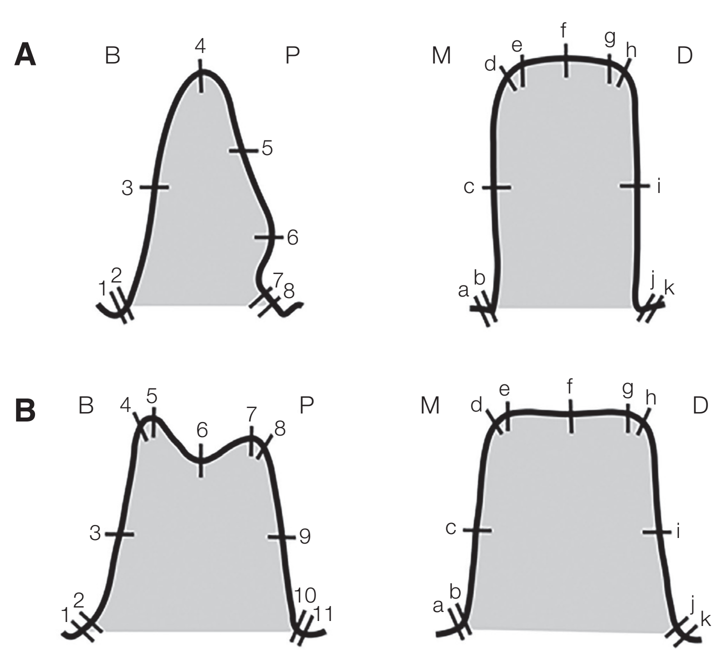

Fig. 2. (A) Marginal and internal discrepancies were measured at 8 points in buccolingual cross-sections and measured at 11 points in mesiodistal cross-sections on canine tooth specimen. Marginal area: 1,2,7,8,a,b,j k. Axial area: 3,5,6,c,i. Axio-occlusal area: d,e,g,h. Occlusal area: 4,f. (B) Marginal and internal discrepancies were measured at 11 points in buccolingual cross-sections and measured at 11 points in mesiodistal cross-sections on premolar tooth specimen. Marginal area: 1,2,10,11,a,b,j k. Axial area: 3,9,c,i. Axio-occlusal area: 4,5,7,8,d,e,g,h. Occlusal area: 6,f.

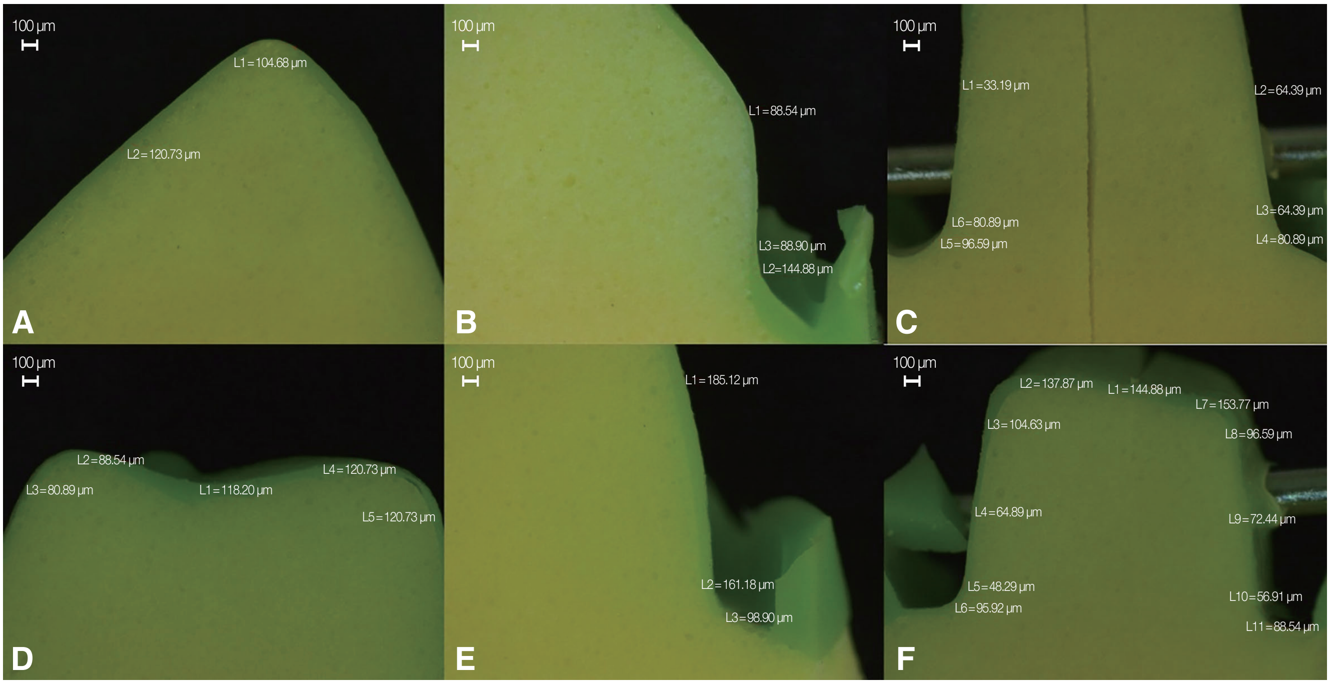

Fig. 3. Representative photomicrographs of marginal, axial, axio-occlusal and occlusal measuring points in bucco-palatal and mesio-distal cross-sections. Original magnification ×40. (A) InEos X5 group specimen no. 2 bucco-palatal cross-section. (B) D900L group specimen no. 1 bucco-palatal cross-section. (C) Primescan group specimen no. 2 mesio-distal cross-section. (D) Omnicam group specimen no. 1 bucco-palatal cross-section. (E) Trios 3 group specimen no. 1 bucco-palatal cross-section. (F) Trios 4 group specimen no. 2 mesio-distal cross-section.

RESULTS

The marginal, axial, axio-occlusal, and occlusal discrepancy values of the canine abutment tooth according to the groups are depicted in Table 1. When these values were examined, the marginal and axial discrepancy values of the PS and OMNI groups were found to be statistically significantly lower than those of the control group InEos X5 ($P < .05$). The marginal and axial discrepancy values of the T3 and T4 groups were found to be lower than those of the control group D900L ($P < .05$). When the results of multiple comparisons among the groups were assessed, it was found that PS had the lowest marginal (85.4 ± 12.0 μm), T3 had the lowest axial (95.7 ± 25.7 μm), and D900L had the highest marginal (128.4 ± 10.9 μm) and axial (129.5 ± 16.5 μm) discrepancy values. Except for the D900L, the marginal discrepancy values in the other groups were found to be well-below the acceptable marginal discrepancy value of 120 μm. When the axio-occlusal discrepancy values were examined, it was determined that T4 showed statistically significantly lower discrepancy value than those of the control group D900L and of the OMNI ($P < .05$). Additionally, it was understood that T4 (90.9 ± 22.9 μm) had the lowest and D900L (127.2 ± 19.0 μm) had the highest axio-occlusal discrepancy value. When the occlusal discrepancy values were examined, no statistically significant difference was found between the control groups and test groups ($P > .05$). The lowest occlusal discrepancy value was seen in T3 (86.4 ± 28.5 μm) and the highest in PS (106.2 ± 12.5 μm).

The marginal, axial, axio-occlusal, and occlusal discrepancy values of the premolar abutment tooth according to the groups are shown in Table 2. When these values were examined, there was no statistically significant difference among the control group InEos X5, OMNI, and PS ($P > .05$) in terms of marginal, axio-occlusal, and occlusal discrepancy values. In terms of axial adaptation, PS showed statistically sig-

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Table 1. Comparison of the results of maxillary left canine tooth according to the groups

	InEos X5	Omnicam	Primescan	D900L	Trios 3	Trios 4	Test statistic	*P*
Marginal	114.4 ± 14.1[bc] 108.2 (100.6 - 139.8)	91.6 ± 19.1[a] 85.9 (65.6 - 118.3)	85.4 ± 12.0[a] 86.0 (67.6 - 104.5)	128.4 ± 10.9[b] 131.6 (105.8 - 140.0)	98.9 ± 22.3[ac] 107.9 (58.2 - 128.3)	97.6 ± 26.6[ac] 102.9 (51.4 - 126.6)	F = 18.237	< .001*
Axial	125.6 ± 14.6 123.3 (104.5 - 146.1)[b]	100.5 ± 9.0 97.4 (86.5 - 116.0)[a]	98.8 ± 11.2 100.3 (69.5 - 108.7)[a]	129.5 ± 16.5 132.8 (95.8 - 148.0)[b]	95.7 ± 25.7 84.8 (67.1 - 137.7)[a]	99.0 ± 13.9 103.1 (76.1 - 115.1)[a]	χ^2 = 30.082	< .001*
Axio-occlusal	112.5 ± 20.7 116.9 (84.9 - 144.9)[ab]	117.8 ± 22.0 127.4 (69.1 - 139.5)[b]	114.1 ± 7.2 113.9 (100.8 - 125.3)[ab]	127.2 ± 19.0 134.1 (88.9 - 148.9)[b]	99.2 ± 31.4 109.6 (40.0 - 136.9)[ab]	90.9 ± 22.9 86.2 (47.9 - 121.5)[a]	χ^2 = 19.286	.002*
Occlusal	101.7 ± 24.3 94.7 (68.4 - 148.9)	97.8 ± 16.5 92.7 (69.2 - 128.8)	106.2 ± 12.5 106.7 (88.7 - 129.0)	97.9 ± 12.8 96.6 (76.5 - 119.0)	86.4 ± 28.5 89.0 (48.3 - 137.2)	90.0 ± 22.9 97.0 (53.8 - 118.9)	F = 1.556	.202
Internal	113.3 ± 16.9[ab] 111.3 (92.6 - 142.0)	105.4 ± 13.7[ab] 108.1 (80.1 - 125.3)	106.4 ± 8.2[a] 105.7 (88.9 - 121.0)	118.2 ± 8.3[b] 119.5 (105.2 - 131.7)	93.8 ± 26.9[ab] 95.5 (55.8 - 137.2)	93.3 ± 16.2[a] 93.1 (70.0 - 116.0)	F = 5.966	.001*

F: One-way analysis of variance test statistic (Welch), χ^2: Kruskal Wallis test statistic, a - c: No difference between groups with the same letter
mean ± s. deviation, median (minimum - maximum), * P < .05 indicates a significant difference.

Table 2. Comparison of the results of maxillary left second premolar tooth according to the groups

	InEos X5	Omnicam	Primescan	D900L	Trios 3	Trios 4	Test statistic	*P*
Marginal	105.3 ± 11.2[a] 104.7 (91.6 - 125.8)	105.3 ± 18.5[a] 98.0 (81.6 - 132.2)	86.9 ± 19.2[a] 80.1 (66.7 - 126.8)	139.5 ± 16.0[b] 142.0 (108.7 - 161.5)	98.1 ± 16.8[a] 104.0 (72.6 - 121.5)	92.8 ± 12.4[a] 92.0 (67.1 - 116.6)	F = 16.214	< .001*
Axial	112.7 ± 13.6[bc] 110.7 (90.6 - 142.5)	97.9 ± 17.0[ac] 99.7 (68.7 - 125.5)	92.4 ± 14.8[a] 88.9 (75.4 - 120.3)	120.0 ± 7.8[b] 122.1 (106.6 - 129.3)	101.4 ± 16.0[ac] 99.1 (81.9 - 137.9)	99.1 ± 12.1[ac] 96.3 (80.8 - 125.1)	F = 6.663	< .001*
Axio-occlusal	121.6 ± 11.9[bc] 118.3 (106.7 - 143.0)	121.1 ± 20.5[bc] 115.2 (93.8 - 154.1)	116.4 ± 7.2[c] 113.8 (107.8 - 128.9)	135.1 ± 14.6[b] 139.6 (112.8 - 154.0)	92.6 ± 21.2[a] 88.1 (63.2 - 120.0)	89.4 ± 15.6[a] 95.1 (58.8 - 115.2)	F = 13.506	< .001*
Occlusal	133.9 ± 29.9 134.9 (48.5 - 165.0)[b]	121.3 ± 25.3 122.7 (76.9 - 149.3)[ab]	134.7 ± 22.0 135.2 (97.9 - 169.0)[b]	141.2 ± 12.2 145.6 (108.7 - 153.1)[b]	101.2 ± 20.1 103.1 (64.9 - 127.1)[a]	89.1 ± 13.9 89.1 (60.6 - 107.4)[a]	χ^2 = 35.18	< .001*
Internal	122.7 ± 13.7[bd] 126.4 (90.3 - 141.6)	113.4 ± 17.4[bc] 106.9 (91.2 - 142.4)	114.5 ± 12.0[cd] 114.0 (95.0 - 131.5)	132.1 ± 6.1[b] 130.2 (124.9 - 142.4)	98.4 ± 16.8[ac] 92.7 (70.0 - 119.0)	92.5 ± 11.1[a] 91.5 (70.5 - 109.2)	F = 26.504	< .001*

F: One-way analysis of variance test statistic (Welch), χ^2: Kruskal Wallis test statistic, a - d: No difference between groups with the same letter
mean ± s. deviation, median (minimum - maximum), * P < .05 indicates a significant difference.

nificantly lower discrepancy values than the control group InEos X5 (P > .05). The marginal, axial, axio-occlusal, and occlusal discrepancy values of the T3 and T4 groups were found to be statistically significantly lower than that of the control group D900L (P < .05). When the results of multiple comparisons between groups were examined, PS had the lowest marginal (86.9 ± 19.2 µm) and axial (92.4 ± 14.8 µm) and T4 had the lowest axio-occlusal (89.4 ± 15.6 µm) and occlusal (89.1 ± 13.9 µm) discrepancy values; while D900L had the highest marginal (139.5 ± 16 µm), axial (120 ± 7.8 µm), axio-occlusal (135.1 ± 14.6 µm) and occlusal (141.2 ± 12.2 µm) discrepancy values. According to the clinically acceptable marginal discrepancy value threshold, the group with the lowest marginal gap was PS (86.9 ± 19.2 µm) and the group with the highest marginal gap was D900L (139.5 ± 16.0 µm).

DISCUSSION

According to the results of this study, differences in marginal and internal adaptation were observed between the control groups and the test groups. Therefore, the first null hypothesis was rejected. Although there was no significant difference among the test groups in terms of marginal fit, some significant differences were found in terms of internal fit. Therefore, the second null hypothesis was partially accepted.

Marginal adaptation of all scanners except the laboratory scanner D900L was within the clinically acceptable range (< 120 µm). The highest marginal discrepancy values were found in the laboratory scanners D900L and InEos X5 groups. This can be attributed to the fact that different parameters such as impression material or cast scanning affect accuracy of the obtained data.[32] In addition, it has been reported that the deformation of the plaster due to a linear expansion between 0.06% and 0.5% of Type IV plasters can affect the marginal fit of the restoration.[33]

Literature depicts the acceptable range of an occlusal mismatch as 100 - 200 µm.[34] According to the results obtained from the present study, the occlusal mismatch values in the canine and premolar teeth are within acceptable limits. In the premolar tooth, the occlusal mismatch values of the Trios 3 (101.2 ± 20.1 µm) and Trios 4 (89.1 ± 13.9 µm) intraoral scanners were significantly lower than those of laboratory scanners (InEos X5: 133.9 ± 29.9, D900L: 141.2 ± 12.2 µm). In addition, when intraoral scanners are compared within themselves, it is seen that occlusal mismatch of these scanners are significantly lower than that of Primescan (134.7 ± 22.0 µm).

Measurement points were determined according to the literature to ensure comparability with previous studies.[27,29,30] The points of measurements were applied in 4 regions with reference to the work of Holmes *et al*.: marginal, axial, axio-occlusal, and occlusal.[31]

Marginal and internal fit are affected by the fabrication technique as well as the impression technique.[35] For both impression techniques, the same zirconia material and the same milling technique were used, by designing them in their own design programs[36] without changing the scanner's data into special formats, in order to avoid any bias in the production process and avoid data loss.[12]

Debate continues as to whether restorations produced by intraoral scanning provide a precision of fit comparable or even superior to restorations produced with laboratory scanners.[26,27,36,37] Regarding the marginal fit of restorations created by CAD-CAM based on intraoral scanning, some *in vitro* studies have shown marginal adaptation better than restorations produced with laboratory scanners.[26,27,37,38] This is supported by the findings of Berrendero *et al*.'s clinical study.[39] In contrast, there are *in vitro* studies that did not show significant differences in marginal accuracy when comparing intraoral scanner and laboratory scanner restoration groups.[20,28,36,40] A clinical study comparing three different intraoral scanning devices showed significant differences in marginal and internal fit among the three intraoral scanner systems tested, thus revealing a significant effect of the intraoral scanner system used.[41]

Su and Sun[27] evaluated the compatibility of 3-unit zirconia frameworks produced by intraoral and laboratory scanners. 3Shape Trios Cart was used as the intraoral scanner and 3Shape D800 was used as the laboratory scanner. It has been reported that the total fit of the restorations obtained by using an intraoral scanner was better. Considering the arc curve and

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length, the results supported the results of the current study and also showed that there was no statistically significant difference between T3 and T4 and that both scanners were statistically significantly better than laboratory scanners.

In a study by Arezoobakhsh *et al*.,[26] 3-unit zirconia FPDs were produced using intraoral scanners (Trios and CS3600) and laboratory scanner (Deluxe scanner; Open Technologies) to scan the cast. Both of the impressions and the plaster casts obtained from the impressions were scanned with the laboratory scanner. As a result, marginal, axial, axio-occlusal, and occlusal fit of zirconia restorations produced by using intraoral scanners were found to give significantly superior results. The marginal fit of the restorations produced by using intraoral scanners gave similar results. There was no detectable significant difference between intraoral scanners in axial adaptation. In axio-occlusal mismatch, Trios showed the lowest value in the molar tooth. Considering the occlusal mismatch, it was found that intraoral scanners were significantly better in premolar teeth. The results are consistent with the current study as it was observed that intraoral scanners were better than laboratory scanners in terms of marginal mismatch, and there was no significant difference among the intraoral scanners. There was no significant difference between T3 and T4 in the premolar tooth in axial alignment. Consistent with the results of this study, T4 intraoral scanner showed a significantly lower mismatch than laboratory scanners in axio-occlusal mismatch. In occlusal mismatch, intraoral scanners were found to be significantly better in premolar teeth.

Nedelcu *et al*.[40] compared intraoral (3M True Definition, OMNI, T3) and laboratory (3Shape D1000) scanners in their clinical study. The area between the maxillary premolars was scanned and all digital data obtained were matched with the best fit algorithm and evaluated. As a consequence, no statistically significant difference between intraoral and laboratory scanners was found. In this study, OMNI, T3, and D900L scanners were used and exhibited different results in terms of marginal adaptation. Significantly more consistent restorations were obtained with OMNI and T3 than with the laboratory scanner D900L. It has been reported that as the scanning span length increases, the data obtained with intraoral scanners show more contradictory results, and the accuracy and sensitivity of intraoral scanners change with the increase in the number of units.[42]

Benic *et al*.[36] evaluated 3-unit zirconia-based restorations by comparing digital (Lava Chairside, iTero, and Cerec Bluecam) and conventional workflow in terms of marginal and internal fit at 4 different points by using the silicone replica method. There was no significant difference between Lava (106.4 ± 103.7 µm), iTero (91.4 ± 95.2 µm), and Cerec Bluecam (108.3 ± 93.8 µm) in terms of marginal mismatch. Considering the axial mismatch, there was no statistically significant difference among iTero (93.1 ± 28.5 µm), Lava (105.8 ± 37.7 µm) and Bluecam (114.7 ± 57 µm). Bluecam scanner (142.4 ± 68.7 µm) showed significantly lower values than Lava intraoral scanner (175.7 ± 82.2 µm) in axio-occlusal adaptation. In occlusal mismatch, iTero (153.5 ± 66.8 µm) showed lower values compared to Lava (203.3 ± 127.9 µm) and Bluecam (179.7 ± 63.1 µm). Similar to the study, there was no difference in marginal and axial mismatch between the intraoral scanners used in this study. Axio-occlusally, Trios 4 (86.2 µm) in comparison to Omnicam (127.4 µm) in the canine tooth, Trios 3 (95.1 µm) and Trios 4 (89.4 µm) in comparison to Omnicam (121.1 µm) and Primescan (113.8 µm) in the premolar tooth gave significantly superior results. Although there was no significant difference among the scanners in the canine in terms of occlusal mismatch, Trios 3 (103.1 µm) and Trios 4 (89.1 µm) were found to be significantly better than Primescan (135.2 µm) in the premolar tooth. Compared to the discrepancy values of the scanners in the study of Benic *et al*., it has been detected that the scanners used in our study exhibited lower results. This situation may be due to the difference in the type of scanner the difference in the applied methods. In addition, it can be thought that the mentioned difference may be due to the fact that the said study was performed on zirconia-based restorations, while our current study was performed on monolithic zirconia restorations.

Shembesh *et al*.[43] used the first premolars and first molars in the mandibular jaw to evaluate the marginal fit of three-unit monolithic zirconia FPDs. Scans were made with Caden iTero and Lava True Definition intraoral scanner. Restorations produced by using the Lava True Definition scanner have been shown to have better marginal fit. Contrary to the study, there was no significant difference in terms of marginal mismatch among the intraoral scanners used in this study. The reason of difference was thought to be due to the difference in the optical systems.

Bosniac *et al*.[28] reported that digital systems were not superior to each other in terms of marginal fit in an *in vivo* study in which they evaluated the effect of cara TRIOS and Omnicam intraoral scanner systems on the marginal fit of single crown restoration by using the silicone replica method. In the current study, Trios 3 and Omnicam intraoral scanners were compared in terms of marginal fit in bridge restoration instead of single crown, and as a result, no significant difference was found in the marginal mismatch of Trios 3 and Omnicam, similar to the results of Bosniac *et al*. In addition, Trios 4 and Primescan scanners were also compared in this study, and no difference was found between these scanners in terms of marginal fit.

Berrendero *et al*.[39] evaluated the fit of zirconia single crowns for posterior teeth on 30 patients. Trios (Standard Cart Model) intraoral scanner was used for direct digitalization. For indirect digitization, plaster models were scanned with the 3Shape D700 laboratory scanner. The fit of the crowns was evaluated by the silicon replica method. When the total fit of the crowns was evaluated, no statistically significant difference was found between the methods. In a similar study, Rödiger *et al*.[20] reported that there was no statistically significant difference between the fit of zirconia crowns produced with the cara Trios intraoral scanner and the laboratory scanner D700 for the same tooth. Unlike the studies of Berrendero and Rodiger, Malaguti *et al*.[38] reported that in the zirconia crowns made using Dental Wings Series 7 and MHT scanner on the upper first molar tooth, the best marginal and internal fit is obtained with intraoral scanners, while the productions made on impression and plaster models are unsuccessful. In the current study, similar to Malaguti *et al*., it was determined that the marginal and internal fit of intraoral scanners were significantly better than those of laboratory scanners.

Shimizu *et al*.[44] evaluated the accuracy and precision of single crowns produced for molar teeth. Unlike other studies, the main cast was scanned directly with both an intraoral scanner (3Shape Trios and CEREC Omnicam) and a laboratory scanner (3Shape D810). It has been reported D810 was better at assessing accuracy. Laboratory scanner results were found to be significantly worse in current study. In the study by Shimizu *et al*., as a result of scanning the base cast without taking an impression, steps such as taking impressions with the conventional method and creating a plaster cast were skipped. For this reason, according to the results obtained in the study of Shimizu *et al*., it was thought that laboratory scanner reveals more statistically accurate values.

Özçelik *et al*.[45] reported that the lowest marginal gap values were seen in the group with 20 - 60 µm cement gap. This result is in accordance with other studies.[46,47] In line with this information, the cement gap value was set as 50 µm to compare the marginal and internal fit of the 3-unit zirconia FPD restorations produced in this study.

In clinical studies, the adaptation quality of the restoration can be estimated by intraoral radiographs, tactile assessment, and the replica technique.[30] When using the replica technique, which is a reliable and non-invasive method that provides accurate measurement, finger pressure can be applied to hold the crowns on the abutment tooth when the polyvinyl siloxane impression material is filled into the restoration. Although this experimental setup is similar to the clinical situation, this may cause varying forces on the crowns and therefore increase the variability of the results.[26] For this reason, in the current study, similar to an *in vitro* study by Kokubo *et al*.,[48] a force of 50 Newton was applied on the abutment teeth with a special mechanism to ensure standardization and eliminate possibility of data variability.

The margin configuration affects the marginal fit of the restoration. Shoulder edge finishing line minimizes stresses that can cause fractures in restoration.[49] Komine *et al*.[50] reported that there was no significant difference among chamfer, shoulder and shoulder edge margin configuration with rounded interior angles on restorations' marginal adaptation. However, Memari *et al*.[4] reported shoulder and rounded shoulder edge finishing lines create less marginal gap compared to the chamfer edge finish.

This study had some limitations. Since it was an *in vitro* study, the negative effects of intraoral conditions on the internal and marginal fit of restorations could not be evaluated. Although the replica technique is a proven method for measuring discrepancy, the technique is sensitive and allows sectioning from only a limited number of aspects. Measurements of the specimens without cementation can be listed among the limitations. Within these limitations, an evidence-based approach should be presented regarding the clinical use of long-span FPDs to be produced with intraoral scanners and the performance of intraoral scanners in future clinical studies on patients.

CONCLUSION

Within the limitations of this comparative *in vitro* study, the following conclusion can be drawn: marginal discrepancy values of all scanners, except the D900L, were found within the clinical acceptability range (< 120 µm), marginal and axial discrepancy values were generally lower in intraoral scanners compared to laboratory scanners ($P < .05$) and were similar to each other ($P > .05$), the lowest marginal discrepancy value was detected in PS and the highest discrepancy value was found in D900L. In occlusal area, the highest discrepancy value was observed in PS in both abutment teeth; the lowest in T3 in the canine tooth and in T4 in the premolar tooth.

When all the results of this study are evaluated, all scanners, except the D900L laboratory scanner, present results within clinically acceptable limits. In addition, it was determined that the superior results were achieved in intraoral scanners. It has been concluded that intraoral scanners can be recommended as a good alternative to laboratory scanners.

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