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Comparison of the Effect of Scan Patterns on the Accuracy of Complete-Arch Implant Intraoral Scans: An *in vitro* Study

Tam Ark İmplant Ağız İçi Taramalarının Doğruluğu Üzerinde Tarama Paternlerinin Etkisinin Karşılaştırılması: Bir *in vitro* Çalışma

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ABSTRACT Objective: To determine the effect of scan pattern on the accuracy of intraoral scanners (IOS) used to digitize implants in edentulous arches. **Material and Methods:** Implant analogs were placed in the tooth regions #26, #24, #23, #11, #13, #14, and #16 of the edentulous maxillary acrylic model. The model was scanned 10 times with a laboratory scanner (E4, 3Shape) to obtain reference data. Intraoral scans (Trios 5, 3Shape) were performed with six different scan patterns including occlusal-buccal-palatine (OBP), buccal-occlusal-palatine (BOP), buccal-palatine-occlusal (BPO), palatine-occlusal-buccal (POB), zigzag (ZZ) and circumferential (C) (n=10). Centroid and centre-axis of scan bodies were determined using a 3D-metrology program. The distance and angles between implants (#26-#24, #24-#23, #23-#11, #11-#13, #13-#14, #14-#16) were calculated. Linear and angular deviation values were determined by subtracting the measurements from the means of reference scans. Two-way analysis of variance and Tukey post-hoc test with Bonferroni adjustment were used to compare the effect of scan pattern and implant regions on scan accuracy (p<0.05). **Results:** The linear deviation of C was higher than POB (p=0.008), ZZ (p=0.035) and BOP (p=0.045). The #16-#26 region had highest linear deviation (p<0.001). The angular deviation of BPO was higher than OBP (p=0.01). #23-#11 and #16-#26 region had highest angular deviations (p<0.001). **Conclusion:** The scan pattern and the distance between the implants affected the linear and angular accuracy of the IOS. C scan pattern negatively affects the linear deviation values. Lower angular deviation values can be achieved with the scan pattern (OBP) recommended by the scanner manufacturer.

Keywords: Dental implants; dental impression technique; dental prosthesis, implant-supported

ÖZET Amaç: Dişsiz arklarda implant pozisyonlarını dijital ortama aktarmak için kullanılan ağız içi tarayıcıların [intraoral scanners (IOS)] doğruluğu üzerinde tarama paternlerinin etkisini belirlenmesidir. **Gereç ve Yöntemler:** Dişsiz maksiller akrilik modelin #26, #24, #23, #11, #13, #14 ve #16 diş bölgelerine implant analogları yerleştirildi. Model, referans veriler elde etmek için bir laboratuvar tarayıcısı (E4, 3Shape) ile 10 kez tarandı. Ağız içi taramalar (Trios 5, 3Shape) okluzal-bukkal-palatin (OBP), bukkal-okluzal-palatin (BOP), bukkal-palatin-okluzal (BPO), palatin-okluzal-bukkal (POB), zigzag (ZZ) ve çevresel (C) olmak üzere 6 farklı tarama paterni gerçekleştirildi (n=10). Tarama gövdelerinin merkezi ve merkez ekseni bir 3D-metroloji programı kullanılarak belirlendi. İmplantlar arasındaki mesafe ve açılar (#26-#24, #24-#23, #23-#11, #11-#13, #13-#14, #14-#16) hesaplandı. Doğrusal ve açısal sapma değerleri, ölçümlerin referans taraması ölçümlerinin ortalamasından çıkarılmasıyla belirlendi. İki yönlü varyans analizi ve Bonferroni düzeltmeli Tukey "post hoc" testi, tarama paterni ve implant bölgelerinin tarama doğruluğu üzerindeki etkisini karşılaştırmak için kullanıldı (p<0,05). **Bulgular:** C'nin doğrusal sapması POB (p=0,008), ZZ (p=0,035) ve BOP'tan (p=0,045) daha yüksekti. 16-#26 bölgesi en yüksek doğrusal sapmaya sahipti (p<0,001). BPO'nun açısal sapması OBP'den daha yüksekti (p=0,01). #23-#11 ve #16-#26 bölgeleri en yüksek açısal sapmalara sahipti (p<0,001). **Sonuç:** Tarama paterni ve implantlar arasındaki mesafe İOS'nin doğrusal ve açısal doğruluğunu etkilemektedir. C tarama paterni doğrusal sapma değerlerini olumsuz etkilemektedir. Tarayıcı üreticisi tarafından önerilen tarama paterni (OBP) ile daha düşük açısal sapma değerleri elde edilebilir.

Anahtar Kelimeler: Diş implantları; diş ölçü tekniği; diş protezi, implant destekli

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Implant-supported fixed dental prostheses (IFDPs) are prosthetic options that can be used successfully completely edentulous patients. Considering factors such as the amount of bone resorption, facial soft tissue profile, and clinical crown length; cemented, screw, or hybrid IFDPs can be applied according to the needs of the case. Regardless of the type of IFDP, IFDP-implant fit is one of the critical steps in success. The accuracy of implant impressions and implant casts is cited as the main factor, although errors in the design and manufacturing phases can cause misfits. The conventional splinted pick-up technique is the gold standard for complete arch IFDPs.[1,2] However, this technique involves the risk of dimensional changes of impression material and improper connection of the components.[3]

Ideally, the misfit between the implant IFDPs should be 0 µm, but this is not achieved with impressions taken using the conventional splinted pick-up technique. Although clinically acceptable misfit values for full-arch IFDPs can be reported up to 200 µm, the consensus is that long-term successful full-arch IFDPs can be performed with misfit values below 100 µm.[4] Also, Angular deviations caused by transfer error can affect clinical success. Although there is no clinically accepted threshold for angular deviation, angular deviations up to 0.4 degrees have been reported to be clinically acceptable.[5] A deviation of 0.4 degrees has been reported to cause a maximum lateral deviation of 50 µm at the implant apex when evaluated using basic trigonometry.[5,6] Values above these linear and angular thresholds increase the risk of peri-implantitis, aseptic loss of osteointegration, implant neck fractures, and fractures in IFDPs.[4]

In recent years, researchers have focused on the use of intraoral scanners (IOS) to digitize implant positions in completely edentulous patients. The material and geometry of the scan body, scanning technology, the scan pattern, ambient light, and experience of the operator are the main factors that affect the accuracy of the IOS.[7] IOSs are reported to be at least as accurate as conventional impression techniques for single or short-span IFDP impressions.[8] However, increasing inter-implant distance, implant placement depth, and implant location adversely affect IOS accuracy.[9] In addition, the number of acquired images increases in full-arch IOS scans, and the reference points needed to create triangular meshes in the mucosa between the implants cannot be determined when combining acquired images. However, it is reported that with the new generation of IOS, this situation has been overcome and implant digital impressions can be taken in accurate, fully edentulous arches.[2,10-15]

The scan pattern may be another factor that affects the accuracy of digitizing implant positions with IOS in complete edentulous arches.[16,17] The scan pattern affects the accuracy of digital impressions taken with IOS in arches with natural teeth, partially edentulous arches, and fully edentulous arches.[6,18-20] However, there are insufficient studies on the effect of the scan pattern on the accuracy of IOSs used in the digital implant impression for complete edentulous arches. The purpose of this study was to evaluate the effect of the IOS manufacturer's recommended scan pattern and other scan patterns defined in this study on linear and angular deviations. The null hypothesis is that the scan pattern does not affect on linear and angular deviations of IOS.

MATERIAL AND METHODS

In this *in-vitro* study, implant positions in the maxillary edentulous self-curing acrylic resin model were determined according to the Misch protocol; (1) no cantilevers, (2) no three adjacent pontics, and (3) key implant positions (canine and first molar).[21] Implant analogs (multi-unit laboratory analog, Oxy implant, Biomec, Lecco, Italy) were placed in tooth sites #26, #24, #23, #11, #13, #14, and #16 according to the alveolar bone contours and fixed with self-curing acrylic resin (Figure 1). Titanium scan bodies were placed on the analogs and the screws were tightened to 15 N using a torque ratchet. The scan bodies were not removed during the study. Human participants or animals, data, and tissues were not used in this study. Therefore, this study did not require any ethical approval.

The implant model was scanned ten times using a laboratory dental scanner (E4, 3Shape, Copenhagen, Denmark) without using scanning powder to obtain reference data. The manufacturer reported 4

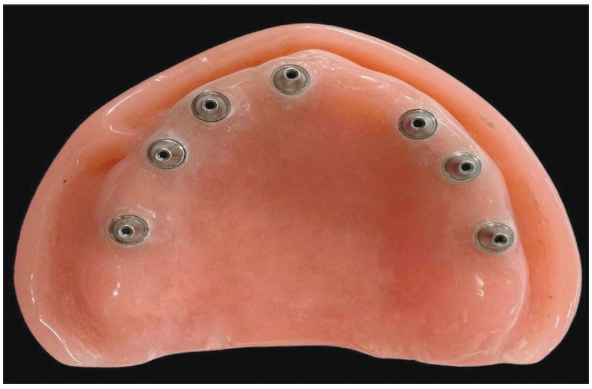

FIGURE 1: Image of the implant model.

μm accuracy of the laboratory scanner. The implant model was then scanned ten times for each scan pattern using an IOS (Trios5, 3Shape, Copenhagen, Denmark). For maxillary arch scans, the IOS manufacturer recommends starting the scan with the occlusal surface, then scanning the buccal surfaces, and finally palatal surfaces [occlusal-buccal-palatine (OBP)]. In this study, besides the scan pattern recommended by the IOS manufacturer, five other scan patterns were implemented. These scan patterns were named buccal-occlusal-palatine (BOP), buccal-palatine-occlusal (BPO), palatine-occlusal-buccal (POB), zigzag (ZZ), and circumferential (C) according to the order of the scanned surface (Figure 2). Each scan was initiated from #16 implant.

All scan data were saved in stereolithography format and imported into a 3D metrology program (Geomagic Control X v2018; 3D Systems, Rock Hill, SC). The ISO 17450-1-2-3 protocol was used to calculate linear and angular deviations. First, the horizontal plane mesh at the top of the scan body was marked, and the top plane was determined using the least squares algorithm. The defined top plane was projected in the negative z-axis direction by the vertical height of the scan body (12 mm) and a multi-unit abutment plane was defined. A cylinder was created using the mesh of the cylinder surface in the middle of the scan body and the center axis of this cylinder was defined as the center axis of the implant. The centroid of the implant was then defined as the intersection of the center axis and the multi-unit abutment plane (Figure 3).[22] The same procedure was applied for each scan body. Linear (centroid to centroid)

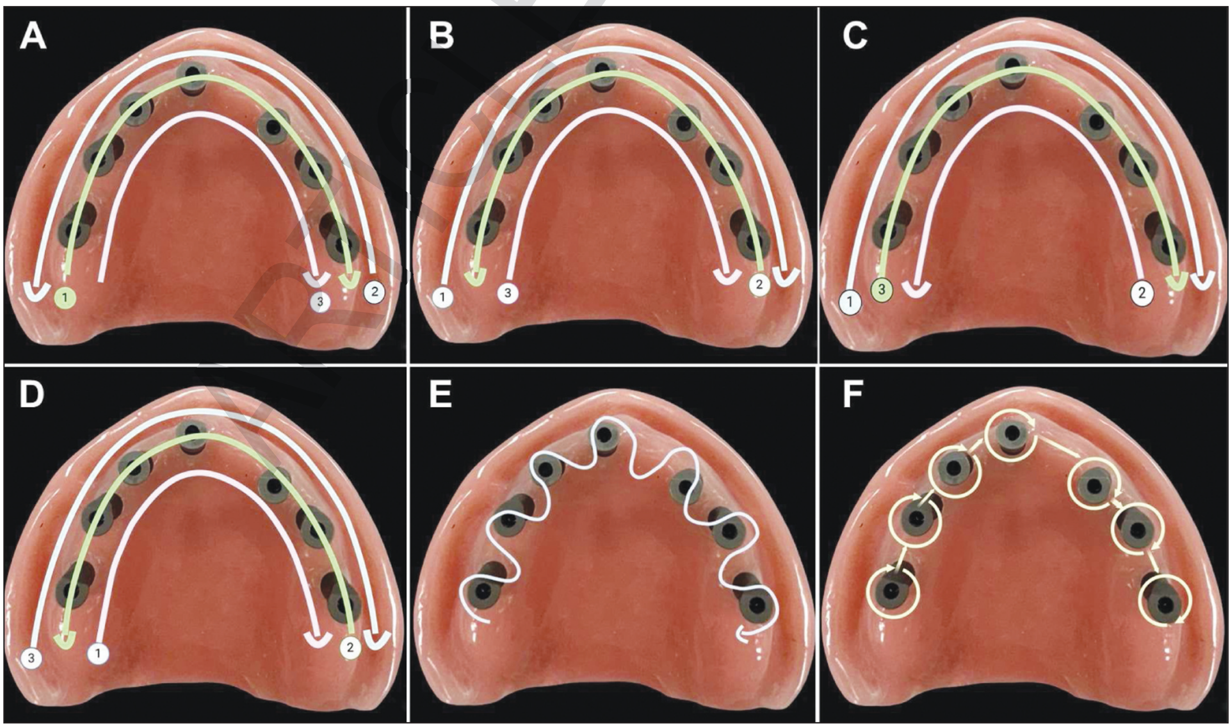

FIGURE 2: Scan patterns (A. Occlusal-buccal-palatine; B. Buccal-occlusal-palatine; C. Buccal-palatine-occlusal; D. Palatine-occlusal-buccal; E. Zigzag; F. Circumferential).

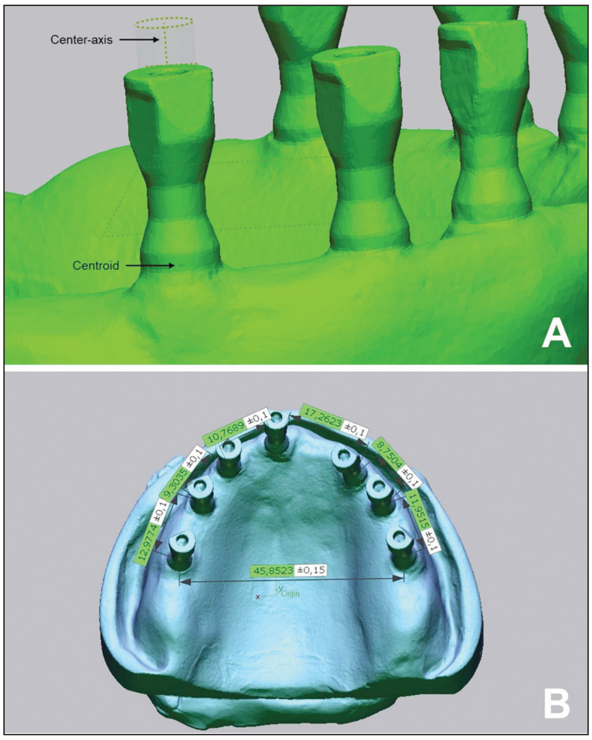

FIGURE 3: Analyzing linear and angular deviations
(**A.** Defining the center axis and centroid; **B.** An example of a measuring process).

and angular (center axis to center axis) measurements were performed and recorded between implants #26-#24, #24-#23, #23-#11, #11-#13, #13-#14, #14-#16 and #16-#26. The arithmetic mean of the measurements from the ten reference scans was used to determine the linear and angular reference values. Accuracy was defined as the closeness of linear and angulation measurements of scanning strategies using IOS to reference data.[23] Accordingly, the linear and angular measurements obtained for each region were subtracted from the reference linear and angular values obtained for the same region. The effect of scan pattern on IOS accuracy was evaluated from the results.

Statistical software (IBM SPSS Statistics for Windows, version 22.0; IBM, Armonk, NY) was used to analyze linear and angular deviations. The numerical magnitude of the identified differences, rather than their vectorial aspects, was evaluated in this study. Therefore, statistical analyses were performed using the absolute value of each difference. The distribution of the data was evaluated with the Shapiro-Wilk test and the Levene test was conducted to test the homogeneity of variance. The effect of the scan pattern on linear and angular deviation was evaluated with a two-way analysis of variance (ANOVA) test. The post hoc Tukey HSD test with Bonferroni adjustment was used to compare the differences. The statistical significance value was accepted as $p<0.05$ in all statistical methods used in this study.

RESULTS

A two-way ANOVA revealed that interactions between the scan pattern and implant region had a significant effect on linear deviations, $F(30, 378)=2.478$, $p<0.001$. The scan pattern ($p=0.011$) and implant region ($p<0.001$) also had significant effects on linear deviations. The mean linear deviation was higher in C than POB ($p=0.008$), ZZ ($p=0.035$), and BOP ($p=0.045$) (Table 1). The highest mean linear deviation value was found in the #16-#26 region ($p<0.001$). Lower mean linear deviations were found in #11-#13, #14-#16, #13-#14, and #26-#24 than in #24-#23 and #23-#11 ($p<0.05$). No significant difference was found between #24-#23 and #23-#11 ($p=0.334$) (Table 2).

The mean linear deviation values for each region in the scan patterns are shown in Figure 4. In the #26-#24 region measurements, the mean linear deviation

TABLE 1: Descriptive statistics of linear (mean±standard deviation µm) and angular deviations (mean±standard deviation degrees) of scan patterns.

	OBP	BOP	BPO	POB	ZZ	C
Linear deviations	54.95±60.34[ab]	49.71±46.27[a]	55.95±56.67[ab]	45.59±37.26[a]	49.08±54.45[a]	71.14±84.5[b]
Angular deviations	0.1599±0.1843[a]	0.203±0.1672[ab]	0.2458±0.1927[b]	0.1976±0.1817[ab]	0.1875±0.1713[ab]	0.2144±0.1782[ab]

The same letters mean there is no statistically significant difference between the groups; OBP: Occlusal-buccal-palatine; BOP: Buccal-occlusal-palatine; BPO: Buccal-palatine-occlusal; POB: Palatine-occlusal-buccal; ZZ: Zigzag; C: Circumferential.

TABLE 2: Descriptive statistics of linear (mean±standard deviation µm) and angular deviations (mean±standard deviation degrees) of implant regions.

	#26-#24	#24-#23	#23-#11	#11-#13	#13-#14	#14-#16	#16-#26
Linear deviations	33.56±23.04[a]	54.15±27.28[b]	71.17±34.07[b]	24.03±17.88[a]	30.92±17.75[a]	25.61±17.31[a]	141.41±108.26[c]
Angular deviations	0.1093±0.1412[a]	0.1504±0.144[a]	0.3334±0.1694[c]	0.2211±0.1721[b]	0.1261±0.1471[a]	0.116±0.0814[a]	0.3521±0.1586[c]

The same letters mean there is no statistically significant difference between the groups.

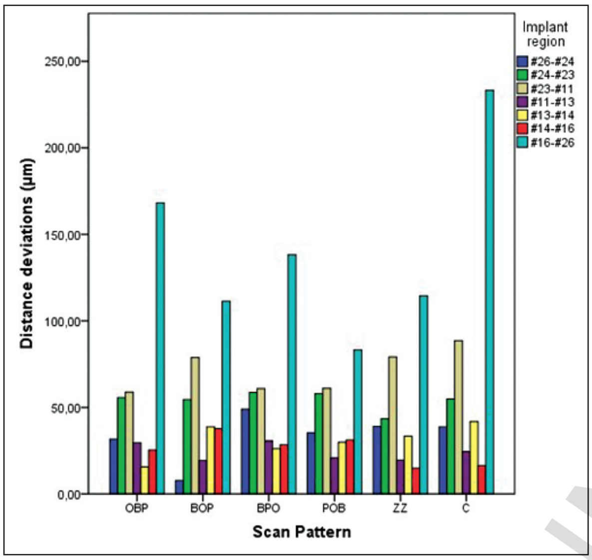

FIGURE 4: Linear deviation values determined at implant regions in scan patterns. OBP: Occlusal-buccal-palatine; BOP: Buccal-occlusal-palatine; BPO: Buccal-palatine-occlusal; POB: Palatine-occlusal-buccal; ZZ: Zigzag; C: Circumferential.

value determined for the BOP (16.1±14.84 µm) was statistically significantly lower than the value determined for the BPO (48.88±24.5 µm) (p=0.037). In addition, a significant difference was found between POB (83.15±61.87 µm) and C (233.25±118.96 µm) in the #16-#26 region (p=0.021).

A two-way ANOVA revealed that interactions between the scan pattern and implant region had no significant effect on angular deviations, F (30, 378)=1.301, p=0.137. The scan pattern (p=0.029) and region (p<0.001) had significant effects on the angular deviations. The mean angular deviation of BPO was higher than that of OBP (p=0.01) (Table 1). The highest mean angular deviations were found in #23-#11 and #16-#26 regions (p<0.001). Moreover, the mean angular deviation of #11-#13 was also significantly higher than that of #26-#24, #14-#16, #13-#14, and #24-#23 (p<0.05) (Table 2).

DISCUSSION

Both the scan pattern and inter-implant distance affected the linear and angular deviations according to the results of this study. Among the scan patterns, C exhibited higher linear deviations than POB, ZZ, and BOP. For the implant regions, the lowest linear accuracy was observed in #16-#26. Higher linear deviations were also observed in the measurements between #23-#11 and #24-#23 compared to other implant regions. When evaluating the angular deviations, it was found that the highest deviation was in the BPO. The highest angular deviations were determined in measurements of #16-#26 and #23-#11. It was also observed that the angular deviation values at implant locations #11-#13 were higher than the angular deviation values at other implant regions. So, the null hypothesis of this study was rejected.

In the clinical use of IOS, the digitization of implant positions in full arch edentulous jaws is perhaps the most challenging aspect of the technical capabilities of IOS.[24] Previous studies have shown that IOS and its technology, geometry and material of the scan body, scan pattern, ambient light, and operator experience can affect the accuracy of digital measurements of IFDPs.[7] Although previous studies have shown that scan pattern affects the accuracy of the digital impression obtained with IOSs in arches with natural teeth, single implant IFDPs, partially edentulous arches, and completely edentulous arches, few studies have evaluated the effect of scan pattern on digital impression accuracy in full arch IFDPs.[6,16-20,25,26] Most clinicians follow the IOS manufacturer's recommended scan pattern during digitalization of IFDPs with IOS. In single IFDP cases, the highest IOS accuracy can be achieved with the manufacturers' recommended scan pattern.[6,19] However, the proposed scan pattern does not distinguish between scanning natural teeth and scanning implants. The optical properties of scan bodies differ from those of natural teeth, which can affect the accuracy of the IOS.[16,17,26] In addition, the length of the edentulous area between the implants and the inadequacy of the reference points used to combine the acquired images may result in a decrease in the accuracy of full-arch implant IOS impressions using a scan pattern designed for natural teeth.[17] These technical features have led researchers to investigate the effects of different scan patterns on the accuracy of IOS applied in full-arch IFDPs. Kanjanasavitree et al. reported that the highest accuracy digital models can be obtained using the scan pattern (62.2 μm), which they defined as the quadrant pattern formed by scanning (Trios 4) the implants in the left quadrant with the PBO and then repeating the same process in the right quadrant in the mandibular 4 implant model according to the all-on-4 concept.[16] Gómez-Polo et al. evaluated the effect of scan pattern on IOS accuracy (Trios 4) in models with 6 implants each in the maxilla and mandible and reported that the lowest linear deviation values for the maxilla were obtained with the C scan pattern (88 μm) and the highest deviation values were obtained with the ZZ scan pattern (142 μm).[26] Li et al. reported that the highest linear deviations were obtained using OBP (91.95 μm) in a maxillary arch model with 6 implants (Trios 3).[17] The manufacturer of the IOS used in this study does not specify a specific scanning pattern for IFDPs, and recommends the OBP for the maxillary arch. In this study, the mean linear deviation values obtained with C were significantly higher than those obtained with POB, ZZ, BOP, and OBP. To precisely combine IOS images to obtain an accurate digital model, a common area of coverage between consecutive images is important. The rotational movement of the scanner head may reduce the common area of coverage between consecutive images, resulting in a decrease in linear accuracy.[19] For the high linear deviation values in C found in this study to be explained by the above conclusions, there should also be a significant difference in the linear deviations between adjacent implants. However, the deviation caused by the rotational motion of the scanner head did not appear to affect the linear deviations between adjacent implants. It can be seen that the high linear deviation values obtained using C are due to the linear deviation values in the #16-#26 region (Figure 4). Therefore, it can be concluded that the rotational movement of the scanner head adversely affects the digitization of the position of the most distant implants relative to each other.

With full-arch IFDP digital impressions, the number of images acquired increases as the scanned area increases. In particular cases where the inter-implant distance is high, the reference points required to obtain the digital model by combining the images cannot be sufficiently determined on the mucosal surface and cause an increase in linear and angular deviations in the digital model.[14,27] Fukazawa et al. evaluated the accuracy of 5 different IOS in partially edentulous models and found linear deviations of 0.2 to 38.1 μm in the model with an inter-implant distance of approximately 9.6 mm and linear deviations of 3.5 to 103.5 μm in the model with an inter-implant distance of approximately 18.4 mm.[28] Thanasrisuebwong et al. also reported the highest linear deviation values (19.68 μm) when the inter-implant distance was 21 mm.[9] It is stated that with the developments in the hardware and software of the new generation of IOSs, full-arch IFDPs can be digitized with higher accuracy, even when the distance between the implants is greater.[2,10-15] It has also been reported that the use of scan aids on the mucosa between the implants or splinting of scan bodies increases the accuracy of the IOS in full-arch IFDPs.[29-31] In this study, no scanning aids were placed on the mucosa between the implants, and no scanning bodies were splinted. Although the mean linear deviations of the digital casts of all scan patterns were found to be below the threshold (100 μm) accepted in the literature for full-arch implant IFDPs, the mean linear deviation value was higher than the threshold (141.41 μm) for #16-#26, where the inter-implant distance was approximately 45.74 mm. However, the increased linear deviation in the #16-#26 region may not be significant in the full-arch restored with partial IFDPs. The main effect of increased linear deviation in this region is observed in cases in which the entire arch is restored with a single one-piece IFDP.

In addition, the mean linear deviation values of the #23-#11 and #24-#23 regions are also significantly higher than those of the other regions. In this study, the scanning process was performed from right to left, starting with implant #16. In this scanning direction, implant #11 was scanned first, and as the scanner head moved toward implant #23, the longer inter-implant distance (16.98 mm) may have made the reference points used to combine the captured images less determinable. Therefore, it can be said that the precise digitalization of #23 was adversely affected, which caused an increase in the linear deviation values.[14,27,28] The location of implant #23 at the apex of the left maxillary quadrant curvature may also have contributed to digitalization errors that resulted in higher distance deviation values for #23-#11 and #24-#23.[32]

Another cause of stress formation on the implant-bone surface and related bone destruction is the angular deviation that occurs during the transfer of implant locations to the physical or digital model.[33] Although there is no clinically accepted threshold for angular deviation, most researchers have accepted 0.4 degrees as defined by Andriessen et al. as the threshold. In this study, the mean angular deviation was below the accepted threshold.[5] Knechtle et al. reported angular deviations ranging from 0.36 to 0.57 degrees with 4 different IOS in their study evaluating the accuracy of full-arch digital impressions.[2] There are few studies evaluating the effect of scan pattern on the angular accuracy of IFDPs.[6,17] A previous study in which partially edentulous cases were restored with 3 implants found that the scan pattern did not affect the accuracy of the IOS in the group in which the implants were placed parallel to each other and reported an angular deviation of 0.24-0.43 degrees.[6] Li et al. reported a mean angular deviation of 0.55 degrees in 6 implant models of the edentulous posterior maxilla and reported that digital models with higher angular accuracy can be obtained using OBP and ZZ.[17] In this study, similar to the results of Li et al., the lowest angular deviation values were obtained using OBP. However, the angular accuracy of OBP was significantly higher than that of BPO alone.[17] The lower angular deviation values in this study compared to that of the previous studies can be explained by the differences in the study methodology, the IOS, and implant systems. In addition, a previous study evaluating the effect of inter-implant distance on IOS accuracy reported that inter-implant distance did not affect angular deviation.[2,9,17] However, according to the results of this study, an increase in the inter-implant distance has an adverse effect on angular deviation. This difference in the results can be explained by the fact that the errors in combining the images obtained from full-arch scans are higher, as mentioned above.

Full-arch IFDPs are usually fabricated in one piece, and the fit of the IFDP and implants is influenced not only by the accuracy of the transfer of the positions of the individual implants to the model but also by the correct transfer of the positions and angles of the implants relative to each other. Therefore, in this study, a method for determining the linear and angular deviations between implants was preferred over evaluating the position and angle changes within the implants themselves. However, this study used a single implant system and IOS. The manufacturer of the implant system used in this study only provided the scan body, which was made of a grade 5 titanium alloy. The use of scan bodies with different geometric shapes and materials yields different results. This situation can be considered a limitation of the study. In addition, due to the in vitro design of the study, the data obtained may not fully reflect clinical practice. Therefore, in vivo studies using different implant systems and IOS are needed to evaluate the effect of scan pattern on IOS accuracy.

CONCLUSION

Within the limitations of this study, the following conclusions were reached: (1) The scan pattern and implant region influence the linear deviation of the IOS. (2) The highest mean linear deviation value was determined for digital models scanned with the C and the #16-#26 region. (3) The lowest mean angular deviation values were found in the OBP. (4) The angular deviations at #23-#11 and #16-#26 were higher than those at all other implant regions.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct con-

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Bahadır Ezmek, Büşra Polat;* ***Design:*** *Bahadır Ezmek;* ***Control/Supervision:*** *Bahadır Ezmek;* ***Data Collection and/or Processing:*** *Bahadır Ezmek, Büşra Polat;* ***Analysis and/or Interpretation:*** *Bahadır Ezmek, Büşra Polat;* ***Literature Review:*** *Bahadır Ezmek, Büşra Polat;* ***Writing the Article:*** *Bahadır Ezmek, Büşra Polat;* ***Critical Review:*** *Bahadır Ezmek;* ***References and Fundings:*** *Bahadır Ezmek, Büşra Polat;* ***Materials:*** *Bahadır Ezmek.*

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