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THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Effect of scan pattern on the scan accuracy of a combined healing abutment scan body system

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ABSTRACT

Statement of problem. A recently introduced scan body combined with a contoured healing abutment enables digital scans of the implant while its healing abutment shapes the soft tissue for an appropriate emergence profile. However, information on the effect of different scan patterns on the scan accuracy of this new system is lacking.

Purpose. The purpose of this in vitro study was to evaluate the effect of scan pattern on the accuracy of digital implant scans by using a combined healing abutment-scan body system.

Material and methods. A combined healing abutment-scan body system was secured on a single implant at the right first molar site in a dentate mandibular model. A master reference model was generated by scanning the model with an industrial light scanner. The model was then scanned with 4 different scan patterns (SP-A, SP-B, SP-C, and SP-D) by using an intraoral scanner (TRIOS 3). Test scans (n=8) were superimposed over the master reference model by using a metrology software, and distance and angular deviations were calculated. Distance and angular deviation data were analyzed with a multivariate analysis of variance and the Tukey honestly significant difference tests for trueness and precision (α=.05).

Results. Distance deviations (trueness [P=.461] and precision [P=.533] deviations) in the scans were not significantly affected by the scan pattern. Scan pattern affected the trueness (P=.001) and precision (P=.002) when angular deviations were considered. In terms of trueness, SP-D resulted in the highest angular deviations in scans ($P\leq$.031), while the difference in deviations in scans obtained by using other scan patterns was not significant ($P\geq$.378). When angular deviation data were considered, SP-D resulted in lower scan precision than SP-A (P=.014) and SP-B (P=.007). The precision of scans using SP-C was similar to the precision of the scans made by using other scan patterns ($P\geq$.055) in terms of angular deviations.

Conclusions. The scan accuracy of a combined healing abutment-scan body system was affected by the scan pattern. The scans performed with SP-D presented the lowest accuracy considering the angular deviation data and, therefore, may be the least favored among the patterns tested for scanning a combined healing abutment-scan body system. (J Prosthet Dent 2022;■:■-■)

With the advancements in computer-aided design and computer-aided manufacturing (CAD-CAM) technologies, intraoral scanners (IOSs) are being used for a wide range of indications,[1] including those in implant prosthodontics.[2,3] IOSs acquire digital scans of the implants by using intraoral scan bodies (SBs)[4,5] in a direct digital workflow without the involvement of impression trays and the materials used with conventional impression methods.[2,6-8] The direct workflow minimizes errors that may be encountered in the clinical and laboratory phases.[9-11]

Commercially available SBs typically consist of 3 main components: the scan region, the body, and the base.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Clinical Implications

A scan pattern that started on the occlusal surface of the canine and did not involve a buccolingual rotational movement resulted in lower accuracy, leading to increased chairside crown adjustments occlusally and on the proximal contacts.

However, those SBs mostly have cylindrical or conical shapes, which do not replicate the anatomic contours of a natural tooth.[6] Interim crowns or custom healing abutments (HAs) are used to form a natural emergence profile, particularly in the anterior region,[12] but these solutions still pose problems as the soft tissue may be traumatized during the removal of the HAs or interim crowns.[13]

A recently introduced system differs from the current SBs as it allows not only anatomic contouring with a polyetheretherketone HA but also the scanning of a medical grade acrylic resin SB (ScanPeg; Neoss Implant System) that is fitted in the screw access hole of the HA. This combined HA-SB (CHA-SB) system is secured by the friction between the vertical groove in the HA and the indentation present on the SB, which prevents rotation of the SB in the HA.[6,7]

Considering that the impression stage is critical for implant-supported prostheses,[6,14] an accurate IOS scan is essential.[15] Trueness and precision define accuracy according to the International Organization for Standardization (ISO) standard 5725-1.[12,16,17] Trueness can be described as the proximity of any measurement to the actual dimensions of the measured object,[18] whereas precision refers to the closeness of the repeated measurements to each other.[19,20] An inaccurate impression may lead to a misfit between the implant and the abutment, which will lead to biological and technical complications.[6] The accuracy of digital implant scans has been investigated in previous studies,[1-5,8-12] and various different factors, including the scan patterns,[1,21,22] were defined as essential. Even though a number of studies are available on the effect of scan pattern on the accuracy of complete arch implant-supported prostheses,[9] completely edentulous jaws,[22,23] and dentate jaws,[1,15,24] information regarding the effect of the scan pattern on the accuracy of single-implant scans is limited.[25] The CHA-SB system is a relatively new approach to scanning implants, and studies of this system are scarce.[12,26] Moreover those studies[12,26] did not investigate the effect of the scan pattern on the scan accuracy of the CHA-SB system, and given the fact that this system differs from the conventional 1-piece SBs in its geometry, the scan pattern might affect the accuracy of the CHA-SB system scans. Thus, the present study aimed to investigate the effect of 4 different scan patterns on the accuracy (trueness and precision) of single-implant scans when using the CHA-SB system. The null hypotheses were that the trueness of the digital scans would not be affected by the scan pattern and that the precision of the digital scans would not be affected by the scan pattern.

MATERIAL AND METHODS

A partially edentulous mandibular polymethyl methacrylate master model was fabricated with a single implant (4.0 mm×11 mm, Neoss ProActive Straight; Neoss Implant System) in the right first molar site. During the implant placement, the inner slot of the implant was located buccally to align the indexed HA (Esthetic Healing Abutment; Neoss Implant System) in the correct position as recommended by the manufacturer.[13] The HA of the CHA-SB system was aligned with the buccal groove in the implant and tightened. Subsequently, the SB (ScanPeg; Neoss Implant System) was fitted into the HA along the vertical groove present in the HA (Fig. 1).[13,27] The CHA-SB system was not separated until all scans were completed to avoid an effect on the scan accuracy.

An industrial-grade blue light scanner (ATOS Core 80 5MP; GOM GmbH) with a stereo camera working on the principle of triangulation (6-μm sphere space error, 8-μm size error, 1-μm probing error, 3-μm probing error size, 5-μm sphere spacing error, and 7-μm length measurement error)[28] was used to scan the master model and to generate the standard tessellation language (STL) file of the master reference model (STL-MRM). This STL file was then reverse-engineered by using a software program (Pro 8.1; GOM GmbH) to obtain a digital data set.[4]

Four different scan patterns were used in the present study, and 8 digital scans were made for each scan pattern. All scans were carried out by the same operator with 5 years of experience with digital dentistry (H.Y.) in a humidity- and temperature-controlled room with a commonly used IOS (TRIOS 3; 3Shape A/S). Before each scan, calibrations were performed by the same operator, and a 5-minute break was taken between each scan pattern tested to prevent fatigue-related deviations.[5] Once all SB and master model surfaces had been captured without any major imperfections, a scan was considered as complete.[4,9] All scan patterns were performed in one continuous motion. Other than scan pattern D (SP-D), all scan patterns started from the same area (occlusal surface of the right second molar) (Fig. 2): (1) scan pattern A (SP-A), scan was started by capturing the occlusal surfaces of the teeth in the entire arch and then turning to the lingual surfaces starting from the contralateral distal molar and terminating at the original starting point. Then, the buccal surfaces were captured starting from the original starting point until the

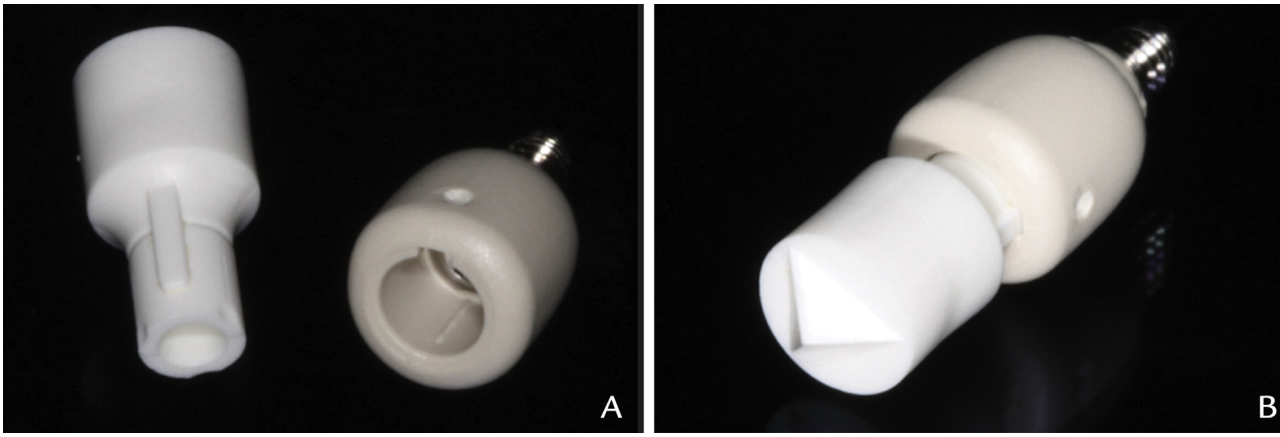

Figure 1. Combined healing abutment-scan body system. A, Separated; B, assembled.

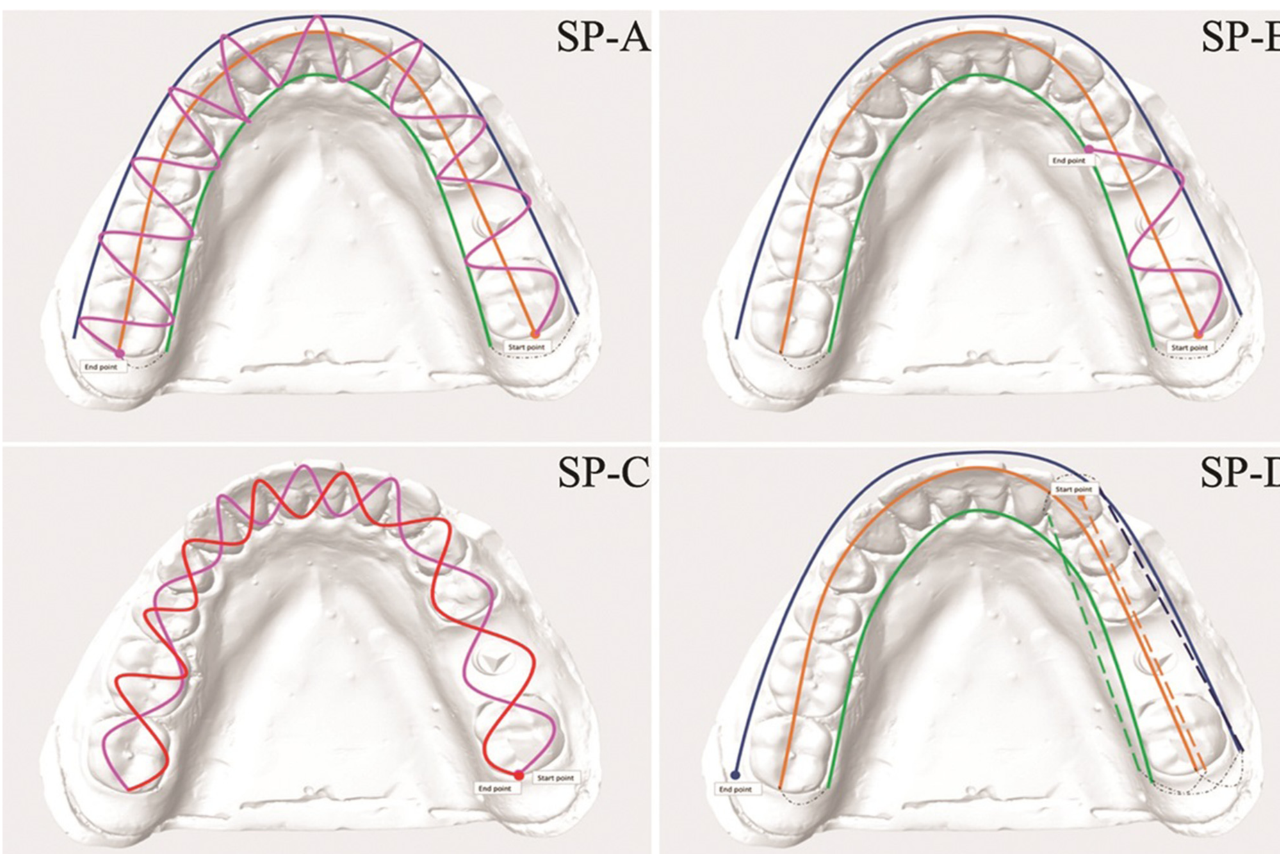

Figure 2. Scan patterns used. *Orange*: occlusal scan; *green*: lingual scan; *blue*: buccal scan; *pink*: buccolingual rotational movement; *red*: reverse buccolingual rotational movement; *colored dotted lines* represent scan of single quadrant, *black lines* with smaller dots at most posterior regions in SP-A, SP-B, and SP-D and at mesial of right canine in SP-D represent turns of IOS. IOS, intraoral scanner.

contralateral distal molar was scanned. The scan was then completed by buccolingual rotational movements starting from the contralateral distal molar throughout the arch. (2) Scan pattern B (SP-B), scans of the occlusal, lingual, and buccal surfaces were similar to those of SP-A. However, buccolingual rotational movements were limited only to the implant site and the adjacent teeth starting from the original starting point. (3) Scan pattern C (SP-C), the whole arch was scanned twice with buccolingual rotational movements without any interruption. (4) Scan pattern D (SP-D), the scan started from the occlusal aspect of the right canine and the occlusal

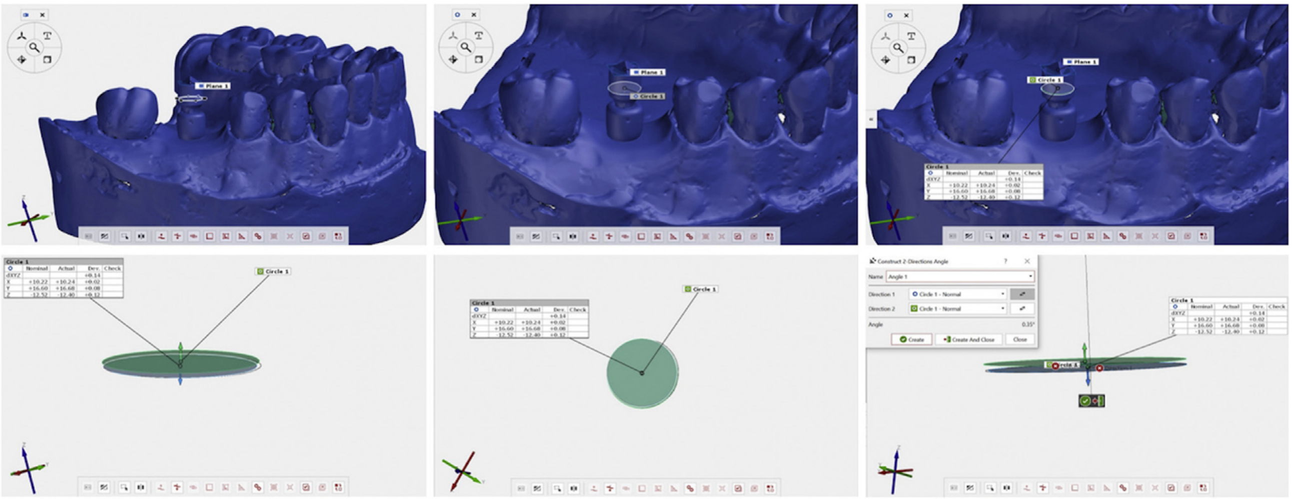

Figure 3. Circular planes generated for distance and angular deviation measurements.

surfaces of the teeth in the quadrant and then the SB were captured with distal movement. The lingual surfaces of teeth in this quadrant were then scanned starting from the molar and then turning buccally around the canine for buccal surface scans. The buccal scans were completed at the original starting point, and the whole arch was then captured as performed in SP-A without any buccolingual rotational movements.

IOS (test) scans were converted to STL files and superimposed over the STL-MRM (nominal scan). The best-fit algorithm feature of a metrology software program (GOM Inspect 2018; GOM GmbH) was used to evaluate the accuracy of the digital data sets.[4] The nominal and test scans were superimposed with the prealignment feature of the software program for initial alignment followed by the "Local best-fit" feature of the software program to minimize possible errors.

To calculate the trueness (distance and angular deviations) of scans with the 4 adopted scan patterns, a coordinate system was created,[4] and the mean distance and angular deviations were calculated for each scan strategy. Two circular planes were generated on the SBs in both nominal and test scans (one plane at the top surface of the SB, and the second plane 3 mm below and parallel to the top circular plane) (Fig. 3). The linear deviations of the center points of these 2 circles were calculated for each scan on the x, y, and z axes. The 3D distance deviations were calculated from the following formula: $3D=(\sqrt{x^2+y^2+z^2})$.[4]

For the angular deviation measurements, the nominal circle was accepted as 0 position, and the 3D angles between the nominal circle and IOS test circles were recorded by using the same software program.[4] The congruence between the STL-MRM and the library file of the CHA-SB was also evaluated before the IOS scans by using the previously mentioned methods to verify the fit between the HA and the SB.

The results were statistically analyzed with a software program (IBM SPSS Statistics for Windows, v25.0; IBM Corp). Means and 95% confidence limits for distance and angular deviation data were calculated for each scan pattern. Multivariate analysis of variance (MANOVA) was used to compare the distance deviation and angular deviation data of the scan patterns for trueness, and the Tukey honestly significant difference (HSD) post hoc analysis was used to resolve significant interactions (α=.05). The number of scans for each scan pattern had been determined by a power analysis (power: 0.80, α: .05, and effect size: 0.6) based on the results of a previous study.[4] The variances of deviations were used to define precision (distance and angular deviation data),[4,22] and variance homogeneities among scan patterns were compared with MANOVA and the Tukey HSD post hoc tests (α=.05).

RESULTS

The superimposition of the STL-MRM over the library CAD file of the CHA-SB system revealed a maximum linear deviation of 5 μm and an angular deviation of 0.03 degrees (Fig. 4).

Table 1 presents the results of the Tukey HSD tests, while Figures 5 and 6 illustrate the box plots of trueness and precision for distance and angular deviation data. In terms of trueness, the scan pattern had a significant effect on angular deviations (F=7.774, df=3, P=.001). Among the patterns investigated, SP-D had the highest angular deviation (P<.001 versus SP-A, P=.006 versus SP-B, and P=.031 versus SP-C), with a mean angular deviation of 1.25 ±0.63 degrees (The estimated difference in means

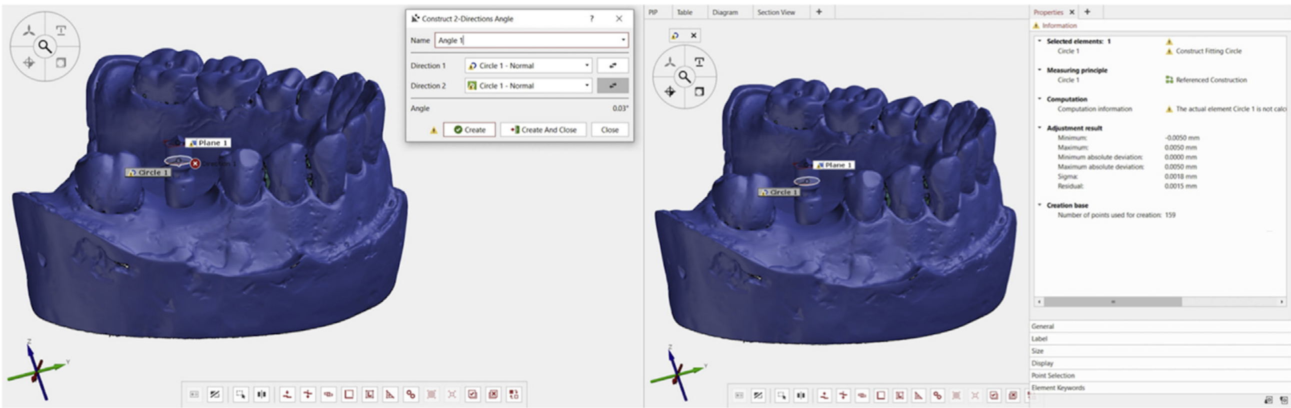

Figure 4. Congruence between library CAD file and STL-MRM for angular and distance deviations. CAD, computer-aided design; MRM, master reference model; STL, standard tessellation language.

was 1.03 degrees with SP-A, 0.81 degrees with SP-B, and 0.66 degrees with SP-C.). However, other scan patterns presented angular deviations, which were not significantly different ($P\geq.378$). The scan patterns' effect on the trueness of distance deviations was not significant (F=0.885, df=3, P=.461).

MANOVA results of the precision revealed that the scan patterns had a significant effect on precision when angular deviation data were considered (F=6.227, df=3, P=.002). Compared with SP-A (P=.014) and SP-B (P=.007), SP-D had significantly lower precision. However, the difference in precision between SP-C and every other scan pattern was not statistically significant ($P\geq.055$). For precision when considering the distance deviation data, no statistical difference was found among scan patterns (F=0.748, df=3, P=.533).

DISCUSSION

The first null hypothesis of this study was rejected as the trueness (angular deviations) of the digital scans was affected by the scan patterns. The second null hypothesis that the precision (distance and angular deviations) would not be affected by the scan pattern was also rejected as precision (angular deviation data) was significantly different among the scans performed with different patterns.

Yilmaz et al[12] reported distance deviations that ranged between 50 and 178 μm when a single central incisor implant was digitized by using the CHA-SB system, consistent with the distance deviations found in the present study. Moreover, in their study, [12] the CHA-SB system was shown to have similar or higher trueness (distance and angular) than a different SB used with direct and indirect digital workflows. However, the accuracy of a digital scan might not just be affected by the components of the scanning process (including IOS, SB, scan technology, scan pattern, ambient light, and operator experience). Prescanning and postscanning factors such as the manufacturing tolerances of the SB[8] and the congruence between the SB mesh and library file available in the CAD software program[3,5] may also affect accuracy. Considering that the CHA-SB system consists of 2 pieces that are attached through friction, unlike conventional SBs, the seating of the SB in the HA was investigated by evaluating the congruence between the library CAD file and STL-MRM in the present study. However, neither the present study nor the study by Yilmaz et al [12] focused on the scan mesh congruence or manufacturing tolerances of the CHA-SB system. Mangano et al[5] reported linear deviations ranging from 25.5 to 38.3 μm while investigating the congruence between the meshes of IOSs and a desktop scanner with the corresponding library file. Taking the results of the study by Mangano et al [5] into account, future studies investigating the effects of the manufacturing tolerance and the congruence between the optical scan and the library file might elaborate on the precision of the CHA-SB system and its possible effects on the accuracy of scans.

The scan patterns tested in the present study showed significant differences in terms of angular deviations (trueness and precision). SP-D was performed to capture more data points from the field of interest with an initial scan of the quadrant with the implant. However, this pattern did not improve accuracy and showed higher deviations than the other scan patterns. This finding might be related to the increased number of data points or the fact that the starting point of this scan was different from that in other scan patterns tested; SP-D started from the canine region where the axis of the scanner changed during the scan. Moreover, the absence of the buccolingual rotational movement in SP-D may have led to an improper stitching of the CHA-SB system. Clinical outcomes of the difference in angular deviations

Table 1. Mean ±standard deviation distance (μm) and angular deviation (degrees) values with 95% confidence limits for different scan patterns

Scan Pattern	Distance Deviation (μm)	Angular Deviation (Degrees)	Precision (Distance Deviation Data) (μm)	Precision (Angular Deviation Data) (degrees)
SP-A	139.1 ±12.9 (128.3-149.4)	0.23 ±0.15^{a} (0.1-0.36)	8.5 ±9.2 (0.8-16.2)	0.12 ±0.09^{a} (0.04-0.19)
SP-B	134.8 ±9.97 (126.5-143.2)	0.44 ±0.11^{a} (0.35-0.53)	5.4 ±8.1 (−1.4-12.2)	0.08 ± 0.07^{a} (0.02-0.14)
SP-C	138.5 ±7.79 (131.9-145)	0.59 ±0.61^{a} (0.08-1.1)	3.9 ±6.6 (−1.5-9.4)	0.42 ±0.41^{ab} (0.08-0.76)
SP-D	131.8 ±9.43 (123.9-139.7)	1.25 ±0.63^{b} (0.72-1.78)	4.4 ±8.2 (−2.5-11.2)	0.53 ±0.28^{b} (0.3-0.76)

Different superscript lowercase letters in same column indicate significant differences among scan patterns (*P*<.05).

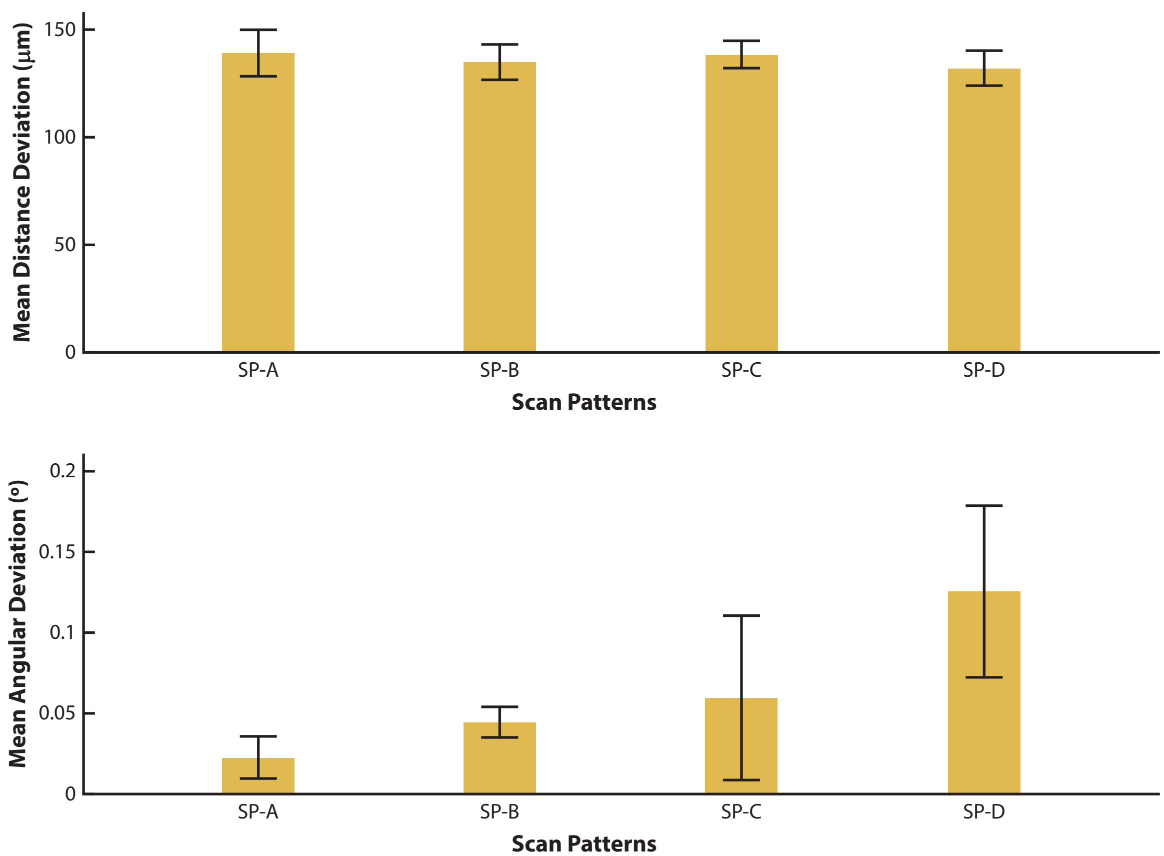

Figure 5. Means and 95% confidence intervals of distance and angular deviations of each scan pattern.

should be further studied as higher deviations may lead to longer chairside adjustments as interproximal and occlusal contacts may be affected, particularly when a fixed partial denture is fabricated. In addition, increased deviations may affect the fit of an implant-supported crown. Therefore, future clinical studies evaluating the passivity and contacts of the restorations fabricated by using the CHA-SB system scans with the scan patterns tested in the present study are needed to further elaborate these findings.

The IOS used in the present study has a recommended scan pattern for dentate arches, which first captures the occlusal surface of the entire arch, returns by the lingual surfaces, and then captures the buccal surfaces.[29] Among the scan patterns performed in the present study, SP-A and SP-B resemble the recommended pattern the most, explaining perhaps the favorable scan accuracy achieved with SP-A and SP-B. Nevertheless, in a previous study investigating the scan accuracy of the CHA-SB system when performed by using 4 different IOSs,[26] the IOS used in the present study showed a mean distance deviation of 127 μm and a mean angular deviation of 0.22 degrees, which were lower than the results of the present study. However, different experimental conditions can affect the results obtained, and direct comparisons could be misleading. To the authors' knowledge, no other study has ever investigated the effect of different scan patterns on the accuracy of the CHA-SB system. Therefore, future studies comparing different scan patterns to the recommended

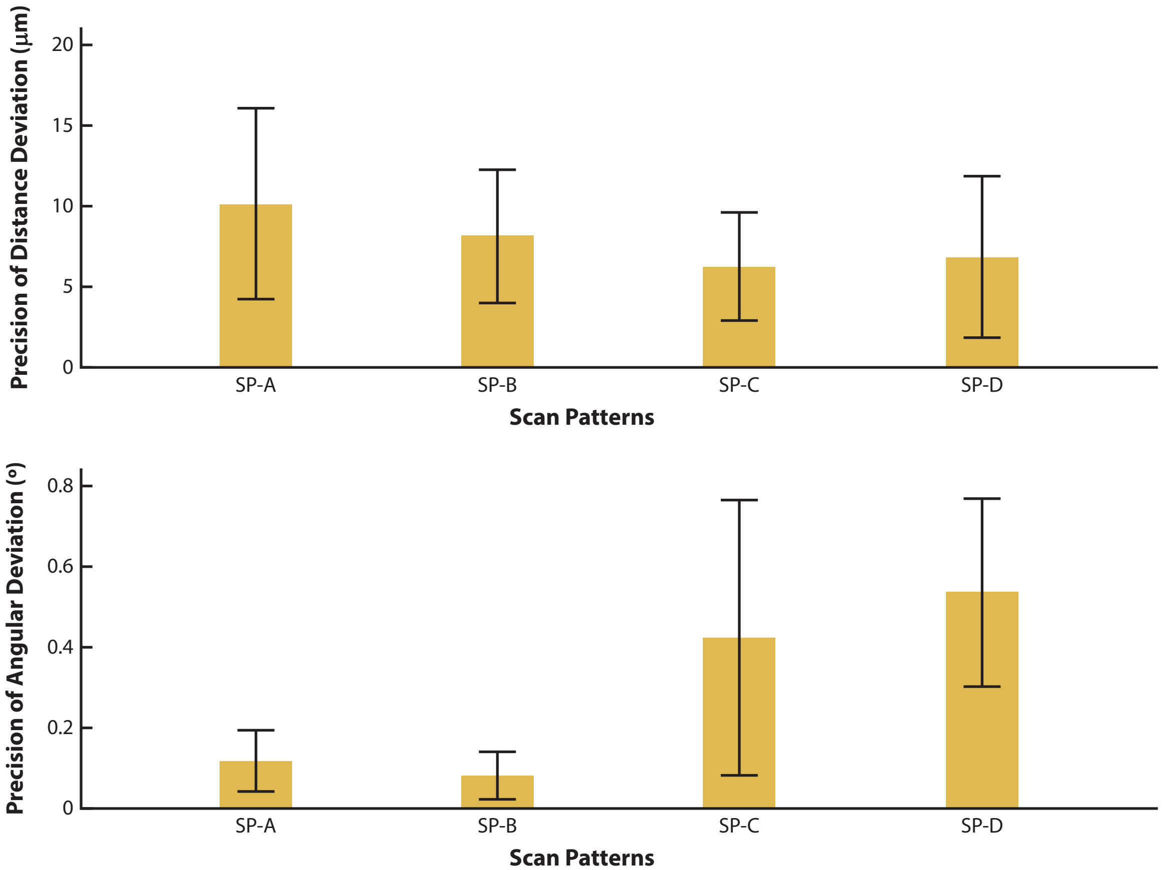

Figure 6. Means and 95% confidence intervals of precision of distance and angular deviations of each scan pattern.

scan pattern on the scan accuracy of the CHA-SB system while using different IOSs are needed.

The influence of different scan patterns on the accuracy of digital scans in various situations has been reported.[1,15,23,24] Oh et al[15] evaluated the effects of scanning strategy and IOS type (TRIOS 3 and i500) on the accuracy of dentate arch scans, comparing 2 continuous (horizontal scan of the whole arch and horizontal scan of the posterior regions combined with the vertical scan of the anterior region) and 1 segmental scan strategies. They concluded that the precision of the scans was not affected by the scan strategy or the type of IOS, while continuous vertical scans had lower trueness than the other scans. In another study, where a dentate model was scanned with 2 different IOSs (Primescan and Omnicam) by using 13 different scan strategies, the effect of scan strategy on the accuracy (trueness and precision) was found to be significant.[24] Scan techniques have also been found to be effective on the digital scans of completely edentulous maxillary scans.[23]

Motel et al[25] examined the impact of different SBs and scan strategies on the accuracy of digital implant scans with the IOS used in the present study, reporting that both SB type and scan strategy affected the accuracy of single-implant scans, whereas the 1-step scan strategy (complete scan of the model and the SBs) achieved significantly higher accuracy than the 2-step scan strategy (The scan of the model for the emergence profile was followed by the scan of the SBs.). Even though the 1-step strategy tested in the study by Motel et al [25] was similar to that used in the scans of CHA-SB, the mean distance deviations reported (71 μm for 1-step scan and 125 μm for 2-step scan) were lower than the distance deviations found in the present study (Table 1). Nevertheless, a direct comparison between the present study and the study by Motel et al [25] is problematic considering the differences in experimental design.

The accuracy of digital scans performed with the IOS used in the present study has been broadly investigated,[2,4,9,10,14,16,18,19,21,22] and the distance deviations when a single implant was digitized have been reported to range from 13.6 to 319 μm.[10,11,18,21,26,30] The distance deviations found in the present study were within this range. However, the effects of different IOSs on the accuracy of single-implant scans have been previously reported.[2,4,10,11,16,18,20,26] In addition, a recent study investigated the effect of 4 different scan patterns performed by using 4 IOSs, including the one used in the present study, on complete arch scans and concluded that both parameters affected the accuracy.[1] Considering these findings and the fact that the CHA-SB is a new approach, future studies should investigate the effects of different IOSs combined with different scan patterns to substantiate the findings of the present study.

Limitations of the present study included that the scan accuracy of 1 implant digitized by a single experienced operator was investigated. However, previous studies have shown that the number of implants,[10] operator experience,[19] and implant sites[11,18] have an effect on the accuracy of scans. Yilmaz et al[21] compared the accuracy of the partial and complete arch scans of an anterior single implant and reported no significant effect of the scan area on the scan accuracy. However, Moon and Lee[31] reported higher deviations in complete arch scans, particularly in the posterior regions. Future studies involving both partial and complete arch scans with an increased number of implants, IOSs, and operators are needed to comprehensively understand the effect of scan pattern on the accuracy of the CHA-SB system. Moreover, the in vitro design of the present study was a limitation as the accuracy of an intraoral scan might be affected by blood, saliva, gag reflex, soft tissue variation, patient movement, lack of space, and the presence of other dental materials.[1,9,10,22] In addition, neither the present study nor the previous studies on the scan accuracy of the CHA-SB system[12,26] have evaluated the accuracy on the gingival level. Even though the scan is made at the HA level while using this system, it is also critical to accurately acquire the contoured gingiva. Therefore, future in vivo studies are needed to substantiate and elaborate the findings of the present study.

CONCLUSIONS

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

1. The angular deviations (trueness and precision) of the combined healing abutment-scan body system scans were affected by the scan pattern, and SP-D resulted in the lowest accuracy.
2. The distance deviations (trueness and precision) of the combined healing abutment-scan body system scans performed with different scan patterns were similar.

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Acknowledgments

Neoss Implant System is gratefully acknowledged for supplying the materials used in this study. The authors also thank Gökhan Akçagöz for supplying the materials.

CRediT authorship contribution statement

Hakan Yilmaz: Data curation, statistical analysis, Formal analysis. **Hakan Arınç:** Conceptualization, Methodology. **Gülce Çakmak:** Investigation, Methodology, Data curation, Project administration. **Sevda Atalay:** Conceptualization, Investigation, Writing − original draft. **Mustafa Borga Donmez:** Writing − original draft, Writing − review & editing. **Ali Murat Kökat:** Conceptualization, Project administration. **Burak Yilmaz:** Project administration, Supervision, Writing − review & editing.

https://doi.org/10.1016/j.prosdent.2022.01.018