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A ccurate transfer of the implant position through impression has great importance in implant dentistry to prevent ill-fitting prostheses and related biologic and mechanical complications. In recent years, direct digital workflow has been increasingly used in implant impressions thanks to the advantages of various intraoral scanners (IOSs). Coded healing abutments (CHAs) and intraoral scan bodies (ISBs) are commercially available scannable implant components. Additionally, a combined healing abutment–scan body (CHA-SB) system was introduced in 2018 as an alternative. The CHA-SB system consists of an aesthetic healing abutment (five different anatomical shapes with different sizes) and a polyether ether ketone scan body (ScanPeg, Neoss Implant System). In the CHA-SB system, healing abutments are screwed after implant placement, and scan bodies are attached whenever an impression is necessary. Therefore, digital scans can be done directly through scanning the patient’s mouth by using digitally scannable implant components and an IOS. Coded healing abutments (CHAs) and intraoral scan bodies (ISBs) are commercially available scannable implant components. Additionally, a combined healing abutment–scan body (CHA-SB) system was introduced in 2018 as an alternative. The CHA-SB system consists of an aesthetic healing abutment (five different anatomical shapes with different sizes) and a polyether ether ketone scan body (ScanPeg, Neoss Implant System).

In the CHA-SB system, healing abutments are screwed after implant placement, and scan bodies are attached whenever an impression is necessary. Therefore, digital scans can be made immediately after implant placement or after osseointegration without the need for an extra surgery to uncover the implant. This allows the soft tissue to be formed in the healing period and create an emergence profile with healing abutments. The created emergence profile can be virtually transferred without the need for a soft tissue record because healing abutments are defined in the digital scan.

Accuracy of Different Complete-Arch Digital Scanning Techniques with a Combined Healing Abutment–Scan Body System

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Purpose: Investigate the effects of three different complete-arch digital implant scanning techniques used with a combined healing abutment–scan body (CHA-SB) system on the accuracy (trueness and precision) and scan time. Materials and Methods: A poly(methyl methacrylate) master model simulating an edentulous maxilla was fabricated with four parallelly inserted dental implants. A CHA-SB system was attached to each implant. The model surface was scanned using a structured blue light industrial extraoral scanner to achieve a reference model standard tessellation language file (MRM-STL). Three different scanning techniques—(1) conventional technique with unmodified master model, (2) scan body splinting technique using orthodontic elastic ligatures and plastic splint materials, and (3) land-marking technique using pyramid-shaped glass-ceramic markers—were performed. Fourteen consecutive digital scans were made by using an intraoral scanner (IOS) for each technique, converted to an STL file, and superimposed on the MRM-STL. Trueness and precision were calculated for each technique. The scan time was also recorded. The data were analyzed with one-way analysis of variance (ANOVA) and Tukey honest significant difference (HSD) tests (α = .05). Results: Effects of different scanning techniques on the trueness (distance and angular deviations; $P < .001$) and scan time ($P = .002$) were statistically significant. For precision, different scanning techniques had only a significant effect on the distance deviation ($P < .001$). Conclusion: Regarding trueness and precision, none of the scanning techniques was superior to others. The scan body splinting technique led to significantly less scan time. Int J Oral Maxillofac Implants 2022;37:67–75. doi: 10.11607/jomi.9209

Keywords: accuracy, implant impression, landmark, precision, splinting, trueness

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implant software library.9,10 This may eliminate soft tissue collapse during impression and replicate the same profile for a definitive prosthesis.9,10 Additionally, the CHA-SB system has the advantage of a reduced need for removal of healing abutments, which may only be one time in single-unit restorations in the prosthesis delivery.9,10

Accuracy can be defined as the proximity to the real dimensions of an object and determined with trueness and precision.13,14 Trueness describes how close a measurement is to the reference object in terms of real size, and precision describes how close a measurement is to another.13,14 In the edentulous maxilla, reference points such as teeth and anatomical landmarks are deficient, and anatomical irregularities are absent.4,5,13,15–17 Therefore, achieving reliable digital scans has been reported to have some challenges due to difficulties in properly stitching images.3,4,17 Additionally, there are large spans and areas among implants, which require more stitching images and point cloud density that makes scanning edentulous arches more prone to errors.4,5,18,19 Reflectance and surface textures of hard and soft tissue surfaces and mucosal morphology may also make it difficult to scan.3,4,16,17,20 Increasing reference points in edentulous areas by using different scanning techniques may help in capturing and stitching images. Although various studies have evaluated the effects of different scanners, operator experience, implant angulation, and insertion depth on the accuracy of complete-arch scans by using ISBs,3–5,21,22 the number of studies that evaluated the effects of different scanning techniques13,23 are sparse. To recommend a scanning technique for edentulous arches, a high trueness and precision is required.13,24 To the best of the authors’ knowledge, no study has compared the accuracy of different digital scanning techniques in completely edentulous arches by using a novel CHA-SB system. The purpose of this study was to investigate the effect of three different scanning techniques (the conventional technique, a novel scan body splinting technique, and a landmarking technique) used with a CHA-SB system on the accuracy (trueness and precision) and scan time in a completely edentulous maxillary arch with four implants. Distance and angular deviations of different scanning techniques were investigated for trueness and precision. The null hypothesis was that different scanning techniques would not affect the trueness of the scans, the scan time, and the precision of the scans.

MATERIALS AND METHODS

A poly(methyl methacrylate) master model simulating an edentulous maxilla was fabricated with four parallel dental implants (4.0 mm × 11 mm, Neoss ProActive Straight, Neoss Implant System). Two anterior implants were placed in the lateral positions, and two posterior implants were placed in the second premolar positions. Approximate distances of 22.5 mm between the centers of two anterior implants and 17 mm between the centers of anterior and posterior implants were left. Implants that were placed with reference to a slot of the implant were positioned buccally to achieve the indexed healing abutment aligned in this slot as recommended by the manufacturer.9,10 All implants were placed 1 mm subcrestally according to the model’s mucosal surface. A CHA-SB was attached to each implant. First, appropriate healing abutments (narrow for anterior, premolar for posterior implants, Esthetic Healing Abutment, Neoss Implant System) were hand-tightened into place according to the buccal slot in the implant (Fig 1).9,10 Then, a scan body (ScanPeg, Neoss Implant System) was placed onto each healing abutment, positioning the vertical indentations of scan bodies in the same line with the vertical grooves in the healing abutments.9,10 A thin layer of antireflective powder (2 µm) was sprayed on the master model surface, then scanned by using an industrial-grade blue light scanner (ATOS Core 80 5 MP,
GOM) and reverse engineered (Pro 8.1, GOM) to create a master reference model standard tessellation language file (MRM-STL; Fig 2). This industrial-grade scanner has 6-μm sphere space error and 8-µm size error.

Three different scanning techniques were evaluated: the conventional (CV) technique, a landmarking (LM) technique, and a novel scan body splinting (SBS) technique. In the CV technique, the unmodified master model was used (Fig 3a). In the LM technique, a pyramid (3 mm in height) was designed in computer-aided design (CAD) software (Cerec Software 4.5.2, Dentsply Sirona) and milled (Cerec MCX milling machine, Dentsply Sirona) from lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent). A total of four pyramids milled from glass-ceramic blocks were placed on the crests among the middle of implants and middle of the palate (Fig 3b). In the SBS technique, different colored orthodontic elastic ligatures (two between anterior and posterior implants and three between anterior implants) were attached on the plastic splint materials, and then, plastic splint materials were fixed on the corresponding axial walls of the scan bodies with orthodontic wax (Fig 3c).

The master model was scanned with each technique by using a structured light IOS (TRIOS 3, 3Shape) that has confocal microscopy and ultrafast optical scanning technology. Fourteen consecutive digital scans (n = 14) were done for each technique in a humidity- and temperature-controlled room by the same operator (H.Y.). Following the manufacturer’s recommendations for IOS, a standard scanning protocol starting from occlusal surface and continuing to capture palatal and buccal surfaces has been followed. All scans were started from the left-hand side of the model. Scanning times were recorded from start to finish, and an average scan time was calculated. A scan was considered as completed when no major hole in the reference model was observed and all CHA-SB surfaces were captured entirely. Then, STL files of test scans were created and superimposed over the MRM-STL using the best-fit algorithm of the software program (GOM Inspect 2019, GOM). Initial alignment was done by superimposing the MRM scan (nominal scan) and test scans (different scanning techniques) with the prealignment feature of the software. Then, certain reference areas were selected on nominal and test scans and further superimposed using the software’s “Local best-fit” feature. These reference areas were unchanged areas; the palate and the holes were located in the posterior of the models. To minimize any errors during alignment, CHA-SB surfaces were excluded as the reference points.
The amount of angular and mean distance deviations measured between the identical CHA-SBs in MRM-STL and the test scan was defined as trueness. For defining the trueness, distance and angular deviations were measured for all CHA-SB positions in each scan of all scanning techniques. The amount of angular deviation and mean distance of the CHA-SBs were calculated for each scanning technique. A coordinate system was produced and used to measure the distance and angular deviations between implants on the scan files. To measure the distance and angular deviations (trueness) in test scans from the nominal scan, two circles (one in nominal and one in test scan) were generated. To generate these circles, first, a flat plane was created on the top surfaces of the scan body parts of CHA-SBs, both for the nominal scan and the test scans initially. To create a flat plane, three points were selected on the top surfaces of the scan body by using the fitting plane function of the software, and then, the flat plane was automatically created using the Gaussian best fit method. Two circles, one of which was in the nominal scan and the other in the test scan, were placed virtually 3 mm below and parallel to the flat planes by using the construct single section function of the software. A 3-mm distance was selected because the scan body has a pyramid-shaped top, and a flatter surface is present 3 mm apical to the top surface. The same procedure was done for each scan body of each scan. After generating these two circles, the linear deviations of these two circles in a 3D space were calculated. The distance deviation was calculated for each CHA-SB using the distance formula $3D = \sqrt{x^2 + y^2 + z^2}$ and averaged among the four CHA-SBs for each test scan.

For the measurement of angular deviation, the same software was used. The nominal unit was accepted as 0-out one position, and the angle between previously created circles (one for nominal and one for test scans) was calculated. The final 3D angulation was noted for every CHA-SB and averaged among the four CHA-SBs for each test scan.

SPSS (Windows) was used for descriptive statistical analysis. Mean values and 95% confidence limits for distance and angular deviation (trueness) and scan time were calculated for different scanning techniques. One-way analysis of variance (ANOVA) was conducted for distance and angular deviation and scan time, in which the main effect was the scanning technique. A Tukey honest significant difference (HSD) test was used to more completely resolve any significant interactions ($\alpha = .05$).

The degree of variance among test scan groups was defined for precision. The homogeneity of the variances
The scanning techniques used for the study showed a significant difference on the scan time ($P = .002$; Table 1). The SBS technique had the lowest scan time ($P \leq .05$; Table 2). For trueness, one-way ANOVA results revealed that different scanning techniques had a significant effect on the distance deviation ($P < .001$) but had no significant effect on the angular deviation ($P = .158$). The LM technique showed a higher mean distance deviation than the CV ($P < .001$) and SBS techniques ($P < .001$; Table 2, Fig 5). However, no significant difference was found between the CV and SBS techniques ($P = .860$). The CV technique was significantly higher in terms of mean angular deviation than the SBS ($P = .001$) and LM techniques ($P = .004$; Table 2, Fig 6). However, no significant difference was found between the SBS and LM techniques ($P = .749$).

RESULTS

According to the one-way ANOVA, the scanning techniques used for the study showed a significant difference on the scan time ($P = .002$; Table 1). The SBS technique had the lowest scan time ($P \leq .05$; Table 2). For trueness, one-way ANOVA results revealed that effects of different scanning techniques on the distance ($P < .001$) and angular deviations ($P < .001$) were significant (Table 1). The LM technique showed a higher mean distance deviation than the CV ($P < .001$) and SBS techniques ($P < .001$; Table 2, Fig 5). However, no significant difference was found between the CV and SBS techniques ($P = .860$). The CV technique was significantly higher in terms of mean angular deviation than the SBS ($P = .001$) and LM techniques ($P = .004$; Table 2, Fig 6). However, no significant difference was found between the SBS and LM techniques ($P = .749$).
techniques (Table 3, Fig 7). However, no significant difference was found between the SBS and CV techniques ($P = .955$). Regarding angular deviation, different scanning techniques showed no significant difference ($P \geq .149$; Table 3, Fig 8).

**DISCUSSION**

Different scanning techniques affected scan time ($P = .002$) and distance and angular deviations in terms of trueness ($P < .001$). For precision, significant differences were only found in distance deviations ($P < .001$) among different scanning techniques. Therefore, the null hypothesis was rejected.

There is no consensus on a certain technique for better accuracy in digital implant scans of completely edentulous arches.\(^{23}\) Some techniques have been tried in previous studies, but there were conflicting results.\(^{13,23}\) The presence of limited reference points among scan bodies in the edentulous arches complicates scanning as a result of difficulties in properly stitching images together or misinterpretation of some parts of the scanned area or possibly cutting out some key parts of the scan during the postprocessing algorithm.\(^{3,16,23}\) Scanning multiple implants has also been reported to have some challenges, because ISBs have an identical shape that is difficult for IOSs to differentiate.\(^{4,5,12,19,27}\)

Conventional digital scans with only attaching the scan bodies onto the implants cannot solve the limited reference point presence in edentulous arches. In particular, when the inter-implant distance and implant number is increased, there can be a greater need for the reference points to stitch images. Therefore, different scanning techniques were applied in the present study with the aim of increasing reference data points among CHA-SBs and improving the stitching process to select the optimal technique for better accuracy. Scan time comparisons were also made to interpret the accuracy results because errors may be more possible due to an increased number of stitched images and overlapping procedures when scanning time is increased.\(^{23}\)

The LM technique was selected because different markers (glass or resin markers) were applied for the digital scans of completely edentulous arches with the same idea in previous studies.\(^{23,28,29}\) The markers used in previous studies\(^{23,28,29}\) were in different shapes and fabricated only for single use. Therefore, a land marker with a reproducible shape was considered, and land markers were fabricated from a durable material like lithium disilicate to sterilize when needed. After making a design and saving the STL file, these land markers

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**Table 3** Mean Distance ($\mu$m) and Angular Deviation (deg) Values for Different Scanning Techniques (n = 14) in Terms of Precision

<table>
<thead>
<tr>
<th>Property</th>
<th>Technique</th>
<th>Mean ± SD</th>
<th>Pairs and P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance deviation ($\mu$m)</td>
<td>Conventional (CV)</td>
<td>21.8 ± 33.28E</td>
<td>CV-SBS = .955/CV-LM &lt; .001/SBS-LM &lt; .001</td>
</tr>
<tr>
<td></td>
<td>Scan body splinting (SBS)</td>
<td>5.9 ± 8.02E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land marking (LM)</td>
<td>27.81 ± 244.29F</td>
<td></td>
</tr>
<tr>
<td>Angular deviation (deg)</td>
<td>Conventional (CV)</td>
<td>0.062 ± 0.062G</td>
<td>CV-SBS = .361/CV-LM = .869/SBS-LM = .149</td>
</tr>
<tr>
<td></td>
<td>Scan body splinting (SBS)</td>
<td>0.036 ± 0.024G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land marking (LM)</td>
<td>0.072 ± 0.056G</td>
<td></td>
</tr>
</tbody>
</table>

Different uppercase letters denote significant differences for different scanning techniques (adjusted $P \leq .05$).
can be milled whenever required or can be milled before and kept ready to use. Milled land markers could also require less clinical adjustment time, just stitching land markers to the crests or palate, which could make this technique easy to apply. The splinted impression technique was selected to replicate the conventional splinted impression technique because the conventional splinted impression technique was reported to be more accurate than the nonsplinted technique for both partially and completely edentulous patients.® Splinting could be made with floss or pattern resin; however, splinting with floss was previously tested by Mizumoto et al® and found to be less precise than using glass beads in four implant scenarios in an edentulous maxilla. Although scan bodies are recommended for single use, many clinicians use scan bodies many times. Therefore, pattern resin was not preferred as a splinting material, as it is difficult to remove after use and requires more clinical adjustment time. In the tested SBS technique, plastic splinting materials were fixed on the axial walls of the scan bodies by using orthodontic wax, which is easy to remove without damaging the scan body surfaces. Colored elastic ligatures were attached on the plastic splinting materials to create contrast in the color for better identification with the IOS because the scanned surface shape and color were known to affect the quality of a digitized surface.

In terms of trueness and precision, significant differences were found when different scanning techniques were used. The LM technique had the highest mean distance deviation in terms of trueness and precision. However, there was no significant difference between the CV and SBS techniques in terms of trueness and precision. The CV technique had the highest mean angular deviation for trueness. However, no significant difference was found between the SBS and LM techniques. Although the SBS technique had slightly lower angular deviation for precision, no significant difference was found among scanning techniques. The SBS technique had significantly less scan time than the CV and LM techniques.

In line with the present study, Mizumoto et al® found that different scanning techniques affected distance deviation for trueness and precision, whereas they did not affect angular deviation for trueness and scan time, and they affected angular deviation for precision in a completely edentulous maxillary arch with four parallel implants. Differences may be due to different scanning techniques, including different splinting techniques and materials, material type and number of glass markers, and different shapes of scan bodies. The authors® reported that the scan body splinting technique had more distance deviation than other techniques, and attaching scan bodies was not found to be beneficial in terms of accuracy to advance the stitching process. Comparatively better accuracy results from the splinting technique of the present study may be due to greater surface areas of the plastic splint materials in comparison with the floss, which might have resulted in more point cloud density and accurate virtual surface reconstruction. Additionally, different colored orthodontic elastic ligatures might have helped the scanning process.

In another study, Mizumoto et al® reported that stitching or unstitching the palate did not affect the accuracy of digital scans in a completely edentulous maxillary arch with four implants. Although a glass marker was inserted on the palate to increase the reference points in the LM technique in the present study, the LM technique had much higher mean distance deviation in contrast with the stitching technique used in Mizumoto et al® study. It could be interpreted that insertion of pyramid-shaped glass markers on the palate did not improve the stitching process and overlapping images.

Although the accuracy level required for clinical applications of the digital implant scan in complete arches is still missing, the range for trueness was reported as 60.6 to 253.4 µm, and for precision, the range was reported as 31.5 to 204.2 µm for maxillary complete-arch digital implant scans in previous studies.® In addition, Papaspyridakos et al® reported that mean 3D deviation of 132 µm at the distal implant results in an unacceptable clinical fit with the one-piece complete-arch implant-fixed prostheses. The means of distance deviation for trueness and precision obtained with the CV and SBS techniques were within the range of previous studies® and below Papaspyridakos et al® study, but the LM technique had higher distance deviation for trueness and precision than these ranges.® The angular deviation mean values for trueness in the present study with different scanning techniques were within the range that was documented in the literature for complete-arch intraoral implant scans (0.21 to 0.78 degrees).®

According to the results of the present study, it could be interpreted that splinting scannable implant components in the SBS technique increased reference points, provided easy and faster scanning, and resulted in better accuracy (trueness and precision), which is contrary to the LM technique. When the accuracy results and technical simplicity are considered, the scan body splinting technique can be recommended. However, the LM technique may result in clinical misfit problems when a 132-µm unacceptable clinical fit level is considered.® The higher distance deviation results of the LM technique may be due to the sharp pyramid shape of the glass markers, which might be difficult for the IOS to differentiate because steep and sharp surfaces have been reported to be difficult to scan and differentiate with the IOS.© Different results may be obtained if
these pyramids are milled in a more rounded shape and previously defined in the IOS software. To validate these findings, in future studies, restorations need to be fabricated from these scans and should be tested in terms of misfit and routine usage.

In the present study, one type of IOS was used for standardization purposes. TRIOS 3 IOS was selected because the accuracy of this scanner was reported as 4.5 µm and was reported as one of the most accurate scanners for complete-arch implant scans.²²,²³ In future studies, other IOSs need to be evaluated with tested techniques. In the present study, although scan body parts were identical, healings in the anterior and posterior implants were different in shape, height, and diameter. Mizumoto et al.²³ reported that the scan body type affected the accuracy, and one scan body had higher angular deviations, which might be due to its complicated design and tallest structure. Huang et al.²⁷ also reported that scanning accuracy can be improved with the design of the extensional structure of the scan body. CHA-SBs have a complicated shape because of a combination of a scan body and a healing abutment design.⁹ Although the scan region part of an ISB is used to digitally detect 3D orientation and angulation of the implant,⁷ the effect of the shape of different healing abutments, which were used in this CHA-SB system, should be evaluated in future studies.

One of the limitations of the present study was its in vitro nature, which was performed on prefabricated models under standardized laboratory conditions. In a clinical scenario, the scanning environment, the presence of saliva, blood, patient-specific factors, such as gag reflex, the hard and soft tissue textures, their reflective properties, and mouth opening may affect the scan accuracy.¹⁶,¹⁷ It has been well reported that several factors, including IOS technology and software program, scanable implant components, operator experience, quadrant, location, and angulation of the implant(s) affect digital implant scan accuracy.³–⁵,²²,²³,²⁵ which should be evaluated in future studies. In addition, the reasons for higher mean distance deviation for trueness and precision obtained in the LM technique and the effects of different shaped milled land markers on the accuracy should be evaluated in future studies.

**CONCLUSIONS**

According to the findings of this in vitro study, the following conclusions were drawn:

1. Different digital implant scanning techniques in a completely edentulous maxillary arch resulted in differences in the trueness (distance and angular deviations) and scan time and distance deviation for precision.
2. In terms of trueness, the conventional technique had the significantly highest mean angular deviation.
3. The LM technique had the significantly highest mean distance deviation for trueness and precision.
4. Use of the scan body splinting technique led to significantly less scan time.
5. One scanning technique was not superior to others when both trueness and precision were considered.

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