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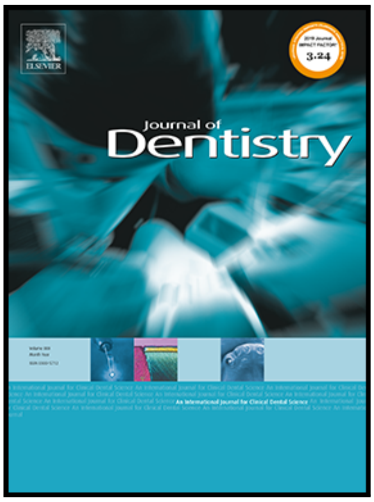

Trueness and precision of combined healing abutment scan body system scans at different sites of maxilla after multiple repositioning of the scan body

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Original article

Full Title: Trueness and precision of combined healing abutment scan body system scans at different sites of maxilla after multiple repositioning of the scan body

Short title: Scan accuracy according to implant location

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ABSTRACT

Objectives: To evaluate the accuracy of the scans of the combined healing abutment-scan body (CHA-SB) system located at different sites of the maxilla when SBs are replaced in between each scan.

Methods: Three SBs were seated into HAs located at the central incisor, first premolar, and first molar sites of a maxillary model inside a phantom head, and the model was scanned extraorally (CEREC Primescan SW 5.2). This procedure was repeated with new SBs until a total of 10 scans were performed. Standard tessellation language files of CHA-SBs at each implant location were isolated, transferred into analysis software (Geomagic Control X), and superimposed over the proprietary library files to analyze surface (root mean square), linear, and angular deviations. Trueness and precision were evaluated with one-way analysis of variance and Tukey tests. The correlation between surface and angular deviations was analyzed with Pearson's correlation (α=.05).

Results: Molar implant scans had the highest surface and angular deviations (*P*≤.006), while central incisor implant scans had higher precision (surface deviations) than premolar implant scans (*P*=.041). Premolar implant scans had higher accuracy than central incisor implant scans on the y-axis (*P*≤.029). Central incisor implant scans had the highest accuracy on the z-axis (*P*≤.018). A strong positive correlation was observed between surface and angular deviations (*r*=.864, *P*<.001).

Conclusion: Central incisor implant scans mostly had high accuracy and molar implant scans mostly had lower trueness. SBs were mostly positioned apically; however, the effect of SB replacement can be considered small as measured deviations were similar to those in previous studies and the precision of scans was high.

Clinical Significance

Repositioning of scan bodies into healing abutments would be expected to result in similar single crown positioning regardless of the location of the implant, considering high scan precision with the healing abutment-scan body system. The duration of the chairside adjustments of crowns in the posterior maxilla may be longer than those in the anterior region.

INTRODUCTION

Computer aided-design and computer-aided manufacturing (CAD-CAM) technologies enabled the digitization of implants with intraoral scanners (IOSs) and scan bodies (SBs) [1, 2]. SBs mainly consist of a highly critical scan region that is the main component for the digital acquisition of implants' orientation and angulation, a body, and a base [2]. Even though SBs vary in terms of size, shape, surface, and connection type, most of the available SBs are cylindrical or conical, which prevents optimum soft tissue contouring for the required emergence profile [3]. Interim implant-supported crowns or custom healing abutments (HAs) may be used to contour peri-implant soft tissue [4-6]. However, soft tissue trauma is still to be considered as these interim crowns or HAs must be removed and replaced during data acquisition [7], which led to the introduction of a combined HA-SB (CHA-SB) system. Polyetheretherketone (PEEK) HA provides anatomical soft tissue contouring, while medical-grade acrylic resin SB is used for data acquisition. Given that the SB is placed into the HA's screw channel, the implant can be simultaneously scanned with the peri-implant soft tissue [8, 9].

SBs should be precisely positioned for an accurate scan to transfer the positional and angular data of the implant, and conventional SBs are based on screw retention [2, 10, 11]. However, in the CHA-SB system, the SB is seated into the screw access channel of the screw-retained HA through friction, which also prevents the rotation of the SB. However, the absence of screw retention arises the question of stability and repeatability of SB positioning in the HA, which might impair scan accuracy. Intraoral factors such as adjacent teeth, opposing arch, and interocclusal distance may also be critical for accurate SB seating particularly in dentate situations, and the location of the implant,, has been reported to affect scan accuracy [12-15].

The effect of scan pattern, implant location, operator, scanning technique, and IOSs on the scan accuracy of the CHA-SB system has been investigated [6, 7, 9, 12, 16, 17]. A maximum mean distance deviation of 178 µm and a maximum mean angular deviation of 1.25° was reported in those studies [6, 7, 9, 12, 16, 17]. However, in all of those studies, the SBs were seated into the HA extraorally, which does not simulate the clinical positioning of the SB into the HA. A study based on the scan accuracy of the CHA-SB system in which SBs are seated into the HAs located at different sites inside a phantom head can better simulate the clinical situation and reflect the effect of difficulty of SB placement to scan accuracy. Therefore, the present study aimed to evaluate the effect of implant location on the trueness and the precision of CHA-SB scans when new SBs are seated into the HAs before each scan. The null hypotheses were that the location of the implant would not affect the trueness and the precision of CHA-SB scans when new SBs are seated into the HAs before each scan.

MATERIALS AND METHODS

Three implants (4.0 mm × 11 mm, Neoss ProActive Straight; Neoss Implant System, Harrogate, England) were placed at the left central incisor, left first premolar, and left first molar sites of a partially edentulous polymethylmethacrylate (PMMA, Weropress; Merz Dental GmbH, Lütjenburg, Germany) maxillary model. The implants were placed, orienting the inner groove buccally [5]. Corresponding HAs (Wide incisor, Premolar, and Molar Esthetic Healing Abutment; Neoss Implant System, Harrogate, England) were aligned with the buccal grooves in the implants and hand-tightened (Figure 1). HAs were not removed until all scans were completed. The maxillary model and its antagonist mandibular model, which was also in PMMA, were then fixed to a phantom head (Phantom heads P-6/3; Frasaco GmbH, Tettnang, Germany). An operator who has 5 years of experience in digital scans (M.B.D.) placed new SBs (ScanPeg; Neoss Implant System, Harrogate, England) into the HAs according to the manufacturer’s recommendations (Figure 2). SBs were initially centered in the screw access hole of the corresponding HA and then, the outdent on the SB was aligned with the vertical groove inside the screw access hole of the esthetic HA. SBs were press-fitted until seated (Figure 3).

After seating the SBs, the same operator performed partial-arch scan of the maxilla from the distal of the left second molar to the distal of the right canine in line with IOS’ (CEREC Primescan SW 5.2; Dentsply Sirona, Bensheim, Germany) scan pattern that followed lingual, occlusal, and buccal surfaces [16]. After ensuring that the scan was captured without any voids, the standard tessellation language (STL) file of each CHA-SB with its surrounding tissue was virtually isolated for each implant. The STLs were exported separately (CHA-SB-T-STL) in a randomized fashion by using the randomization function of a software (Excel; Microsoft Corp) to facilitate further alignments, as the proprietary library CAD file of the CHA-SB system for each HA (CHA-SB-LIB-STL) was used as the reference. SBs were then removed and the maxillary model was placed inside the phantom head again. To avoid the possible effect of repetitive placement on the retention of SBs, a new SB was seated into each HA and this process was repeated until 10 CHA-SB-T-STLs were generated per implant. Most of the previous studies on the scan accuracy of CHA-SB system have used 8 scans per test group and reported significant differences [7, 9, 12, 16], and a power analysis based on the results of one of those studies with similar methodology [12] was performed and 9 scans per group were deemed sufficient (for % 95 CI (1-α), 80% power (1-β), and effect size of f = 0.64). However, 10 scans were performed to increase the statistical power. IOS was calibrated by the same operator before each scan and the operator rested for 5 minutes between scans before replacing the SBs to prevent fatigue-related issues that may affect the seating of the SBs and the quality of the scans [9]. All scans were performed in the same temperature- (20 °C) and humidity-controlled (45%) room, under proper ambient light [7].

To evaluate the dimensional congruence between the CHA-SB-LIB-STL and the CHA-SB-T-STL according to the implant location, all STL files were imported into a metrology-grade 3-dimensional (3D) analysis software (Geomagic Control X 2022; 3D Systems, Morrisville, NC, USA). CHA-SB-LIB-STL of each HA was set as reference data and virtually separated into three regions as the HA, SB-neck, and SB-body by using the "Region Tool" of the software. Given that HAs were not removed in between scans, the HA region of the CHA-SB-LIB-STLs was used for the reference best fit alignment [18], which is based on superimposition by using only the selected data, to minimize the errors that may have occurred during initial alignment (Figure 4). Color maps generated by using the "3D

Compare Tool" of the software was used for quantitative evaluation and the root mean square (RMS) method was used for qualitative evaluation of the SB-body regions' surface deviations. The maximum and minimum deviation values were set to be +100 µm and -100 µm with the tolerance range being +10 µm and -10 µm (green) [19]. To measure linear deviations, the "simulated CMM point" feature of the software was used to mark the top of the pyramid on CHA-SB-LIB-STLs, which were then paired with respective CHA-SB-T-STLs, and the deviations in the x- (mesiodistal), y- (buccopalatal), and z- (occlusogingival) axes were measured. Even though negative (distal, buccal, and gingival) and positive (mesial, palatal, and occlusal) deviation values indicated the direction of the deviation, absolute values were used for statistical analyses. In addition, cylinders that encompass the lateral surface of the SB of CHA-SB-LIB-STLs were generated by using the "Geometric Feature Descriptor Tool" of the software. These cylinders were then superimposed over respective CHA-SB-T-STLs of the CHA-SB-LIB-STL, which facilitated the automatic measurement of angular deviations between the SB-body regions of CHA-SB-T-STLs and CHA-SB-LIB-STL (Figure 5). An operator (M.E.G) with 2 years of experience in 3D analysis software performed all deviation analyses.

Shapiro-Wilk tests were used to evaluate the distribution of data, while Levene tests were performed to evaluate the homogeneity of variances for each parameter. Further statistical analyses were performed by using one-way analysis of variance and Tukey tests to evaluate surface, linear, and angular deviation data among the scans of implants at different locations for both trueness and precision. The correlation between surface and angular deviations was evaluated by using Pearson's correlation analysis. A statistical analysis software (Jamovi v2.3.21; The Jamovi Project, Sydney, Australia) was used for all analyses with α=.05.

RESULTS

Shapiro-Wilk tests yielded normal distribution ($P \geq .190$), while Levene tests showed the homogeneity of variances ($P \geq .052$) for every parameter tested. The scans of implants at different locations had significant differences ($P = .002$ for surface deviations, $P < .001$ for linear deviations on the y-axis, $P = .002$ for linear deviations on the z-axis, and $P < .001$ for angular deviations), except for linear deviations on the x-axis ($P = .088$). Molar implant scans had the highest deviations when the surface ($P \leq .006$) and angular deviations ($P < .001$) were considered, while the differences between other implants were nonsignificant ($P \geq .792$). These two parameters also had a strong positive correlation ($r = .864$, $P < .001$). When deviations on the y-axis were considered, premolar implant scans had the lowest ($P \leq .014$), and molar implant scans had the highest deviations ($P < .001$). When deviations on the z-axis were considered, central incisor implant scans had the lowest deviations ($P \leq .018$), while the difference between other implants was nonsignificant ($P = .557$) (Table 1). Figure 6 shows the distribution of raw linear deviations on each axis for each implant location.

When surface deviations were considered, central incisor implant scans had higher precision than premolar implant scans ($P = .041$), while the precision differences between every other pair were nonsignificant ($P \geq .380$). When linear deviations on the y-axis were considered, premolar implant scans had higher precision than that of central incisor implant scans ($P = .029$). However, when linear deviations on the z-axis were considered, central incisor implant scans had the highest precision ($P \leq .017$). The location of the implant did not affect the precision of the scans when linear deviations on the x-axis and angular deviations were considered ($P \geq .224$).

DISCUSSION

The present study focused on the effect of implant location on the trueness and precision of CHA-SB system scans when SBs were replaced with the new ones after each scan. Considering detected significant differences in the trueness and precision of scans among implants located at different sites, the null hypotheses were rejected. Central incisor implant scans mostly had high accuracy, which may be related to the adjacent teeth, curvature of the maxillary arch, linear scan path of the anterior arch, and the morphology of the incisal and occlusal surfaces [7].

The present study differs from previous studies on the scan accuracy of the CHA-SB system [6, 7, 9, 12, 16, 17]; SBs were replaced with new ones after each scan to better simulate clinical conditions and reflect the possible effect of SB seating on measured deviations. Two of those previous studies have also investigated the effect of implant location on measured deviations and reported results in line with those in the present study as molar implant scans were shown to mostly have lower trueness or precision [7, 12]. In addition, the linear deviations measured in the present study are within the range of distance deviations previously reported [7, 12], which ranged between 35.01 µm and 123.5 µm for central incisor, 63.2 µm and 158 µm for premolar, and 71.98 µm and 124.7 µm for molar implant scans. Atalay et al [12] investigated the effect of implant location on angular deviations and the means of the deviations were 0.35° for central incisor, 0.63° for premolar, and 0.57° for molar implant scans. The differences in angular deviations between the present and Atalay et al's [12] studies may be negligible for central incisor and premolar implants; however, the mean angular deviation of the molar implant scans in the present study was 1.15°. The authors think that this difference could be related to the methodology of the present study; increased difficulty in seating SBs due to the limited interocclusal space in the phantom head might have contributed to higher angular deviations in molar implant scans. In addition, correct SB positioning at the central incisor and to a certain extent, at the premolar sites, can be related to their easier accessibility, whereas the molar site allowed only indirect visual evaluation by using a mirror or to the haptic control of positioning. This difference may be amplified in actual clinical situations, because the presence of saliva, limited space available due to the presence of the cheek, and the movements of the tongue may compromise image stitching and have been held responsible for the higher scan inaccuracy at posterior implant sites [20]. Previous studies have also shown that when the precision of the scans was considered, the distance deviations ranged between 12.1 µm and 47.7 µm for the central incisor, 15.4 µm and 29.3 µm for the premolar, 15.4 µm and 43 µm for the molar implant, and angular deviations ranged between 0.13° and 0.25° [7, 12]. These values are in line with the results of the present study and could be related to the fact that all scans were performed extraorally by an experienced operator, similar to Atalay et al's [12] and Donmez et al's [7] studies, despite the methodological differences based on the number of operators [12] and the scan patterns used [7]. Considering the fact that the IOS used in the present study is accurate [21] and commonly used in dental practices to deliver single implant crowns, and measured scan deviations being within a certain range that is achieved with similar scanners in previous studies, scans of the SBs after multiple repositioning could be considered clinically acceptable. In addition, it should be emphasized that the medical grade acrylic resin and PEEK that are used to fabricate the components of the CHA-SB system have different hardness and the medical grade acrylic resin is softer. Any wear at the inner surface of the HA due to the difference in material hardness could be clinically negligible, considering the high precision of the scans in the present study.

When raw deviation values were evaluated for possible clinical outcomes, it can be interpreted that central incisor crowns fabricated by using tested scans may have tighter mesial contacts, whereas the premolar and molar crowns may have tighter distal contacts. In addition, central incisor and molar crowns may have buccal overcontouring and all crowns may need additional veneering depending on the lightness of the occlusal contacts. Considering that only the deviations on the z-axis had a common direction (apical) among all sites evaluated, the pressure applied during the fit of the SB into the HA might have deteriorated the most apical part of the socket of the HA. Another factor that may have affected varied deviations on other axes among tested sites may be the manufacturing tolerances of SBs [22]. These deviations are neglected in studies that are based on the scanning of the same SB to generate test and reference scan files [6, 7, 9, 12, 16, 17]. Thus, the results of the present study should be carefully interpreted, as the deviations measured in the present study may have also been affected by the manufacturing tolerances. Even though a comparison among the linear deviations of different axes within each implant site was not performed, deviations on the y-axis were higher than those on other axes for central incisor and molar implants. However, this difference was more evident for the molar implant and all specimens were buccally deviated. Increased deviations to buccal may be due to the presence of the indentation on HA surface on the buccal side and the limited interocclusal space at the posterior region inside the phantom head, which may have led to directional issues during SB placement.

Previous studies have also used proprietary library CAD files as reference file to evaluate the deviations in test scans [8, 23]. The digital analysis software used has been tested in previous dental studies [24, 25] and it is recommended by the International Organization for Standardization [26]. The best fit alignment method used in the present study was based on the superimposition of datasets by restricting alignment to operator-identified sections that most likely remain stable throughout the scans [18]. Excluding variable or mobile structures such as SBs or non-attached mucosa was shown to be reliable and reproducible for the superimposition of corresponding surface datasets [6, 27]. In addition, point-based deviation analysis of CHA-SB scans was shown to have a correlation within different operators [28].

A limitation of the present study was that the scans were performed under standardized conditions, which omitted patient-related factors that could affect the scan accuracy [29]. The partially edentulous model used in the present study did not have any edentulous areas between implants and long-span edentulous areas may affect measured deviations, even though SB placement would potentially be easier in the absence of teeth adjacent to an implant. In addition, the present study did not focus on manufacturing tolerances of tested SBs, which may have affected the results. The IOS tested in the present study has been used in previous studies on scan accuracy [1, 16, 23, 27, 28] and was shown to have high precision [21]. However, different IOSs may lead to different results. Finally, a single operator performed all replacements and scans. Future in vivo studies that involve different clinical situations with varying number of implants located at different sites of both maxilla and mandible are needed to better interpret the scan accuracy of the CHA-SB system.

CONCLUSIONS

Considering the limitations of the present study, the following conclusions were drawn:

1. Accuracy (trueness and precision) of the scans was affected by implant location. Central incisor implant scans mostly had high accuracy and molar implant scans mostly had lower trueness.

2. There was no clear trend in mesiodistal and buccopalatal deviations of the scan bodies. However, deviations towards apical were evident for all locations.

3. Scan body replacement may have a small effect on scan accuracy, considering that the deviation values were mostly similar to those in previous studies and the high precision of scans.

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TABLES

	Surface deviations (μm)	**Linear deviations on x-axis (μm)**	**Linear deviations on y-axis (μm)**	**Linear deviations on z-axis (μm)**	**Angular deviations (Degree)**
Central Incisor	31.12 ±7.16[a]	29.42 ±12.83[a]	48.67 ±23.99[b]	9.60 ±7.31[a]	0.42 ±0.25[a]
Premolar	31.99 ±16.05[a]	32.60 ±17.04[a]	23.16 ±9.91[a]	32.55 ±18.95[b]	0.49 ±0.31[a]

Molar	50.15 ±11.38[b]	18.79 ±11.63[a]	116.92 ±19.65[c]	40.21 ±18.62[b]	1.15 ±0.17[b]

Table 1. Descriptive statistics (mean ±standard deviation) of measured deviations per implant location

Different superscript lowercase letters indicate significant differences in columns (*P*<.05)

Table 2. Descriptive statistics (mean ±standard deviation) of precision of scans for measured deviations per implant location

	Surface deviations (µm)	**Linear deviations on x-axis (µm)**	**Linear deviations on y-axis (µm)**	**Linear deviations on z-axis (µm)**	**Angular deviations (Degree)**
Central Incisor	5.46 ±4.26[a]	9.03 ±8.61[a]	20.05 ±11.36[b]	5.81 ±4.71[a]	0.20 ±0.14[a]

Premolar	12.97 ±8.41[b]	14.68 ±8.18[a]	8.15 ±4.95[a]	15.42 ±9.74[b]	0.22 ±0.14[a]
Molar	9.02 ±6.25[ab]	9.01 ±6.71[a]	15.14 ±11.46[ab]	16.57 ±6.46[b]	0.13 ±0.09[a]

Different superscript lowercase letters indicate significant differences in columns (P<.05)

FIGURES

Figure 1. Master model with esthetic healing abutments

Figure 2. Representative step-by-step placement of SB into molar HA

Figure 3. Occlusal view of CHA-SB system after all SBs are placed

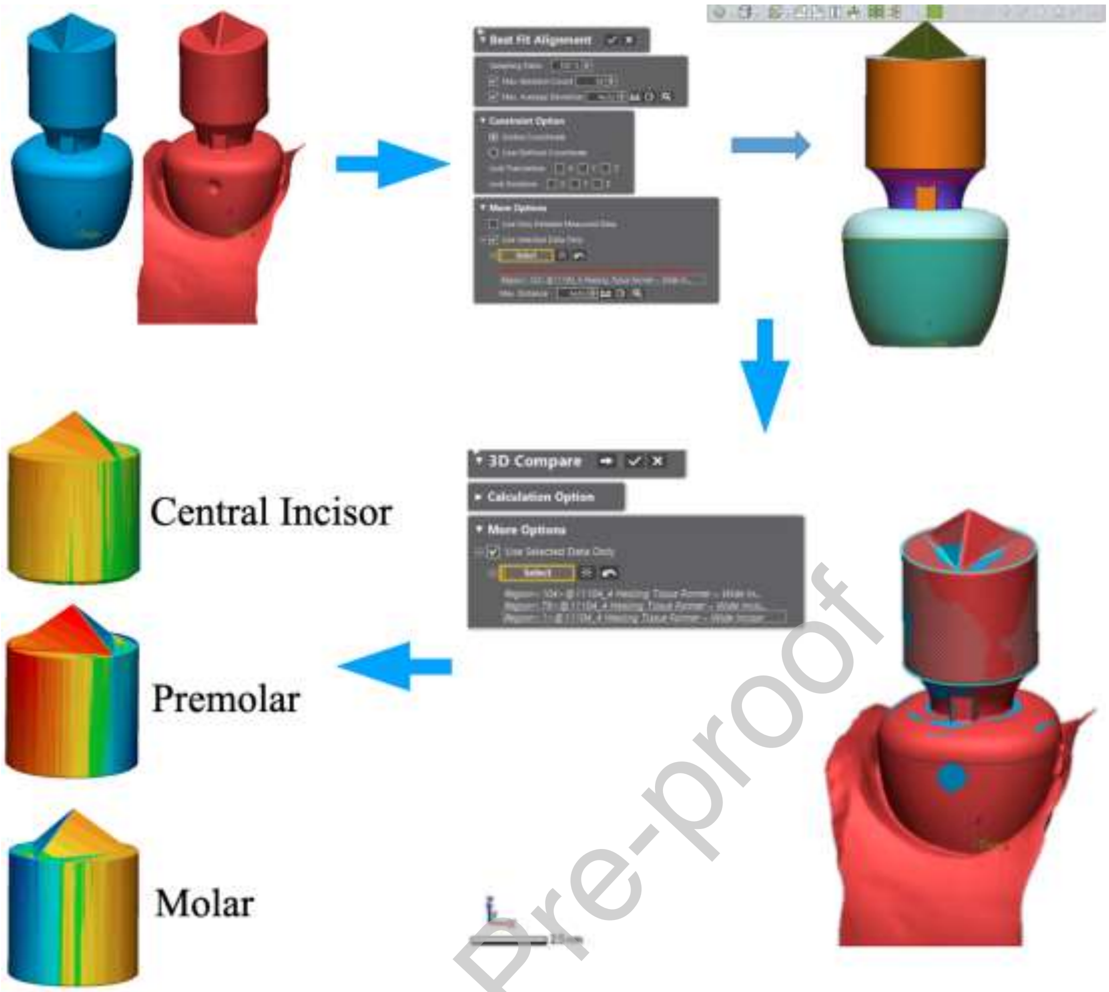

Figure 4. Overview of superimposition process. Blue CHA-SB represents library CAD file (CHA-SB-LIB-STL) and red CHA-SB represents test scan file (CHA-SB-T-STL).

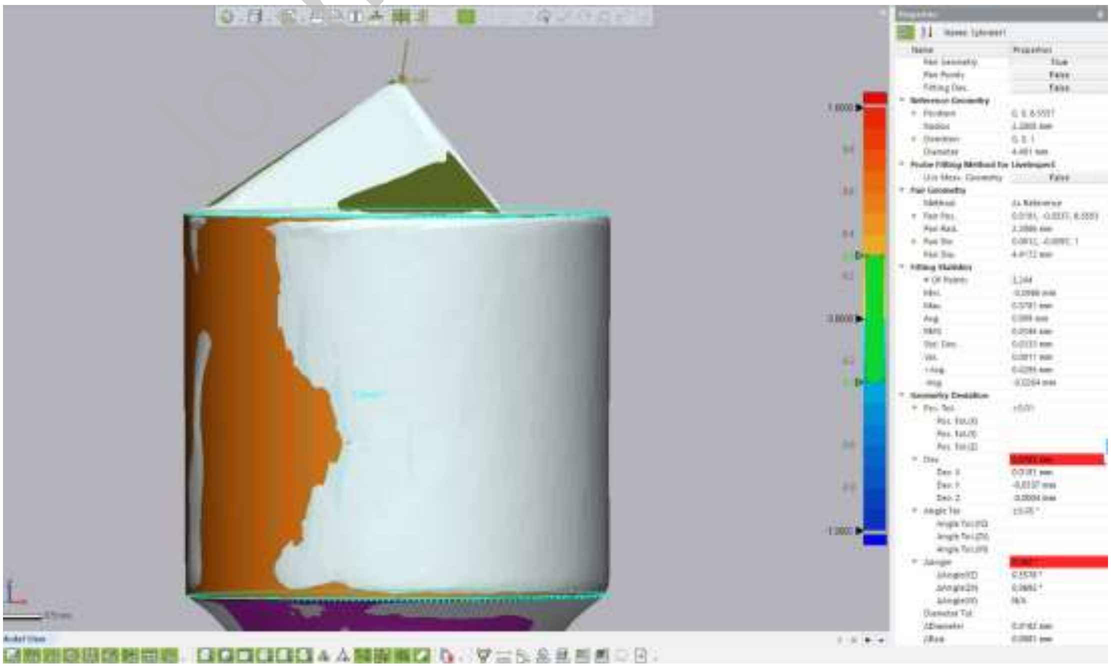

Figure 5. CMM point marked on top of the pyramid on the SB to measure linear deviations and cylinder (dashed turquoise line) generated to measure angular deviations

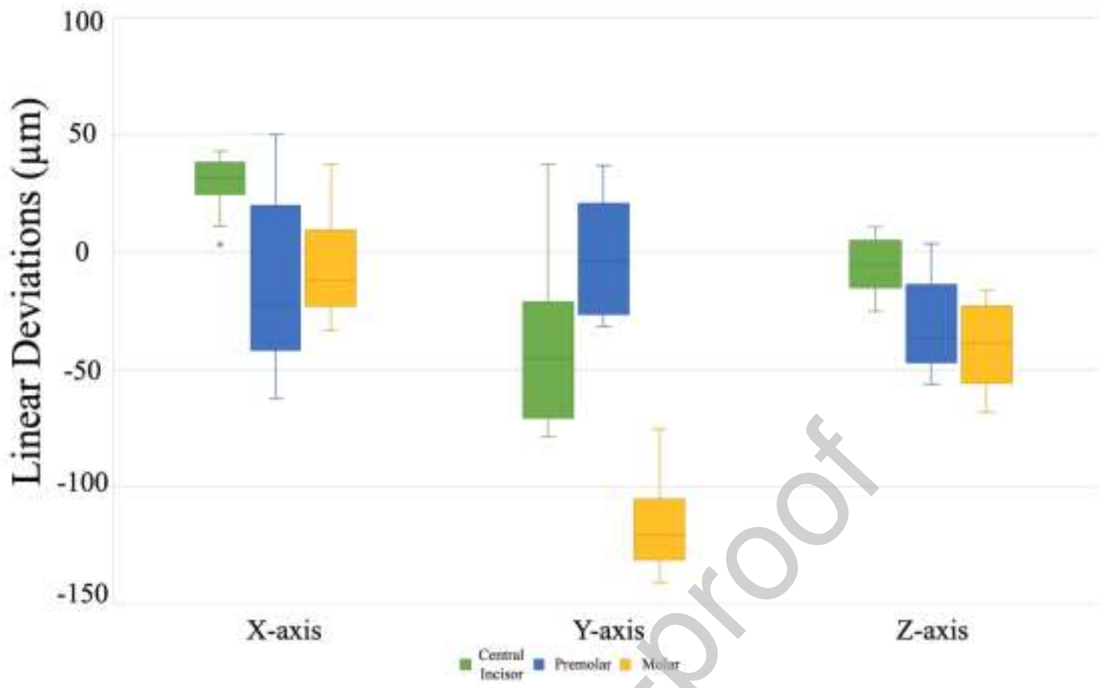

Figure 6. Box-plot graph of raw linear deviations of each implant location-axis pair

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Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: