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Original paper

The Accuracy of Digital Implant Impressions when Using and Varying the Material and Diameter of the Dental Implant Scan Bodies

Keywords
titanium, optical scanner, precision, polyether ether ketone, narrow diameter, regular diameter

Abstract
The effects of using and varying the material and diameter of implant scan bodies (ISBs) on the level of accuracy of digital implant impressions is unclear. The purpose of this study was to investigate these effects on the level of accuracy of scans made by an extraoral scanner (EOS) and intraoral scanner (IOS). A stone cast with two sets of ISBs was used. ISBs were made of titanium (TI) or polyether ether ketone (PEEK). Each set consisted of two narrow diameter (ND) and two regular diameter (RD) ISBs. Sixty-six scans were performed and imported into an inspection and metrology software to conduct the three-dimensional (3D) comparisons (N=140) and obtain root mean square (RMS) values. RMS values were analyzed with descriptive and inferential non-parametric statistics (α=.05). The use of ISBs did not improve the overall EOS and IOS scans accuracies. Also, varying the ISBs' diameter and material influenced the EOS and IOS accuracies. For the EOS, the precision in descending order was as follows RD TI, ND TI, RD PEEK, ND PEEK. In contrast, for the IOS an inverse relationship was noted. Finally, precision assessment should always be performed for any reference scanner under the proposed test conditions.

Explanation letter

The review received was not related to this manuscript. Correct review was received by email from the editor.

The methodology was not as described by the reviewer. Apology for the confusion. A lot of effort was made to improve the current version of the manuscript. Only one technique used (Precision) not (Trueness), more explanation added to M&M and discussion.

Root mean square values and measurement were further explained.

Accuracy of the impressions was calculated without the use of ISBs because such data is not available. This was added to current version of manuscript.

All other comments were considered.

Digital workflows are challenging traditional analogue processes, both in clinic and laboratory settings. One crucial aspect, influencing full adoption of digital workflows, is accuracy. In particular, when it comes to dental implant impressions, a high level of precision is important due to the low tolerances of misfit.[1] Impression inaccuracies may lead to a prosthesis misfit that could prompt biomechanical issues because of excessive stress, both inside the prosthesis and within the interfaces amongst the bone, implant and prosthesis.[2-5] Digital impressions are capable of capturing fine details when compared to conventional methods, however to facilitate the acquisition of digital implant impressions, manufacturers have introduced implant scan bodies (ISBs).[6-9]

ISBs are implant location transfer devices that attach to the respective implants and are then scanned with either an intraoral scanner (IOS) or extraoral scanner (EOS).[10] ISBs have a unique surface material, or surface treatment, that reduces light reflection and facilitates optical scanning. The ISB surface can be made of a polymeric material for example polyether ether ketone (PEEK), or a metallic material such as titanium (TI) that has been specially treated to aid scanning. The mating surface may also be made of either PEEK or metallic materials. A wide range of ISBs are commercially available; they are made in different sizes and surface geometries. The ISBs are produced by either the respective implant company, the scanner company or a third-party manufacturer. Despite today's widespread use of ISBs in digital implant dentistry, a recent systematic review highlighted the limited information available pertaining to ISBs and concluded that further studies are required to investigate the accuracy of digital implant impressions using ISBs.[10] Published studies have identified aspects directly related to the accuracy of ISBs including the reproducibility of fit, manufacturing tolerances, exposure, displacement while tightening the screws, defect-free scanning, and the effect of surface geometries, designs, types or shapes.[11-22] To the authors' best knowledge, no studies have evaluated the effect of using ISBs on the overall scan accuracy nor evaluated the combined effect of varying the diameter and material of ISBs. Furthermore, the literature shows heterogeneity between performed studies thus making comparisons between the studies pertaining to digital implant impressions challenging.[23-32]

The aims of this study were to investigate first the effect of using two commercially available ISBs on the overall scan accuracy of digital impressions and second the combined effect of varying diameter and material of same ISBs on the level of accuracy of digital impressions for both an EOS and IOS. The former was investigated in terms of overall precision and the later in terms of specific precision. Furthermore, a validity confirmation of the use of the inspection and metrology software was included to establish its level of accuracy. The following null hypotheses were tested, H_{0i}: there would be no differences in the overall precision between the EOS groups with and without the TI or PEEK ISBs; H_{0ii}: there would be no differences in the overall precision between the IOS groups with and without the TI or PEEK ISBs; H_{0iii}: there would be no differences in the specific precision between the EOS groups when varying the diameter and material of the ISBs; H_{0iv}: there would be no differences in the specific precision between the IOS groups when varying the diameter and material of the ISBs.

MATERIALS AND METHODS

Cast preparation

A Kennedy Class III modification 1 partially edentulous mandibular arch cast with missing premolars and first molar teeth was selected for the purpose of this study. The cast was duplicated by using silicone material and this was poured twice with dental stone; one cast was left intact (original cast) (Fig. 1A) and the other cast was used to fabricate the master cast (Fig. 1B and 1C).

To fabricate the master cast, four laboratory implant analogues, two narrow (NC) and two regular (RC) platforms were inserted in the prepared sites on the right and left sides, respectively, of the stone cast. The respective screw-retained open tray impression posts attached to their implant analogues. A pick-up, open-tray impression was made with light and heavy bodied polyvinylsiloxane impression materials.

The respective implant analogue was attached to each of the impression posts. A silicone gingival mask was then applied around the implant analogue. The impression was poured with Type IV dental stone.

Implant scan bodies

To assess the impact of material and diameter of ISBs on accuracy, two different commercially available sets of ISBs were used. The first was made of titanium and the second was made of PEEK. Each set included two narrow diameter (ND) and two regular diameter (RD) ISBs for the right and left sides, respectively. The ISBs were attached to the respective implant analogues and hand tightened according to the manufacturer’s recommendations (Fig. 1B and 1C). All required scans were performed in one single experimental period, before the detachment of the ISBs.

EOS and IOS scans

An optical laboratory EOS and a confocal technology-based dental IOS were used for the purpose of this study. The manufacturer’s calibration instructions and relative scanning workflows were followed for each device. Eleven scans (S1-S11) using both the EOS and IOS were acquired for each of the following: the original cast (No implants or ISBs), master cast with

TI ISBs, and master cast with PEEK ISBs. This produced a total of 66 scans for the three-dimensional (3D) comparisons (Fig. 2).

Software, overall and specific precisions

The international organization for standardization (ISO) 5752 uses two terms, "precision" and "trueness", to describe the accuracy of a measurement method. "Precision" refers to the closeness of agreement between test results. "Trueness" refers to the closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference value. In this study, only accuracy assessment in terms of precision assessment was considered.

For validity testing of the inspection and metrology software, a software precision was conducted. To evaluate the software precision, both the reference and test scans were the same scan, i.e., the same scan was superimposed on itself. This was repeated three times only since identical readings were obtained (n=3) and no inferential statistics will be performed. For this study, only the first scan (S1) and the fifth scan (S5) from each ISB set were used to assess the software precision (Fig 3). Ideally, the RMS should record zero as there should be no difference between the scan and its superimposed identical scan.

To measure overall and specific precisions of both the EOS and IOS for testing the four null hypotheses, the first scan of each set of scans (S1) was considered the reference scan whilst the remaining 10 scans across the same set were considered the test scans (S2-S11) which gives 10 samples per group (Fig 3). In the overall precision testing, all scan data were considered including the ISB data and remaining teeth while in the specific precision, only ISB data were compared without the teeth.

3D comparisons (superimpositions)

All scans were imported into a 3D inspection and metrology software for evaluation. Initially, all scans were trimmed to remove extraneous and excess data, so only teeth and ISBs were left. A specific workflow was followed to compare test scans against their respective reference scans. For each 3D comparison the ‘reference scan’ (S1) was imported first and data segmentation was performed to allow for selection of either teeth or ISB data (Fig. 4A). The ‘test scan’ was then imported into the software (Fig. 4B) and aligned to the ‘reference scan’ using the ‘initial’ alignment tool, followed by the ‘best fit’ alignment tool. The segmented teeth data were used as the reference for the ‘best fit’ alignment (Fig. 4C-E). Figures 4F and 4G illustrate the overall deviation and specific deviation, respectively, that compared scan data between the ‘test’ and ‘reference’ scans.

For the 3D comparisons to assess overall deviation, both teeth and ISBs data were used. This ensured that the differences between no ISB and the different ISBs could be assessed for each of the scanners. For specific deviation, only the ISBs data were used. This enabled a comparison between the different diameters and materials of the ISBs.

A total of 164 3D comparisons were conducted using the inspection software of which 24 3D comparisons were used to validate the software precision while the remaining 3D comparisons (N=140, distributed across 14 groups) were used to test the four null hypotheses for both the overall and specific precisions. Figure 3 is a flow chart of the 3D comparisons that illustrates the formation of the experimental groups.

Root mean square value calculations

For each 3D comparison, the software calculated the deviation values of the vertexes in the test scan data. Every test vertex is defined by a test position (P_t) and is associated with a reference position (P_r), which defined by the projection direction (shortest).

$$P_t = \langle x_t, y_t, z_t \rangle,\ P_r = \langle x_r, y_r, z_r \rangle$$

For each test point the software calculated a gap vector (*GV*), which is a vector that goes from the P_r to P_t.

$$GV = \langle x_t - x_r, y_t - y_r, z_t - z_r \rangle$$

This gap vector is then converted to a scalar magnitude called the gap distance (or deviation). Gap distance is the deviation value at any given point. If the test point is on the negative side of the reference data, the gap distance is given a negative value.

$$D = \sqrt{{GV_x}^2 + {GV_y}^2 + {GV_z}^2}$$

Average (*A*) is the arithmetic mean of all the gap distances. *n* represents the number of points in the 3D comparison.

$$A = \frac{1}{n} \sum_{i=1}^{n} D_i$$

However, to avoid the influence of the direction of the deviations on the magnitude of all deviations, the root mean square which is a measure of the magnitude of all deviation values (regardless of the direction) was calculated.

$$RMS = \sqrt{\frac{1}{n} \sum_{i=1}^{n} {D_i}^2}$$

Power analysis, sample size calculation and statistical analysis

Power analysis was performed to determine the appropriate sample size. A standard deviation of 16.78 µm was calculated from a pilot study. Calculated effect size d was 1.43. A priori test showed that 10 samples per group would be needed to achieve a power of 80% (α=.05). Sample size was limited to 3 (n=3) in the software testing groups as identical readings were obtained within each group and only descriptive statistics were considered.

As the RMS value is the root of a squared value, normal distribution of data was not assumed. Data were imported into the statistical software to analyze the results. Descriptive and inferential statistics, the Kruskal-Wallis test and pairwise Wilcoxon rank sum test with Bonferroni adjustment, were performed (α=.05).

RESULTS

Within the chosen setting of inspection software, the 3D comparisons of the scans performed by the EOS showed perfect software precision with a mean RMS value of 0 µm (4 groups). However, less consistent findings in software precision were seen in the 3D comparison groups for scans made with the IOS. The average RMS for IOS groups was 0.45 ±0.71 µm (4 groups).

The mean and median RMS values of the groups of 3D comparisons used to test the overall and specific precisions are illustrated in table 1. A boxplot of the overall precision RMS values for both the EOS and IOS comparing 'No ISB', 'TI ISBs' and 'PEEK ISBs' is presented in figure 5. There was a significant difference ($p<.05$) between the groups with and without ISBs. Consequently, the null hypotheses that there would be no difference in the overall precision between the EOS groups (H_{0i}) and the IOS groups (H_{0ii}) with and without the TI or PEEK ISBs were rejected. The EOS had the highest overall precision across all groups when scanning the cast with no ISB (original cast).

Figure 6 illustrates the results from the 3D comparisons for the groups evaluating the specific precision of the EOS and IOS. It shows the combined effect of varying material (TI or PEEK) and diameter (RD or ND) of the ISBs and the significance levels for the inferential statistics of testing the null hypotheses and pairwise comparisons. The null hypotheses for both the EOS (H_{0iii}) and the IOS (H_{0iv}), that there would be no difference between the groups when varying the diameter and material of the ISBs were rejected. Interestingly, an inverse relationship between the EOS and IOS for specific precision of the four groups was illustrated. Additionally, it should also be noted that rotational misalignment was evident with EOS scanning workflow of ND PEEK ISBs (Fig. 7)

DISCUSSION

The aims of this study were to determine if the use and combined effect of varying material and diameter of two commercially available ISBs impacted on the level of accuracy of digital scans using either an EOS or IOS.

In this study, a cast with tooth-bounded partially edentulous areas was selected so that teeth could be used as a reference to aid the alignment or 'best fit' process (excluding ISBs data). This arrangement was employed to avoid possible deviation of the test scans when aligned to the reference scan. The superimposition assessment technique (3D comparison) was adopted for this study because it requires minimal intervention and hence may help to reduce any possible measurement errors. In comparison, other studies have utilized linear measurements between single specified points on ISBs.[11, 18, 33] This technique has its shortcomings as it does not reflect the deviation due to any possible rotational misalignment of the test scan to the reference scan which was evident during this study (Fig. 7). Whilst neither technique can be directly translated to the amount of marginal discrepancy, which is more clinically relevant, this study illustrated that superimposition allows all deviations of point clouds to be recorded to get a more comprehensive assessment.

Precision testing of the software was conducted first. Based on the results; the software precision was considered excellent for scans made with the EOS (RMS=0). The IOS groups recorded a slightly higher but acceptable RMS value (0.45 ±0.71 µm). These results validated the performance of the inspection and metrology software for the 3D comparisons.

The overall precision of a digital impression is important because it evaluates the whole scan and allows a better understanding of the influence of the use of ISBs versus no ISBs (Fig. 5). To the authors' best knowledge, none of the ISB studies previously published have investigated this effect.[11-22, 33] Based on the finding of our study, the utilization of ISBs did not improve the overall precision of the scans by providing more reference points during the stitching process of images to construct 3D virtual casts. The scans of the casts using ISBs had reduced overall precision when compared against the cast without ISBs. In fact, this analysis suggests that the utilization of ISBs resulted in a reduction of the overall precision. Consequently, casts fabricated with stone material only led to less systematic errors during scanning compared to the casts with ISBs made from titanium or polymer.[22] However, this analysis will not eliminate the need for ISBs to transfer the location of the implants but shed the light to the actual effect of using ISBs on the overall scan accuracy.

The present study also showed an inverse relationship in precision between the scans with the different ISBs and the type of scanner (Fig. 5). The EOS overall precision was better when TI ISBs were used whilst for the IOS the overall precision was better when PEEK ISBs were used. This could be attributed to the difference in light source between the scanners for example monochromatic blue and polychromatic white lights, and/or the optical properties of the ISB materials for example light reflection and absorption. Nevertheless, the EOS overall precision and predictability (demonstrated by the narrow distribution) remain better than the IOS.

The specific precision of the scans represented by the deviations of the ISBs data only without the influence of the rest of the scan data was evaluated to determine the combined effect of varying the diameter and material of the ISBs (Fig. 6). Interestingly, an inverse relationship was noted with respect to the ISBs' material and diameter. That is, the EOS specific precision was in the order RD TI > ND TI > RD PEEK > ND PEEK whilst the IOS specific precision followed the opposite order (ND PEEK > RD PEEK > ND TI > RD TI). Subsequently, given the results for both the specific and overall precision, this suggests a relationship, not only between the ISBs material and the precision of the scanner, but also the influence of the diameter on the precision of the scans.

Any trueness assessment based on the ISO definition would require the use of independent method of scanning that is extremely accurate to generate an accurate reference scan to which test scans will be compared. Despite the documented high level of accuracy for EOS scanners, the majority of studies which have used a reference scanner did not attempt to investigate whether or not the reference scanner was influenced by the test conditions.[12-21] In the current study, the EOS documented scanning precision reported by the manufacturer was between 10-12 μm but based on the current study precision tests, the EOS scans were significantly affected by the test conditions through varying the ISB's material and diameter as discussed above. This would make the EOS unreliable as a reference scanner. Therefore, although being conducted the trueness results were not included. The current study strongly suggests that a validity confirmation for the use of any reference scanner is needed. This can be achieved with conducting a precision test under the proposed test conditions for any reference scanner as shown in the current study. The precision assessment should precede any trueness assessment. This is to assure researchers that the results are not influenced by the reference scanner itself. Similarly, reliance on manufacturers' reported levels of accuracy may be insufficient.

Of course, the findings of this study apply to the specific ISB brands and scanners investigated in this study only and generalization to other commercially available ISBs and scanners could not be possible without further investigations. This study is an in vitro study and clinical validation is still required.

CONCLUSIONS

Within the limitations of this in vitro study, the use of ISBs, varying the ISBs' material and diameter, as well as the type of scanner influenced the accuracy of the digital implant impressions. The following conclusions could be drawn:

- The use of ISBs led to a reduction in scan accuracy compared to the stone cast without ISBs.
- The EOS had a better mean overall precision than the IOS.
- The mean specific precision for the EOS scans was better when TI ISBs were used, and the diameter was regular (RD). In comparison, the mean specific precision for the IOS scans was better when narrow diameter (ND) PEEK ISBs were used.
- An inverse relationship was noted between the EOS and IOS when varying the ISBs' material and diameter in the following order RD TI, ND TI, RD PEEK, ND PEEK.
- The accuracy of any reference scanner might be influenced by the test conditions which will influence the reliability of trueness assessment. Therefore, precision assessment of the reference scanner should always be performed under the proposed test conditions.

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MANUFACTURERS' DETAILS

Silicone (Gemini; Bracon Limited, Heathfield, United Kingdom)

Dental stone (DENTSTONE KD; Saint-Gobain Formula, Newark, United Kingdom)

Narrow (NC) and Regular (RC) platforms (Narrow CrossFit and Regular CrossFit, Bone Level Implant Analogues; Straumann, Basel, Switzerland)

Impression posts (long NC and RC impression posts; Straumann, Basel, Switzerland)

Light and heavy bodied polyvinylsiloxane impression material (Aquasil Ultra; Dentsply Sirona, York, PA, United States).

Silicone gingival mask (Gingifast Elastic; Zhermack S.p.A, Badia Polesine RO, Italy)

Type IV dental stone (Silky-Rock; Whip Mix®, Louisville, KY, United States)

Titanium ISBs (Scanbodies: REF L1400 and REF L1410; MEDENTiKA GmbH, Hügelsheim, Germany)

PEEK ISBs (Straumann CARES Mono Scanbody: REF 025.2915 and REF 025.4915; Straumann, Basel, Switzerland)

Optical laboratory EOS (E1; 3Shape, Copenhagen, Denmark)

Confocal technology-based dental scanner (Trios 3; 3Shape, Copenhagen, Denmark)

3D inspection and metrology software (Geomagic® Control X 2018; 3D Systems, Rock Hill, SC, United States)

Statistical software (IBM SPSS software, version 25; IBM©, Armonk, NY, United States)

Statistical software (RStudio, version 1.4.1103: Integrated Development for R; RStudio, PBC, Boston, MA, United States)

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TABLES

Table 1. Mean, standard deviation (SD) and median values for the root mean square (RMS) values (µm) for the overall and specific precisions of the EOS and IOS.

Overall precision					
	EOS			IOS	
Group	**Mean (SD)**	**Median**	**Group**	**Mean (SD)**	**Median**
No ISB	15.96 (1.67)	15.40	No ISB	56.87 (14.94)	53.35
TI ISBs	21.68 (3.48)	20.40	TI ISBs	113.05 (16.78)	109.62
PEEK ISBs	57.57 (3.98)	57.90	PEEK ISBs	76.16 (14.18)	70.25
Specific precision					
	EOS			**IOS**	
Group	**Mean (SD)**	**Median**	**Group**	**Mean (SD)**	**Median**
RD TI	39.54 (6.27)	38.60	RD TI	148.44 (23.03)	146.95
ND TI	92.5 (4.21)	92.80	ND TI	108.41 (36.67)	102.40
RD PEEK	103.05 (15.61)	105.45	RD PEEK	91.07 (32.60)	87.60
ND PEEK	109.35 (7.56)	108.00	ND PEEK	69.12 (17.04)	66.15

EOS, extraoral scanner. IOS, intraoral scanner. TI, titanium ISB. PEEK, polyether ether ketone ISB. ND, narrow diameter ISB. RD, regular diameter ISB.

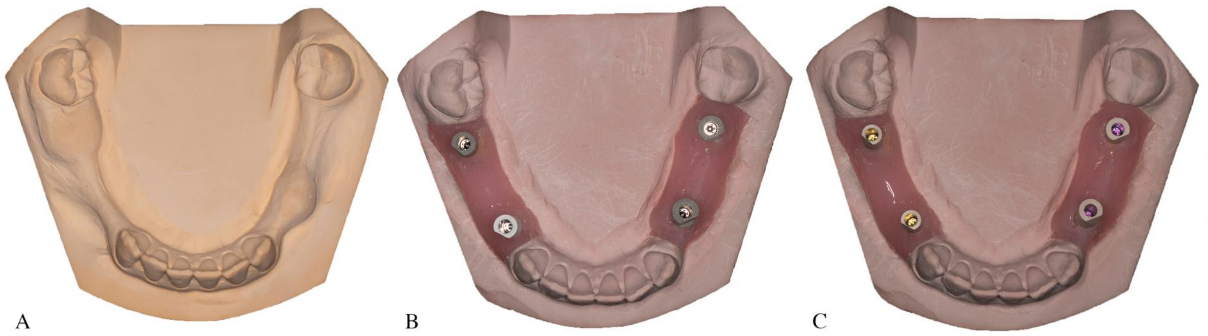

Fig. 1. Casts. A) Original Cast, B) Master Cast with TI ISBs, C) Master Cast with PEEK ISBs.

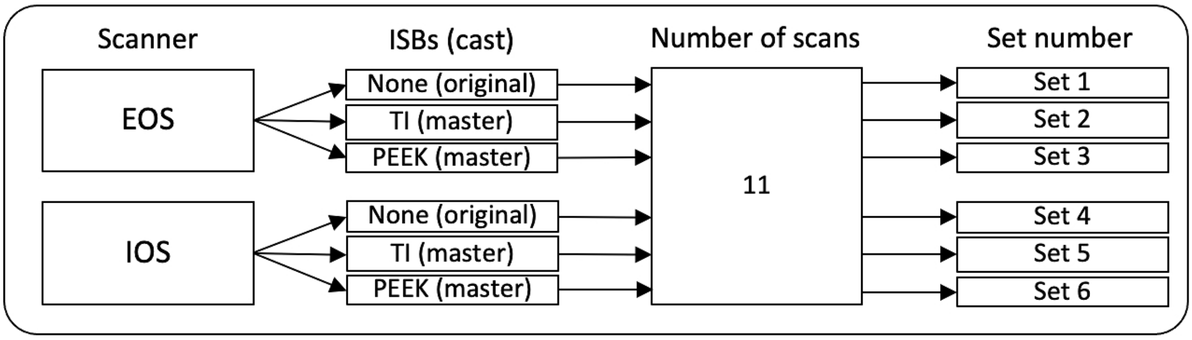

Fig. 2. Flow chart of EOS and IOS scans.

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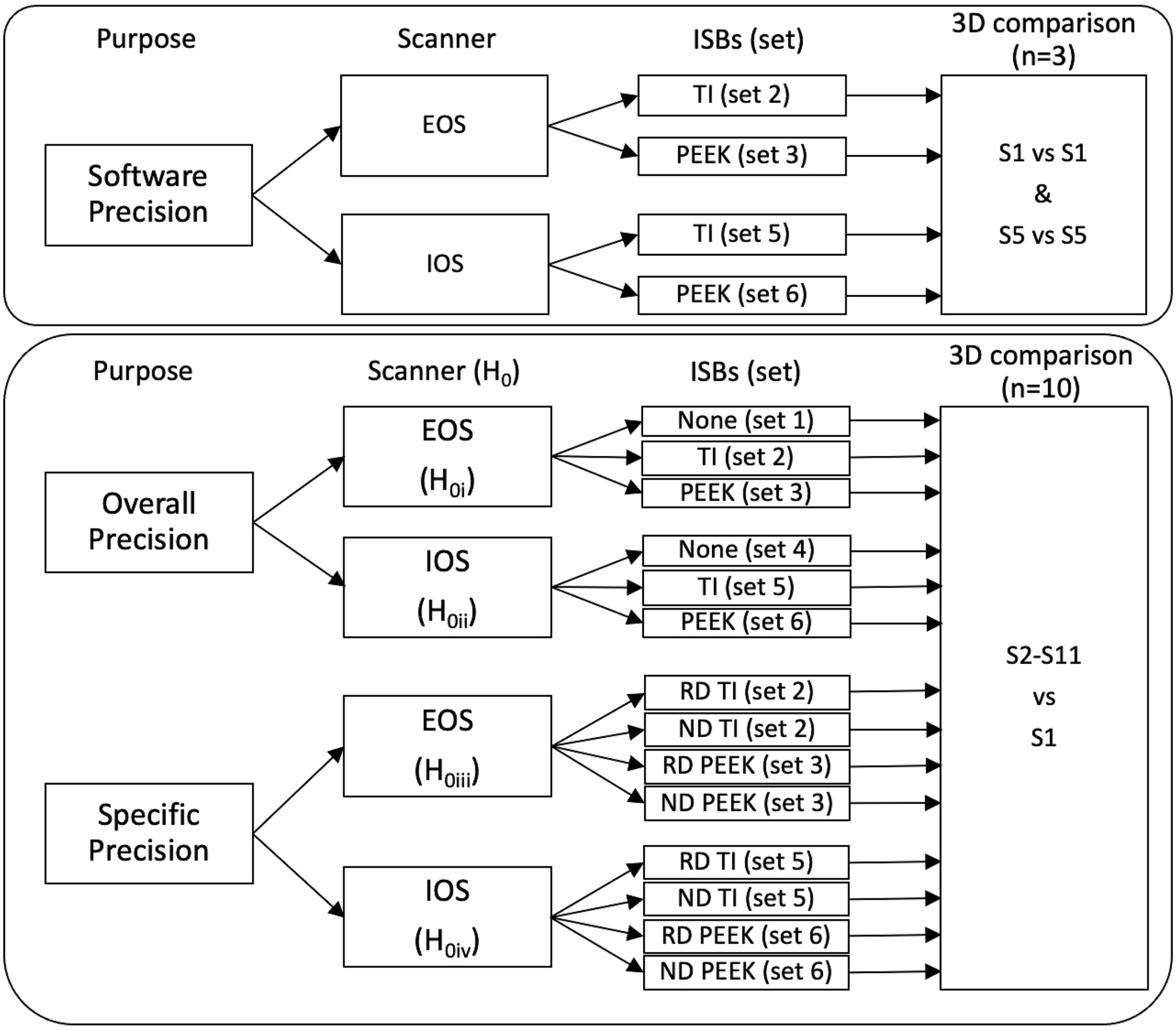

Fig. 3. Flow chart of 3D comparisons.

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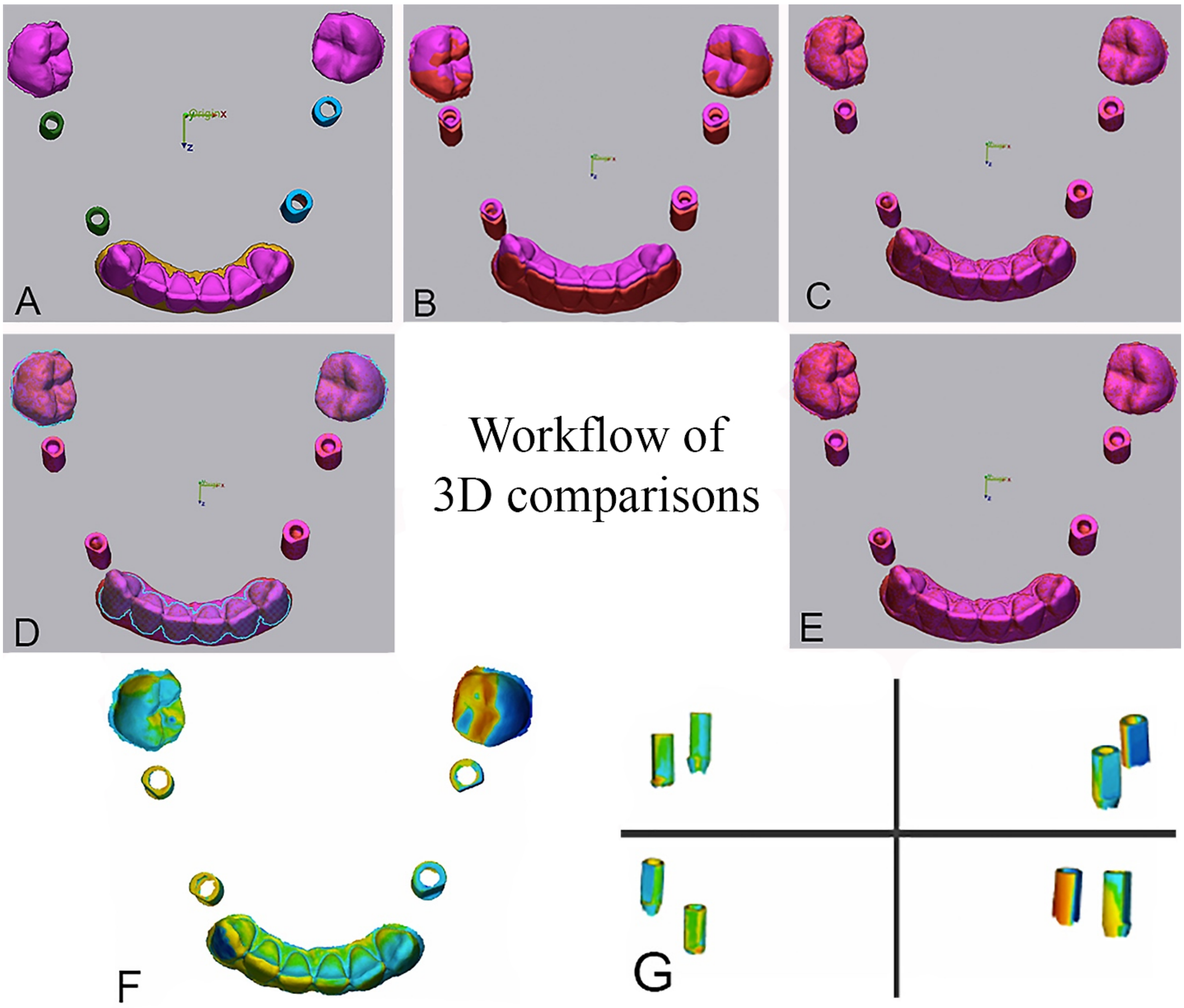

Fig. 4. Workflow of 3D comparisons. A) Reference data segmented into three color-coded regions, B) Test and reference data not yet aligned, C) Initial alignment, D) Selection of segmented data (teeth) prior to Best-Fit alignment, E) Best-Fit alignment, F) Color-coded map illustrating overall deviation, G) Specific deviations around ND, left, and RD, right, ISBs were investigated separately.

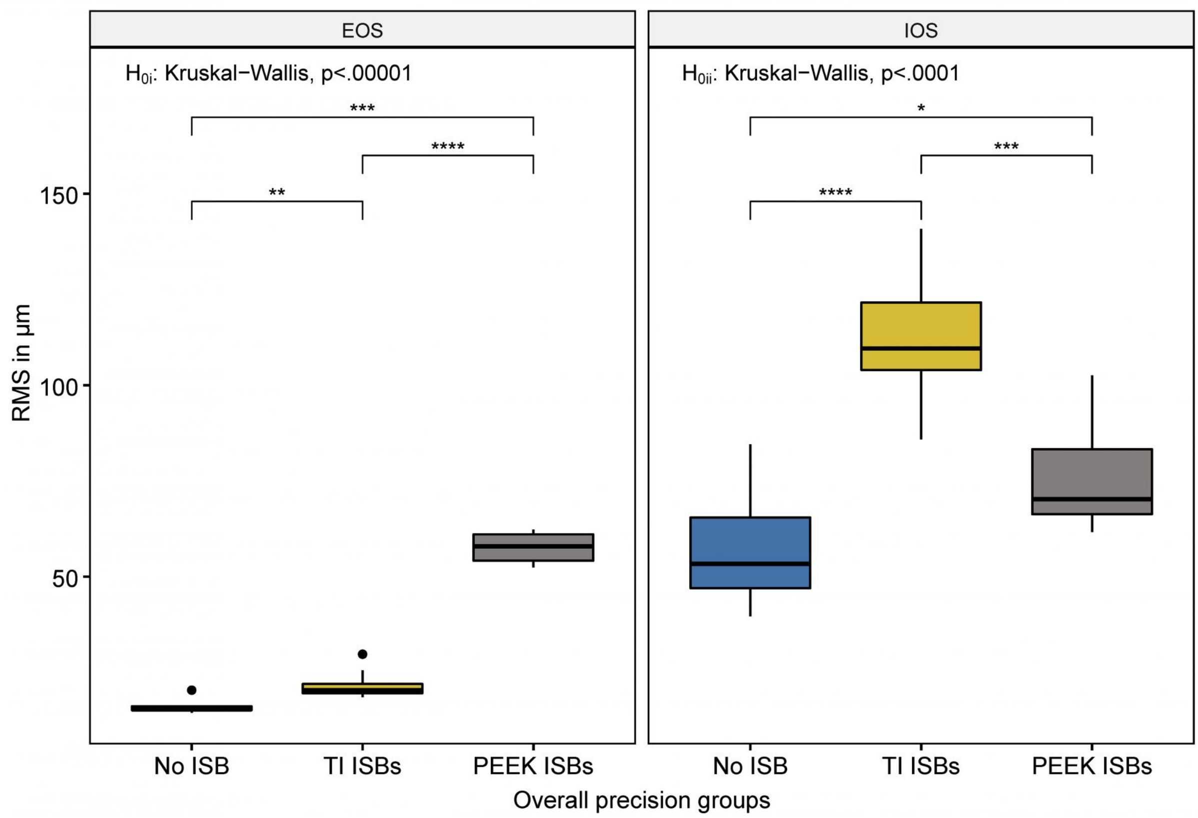

Fig. 5. Boxplot of the groups used to test the overall precision of the EOS and IOS scans. Statistically significant nonparametric Kruskal-Wallis test statistics (α=.05) and pairwise Wilcoxon rank sum test comparisons values adjusted by Bonferroni correction for multiple tests are displayed. *: p≤.05, **: p≤.01, ***: p≤.001, ****: p≤.0001

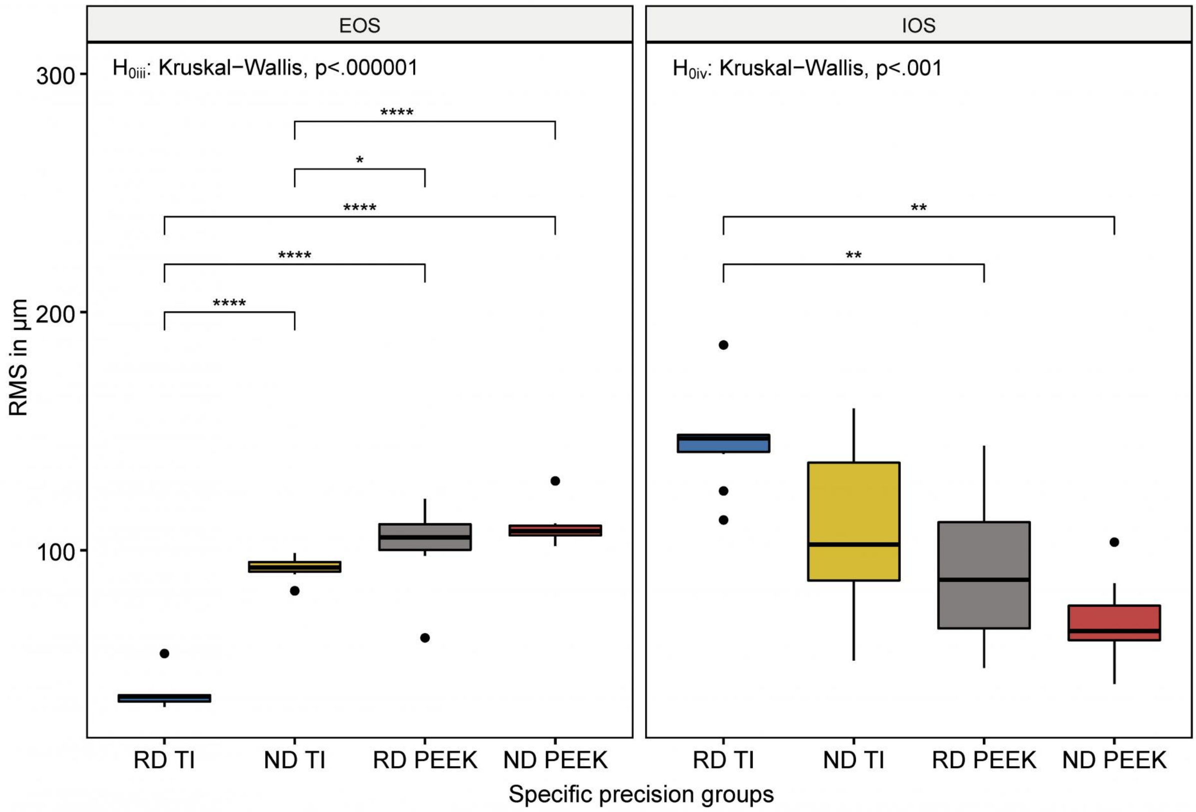

Fig. 6. Boxplot of the groups used to test the specific precision of the EOS and IOS. Statistically significant nonparametric Kruskal-Wallis test statistics (α=.05) and pairwise Wilcoxon rank sum test comparisons values adjusted by Bonferroni correction for multiple tests are displayed. *: p≤.05, **: p≤.01, ***: p≤.001, ****: p≤.0001

Figure 7

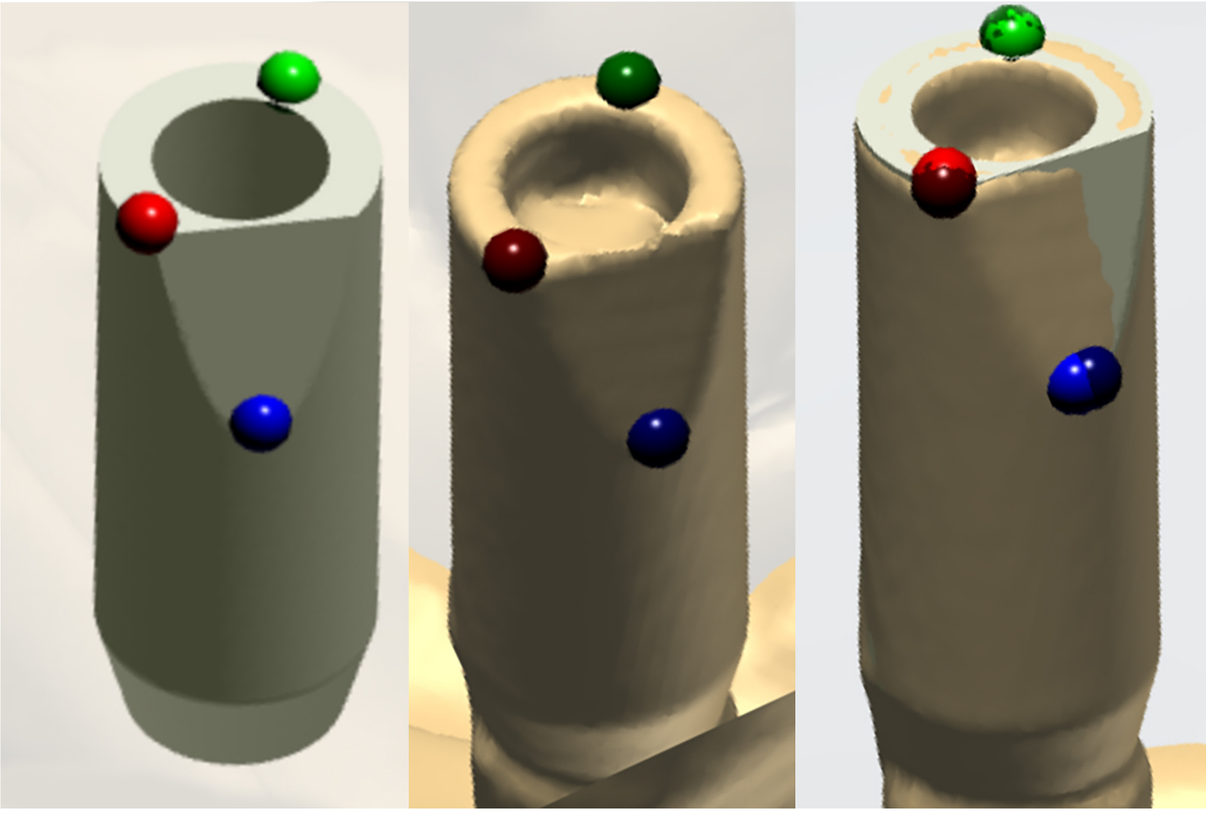

Fig. 7. Rotational misalignment was frequently seen. An example from the EOS scanning workflow of ND PEEK ISBs is illustrated.

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Fig. 2. Flow chart of EOS and IOS scans.

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Fig. 3. Flow chart of 3D comparisons.

Figure 4 - Download source file (958.99 kB)
Fig. 4. Workflow of 3D comparisons. A) Reference data segmented into three color-coded regions, B) Test and reference data not yet aligned, C) Initial alignment, D) Selection of segmented data (teeth) prior to Best-Fit alignment, E) Best-Fit alignment, F) Color-coded map illustrating overall deviation, G) Specific deviations around ND, left, and RD, right, ISBs were investigated separately.

Figure 5 - Download source file (1.41 MB)
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Figure 6 - Download source file (1.46 MB)
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Figure 7 - Download source file (416.86 kB)
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