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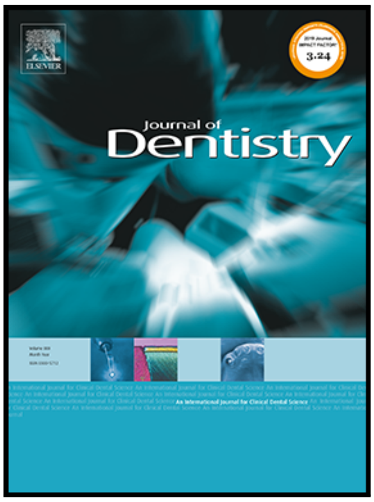

Effect of measurement techniques and operators on measured deviations in digital implant scans

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Effect of measurement techniques and operators on measured deviations in digital implant scans

Short title: Implant scan deviations based on technique and operator

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HIGHLIGHTS

1. Point-based measurement technique resulted in lower deviations.

2. Different operators' measurements had correlation when point-based technique was used.

ABSTRACT

Objectives: To evaluate the effect of different measurement techniques and operators on measured deviations in in vitro implant scans.

Methods: A 2-piece system that comprises a healing abutment (HA) and a scan body (SB) was mounted onto an implant at right first molar site of a polymethylmethacrylate mandibular dentate model. Model was digitized by using an industrial scanner (reference model scan, n=1) and an intraoral scanner (test scan, n=20). All standard tessellation language files were imported into a 3-dimensional analysis software and superimposed. Three operators with similar experience performed circle-based and point-based deviation analyses (n=20). Deviations measured with different techniques were compared with paired samples t-test within each operator, while the reliability of the operators was assessed by using F-tests for both technqiues (α=.05).

Results: Point-based technique resulted in lower deviations than circle-based technique for all operators (*P*=.001) with to higher reliability among operators (ICC=.438, P=.001). The correlation among the operators was nonsignificant when circle-based technique was used (ICC=.114, P=.189).

Conclusion: Lower deviations were detected with the point-based technique. In addition, different operators' measurements had higher correlation when point-based technique was used compared with circle-based technique.

Clinical Significance: Point-based technique may be preferred over circle-based technique for research studies on scan accuracy of implants, given its higher reliability. The accuracy of measured deviations may increase if the number of planes are increased, which can facilitate point generation at different surfaces of the scan body.

INTRODUCTION

Incorporation of digital technologies into dentistry has facilitated the use of intraoral scanners (IOSs) [1]. Digital scans have advantages over conventional impressions such as the elimination of impression trays and impression materials, increased patient comfort, and efficient communication with the dental technician [2, 3]. Therefore, a wide range of dental applications are becoming digitized [4], including those in implant prosthodontics [5].

Advancements in digital technologies have also enabled accuracy evaluation by using 3-dimensional (3D) technologies [6]. For accuracy evaluation, a digital scan is superimposed over a reference scan [7] by using a compatible software [8]. An accurate impression is vital for implant-supported restorations considering biological and mechanical complications that could be encountered if passive fit is not achieved [9]. Thus, accuracy of digital implant impressions has been broadly investigated and various factors were reported to be influential [10-13]. There are various techniques to evaluate the accuracy of an implant scan and either the entire scan body (SB) surface or only selected points, angles, and areas of specific interest have been used during analyses [10]. However, because the results may be affected by evaluation technique used, comparison of findings of similar studies becomes complicated. A standardized evaluation technique for implant scan accuracy analyses could enable more reliable comparisons.

Recent studies on scan accuracy of single implants digitized by using the same SB have reported 2 different techniques that were either based on circular planes [14-17] or points [10] generated to measure distance deviations. However, to the authors' knowledge, no study has investigated the effect of these 2 techniques on measured deviations. In addition, the effect of operator has not been evaluated while using either one of those techniques. Therefore, the present study aimed to compare the measured deviations of a SB when 2 different measurement techniques were used, and the repeatability of the measured deviations when performed by 3 operators. The null hypotheses were that i) measurement technique would not affect the measured deviations in the scans of a SB within operator and ii) operator would not affect the measured deviations in SB scans within measurement technique.

METHODS

As described in previous studies [14-16], a mandibular dentate model was prepared by using auto-polymerized polymethylmethacrylate (Weropress; Merz Dental GmbH). One implant (4.0 mm×11 mm, Neoss ProActive Straight; Neoss Implant System, Harrogate, England) was placed in mandibular model at right first molar site. A 2-piece system that consists of a polyetheretherketone healing abutment (HA) and a medical grade acrylic resin scan body (SB, ScanPeg; Neoss Implant System, Harrogate, England) that is fitted into HA's screw access hole was placed onto the implant [18]. The SB has an outdent that allows its proper fit into the groove present on the HA by friction.

The model was digitized by using an industrial blue-light scanner (ATOS Core 80 5MP; GOM GmbH, Braunschweig, Germany) to generate a reference model (RM) and by using an IOS (CEREC Primescan; Dentsply Sirona, Bensheim, Germany) to generate a test-scan (TS) (n=20), in standard tessellation language (STL) format. Manufacturer's recommended scan pattern was implemented starting from lingual surfaces, followed by capturing of occlusal and buccal surfaces [15]. A thin layer (2 µm) of scan powder was applied to the surface of the model to facilitate scanning prior to data acquisition and this layer was not altered until all scans were completed [14-17].

RM-STL and TS-STL files were imported into a metrology-grade 3D analysis software (GOM Inspect 2018; GOM GmbH, Braunschweig, Germany) for deviation analyses. TS-STL was superimposed over the RM-STL by using best-fit algorithm feature of the software. Prealignment feature was used for the initial alignment, which was followed by the local best fit feature to minimize errors [19].

Deviation measurements were performed by 3 different operators (operator 1, operator 2, and operator 3) with similar experience in deviation analysis. The operators performed 10 evaluations before the actual analyses for training. Operators performed deviation measurements on 20 scans by using 2 different techniques.

For measurements with circle-based technique [14-16], flat planes at the top of the SB were generated in both RM-STL and TS-STL. These flat planes were generated by selecting 3 points on top of the SB to ensure that they were parallel to the top surface. Then, parallel to these planes, 4 additional circles that were 1 mm apart from each other were generated on the SB. Analysis software did not allow an overlap between the flat plane and parallel circles. Therefore, the first circle was generated 0.1 mm below the flat plane to ensure that it was as close as possible to the top of the SB within software's limitations (Figure 1). The analysis software automatically calculated linear deviations between all surface points on the outline of corresponding circle in RM-STL and TS-STL files on x, y, and z axes by using Gaussian best-fit method. These values were used to calculate 3D distance deviations by using the formula below [19] and mean deviation values of these 4 circles were used for statistical analysis:

$$3D=(\sqrt{x^2+y^2+z^2})$$

After completing circle-based measurements, a buccolingually oriented plane that passes through the center of the top surface of the SB was generated for point-based measurements. Eight points (4 on the buccal side and 4 on the lingual side of the SB) located at the intersection of buccolingual plane and 4 circles used in circle-based technique were selected (Figure 2). Then, the software algorithm calculated 3D distance deviations of these points generated both on RM-STL and TS-STL. Mean deviation values of these 8 points were used for the statistical analyses.

A statistical analysis software was used to evaluate the data (R v3.6.1; R Core Team 2021, Vienna, Austria). Paired samples t-tests were used to compare the deviations measured by using different techniques within each operator. Inter-rater reliability between the operators for each technique was assessed with intraclass correlation by using F-tests. All analyses were performed at a significance level of α=.05.

RESULTS

Table 1 lists descriptive statistics of both measurement techniques within each operator. Paired samples t-tests revealed that point–based technique resulted in significantly lower deviations than circle-based technique for all operators (*P*=.001 and estimated difference in means: 52.34 µm for operator 1, *P*=.001 and estimated difference in means: 36.53 µm for operator 2, *P*=.001 and estimated difference in means: 84.11 µm for operator 3) (Figure 3).

F-tests showed significant correlation among the operators when point-based measurement technique was used, which indicates nearly moderate inter-rater reliability (ICC=.438, P=.001). No correlation was found among the operators when circle-based measurement technique was used (ICC=.114, P=.189).

DISCUSSION

The first null hypothesis was rejected as measurement technique resulted in significant differences within each operator. The operator had no significant effect on measured deviations when point-based technique was used, however, significant differences among the operators were observed when circle-based technique was used. Therefore, the second null hypothesis was also rejected.

Circle-based technique resulted in significantly higher deviations than point-based technique. It should be noted that only additional surface points on the circles were used for the deviation analyses in circle-based technique. Inclusion of these additional surface points in circle-based method may lead either to larger variations in deviations if selected points in point-based method do not contain outliers or to smaller variations if there are outliers. Points in point-based technique are selected by using the intersection of the buccolingually oriented plane and the circles. This led to a point selection on buccal and lingual surfaces of the SB, which were particularly accessible for the light during data acquisition with the IOS. Therefore, these points can be considered accurate. This could also be the reason for significantly lower influence of the operator while using point-based technique. Considering that these points were also included in deviation measurements while using circle-based technique, remaining surfaces on circles could be associated with higher deviations measured with circle-based technique. Those remaining surfaces included proximal areas that are particularly hard to scan. Scans of narrow spaces are challenging as IOSs may have lower scan resolution due to lower light access and lower point density [20]. Generating circles based on a lower number of surface points with an increased inter-point distance may have led to greater variability in generating circles and consequently to greater variability in measured deviations.

It can be speculated that the deviations measured with point-based technique would have been higher than those measured with circle-based technique if the points were chosen on the intersection of a mesiodistally oriented plane passing through the SB. If this assumption is correct, circle-based technique may result in more reliable deviation measurements, as it would include all areas of the SB whether light reaches the area or not. The scan region of a SB, which is the part that is used for the alignment between the SB mesh and the library file in CAD software, is accessible when the guidelines are followed to orientate it buccally or lingually during digital implant scans [9]. This means that the surface points from interproximal region, which are difficult to access during data acquisition, are not used for further data processing. In addition, the combined HA-SB system used in the present study is indicated for its HA to be fixed to the implant in a way that allows the outdent on the SB to face the buccal side [18]. Therefore, the point-based technique could be more clinically relevant than the circle-based technique. However, this interpretation should be analyzed carefully as the present study evaluated the influence of deviation measurement technique on measured deviations in digital implant scans, which has no effect on the quality of the scan. Rather than having clinical conclusions, the present study aimed to investigate whether direct comparisons between studies that use different analysis methods is applicable or not. For a clinical conclusion, in vivo studies on the accuracy of IOSs should include comparisons with conventional impressions as they have shown their applicability for the fabrication of implant-supported restorations [21].

Previous studies on the discrepancy between corresponding surface datasets have shown that software, superimposition algorithm, and operator may affect measured deviations [8, 22-24]. In the present study, a single software, with the same superimposition algorithm for all analyses, was used to analyze solely the effect of measurement technique and operator on measured deviations. The applied software and the superimposition algorithm have been widely used for deviation analyses [8, 10, 24, 25]. Using an industrial-grade structured light scanner to obtain reference dataset was described as one of the most reliable methods available [26]. In addition, the IOS used for test scans has been demonstrated to be one of the most accurate scanners available [27]. However, it should be noted that it is not possible to quantify the accuracy of both scanners used in the present study as different analyses methods are needed for such measurements. Nevertheless, data acquisition does not have an effect on the results of the present study as the same corresponding test and reference scans were used for both techniques. The scan spray used to digitize the models was applied only once; thus, possible deviations caused by inconsistent thicknesses of the powder on the surface was standardized. In addition, the SB, which is susceptible to manufacturing tolerances was always kept in place. Therefore, possible effect of these 2 factors on measured deviations was eliminated [28, 29]. Considering these efforts to minimize the influence of other factors, the differences shown could most likely be attributed to different measurement techniques used.

A limitation of the present study was the lack of additional comparisons by selecting surface points on the intersection of a mesiodistally oriented plane and the circles generated. Such analysis would be ideally suited for a follow-up project to identify and elaborate the differences between the tested techniques. In addition, it would be interesting to compare the results to those from other frequently used deviation analysis methods such as the combination of global best-fit algorithm and root mean square. This would also facilitate establishing a standardized analysis procedure and having comparable results within different studies, which use different analysis protocols. The absence of a sample size calculation was another limitation of the present study. However, because detectable minimum significant differences between the tested techniques and between the operators within the circle-based technique can be considered clinically small, and the fact that number of measurements performed by each operator was more than those previous studies that have evaluated the scan accuracy of tested combined HA-SB system [10, 14-17], the statistical power is deemed sufficient.

CONCLUSIONS

Based on the limitations of the present study, following conclusions could be drawn:

1. Measurement technique had a significant effect on measured deviations and point-based technique led to the measurement of lower deviations for all operators.

2. Measured deviations performed by using the circle-based technique did not have correlation among tested operators, however, different operators' measurements had correlation when using the point-based technique.

The authors of the manuscript contributed in the following ways to the submitted manuscript:

Gülce Çakmak: Design, Data collection

Mustafa Borga Donmez: Drafting article, Critical revision of article

Canan Akay: Design, Data collection

Marcella Paula de Silva: Design, Data collection

Francesco Guido Mangano: Critical revision of the article

Samir Abou-Ayash: Drafting article

Burak Yilmaz: Critical revision of the article, Approval of the submitted and final versions

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.

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TABLES

Table 1. Descriptive statistics of measured deviations (µm) of each operator-technique pair

Technique	Circle-Based Technique	Point-Based Technique	*P*-value (Estimated difference)
Operator 1	110.71 ±51.71	58.38 ±34.66	.001 (52.34 µm)
Operator 2	93.09 ±54.34	56.56 ±35.04	.001 (36.53 µm)
Operator 3	144.24 ±121.56	60.13 ±32.77	.001 (84.11 µm)

*Different uppercase letters indicate significant differences between measurement techniques within operator ($P<.05$)

FIGURES

Figure 1. Circles generated for circle-based measurement technique

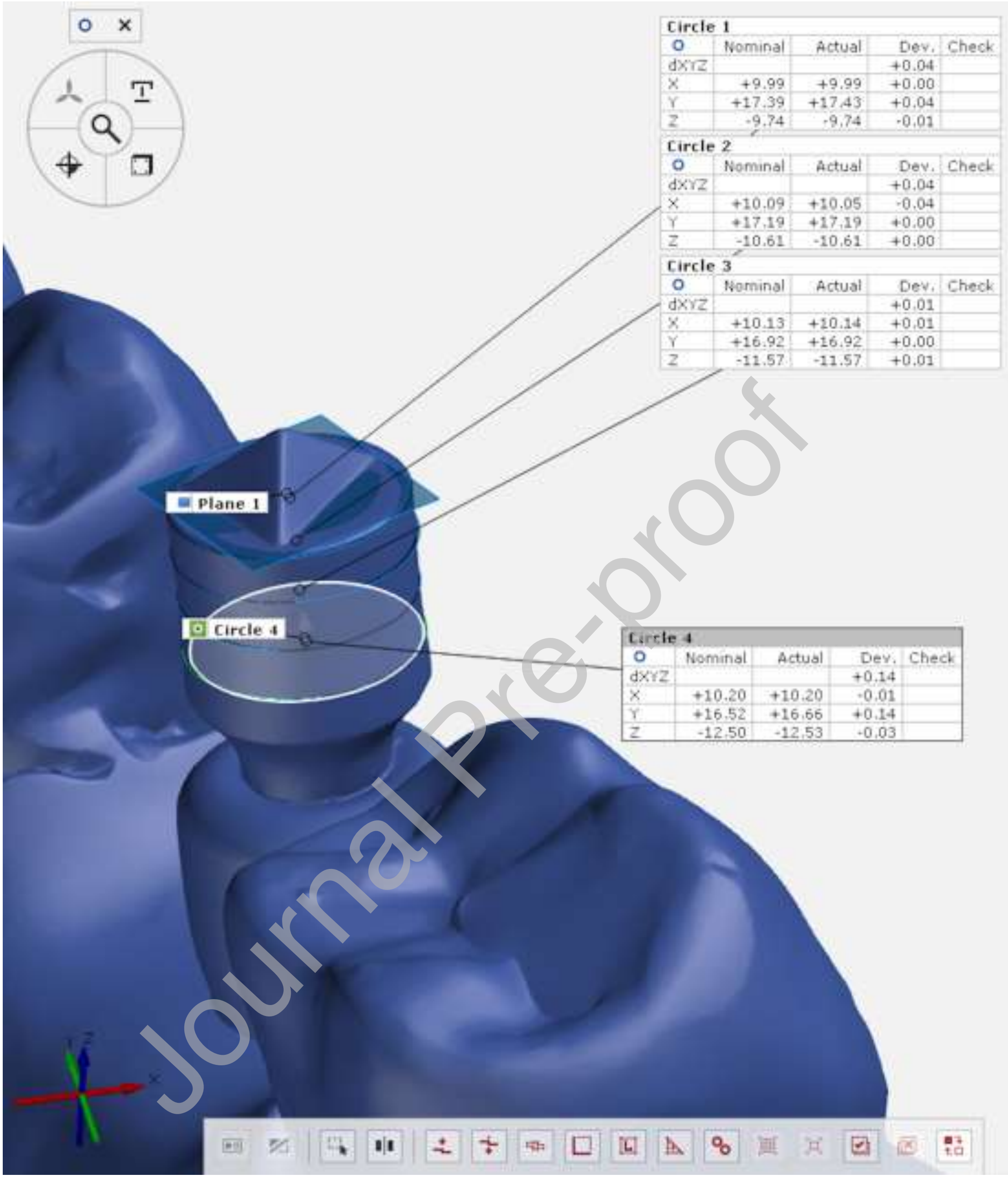

Figure 2. Buccolingually oriented plane generated for point-based measurement technique

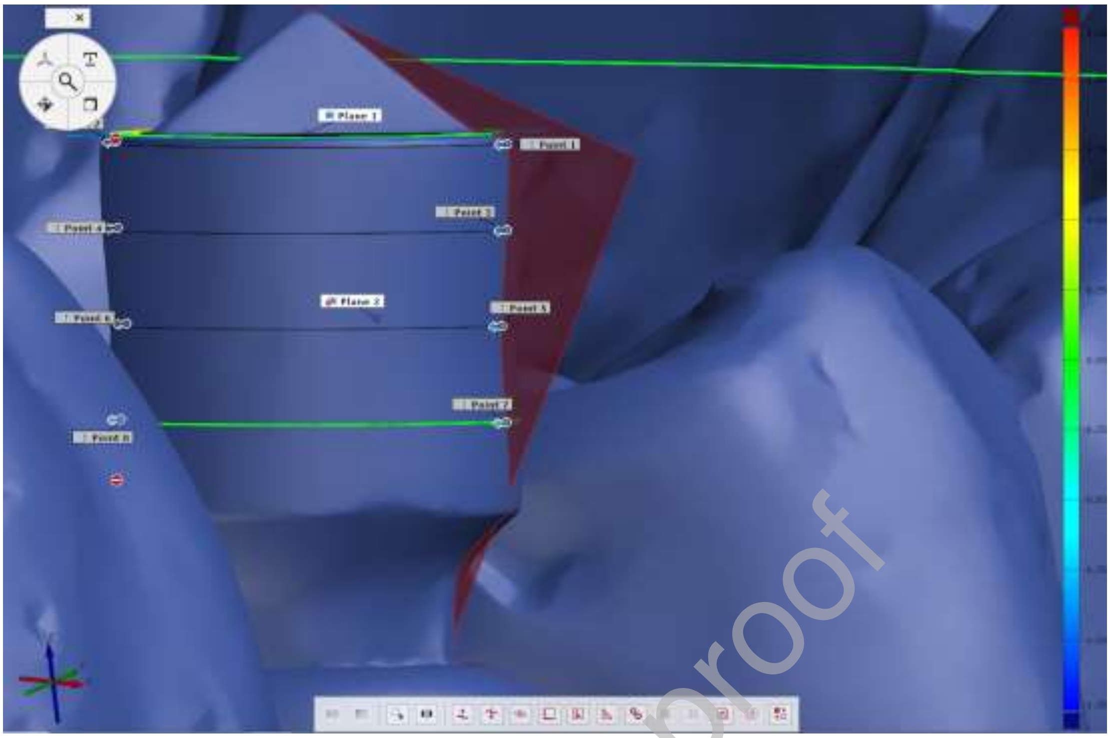

Figure 3. Points generated for point-based measurement technique

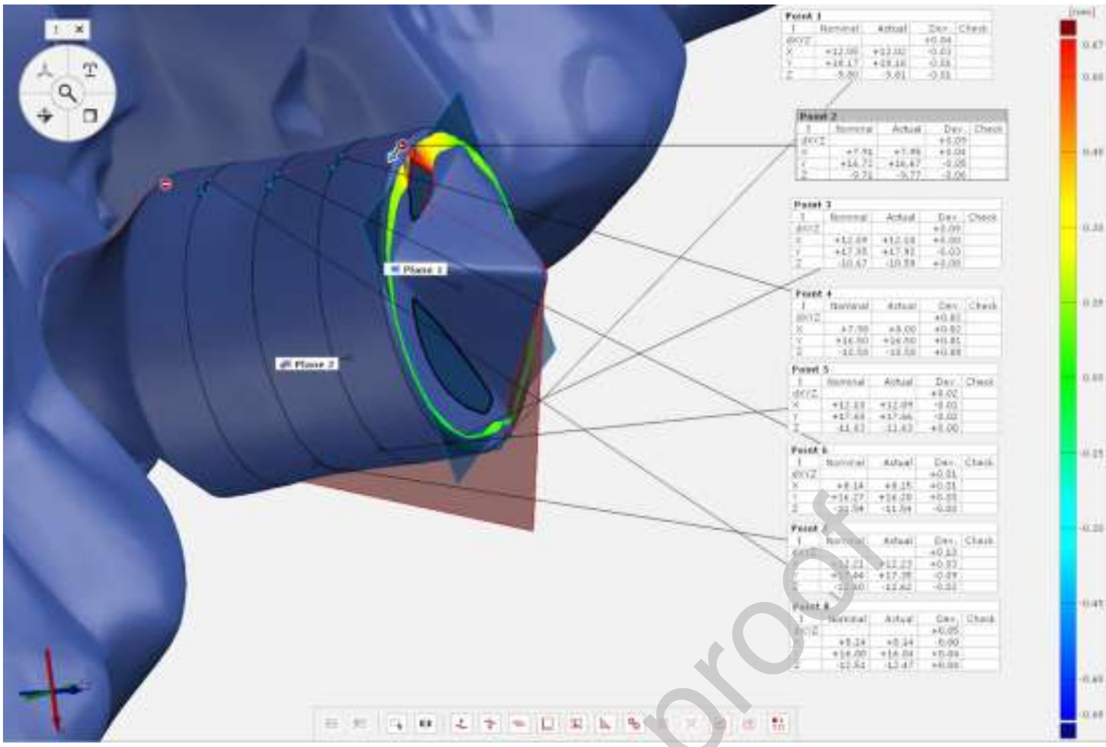

Figure 4. Box-plot graph of measured deviations (μm) for each operator-technique pair