

## Journal Pre-proof

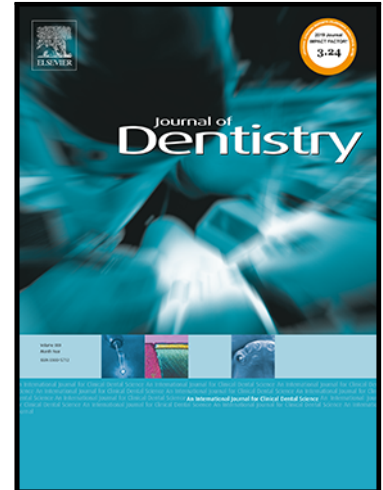
Effect of measurement techniques and operators on measured deviations in digital implant scans

Gülce Çakmak , Mustafa Borga Donmez , Canan Akay ,  
Marcella Paula de Silva , Francesco Guido Mangano ,  
Samir Abou-Ayash , Burak Yilmaz

PII: S0300-5712(22)00440-7

DOI: <https://doi.org/10.1016/j.jdent.2022.104388>

Reference: JJOD 104388



To appear in: *Journal of Dentistry*

Received date: 15 August 2022

Revised date: 21 November 2022

Accepted date: 6 December 2022

Please cite this article as: Gülce Çakmak , Mustafa Borga Donmez , Canan Akay ,  
Marcella Paula de Silva , Francesco Guido Mangano , Samir Abou-Ayash , Burak Yilmaz , Ef-  
fect of measurement techniques and operators on measured deviations in digital implant scans,  
*Journal of Dentistry* (2022), doi: <https://doi.org/10.1016/j.jdent.2022.104388>

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2022 Published by Elsevier Ltd.

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

**Short title:** Implant scan deviations based on technique and operator

**Authors:** Gülce Çakmak, DDS, PhD,<sup>a</sup> Mustafa Borga Donmez, DDS, PhD,<sup>b,c</sup> Canan Akay, DDS, PhD,<sup>d</sup> Marcella Paula de Silva, DDS, PhD,<sup>c,e</sup> Francesco Guido Mangano, DDS, PhD,<sup>f</sup> Samir Abou-Ayash, Dr med dent,<sup>g</sup> and Burak Yilmaz DDS, PhD<sup>h,i,j</sup>

<sup>a</sup>Senior Research Associate, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; guelce.cakmak@unibe.ch

<sup>b</sup>Assistant Professor, Department of Prosthodontics, Istinye University Faculty of Dentistry, Istanbul, Turkey

<sup>c</sup>Visiting Researcher, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; mustafa-borga.doenmez@unibe.ch

<sup>d</sup>Associate Professor, Department of Prosthodontics, Eskisehir Osmangazi University Faculty of Dentistry, Eskisehir, Turkey; cngcr2@hotmail.com

<sup>e</sup>PhD Student, Universidade Federal de Goiás, Department of Prevention and Oral Rehabilitation, Goiânia, GO, Brasil; mspmarcella@gmail.com

<sup>f</sup>Lecturer, Department of Pediatric, Preventive Dentistry and Orthodontics, Sechenov First State Medical University, Moscow, Russia; francescoguidomangano@gmail.com

<sup>g</sup>Senior Lecturer and Head of the Section of Digital Implant and Reconstructive Dentistry, Department of Reconstructive Dentistry and Gerodontology, University of Bern, Bern, Switzerland

<sup>h</sup>Associate Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

<sup>i</sup>Associate Professor, Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland; burak.yilmaz@unibe.ch

<sup>j</sup>Adjunct Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Ohio, USA

Corresponding author:

Dr Mustafa Borga Dönmez

Department of Reconstructive Dentistry and Gerodontology,

School of Dental Medicine, University of Bern,

Freiburgstrasse 7 3007

Bern, Switzerland

email: mustafa-borga.doenmez@unibe.ch

**Keywords:** Deviation, digital implant scan, measurement technique, operator

**Acknowledgments**

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

**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 techniques ( $\alpha=.05$ ).

**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  $\alpha=.05$ .

## 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:  $52.34 \mu\text{m}$  for operator 1,  $P=.001$  and estimated difference in means:  $36.53 \mu\text{m}$  for operator 2,  $P=.001$  and estimated difference in means:  $84.11 \mu\text{m}$  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 ( $\text{ICC}=.438$ ,  $P=.001$ ). No correlation was found among the operators when circle-based measurement technique was used ( $\text{ICC}=.114$ ,  $P=.189$ ).

## 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.

**REFERENCES**

- [1] F. Mangano, A. Gandolfi, G. Luongo, S. Logozzo, Intraoral scanners in dentistry: a review of the current literature, *BMC Oral Health* 17(1) (2017) 149. <http://doi.org/10.1186/s12903-017-0442-x>.
- [2] F.G. Mangano, O. Admakin, M. Bonacina, H. Lerner, V. Rutkunas, C. Mangano, Trueness of 12 intraoral scanners in the full-arch implant impression: a comparative in vitro study, *BMC Oral Health* 20(1) (2020) 263. <http://doi.org/10.1186/s12903-020-01254-9>.
- [3] F.G. Mangano, U. Hauschild, G. Veronesi, M. Imburgia, C. Mangano, O. Admakin, Trueness and precision of 5 intraoral scanners in the impressions of single and multiple implants: a comparative in vitro study, *BMC Oral Health* 19(1) (2019) 101. <http://doi.org/10.1186/s12903-019-0792-7>.
- [4] J. Latham, M. Ludlow, A. Mennito, A. Kelly, Z. Evans, W. Renne, Effect of scan pattern on complete-arch scans with 4 digital scanners, *J Prosthet Dent* 123(1) (2020) 85-95. <http://doi.org/10.1016/j.prosdent.2019.02.008>.
- [5] A. Schmidt, J.W. Billig, M.A. Schlenz, P. Rehmann, B. Wöstmann, Influence of the accuracy of intraoral scanbodies on implant position: differences in manufacturing tolerances, *Int J Prosthodont* 32(5) (2019) 430-432. <http://doi.org/10.11607/ijp.6371>.
- [6] B.Y. Yu, K. Son, K.B. Lee, Evaluation of intaglio surface trueness and margin quality of interim crowns in accordance with the build angle of stereolithography apparatus 3-dimensional printing, *J Prosthet Dent* 126(2) (2021) 231-237. <http://doi.org/10.1016/j.prosdent.2020.04.028>.
- [7] S. O'Toole, C. Osnes, D. Bartlett, A. Keeling, Investigation into the accuracy and measurement methods of sequential 3D dental scan alignment, *Dent Mater* 35(3) (2019) 495-500. <http://doi.org/10.1016/j.dental.2019.01.012>.
- [8] B. Yilmaz, V.R. Marques, M.B. Donmez, A.R. Cuellar, W.E. Lu, S. Abou-Ayash, G. Çakmak, Influence of 3D analysis software on measured deviations of CAD-CAM resin crowns from virtual design file: An in-vitro study, *J Dent* 118 (2022) 103933. <http://doi.org/10.1016/j.jdent.2021.103933>.
- [9] R.M. Mizumoto, B. Yilmaz, Intraoral scan bodies in implant dentistry: A systematic review, *J Prosthet Dent* 120(3) (2018) 343-352. <http://doi.org/10.1016/j.prosdent.2017.10.029>.

- [10] B. Yilmaz, V. Rizzo Marques, X. Guo, D. Gouveia, S. Abou-Ayash, The effect of scanned area on the accuracy and time of anterior single implant scans: An in vitro study, *J Dent* 109 (2021) 103620. <http://doi.org/10.1016/j.jdent.2021.103620>.
- [11] M. Sanda, K. Miyoshi, K. Baba, Trueness and precision of digital implant impressions by intraoral scanners: a literature review, *Int J Implant Dent* 7(1) (2021) 97. <http://doi.org/10.1186/s40729-021-00352-9>.
- [12] Y.J. Zhang, J.Y. Shi, S.J. Qian, S.C. Qiao, H.C. Lai, Accuracy of full-arch digital implant impressions taken using intraoral scanners and related variables: A systematic review, *Int J Oral Implantol (Berl)* 14(2) (2021) 157-179.
- [13] S. Marques, P. Ribeiro, C. Falcão, B.F. Lemos, B. Ríos-Carrasco, J.V. Ríos-Santos, M. Herrero-Climent, Digital impressions in implant dentistry: a literature review, *Int J Environ Res Public Health* 18(3) (2021). <http://doi.org/10.3390/ijerph18031020>.
- [14] S. Atalay, G. Çakmak, M.B. Donmez, H. Yilmaz, A.M. Kökat, B. Yilmaz, Effect of implant location and operator on the accuracy of implant scans using a combined healing abutment-scan body system, *J Dent* 115 (2021) 103855. <http://doi.org/10.1016/j.jdent.2021.103855>.
- [15] G. Çakmak, M.B. Donmez, S. Atalay, H. Yilmaz, A.M. Kökat, B. Yilmaz, Accuracy of single implant scans with a combined healing abutment-scan body system and different intraoral scanners: An in vitro study, *J Dent* 113 (2021) 103773. <http://doi.org/10.1016/j.jdent.2021.103773>.
- [16] H. Yilmaz, H. Arınc, G. Çakmak, S. Atalay, M.B. Donmez, A.M. Kökat, B. Yilmaz, Effect of scan pattern on the scan accuracy of a combined healing abutment scan body system, *J Prosthet Dent* (2022). <http://doi.org/10.1016/j.prosdent.2022.01.018>.
- [17] M.B. Donmez, G. Çakmak, S. Atalay, H. Yilmaz, B. Yilmaz Trueness and precision of combined healing abutment-scan body system depending on the scan pattern and implant location: An in-vitro study. *J Dent* 124 (2022) 104169. <http://doi.org/10.1016/j.jdent.2022.104169>.
- [18] B. Yilmaz, S. Abou-Ayash, A digital intraoral implant scan technique using a combined healing abutment and scan body system, *J Prosthet Dent* 123(2) (2020) 206-209. <http://doi.org/10.1016/j.prosdent.2019.01.016>.
- [19] G. Çakmak, H. Yilmaz, A. Treviño, A.M. Kökat, B. Yilmaz, The effect of scanner type and scan body position on the accuracy of complete-arch digital implant scans, *Clin Implant Dent Relat Res* 22(4) (2020) 533-541. <http://doi.org/10.1111/cid.12919>.

- [20] S.A. Son, J.H. Kim, D.G. Seo, J.K. Park, Influence of different inlay configurations and distance from the adjacent tooth on the accuracy of an intraoral scan, *J Prosthet Dent* (2021). <http://doi.org/10.1016/j.prosdent.2020.12.044>.
- [21] P. Paspaspyridakos, K. Vazouras, Y.W. Chen, E. Kotina, Z. Natto, K. Kang, K. Chochlidakis, Digital vs conventional implant impressions: a systematic review and meta-analysis, *J Prosthodont* 29(8) (2020) 660-678. <http://doi.org/10.1111/jopr.13211>
- [22] K. Son, W.S. Lee, K.B. Lee, Effect of different software programs on the accuracy of dental scanner using three-dimensional analysis, *Int J Environ Res Public Health* 18(16) (2021) 8449. <http://doi.org/10.3390/ijerph18168449>.
- [23] S. Peroz, B.C. Spies, U. Adali, F. Beuer, C. Wesemann, Measured accuracy of intraoral scanners is highly dependent on methodical factors, *J Prosthodont Res* 66(2) (2022) 318-325. [http://doi.org/10.2186/jpr.JPR\\_D\\_21\\_00023](http://doi.org/10.2186/jpr.JPR_D_21_00023).
- [24] G. Cakmak, V.R. Marques, M.B. Donmez, W.E. Lu, S. Abou-Ayash, B. Yilmaz, Comparison of measured deviations in digital implant scans depending on software and operator, *J Dent* (2022) 104154. <http://doi.org/10.1016/j.jdent.2022.104154>.
- [25] M. Schimmel, N. Akino, M. Srinivasan, J.G. Wittneben, B. Yilmaz, S. Abou-Ayash, Accuracy of intraoral scanning in completely and partially edentulous maxillary and mandibular jaws: an in vitro analysis, *Clin Oral Investig* 25(4) (2021) 1839-1847. <http://doi.org/10.1007/s00784-020-03486-z>.
- [26] B. Yilmaz, X. Guo, M. Schimmel, S. Abou-Ayash, Effect of industrial scanner and framework material interaction on the marginal gaps of CAD-CAM complete-arch implant frameworks, *J Prosthet Dent* (2022). <http://doi.org/10.1016/j.prosdent.2021.10.013>.
- [27] M. Zimmermann, A. Ender, A. Mehl, Local accuracy of actual intraoral scanning systems for single-tooth preparations in vitro, *J Am Dent Assoc* 151(2) (2020) 127-135. <http://doi.org/10.1016/j.adaj.2019.10.022>.
- [28] H. Lerner, K. Nagy, F. Luongo, G. Luongo, O. Admakin, F.G. Mangano, Tolerances in the production of six different implant scanbodies: a comparative study, *Int J Prosthodont* 34(5) (2021) 591-599. <http://doi.org/10.11607/ijp.7379>.
- [29] H.S. Oh, Y.J. Lim, B. Kim, W.H. Kim, M.J. Kim, H.B. Kwon, Influence of applied liquid-type scanning-aid material on the accuracy of the scanned image: an in vitro experiment, *Materials (Basel)* 13(9) (2020) 2034. <http://doi.org/10.3390/ma13092034>.

**TABLES**Table 1. Descriptive statistics of measured deviations ( $\mu\text{m}$ ) of each operator-technique pair

Technique	Circle-Based Technique	Point-Based Technique	<i>P</i> -value (Estimated difference)
Operator 1	110.71 $\pm$ 51.71	58.38 $\pm$ 34.66	.001 (52.34 $\mu\text{m}$ )
Operator 2	93.09 $\pm$ 54.34	56.56 $\pm$ 35.04	.001 (36.53 $\mu\text{m}$ )
Operator 3	144.24 $\pm$ 121.56	60.13 $\pm$ 32.77	.001 (84.11 $\mu\text{m}$ )

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



## FIGURES

Figure 1. Circles generated for circle-based measurement technique

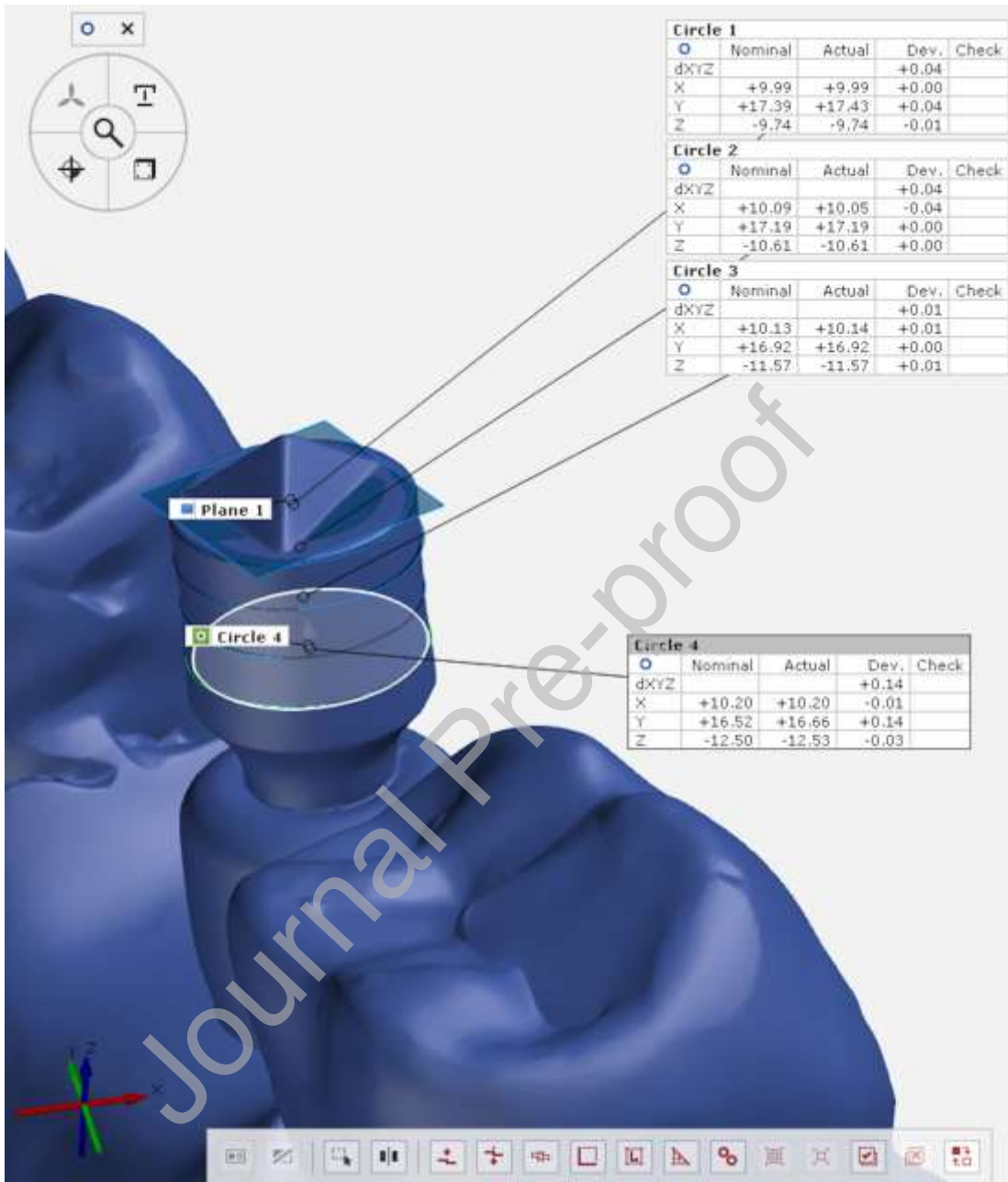


Figure 2. Buccolingually oriented plane generated for point-based measurement technique

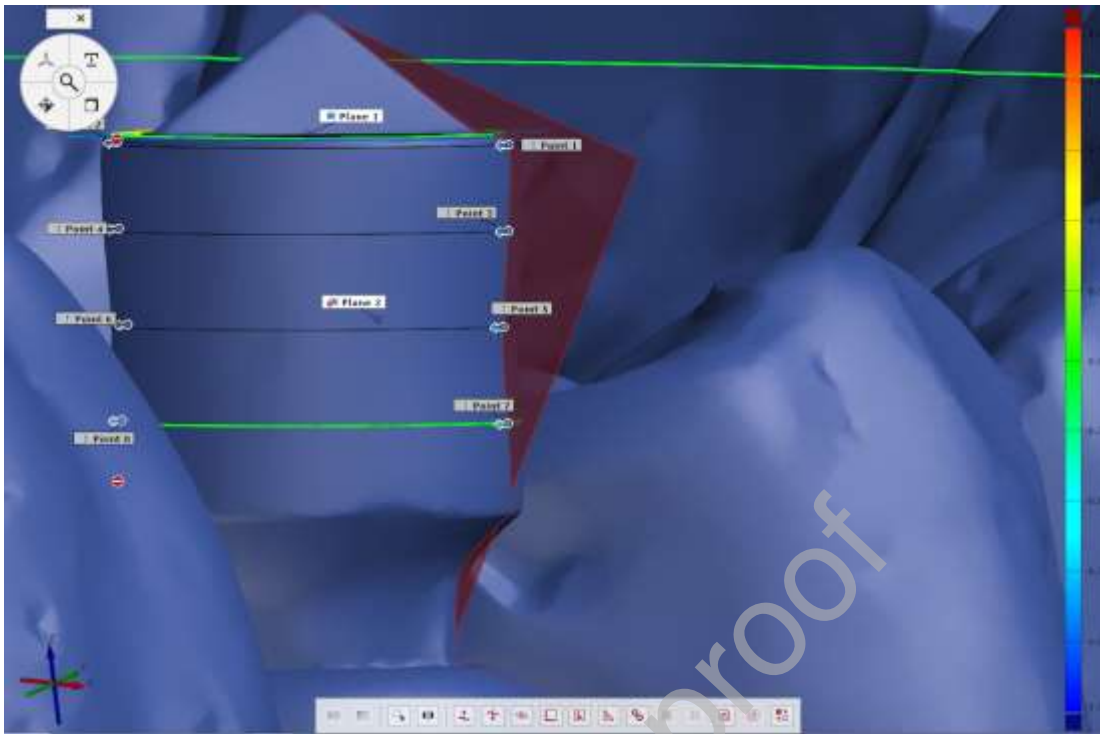


Figure 3. Points generated for point-based measurement technique

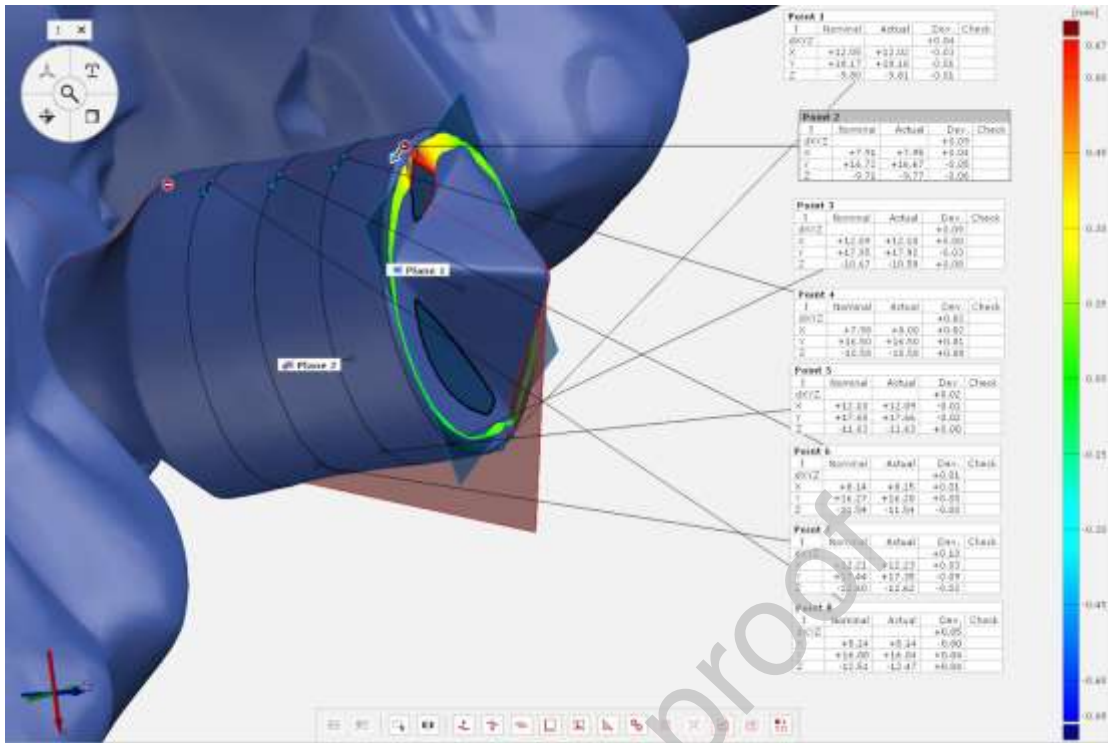


Figure 4. Box-plot graph of measured deviations ( $\mu\text{m}$ ) for each operator-technique pair