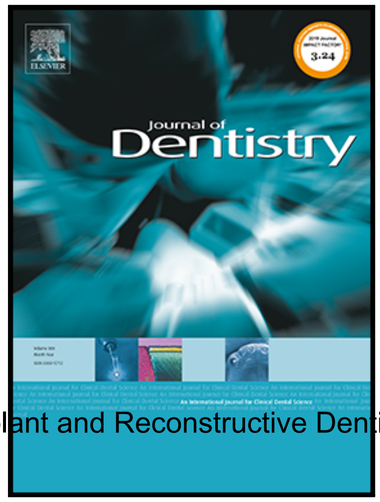
Journal Pre-proof



Comparison of measured deviations in digital implant scans depending on software and operato

Gulce Cakmak Buser Foundation Scholar for Implant Dentistry ,
Vinicius Rizzo Marques ,
Mustafa Borga Donmez Assistant Professor ,
Wei-En Lu Bachelor of science ,
Samir Abou-Ayash Senior Lecturer and Head of the Section of Digital Implant and Reconstructive Dentistry ,
Burak Yilmaz Associate Professor

PII: S0300-5712(22)00210-X
DOI: https://doi.org/10.1016/j.jdent.2022.104154
Reference: JJOD 104154

To appear in: *Journal of Dentistry*

Received date: 6 February 2022
Revised date: 29 March 2022
Accepted date: 4 May 2022

Please cite this article as: Gulce Cakmak Buser Foundation Scholar for Implant Dentistry , Vinicius Rizzo Marques , Mustafa Borga Donmez Assistant Professor , Wei-En Lu Bachelor of science , Samir Abou-Ayash Senior Lecturer and Head of the Section of Digital Implant and Reconstructive Dentistry , Burak Yilmaz Associate Professor , Comparison of measured deviations in digital implant scans depending on software and operato, *Journal of Dentistry* (2022), doi: https://doi.org/10.1016/j.jdent.2022.104154

Deviations in implant scans depending on software and operator

Original article

Comparison of measured deviations in digital implant scans depending on software and operato

Gulce Cakmak[a], Vinicius Rizzo Marques[b], Mustafa Borga Donmez[c], Wei-En Lu[d], Samir Abou-Ayash[e,*], Burak Yilmaz[f,g,h]

[a]Buser Foundation Scholar for Implant Dentistry, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland. guelce.cakmak@zmk.unibe.ch.

[b]Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland. Electronic address: marqvr@gmail.com.

[c]Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; Assistant Professor, Department of Prosthodontics, Biruni University Faculty of Dentistry, Istanbul, Turkey. Electronic address: bdonmez@biruni.edu.tr.

[d]Bachelor of science, Ph.D. student, Division of Biostatistics, College of Public Health, The Ohio State University, Columbus, OH, USA. Electronic address: lu.1408@osu.edu

[e]Senior Lecturer and Head of the Section of Digital Implant and Reconstructive Dentistry, Department of Reconstructive Dentistry and Gerodontology, University of Bern, Freiburgstrasse 7, 3007 Bern, Switzerland; samir.abou-ayash@zmk.unibe.ch

[f]Associate Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Freiburgstrasse 7, 3007 Bern, Switzerland

[g]Associate Professor, Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Freiburgstrasse 7, 3007 Bern, Switzerland

[h]Adjunct Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Columbus, Ohio 43210 USA; burak.yilmaz@zmk.unibe.ch

[*]**Corresponding author:** Dr. Samir Abou-Ayash, Reconstructive Dentistry and Gerodontology, University of Bern: Universitat Bern, Freiburgstrasse 7, 3010 Bern, Bern, Switzerland, E-mail: Samir.abou-ayash@zmk.unibe.ch

ABSTRACT

Objectives: To investigate the effect of 3-dimensional (3D) analysis software and operator on the measured deviations in implant scans.

Material and Methods: A combined healing abutment-scan body (CHA-SB) system was digitized with an industrial scanner (ATOS Core 80) to generate a master standard tessellation language file (MRM-STL) and an intraoral scanner (TRIOS 3) to generate 9 test-scan STL files, which were transferred into metrology-grade (Geomagic Control X, GX and GOM Inspect, GM) and nonmetrology-grade (Medit Link, ML) software for deviation analysis. Test-scan STLs were superimposed over MRM-STL and 2 planes passing through the center of the SB were generated. Distance deviations at 8 points on these planes were analyzed by two different operators with similar level of experience. Data were analyzed with analysis of variance and F tests (α=.05).

Results: Only model 1 (*P*=.049) analyzed by operator 2 showed significant differences among tested software, and the highest deviations were measured with GM (*P*≤.037). However, the difference in values measured with GX and ML was nonsignificant (*P*=.91). Operator correlation was high (ICC≥.712, P≤.011), except for models 1 (GM, ICC=-.335, *P*=.813), 2 (GM, ICC=.025, *P*=.468 and ML, ICC=-.013, *P*=.507), 6 (GM, ICC=-.085, *P*=.583), and 8 (GM, ICC=-.386, *P*=.85).

Conclusion: The measured deviations in implant scans in all models, except for one, were similar among the tested software, regardless of the operator. The inter-rater reliability of

operators while using tested 3D analysis software was overall high. When observed, low inter-rater reliability was mostly with only one of the metrology grade software.

Clinical Significance: Nonmetrology-grade 3D analysis software may be a suitable alternative to metrology-grade software to measure the deviations in digital implant scan body scans. When GOM metrology-software is used, measured deviations in implant scan body scans may vary more across operators.

Keywords: *software, deviation, implant, scanbody, scan*

1. INTRODUCTION

With the recent advancements in computer aided design-computer aided manufacturing (CAD-CAM) technologies, digitization of implants by using intraoral scanners (IOSs) and scan bodies (SBs) have become feasible [1]. However, the accuracy of digital implant scans may vary, depending on various factors [2, 3], and have been commonly analyzed in dental research studies in recent years [4].

Improvements in digital technologies have enabled 3-dimensional (3D) analysis of industrial products [5] and metrology-grade 3D analysis software have been preferred in dental research studies to evaluate SBs, digital scans, and restorations [6, 7, 8, 9]. A common method used for 3D analysis is the superimposition of the test scan mesh over the reference file through best-fit alignment [2, 10], which allows an accurate analysis [11]. International Organization for Standardization (ISO) standard 12836 recommended using a metrology-grade software (Geomagic Control X; 3D Systems, Morrisville, NC, USA) for 3D analysis after digitizing an object with an optical or mechanical-contact system [12]. Nevertheless, the results of the best-fit alignment may change depending on the type and version of the software utilized due to the differences in alignment protocols [13]. Another metrology-grade 3D analysis software (GOM Inspect 2018; GOM GmbH, Braunschweig, Germany) also allows similar analyses with its free version, even though not specifically recommended by the ISO.

A recently introduced nonmetrology-grade 3D analysis software (Medit Link, Medit, Seoul, Republic of Korea) allows the analysis of any standard tessellation language (STL) file regardless of the source and can be downloaded without a cost. Considering these features, even though it is a nonmetrology-grade, this software may be considered as an alternative to the metrology-grade software [14]. However, to the authors' knowledge, only one study has compared the nonmetrology-grade software with a metrology-grade software [14], and the number of studies on the reliability of 3D analysis software is limited [14, 15, 16]. Previous studies have compared different 3D analysis software for the deviations in dentate models [15, 16] or crowns [14]. However, no study has yet compared the difference in measured deviations in implant SB scans when different 3D analysis software are used. Therefore, the aim of the present study was to compare the measured deviations in the scans of a SB when 3 different 3D analysis software (2 metrology-grade and 1 nonmetrology-grade) were used, and the repeatability of measured deviations when utilized by 2 operators. The null hypotheses of the present study were that i) 3D analysis software 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 3D analysis software.

2. MATERIALS AND METHODS

A single implant (4.0 mm×11 mm, Neoss ProActive Straight; Neoss Implant System, Harrogate, England) was placed at the first molar site of a polymethyl methacrylate mandibular dentate model. An indexed polyetheretherketone healing abutment (HA, Esthetic Healing Abutment, Neoss Implant System, Harrogate, England) was fixed onto the implant in accordance with the buccal inner slot of the implant. Then, a SB (ScanPeg, Neoss Implant System, Harrogate, England) was fitted into the screw access hole of the HA, which gives an antirotational feature to the system [7, 10, 17, 18, 19]. HA and SB were not disassembled until all test scans were completed.

After a thin layer (2 μm) of antireflective spray application, the model was scanned with an industrial blue-light optical scanner (ATOS Core 80 5MP; GOM GmbH, Braunschweig, Germany), which utilizes a triangulation based stereo camera (1 μm probing error form, 3 μm probing error size, 5 μm sphere spacing error, and 7 μm length measurement error, ATOS referans). This scan was converted to an STL file by using a metrology software (Pro 8.1; GOM GmbH, Braunschweig, Germany) and exported to a mesh software (Meshmixer v3.5.474, Autodesk Inc, San Rafael, CA, USA). A total of 6 points, 3 in buccolingual and 3 in mesiodistal direction (Figure 1), were determined on the SB that would be used to facilitate the generation of buccolingual and mesiodistal oriented planes for deviation analyses. This file was exported as an STL file and used as a master reference model scan (MRM-scan STL).

Nine complete-arch scans were performed by using the TRIOS 3 (Cart version 1.4.7.5; 3Shape, Copenhagen, Denmark) [7, 10, 17] IOS according to the manufacturer's recommendations by one experienced operator (G. Ç), who has more than 4 years of experience with intraoral scanning. A 5-minute rest was taken between each scan to prevent any fatigue that may affect the scan quality [20]. Scans and calibration of the scanner were performed in a (18-22 °C) and humidity (40%)-controlled room [21]. Scans were inspected for imperfections and accepted as completed once all the SB surfaces were scanned without any flaws and major imperfections [7, 17]. The completed scan files were then converted to STL files to generate test-scan STLs.

Two different operators performed the quantitative (mean ± standard deviation (SD)) evaluation of the CHA-SB system scan deviations by using 2 different metrology-grade (GOM Inspect 2018; GOM GmbH, Braunschweig, Germany, (GM) and Geomagic Control X v.2018.1.1; 3D Systems, Morrisville, NC, USA (GX)) and 1 nonmetrology-grade software (Medit Link v 2.4.4; Medit, Seoul, Republic of Korea (ML)). Both operators had similar experience with 3D analysis software and performed at least 10 evaluations before the actual analyses.

For the analysis performed by using GM, MRM-scan STL and test-scan STLs were imported into the software, and MRM-scan STL was used as reference data. The initial alignment was done by using the pre-alignment feature. "Local best-fit" tool of the software was then used to minimize errors, which involves the manual selection of the teeth for superimposition by drawing a polygon and excluding the CHA-SB. Then by using the "construct 3-point plane" and "construct single section" functions of the software, 2 planes (one in buccolingual orientation and 1 in mesiodistal orientation) were generated by using the previously determined points on the MRM-scan STL. These 2 planes were aligned to pass through the center of the top surface of the SB (Figure 2). A total of 8 points; 4 on the buccolingual oriented plane (1 on top of the buccolingual oriented plane, 1 on the most buccal-coronal of the SB, 1 on the buccal surface of the buccolingual oriented plane, and 1 on the concavity between the SB and the HA) and 4 on the mesiodistal oriented plane (1 on top of the mesiodistal oriented plane, 1 on the most distal-coronal of the SB, 1 on the distal surface of the mesiodistal oriented plane, and 1 on the concavity between the SB and the HA) [2, 10] were generated by using the "construct surface point" function of the software. Coordinates of the points in the first superimposition of each operator were recorded and accordingly, the points were standardized within each operator. Then, the software algorithm calculated the 3D distance deviations of these points generated both on MRM-STL and test-scan STL (Figure 3).

For the deviation analysis with GX, MRM-scan STL and test-scan STLs were imported into the software, and MRM-scan STL was selected as the reference data by using "model alignment" feature of the software. For the superimposition, the initial alignment was done by using the "N" points method of the "transform alignment" feature of the software, in which 3 points (1 on the adjacent molar, 1 on the ipsilateral canine, and 1 on the contralateral second molar) were simultaneously selected on MRM-STL and test-scan STL. Further alignment was done by using the “best-fit alignment” tool of the software to minimize errors. Planes were generated by using the “add plane” feature and selecting the predetermined points on the MRM-scan STL. After planes were generated, “2-dimensional (2D) compare” feature of the software was used for the deviation analysis of 8 points generated on the planes (Figure 4).

For the deviation analysis with ML, MRM-scan STL and test-scan STLs were imported into the software, and MRM-scan STL was selected as the reference data by using the “assign data” tool. For the superimposition, “selected area-smart teeth selection” tool of the “align with selected area” feature was used. This tool involves the manual selection of the teeth and CHA-SB was excluded. By using the “create sections” tool of the “measurement mode”, planes were generated by drawing 2 lines in buccolingual and mesiodistal directions that intersect the predetermined points on MRM-scan STL. Eight points were generated on these planes and the “measure distance by 2 points” feature of the software was used for the deviation analysis of these points (Figure 5). As both GX and ML software did not have the coordinate selection feature, both operators were calibrated to select the 8 points defined while using the GM software (4 on the buccolingual oriented plane; 1 on top of the buccolingual oriented plane, 1 on the most buccal-coronal of the SB, 1 on the buccal surface of the buccolingual oriented plane, and 1 on the concavity between the SB and the HA and 4 on the mesiodistal oriented plane; 1 on top of the mesiodistal oriented plane, 1 on the most distal-coronal of the SB, 1 on the distal surface of the mesiodistal oriented plane, and 1 on the concavity between the SB and the HA). In addition, GX and GM software allowed to set a maximum average deviation during superimposition, which was set to 10 μm. However, parameters on the ML software were set automatically.

Average deviation values of the 8 points generated in each analysis were used for the statistical analysis. Nine 1-way analysis of variance (ANOVA) tests were performed within each operator to determine whether software influenced the measurements, and statistically significant differences were further resolved with pairwise comparisons. Inter-rater reliability between the operators for each software and model was assessed with intraclass correlation by using F-tests. All statistical analyses were performed by using an analysis software (SPSS for Windows, IBM SPSS Statics 25.0, SPSS Inc, Chicago, IL) at a significance of □=.05.

3. RESULTS

Figure 6 illustrates the distribution of the deviation values for each model and software within the operators. For operator 1, one-way ANOVA revealed no significant differences among the tested software within each model (*P*≥.069). For operator 2, the differences among software were nonsignificant (*P*≥.173) except for model 1 (*P*=.049). Pairwise comparisons for statistically significant model revealed that the deviations measured with GM was significantly higher (*P*=.037 vs ML and *P*=.029 vs GX), whereas the difference between ML and GX was nonsignificant (*P*=.91). Table 1 summarizes the estimated deviation values of each model for each software and operator.

Table 2 shows the results of the F-tests performed for inter-rater reliability. A significant correlation was observed between the operators in all model-software pairs (P≤.011) except for with GM in model 1 (ICC=-.335, *P*=.813), in model 6 (ICC=-.085, *P*=.583), and model 8 (ICC=-.386, *P*=.85), and with GM (ICC=.025, *P*=.468) and ML (ICC=-.013, *P*=.507) in model 2.

4. DISCUSSION

The present study evaluated the effect of 3D analysis software and operator on measured deviations of single implant scans in a dentate arch, relative to the reference dataset. Significant differences among the evaluated software were found in only one model when the analyses were performed by operator 2. Accordingly, the first null hypothesis that 3D analysis software would not affect the measured deviations within the operators was rejected. A significant correlation between the two operators' analyses was demonstrated in most of the models. However, significant differences between the operators were observed in 4 models. Therefore, the second null hypothesis that the operator would not affect the measured deviation in SB scans within 3D analysis software was also rejected.

Only one model of operator 2 showed significant differences among the tested 3D analysis software in the present study, which may be attributed to the alignment algorithms. It has been shown that the alignment algorithm has a significant impact on deviation analyses [16]. Peroz et al [16] recommended to use best-fit alignments, which were more reliable than using boundary values for superimposition. However, best-fit alignments are also reported to result in an underestimation of the actual deviations as the algorithm attempts to find the closest distance between all surface points [22]. In the present study, best-fit algorithm was used for all superimpositions. Nevertheless, there was a decisive difference among the applied software; the GX software was used applying a global best-fit alignment considering all surface data, while the GM an ML software were used with a local best-fit alignment, considering only the surface data from the teeth on the model. Previous studies have demonstrated that the size of the scanned area significantly affected deviations between intraoral scan and reference data [15, 23, 24]. Schimmel et al [25] suggested that the relatively small deviations found in their study on edentulous and partially dentate models were due to the local best-fit algorithm, which neglected surface data from the mucobuccal fold and the adjacent area. Surface data of the peripheral area might have a negative effect on the measured deviations due to stitching issues [26]. Another in vitro study on intraoral scans of completely dentate models showed that deviations were higher analyzing the complete arch compared to smaller regions of interest of the identical scan [24]. The explanation for the smaller deviations in the regions of interest, even though the same scan was analyzed, was the smaller number of surface points that must be compared [24]. However, the findings of the present study contradicted this explanation; measured deviations using the GM software were highest in the only model, where there were differences between the software. The reason for this could be that the selection of the teeth for the local best-fit algorithm in GM software is not automatic as in the ML software, but operator dependent. In general, either the initial alignment of the reference and the test file or the following best-fit alignment was based on an operator dependent selection in the software tested. In addition, despite the efforts to standardize the plane selection process with predetermined points on the MRM-scan STL, these points were a certain size, which would allow possible selection of different planes. Accordingly, the operators might have generated different cross sections even when analyzing different models with the same software. However, the main difference amongst the tested 3D analysis software was that each point selection in each model was operator dependent in GX and ML software, whereas GM enables the use of coordinates to determine points. Considering that the manual selection of points is always a subjective component even if based on clear anatomical landmarks [27], the use of coordinates to determine points with GM makes this software more user-friendly, particularly when performing repeated measurements of the same model. However, GM was the common software used for those models no correlation between the operators was found. This finding may indicate that the influence of the manual tooth selection for the local best-fit alignment is potentially greater than the selection of the points to be analyzed. However, this hypothesis needs further support with studies focusing on the effect of surface selection on local-best fit algorithm.

Previous studies have compared the deviations of dentate models measured by using GX and GM [15, 16]. Son et al [15] stated that GM resulted in lower deviations while evaluating the deviations of a tooth preparation scan, whereas GX resulted in lower deviations while evaluating the deviations of a half-arch scan. However, no significant differences were reported while analyzing complete-arch scans, which is in line with Peroz et al’s [16] study. Nevertheless, Peroz et al [16] have also concluded that GX had higher repeatability than GM. To the authors’ knowledge only one other study has compared ML with GX [14]. Yilmaz et al [14] reported that ML performed similar to GX while measuring the deviations of fabricated crowns from the design file. Nevertheless, a direct comparison between the present study and those studies [14, 15, 16] might be problematic considering that none of those studies were based on the effect of 3D analysis software on the measured deviations of digital implant scans.

A previous study has also evaluated the effect of operator on measured deviations between the reference and the test datasets and demonstrated no difference [16]. However, the intermolar distance of a maxillary dentate model with bar-shaped reference bodies was measured in Peroz et al's [16] study, which may be attributed to this difference. In general, deviations are expected while scanning identical situations repeatedly due to the precision of the intraoral scanner [28]. The mean precision of TRIOS 3 has been reported to be 14.1 14.9 µm when used for the acquisition of the same model under same conditions [7]. The scanner's precision may also explain the intra-operator deviations within each software.

One of the latest developments in digital implant dentistry was the introduction of a 2-piece CHA-SB system, which allows the acquisition of both the implant and the peri-implant soft tissue without the need of HA removal [18]. Previous studies on the scan accuracy of this system when digitized by using TRIOS 3 have reported mean deviations ranging from 35.01 to 178 µm while using GM [7, 10, 17], and as 37.8 µm while using GX [29]. The mean deviations while using GM ranged from 57 µm to 174.4 µm in the present study, which coincide with those previous studies [7, 10, 17]. However, the mean deviations of the present study while using GX (65.4 µm to 99 µm) were higher than Donmez et al's [29] study, which may be related to the different measurement method (root mean square) they utilized. In addition, the authors are unaware of a study analyzing the deviations of the CHA-SB system scans with ML. Therefore, the mean deviations observed in the present study while using ML (59 µm to 106.5 µm) should be substantiated with future studies. The reason CHA-SB system was analyzed in this study is that there is previous comparable data [7, 10, 17, 29] and the shape of the SB has corners, which enable easier determination of the selection of points to compare detected deviations by different operators at a certain location intended to be standardized. The possibility of easier point selection at corners is particularly important for GX and ML, where operators select the points for analysis without coordinate help. Selecting points on a rounder shaped SB may be harder to standardize for different operators, which may further affect the detected deviation values.

An industrial scanner, which has been preferred in previous dental studies [6, 7, 17] was used in the present study to generate a reference scan. However, there are studies, which investigated the accuracy of digital implant scans by using reference scans generated with a coordinate measuring machine (CMM) [30, 31, 32, 33]. The authors are unaware of a study investigating the effect of reference scan generation method on measured deviations or the effect of 3D analysis software on measured deviations when CMM was used to generate a reference scan. Future studies investigating the effect of master scan generation method along with different 3D analysis software would elaborate the findings of the present study.

The limitations of the present study were the lack of sample size calculation, the use of only one IOS, the evaluation of the scans by two operators with similar level of experience, and that only one geometry was analyzed. In addition, scans were performed under standardized conditions and possible factors that may affect the accuracy of a digital scan such as space limitation, gag reflex, and presence of saliva or blood were excluded [29]. Recent studies have shown the effect of calculation method on the measured deviations [34, 35]. Therefore, the findings of the present study should be corroborated with future studies, which involve different calculation methods, scans from different scanners, increased number of operators with varying experience levels, and varying clinical situations to broaden the knowledge on the limitations of 3D analysis software.

5. CONCLUSIONS

Considering the limitations of the present study, it can be concluded that measured deviations in implant scan body scans were mostly similar when metrology grade or nonmetrology grade software were used. The nonmetrology grade software might be an alternative to metrology-grade software while analyzing the deviations of implant scan body scans. The effect of operator with similar experience on the measurements performed by using the tested 3D analysis software was, in general, low, but higher with one of the metrology-grade software tested.

6. Author Statement

The authors of the manuscript contributed in the following ways to the submitted manuscript: Gülce Çakmak: Design, Investigation, Critical revision of article, Vinicius Rizzo Marques: Design, Investigation, Data interpretation, Mustafa Borga Donmez: Writing-Original Draft, Wei-En Lu: Formal Analysis, Samir Abou-Ayash: Writing-Original Draft, Burak Yilmaz: Data interpretation, Critical revision of the article, Approval of the submitted and final versions

Declaration of Competing Interest

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

Acknowledgement

All other authors have no conflicts of interest to declare. The authors do not have any financial interest in the companies whose materials are included in this article. Neoss Implant System is gratefully acknowledged for supplying the materials used in this study. The authors also thank Gökhan Akcagöz for supplying the materials.

References

[1] 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. https://10.1186/s12903-020-01254-9

[2] 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 (2021) 103620. https://10.1016/j.jdent.2021.103620

[3] 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). https://10.3390/ijerph18031020

[4] 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. https://10.1186/s40729-021-00352-9

[5] 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. https://10.1016/j.prosdent.2020.04.028
[6] 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. https://10.1111/cid.12919
[7] 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 (2021) 103773. https://10.1016/j.jdent.2021.103773
[8] A. Schmidt, C.R. Benedickt, M.A. Schlenz, P. Rehmann, B. Wöstmann, Torsion and linear accuracy in intraoral scans obtained with different scanning principles, J Prosthodont Res 64(2) (2020) 167-174. https://10.1016/j.jpor.2019.06.006
[9] K. Son, J.H. Lee, K.B. Lee, Comparison of intaglio surface trueness of interim dental crowns fabricated with SLA 3D printing, DLP 3D printing, and milling technologies, Healthcare (Basel) 9 (2021) 983. https://10.3390/healthcare9080983
[10] B. Yilmaz, D. Gouveia, V.R. Marques, E. Diker, M. Schimmel, S. Abou-Ayash, The accuracy of single implant scans with a healing abutment-scanpeg system compared with the scans of a scanbody and conventional impressions: an in vitro study, J Dent (2021) 103684. https://10.1016/j.jdent.2021.103684
[11] A. Ender, T. Attin, A. Mehl, In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions, J Prosthet Dent 115(3) (2016) 313-20. https://10.1016/j.prosdent.2015.09.011
[12] International Organization of Standardization, ISO 12836. Dentistry Digitizing Devices for CAD/CAM Systems for Indirect Dental Restorations: Test Methods for Assessing Accuracy, ISO, Geneva, 2015. Available at: https://www.iso.org/obp/ui/#iso:std:iso:12836:ed-2:v1:en.
[13] G.H. Park, K. Son, K.B. Lee, Feasibility of using an intraoral scanner for a complete-arch digital scan, J Prosthet Dent 121(5) (2019) 803-810. https://10.1016/j.prosdent.2018.07.014
[14] 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 (2021) 103933. https://10.1016/j.jdent.2021.103933

[15] 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). https://10.3390/ijerph18168449

[16] 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 (2021). https://10.2186/jpr.JPR_D_21_00023

[17] 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. https:// 10.1016/j.jdent.2021.103855

[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. https://10.1016/j.prosdent.2019.01.016

[19] Neoss Implant System Website. https://resources.neoss.com/uploads/11926_3-IFU Esthetic- Healing-Abutments-with-ScanPeg-EN-spread-PRINTINT. pdf? mtime=20210330102135. Accessed April 14, 2021.

[20] F. Mangano, H. Lerner, B. Margiani, I. Solop, N. Latuta, O. Admakin, Congruence between meshes and library files of implant scanbodies: an in vitro study comparing five intraoral scanners, J. Clin. Med. 9 (2020) 2174. https://10.3390/jcm9072174

[21] H. N. Park, Y.J. Lim, W.J. Yi, J.S. Han, S.P. Lee, A comparison of the accuracy of intraoral scanners using an intraoral environment simulator. J. Adv. Prosthodont. 10 (2018) 58-64. https://10.4047/jap.2018.10.1.58.

[22] 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 (2019) 495-500. https://10.1016/j.prosdent.2020.01.004

[23] Y.G. Moon, K.M. Lee, Comparison of the accuracy of intraoral scans between complete-arch scan and quadrant scan, Prog Orthod 21(1) (2020) 36. https://10.1186/s40510-020-00337-1

[24] A. Ender, M. Zimmermann, A. Mehl, Accuracy of complete- and partial-arch impressions of actual intraoral scanning systems in vitro, Int J Comput Dent 22(1) (2019) 11-19.

[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. https://10.1007/s00784-020-03486-z

[26] Z. Nagy, B. Simon, A. Mennito, Z. Evans, W. Renne, J. Vág, Comparing the trueness of seven intraoral scanners and a physical impression on dentate human maxilla by a novel method, BMC Oral Health 20(1) (2020) 97. https://10.1186/s12903-020-01090-x

[27] K. Becker, B. Wilmes, C. Grandjean, D. Drescher, Impact of manual control point selection accuracy on automated surface matching of digital dental models, Clin Oral Investig 22(2) (2018) 801-810. https://10.1007/s00784-017-2155-6

[28] International Organization for Standardization. ISO 5725-1. Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions. Geneva: International Organization for Standardization; 2018. (Date: 1994-12) Available at: https://www.iso.org/obp/ui/#iso:std:iso:5725:-1:ed-1:v1:en.

[29] M.B. Donmez, V.R. Marques, G. Çakmak, H. Yilmaz, M. Schimmel, B. Yilmaz, Congruence between the meshes of a combined healing abutment-scan body system acquired with four different intraoral scanners and the corresponding library file: an in vitro analysis, J Dent (2021) 103938. https://10.1016/j.jdent.2021.103938

[30] M. Revilla-León, J. Rubenstein, M.M. Methani, W. Piedra-Cascón, M. Özcan, W. Att, Trueness and precision of complete-arch photogrammetry implant scanning assessed with a coordinate-measuring machine. J. Prosthet. Dent. (2021) https://10.1016/j.prosdent.2021.05.019.

[31] M. Revilla-León, W. Att, M. Özcan, J. Rubenstein, Comparison of conventional, photogrammetry, and intraoral scanning accuracy of complete-arch implant impression procedures evaluated with a coordinate measuring machine. J. Prosthet. Dent. 125 (2021) 470-478. https://10.1016/j.prosdent.2020.03.005.

[32] M. Revilla-León, R. Fogarty, J.J. Barrington, A. Zandinejad, M. Özcan, Influence of scan body design and digital implant analogs on implant replica position in additively manufactured casts. J. Prosthet. Dent. 124 (2020) 202-210. https://10.1016/j.prosdent.2019.07.011.

[33] M. Revilla-León, Z. Smith, M.M. Methani, Zandinejad, M. Özcan, Influence of scan body design on accuracy of the implant position as transferred to a virtual definitive implant cast. J. Prosthet. Dent. 125 (2021) 918-923. https://10.1016/j.prosdent.2020.03.019.

[34] B.B. Yatmaz, S. Raith, S. Reich, Trueness evaluation of digital impression: The impact of the selection of reference and test object, J Dent 111 (2021) 103706. https://10.1016/j.jdent.2021.103706

[35] H. Lerner, K. Nagy, N. Pranno, F. Zarone, O. Admakin, F. Mangano, Trueness and precision of 3D-printed versus milled monolithic zirconia crowns: An in vitro study, J Dent 113 (2021) 103792. https://10.1016/j.jdent.2021.103792

Table 1. Estimated deviation values and 95% confidence intervals (μm) of each model when analyzed with different software

Model	Software	Operator 1	Operator 2
1	GM	93	174.4[b]
		(55.3-130.7)	(117.4-231.3)
	ML	90.7	88[a]
		(37.3-144.1)	(7.5-168.5)
	GX	86.1	83.5[a]
		(32.8-139.5)	(3-164.1)
2	GM	153	113.1
		(103.3-202.7)	(76.5-149.7)
	ML	106.5	73
		(36.2-176.8)	(21.3-124.7)
	GX	69.8	73
		(-0.5-140.2)	(21.3-124.7)
3	GM	73.4	73.6
		(45.1-101.7)	(44.2-103.1)
	ML	76.8	75.9
		(36.7-116.8)	(34.3-117.5)
	GX	83.7	86.6
		(36.7-116.8)	(45-128.2)
4	GM	72.9	78[a]
		(46.4-99.4)	(49.6-106.4)
	ML	75.9	74.4[a]
		(38.4-113.3)	(34.1-114.6)
	GX	73.9	73.5[b]
		(36.4-111.3)	(33.2-113.7)
5	GM	70.5	87.6
		(44-97)	(54.2-121)
	ML	67.3	66.4
		(29.8-104.8)	(19.1-113.6)
	GX	65.4	75.4
		(27.8-102.9)	(28.2-122.6)
6	GM	134.1	81.6
		(81.9-186.4)	(48.7-114.5)
	ML	86	93.4

		(12.1-159.8)	(46.8-139.9)
	GX	90.8	87.3
		(16.9-164.6)	(40.7-133.8)
7	GM	83.1	83
		(53.1-113.2)	(53.7-112.3)
	ML	89.7	80.8
		(47.3-132.2)	(39.2-122.3)
	GX	99	88
		(56.5-141.5)	(46.5-129.5)
8	GM	124.4	67.1
		(82.6-162.2)	(41.4-92.9)
	ML	78.9	78.8
		(22.6-135.2)	(42.3-115.2)
	GX	79.9	82.3
		(23.6-136.2)	(45.9-118.7)
9	GM	58.8	57
		(29.6-87.9)	(28.3-85.7)
	ML	59	59.6
		(17.8-100.2)	(19.1-100.2)
	GX	68.3	69.5
		(27.2-109.5)	(29-110.1)

*Different superscript letters indicate significant differences among 3D analysis software within each model-operator pair (*P*<.05)

Table 2. Intraclass coefficients (ICC) and *P*-values for the inter-rater reliability (ICC of 1 means perfect agreement; ICC close to 0 or negative ICC suggests poor agreement)

Model	Software	ICC	*P*-value
1	GM	-.335	.813
	ML	.983	<.001
	GX	.94	<.001
2	GM	.025	.468
	ML	-.013	.507
	GX	.917	<.001
3	GM	.999	<.001

	ML	.902	<.001
	GX	.986	<.001
4	GM	.942	<.001
	ML	.959	<.001
	GX	.994	<.001
5	GM	.712	.011
	ML	.97	<.001
	GX	.886	<.001
6	GM	-.085	.583
	ML	.924	<.001
	GX	.8	.003
7	GM	1	<.001
	ML	.873	.001
	GX	.748	.007
8	GM	-.386	.85
	ML	.918	<.001
	GX	.933	<.001
9	GM	.999	<.001
	ML	.967	<.001
	GX	.985	<.001

*P<.05 indicates a significant correlation

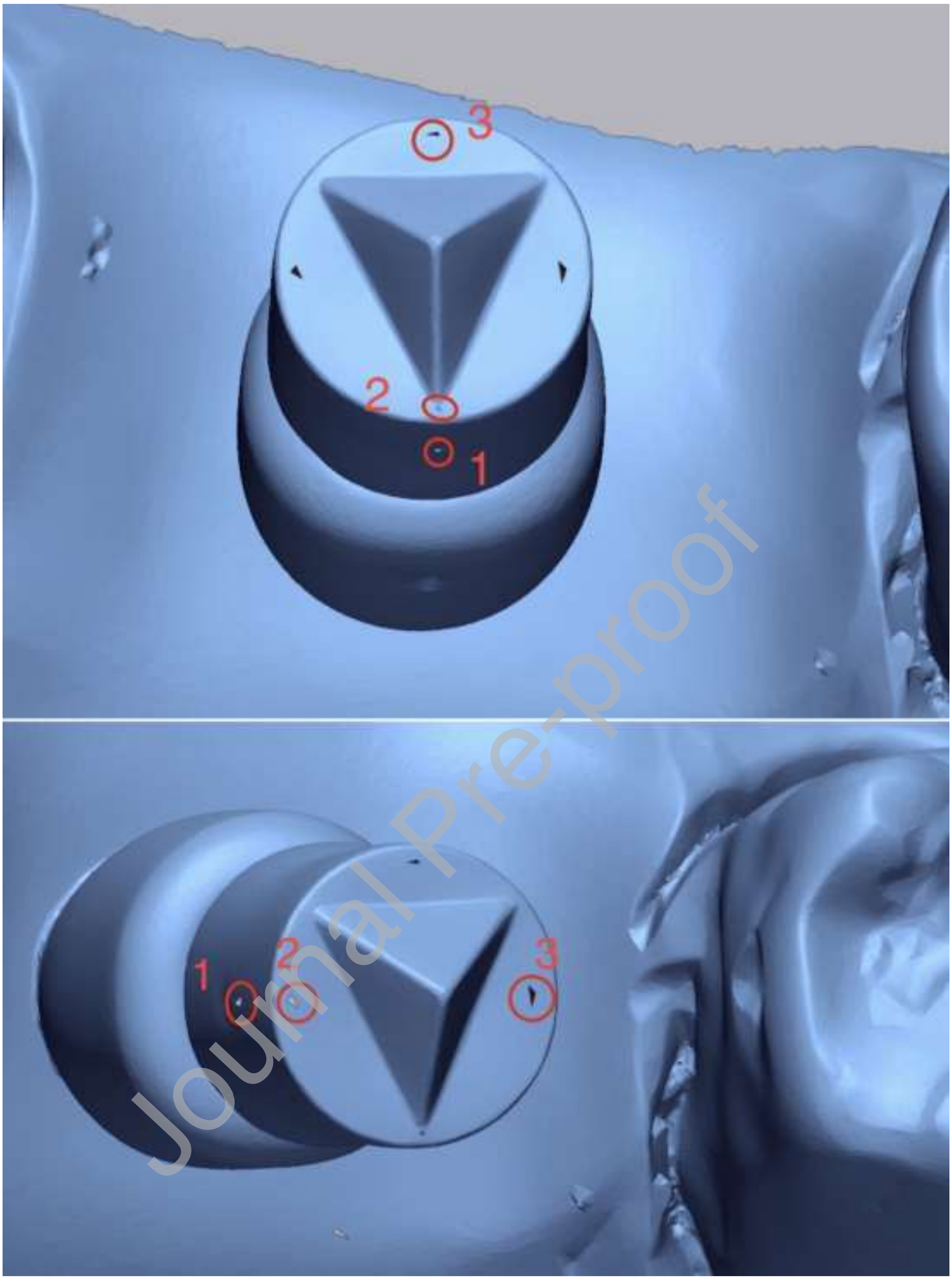


Figure 1. Points selected to generate buccolingual and mesiodistal planes, A. Points selected in buccolingual direction, B. points selected in mesiodistal direction

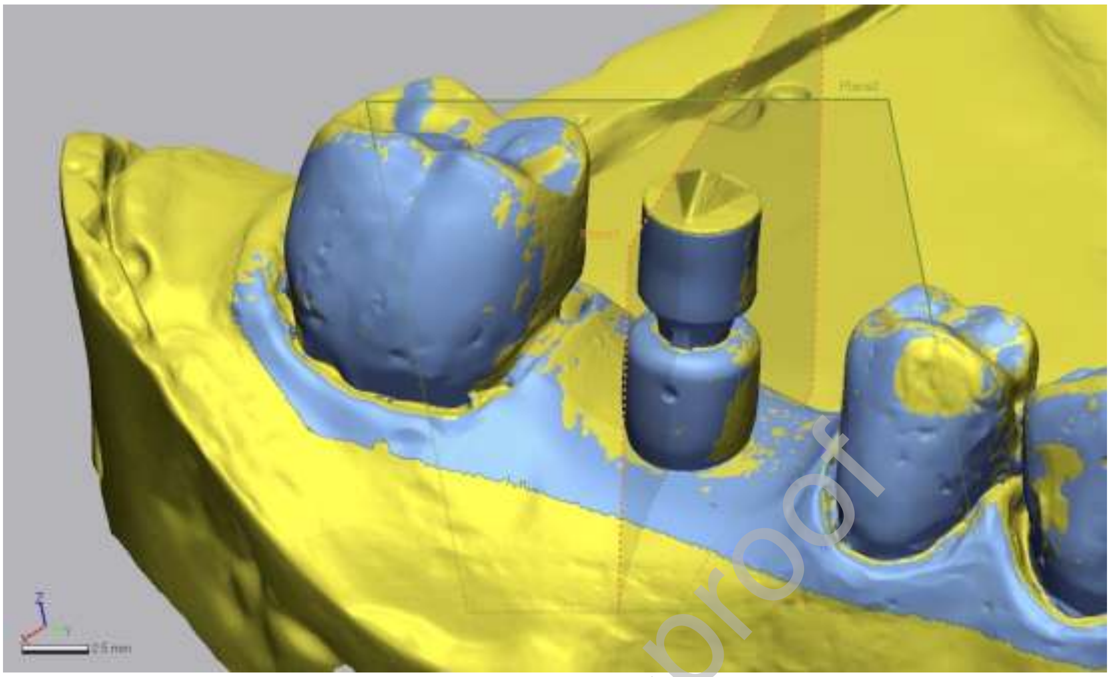


Figure 2. Buccolingual and mesiodistal planes generated for deviation analyses

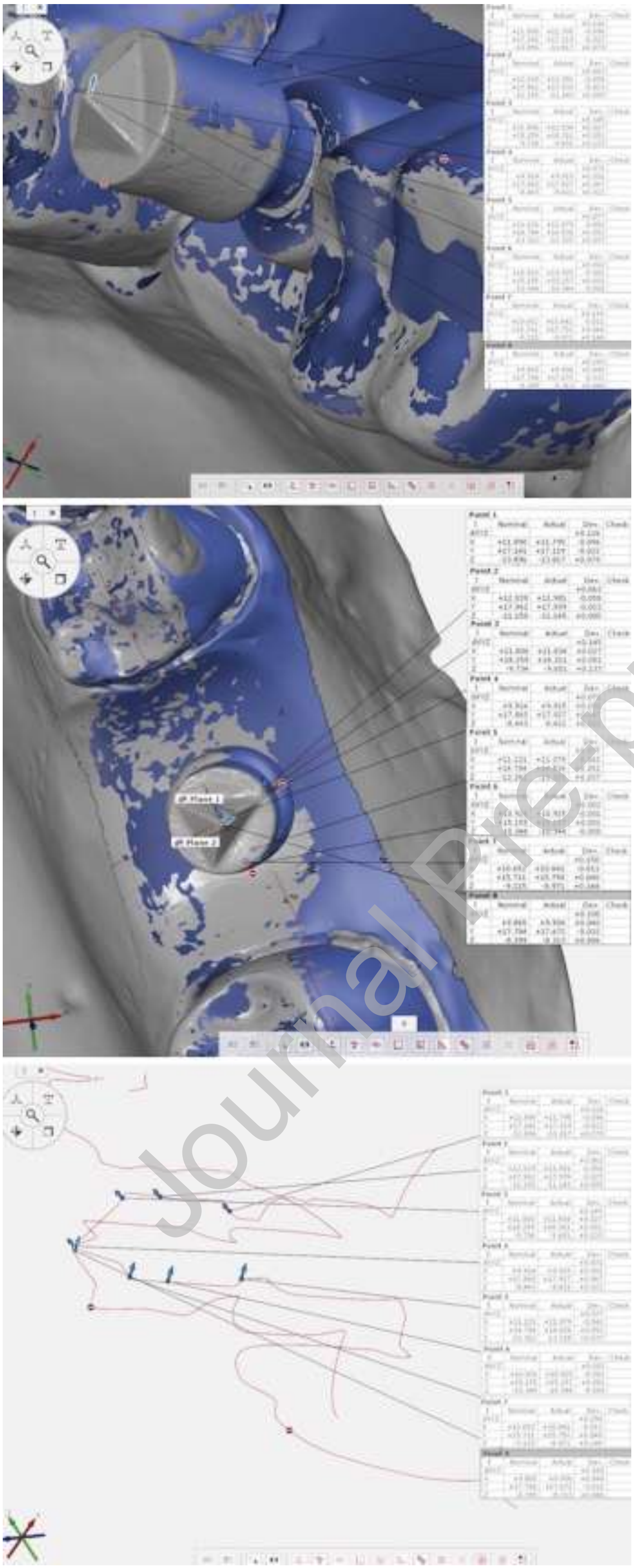


Figure 3. Points and planes generated on GM software for the deviation analyses

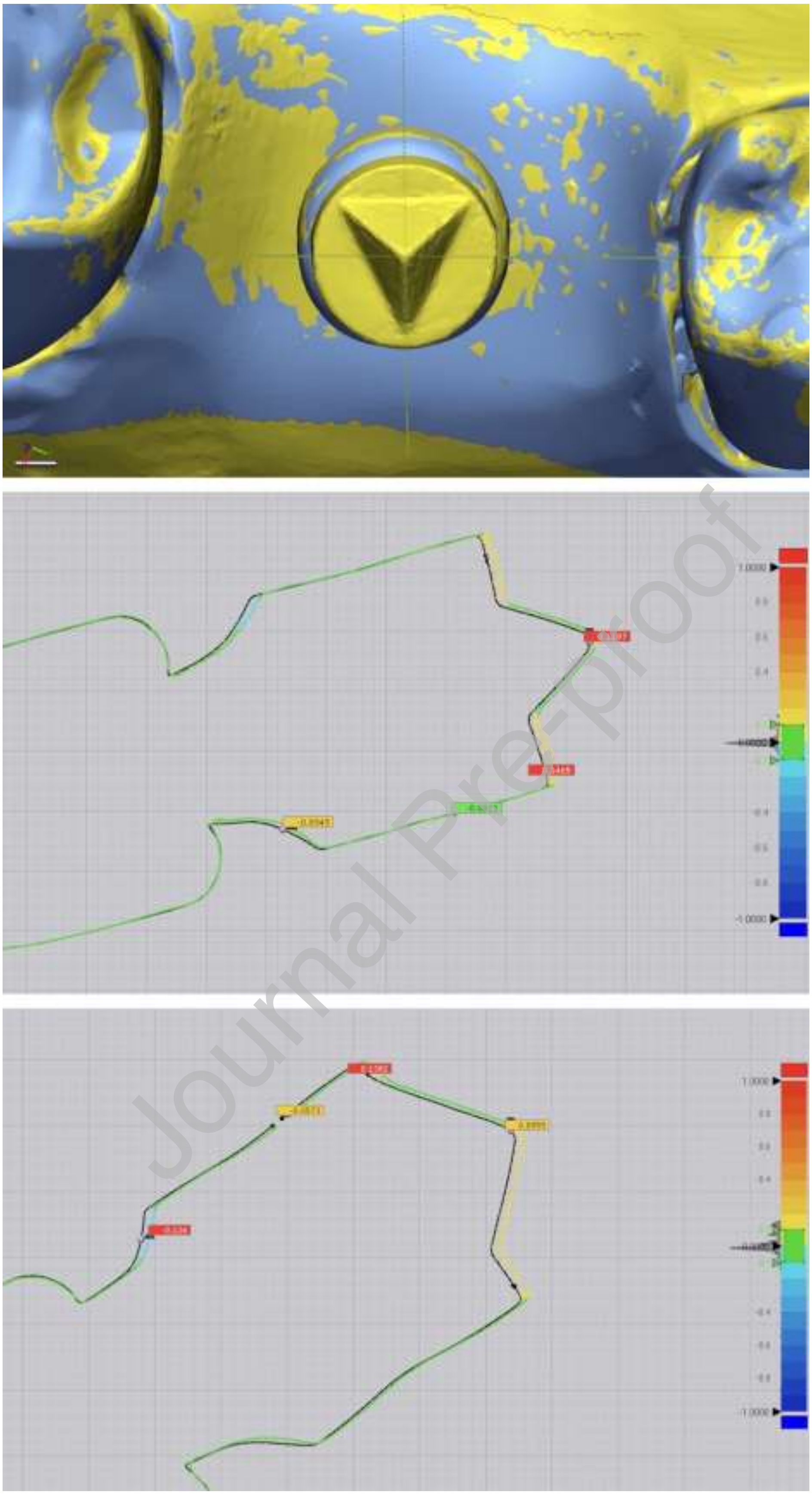


Figure 4. Points and planes generated on GX software for the deviation analyses

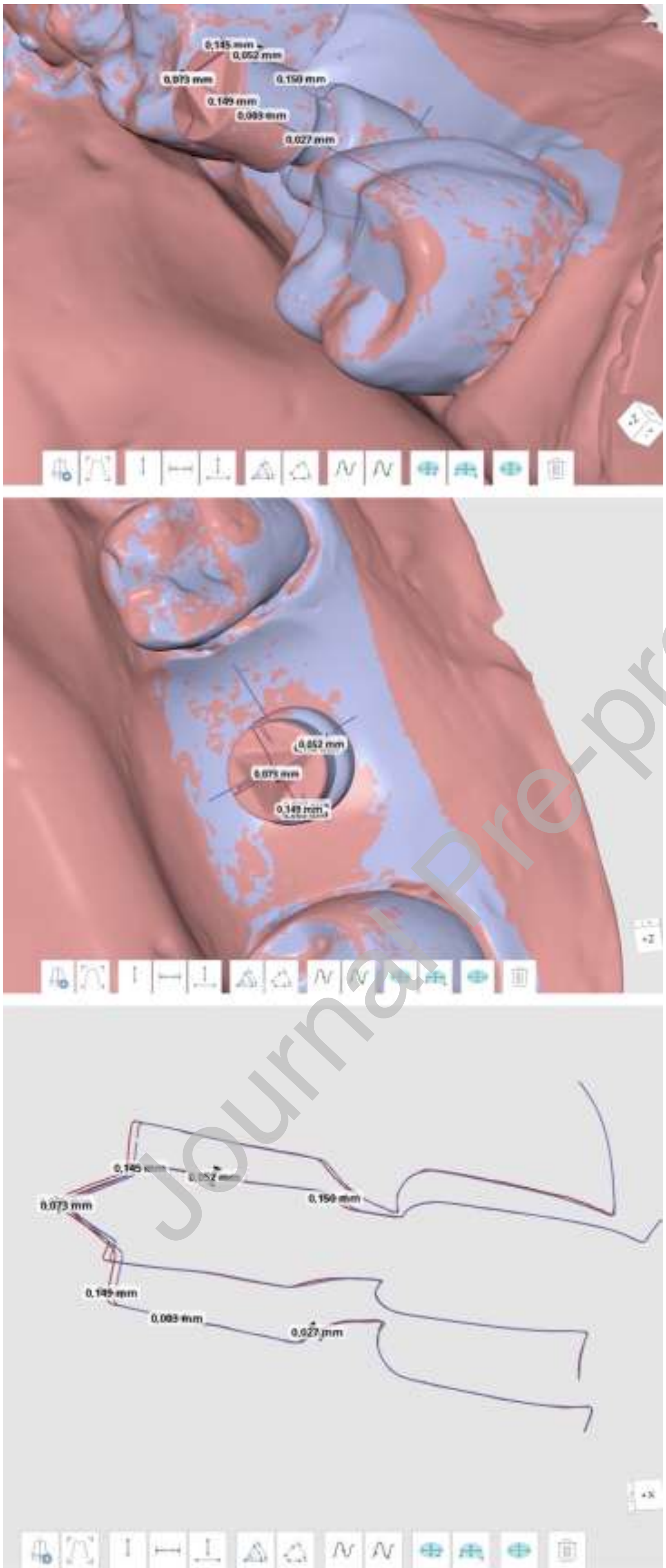

0,145 mm
0,052 mm
0,073 mm
0,150 mm
0,149 mm
0,027 mm

Figure 5. Points and planes generated on ML software for the deviation analyses

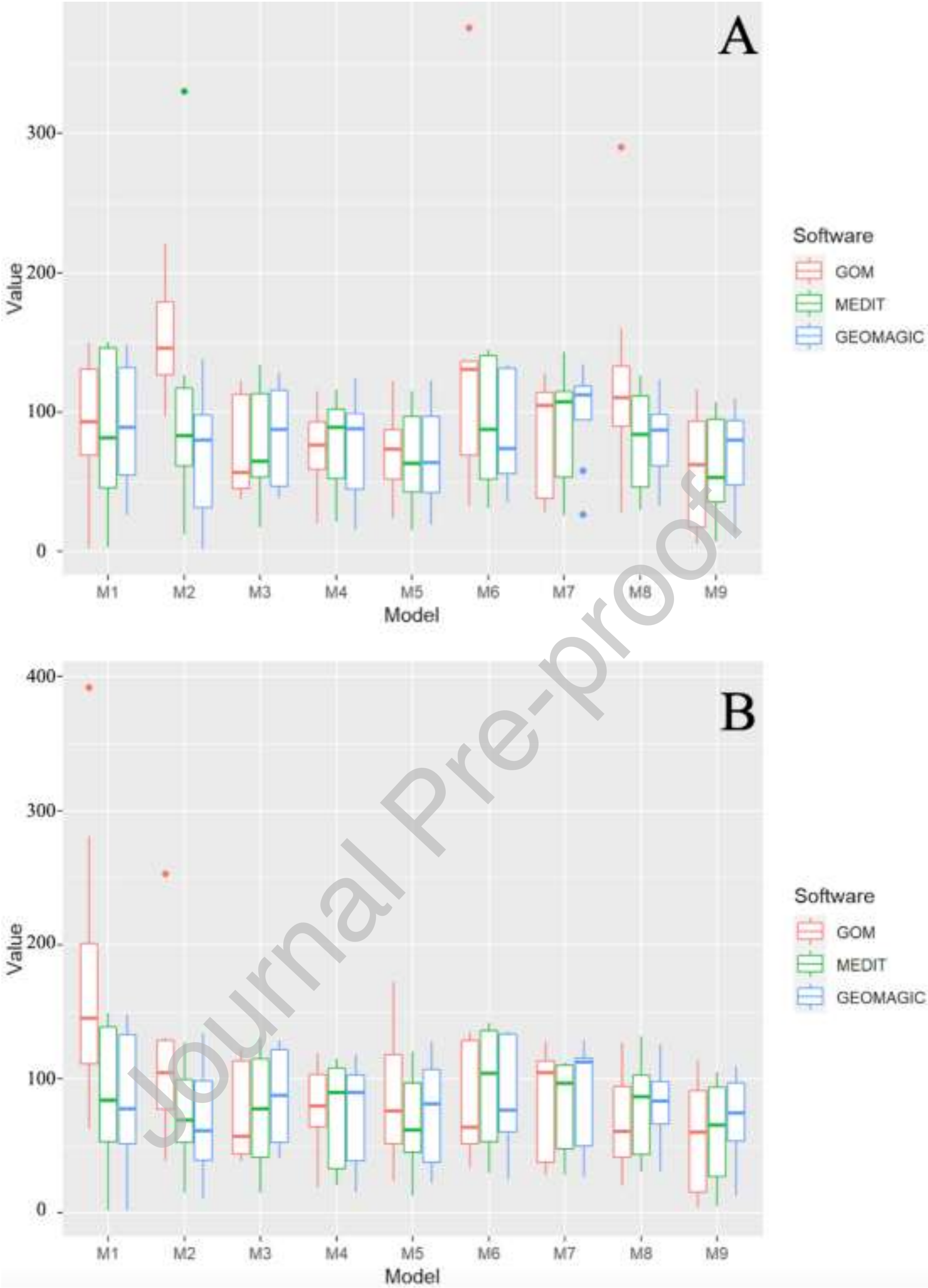


Figure 6. Boxplot of the deviations for each model and software (A: Operator 1, B: Operator 2)