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An *in vitro* study of the accuracy of a three-dimensional virtual patient representation guided by an extraoral scan body

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In modern prosthodontic treatment, digital technology is rapidly gaining popularity in terms of facilitating treatment planning and the design and manufacture of prosthesis. Recently, technology to integrate three-dimensional data of facial structures and dentition has also been developed. We investigated the accuracy of two dental facial scan systems guided by an extraoral scan body currently available in Japan. The null hypothesis was that there was no difference in the accuracy of the three-dimensional virtual facial model between the two systems. The manikin head on which the maxillary arch model was mounted was scanned by a reference high-precision laser scanner (FARO) and two dental face scanners, FACE HUNTER (FH) and FREEDOM F (FF). The scans from FH and FF were superimposed on the reference scan from FARO using the iterative closest point (ICP) method, and the mean deviation of the arch model was calculated. The accuracy (trueness and precision) was 0.403 ± 0.120 mm for the FH and 3.053 ± 0.568 mm for the FF, when compared with the FARO. The accuracy of the system was better in the FH than in the FF. (J Osaka Dent Univ 2024; 58: 29-39)

Key words: Accuracy; Virtual patient; Virtual facebow; Face scanner; Computer-aided design

INTRODUCTION

Predictable treatment planning and successful dental care requires collection of detailed patient information, history, and records. In modern prosthodontic treatment, digital technology is rapidly gaining popularity in terms of facilitating treatment planning and the design and fabrication of prosthesis. In particular, facial scanners have garnered attention as a tool for digitizing the structure of extraoral soft tissues and acquiring facial appearance information.[1] In the fields of prosthodontics, surgery, orthodontics, and other craniofacial treatments, accurate understanding of three-dimensional relationships is important.[2] Traditional diagnostic processes have involved independent collection of information about the dentition through dental models, intraoral photographs, dental radiographs, and panoramic radiographs. Facial photographs and cephalometric radiographs have been used for facial analysis.[3-5] Recently, the use of technology such as computed tomography and magnetic resonance imaging has made it possible to record the three-dimensional relationship between the dentition and facial structures. However, there are challenges associated with patient exposure and artifacts due to intraoral metal restrations.

The use of optical scanners serves as a radiation-free method for easy measurement of various objects, such as dentition and facial structures. Facial scanners facilitate interdisciplinary communication, virtual articulation, and smile design. Facial recording plays an important role in the digital workflow.[6] In the future, facial scanning technology is expected to find further applications in fields such as craniofacial research and in the diagnosis and treatment planning of craniofacial diseases.[6]

Recently, technology to integrate three-dimensional data of facial structures and dentition has also been developed. However, the trueness and precision of a three-dimensional virtual patient representation (a facial three-dimensional virtual model) that integrates facial scan data and a three-dimensional dentition model have not been clarified. In this study, we used two types of dental facial scanning systems available in Japan to investigate the accuracy of three-dimensional virtual facial models. The null hypothesis was that there was no difference in the accuracy of the three-dimensional virtual facial model between the two systems.

MATERIALS AND METHODS

Creation of a digital reference model

As a reference model, we used an epoxy model that was a duplicate of the maxillary dentition model D51FE-500A (Nissin, Kyoto, Japan) and incorporated it into a mannequin head HD-18 (Displan Corporation, Toyama, Japan). A maxillary dentition model was constructed such that it could be attached and detached using a magnet in order to be scanned separately from the facial area (Fig. 1). The Design Scan Arm 2.0 line laser scanner (FARO, Lake Mary, FL, USA)[7] was used to perform a single scan of the reference model with the maxillary dentition model attached inside a mannequin head. The obtained morphological data was converted from polygon file (PLY) format to standard tessellation language (STL) format. The maxillary dentition model that was removed from inside the mannequin head was scanned once using a laboratory desktop scanner (S300 ARTI; Zirkonzahn, Gais, Italy).[8-10] Using the three-dimensional evaluation software Geomagic Control X 2020.1 (3D Systems, Rock Hill, SC, USA), the digital reference model (DRM) (Fig. 2) was completed by aligning and replacing the dentition data of the reference model with the data of the maxillary dentition model attached inside the mannequin head that was acquired by a laser scanner with the data of the maxillary dentition region taken by a desktop scanner using the iterative closest point (ICP) algorithm.[11]

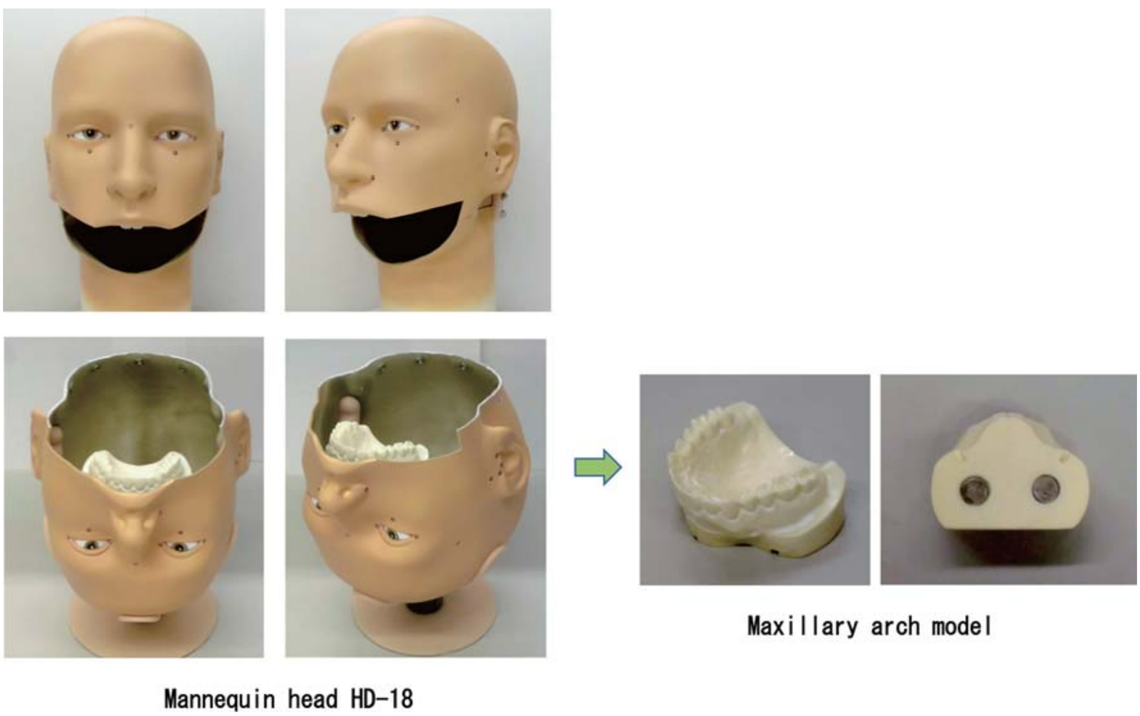

Fig. 1 Reference models.

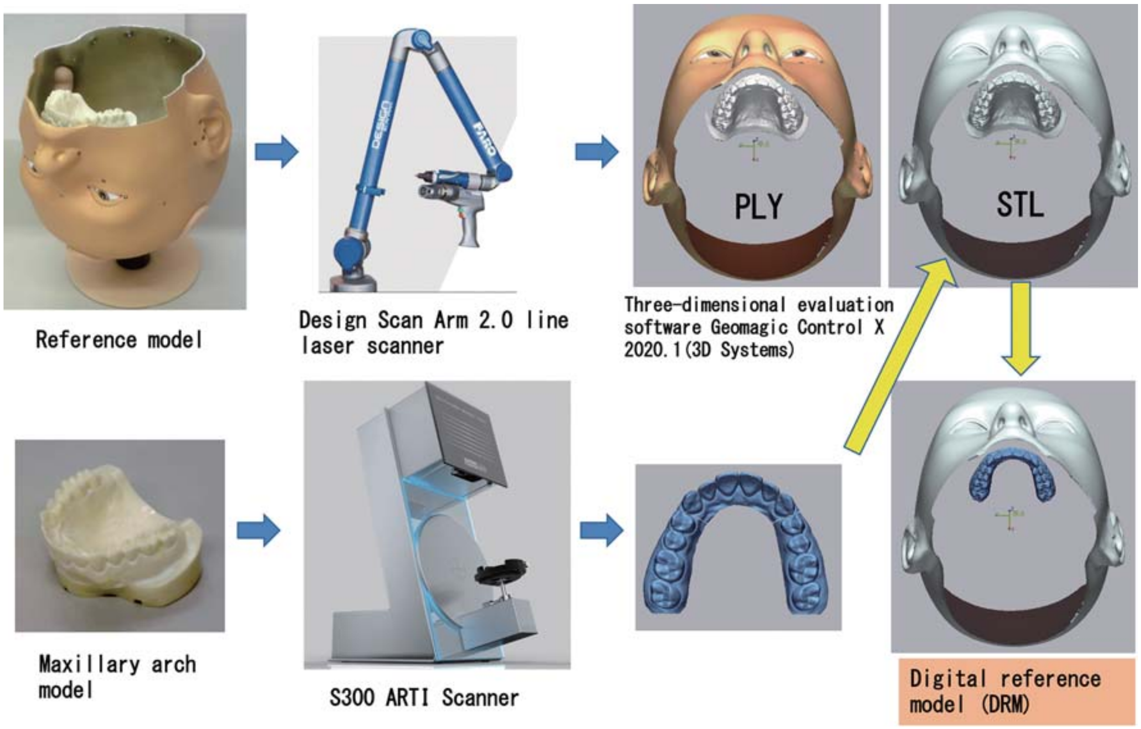

Fig. 2 Creating a digital reference model.

Creating a digital model with a dental face scanning system

Two structured light dental face scan systems, i.e., FACE HUNTER (FH; Zirkonzahn)[1, 12] and FREEDOM F (FF; DOF, Seoul, Korea)[13] were used as experimental systems (Fig. 3). Digital models were created using both systems according to the manufacturer's instructions. As scan bodies, Transfer Fork (Zirkonzahn) was used for FH, and Target Plate version 2 (DOF) coupled with Bite Tray version 2 was used for FF.

Polyvinylsiloxane impression material EXABITE II (GC, Tokyo, Japan) was inserted for occlusal registration into the part of the scan body corresponding to the maxillary dentition of each system, and the occlusal surface of the maxillary dentition model was marked. The scan body of each system was scanned using S300 ARTI. The reference model was mounted on a tripod. For the indoor lighting environment during scanning, a ceiling light was used in a room that was shielded from external light. Luminance was set to 7.4 lux using a digital illuminometer (LX-105; Custom Corporation, Tokyo, Japan).

For FH photography, the scanner was mounted on a tripod and placed in front of the reference model at a distance of 70 cm. Scanning was controlled by software (.SCAN version 5051; Zirkonzahn). The reference model without the scan body was scanned three times in total, once from the front and once each from the left and right sides at 45°. Subsequently, one scan from the front was performed with the scan body fixed to the maxillary dentition model of the reference model.

In FF, the operator held the scanner's main unit connected to a tablet-type computer (Surface Pro 7; Microsoft, Redmond, WA, USA) with both hands while capturing the reference model. A scanning software (SmileApp version 1.4.57.103; DOF) was used. Once the scanner was positioned such that the front of the reference model without the scan body was displayed on the screen, scanning was started. The scanner was rotated toward the right side of the reference model to capture data, returned to the front, and then rotated toward the left side of the reference model to capture data. Next,

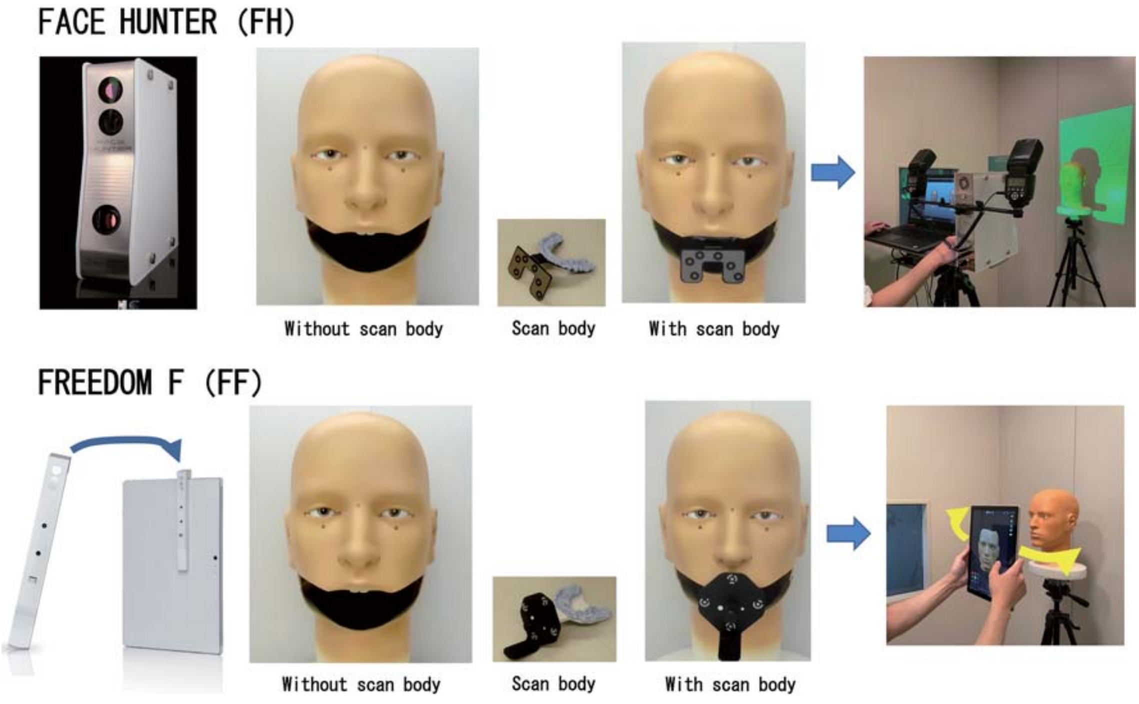

Fig. 3 Structured light-based dental face scan systems.

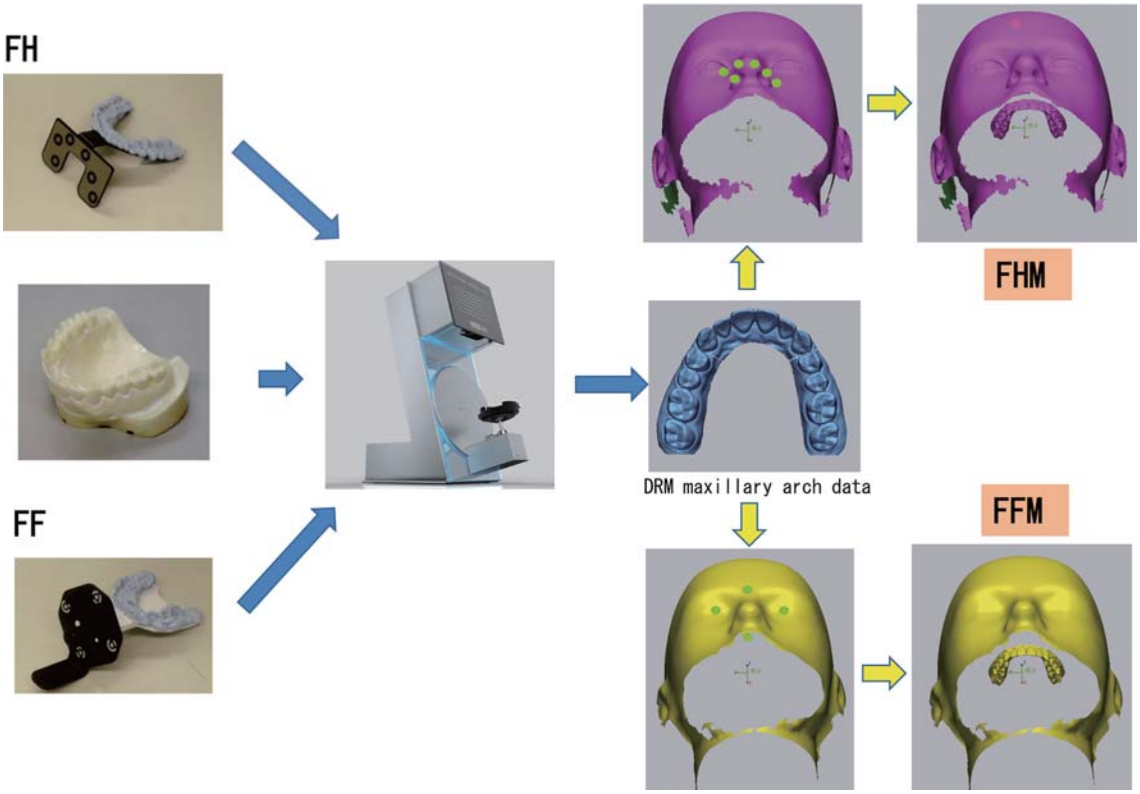

Fig. 4 Scanning scan bodies and creating digital models (FHM and FFM).

one scan from the front was performed with the scan body fixed to the maxillary dentition model of the reference model.

For the integration of scanned data, .SCAN version 5051 (Zirkonzahn) was used for FH, and MatchApp version 2.0 (DOF) was used for FF. The marked part of the dentition model occlusal surface of the scan body was aligned with the maxillary dentition data common to DRM. Furthermore, the scan body based on the reference points on the plate on the front of the scan body was aligned with the face scan data, while the scan body was fixed to the maxillary dentition model part of the reference model. Thus, we created a digital model (FHM) using FH and a digital model (FFM) using FF (Fig. 4). The obtained data were converted to STL format.

Accuracy measurements

Alignment of DRM with FHM and DRM with FFM was performed in the upper and midface regions. Trueness was calculated from the deviation distance of the upper dentition scan data, and precision was calculated from the standard deviation (Fig. 5).[14] Geomagic Control X 2020.1 was used for three-dimensional deviation measurements.

Mean deviation distance of the full maxillary arch (MDD)

We calculated the average deviation distance (trueness) and standard deviation (precision) between the mesh vertices of the corresponding STL for the entire dentition (Fig. 6).

Three-dimensional mean deviation distance of the maxillary arch (MDD3D)

The deviation distance (trueness) was calculated for each vertical, horizontal, and front-back direction.

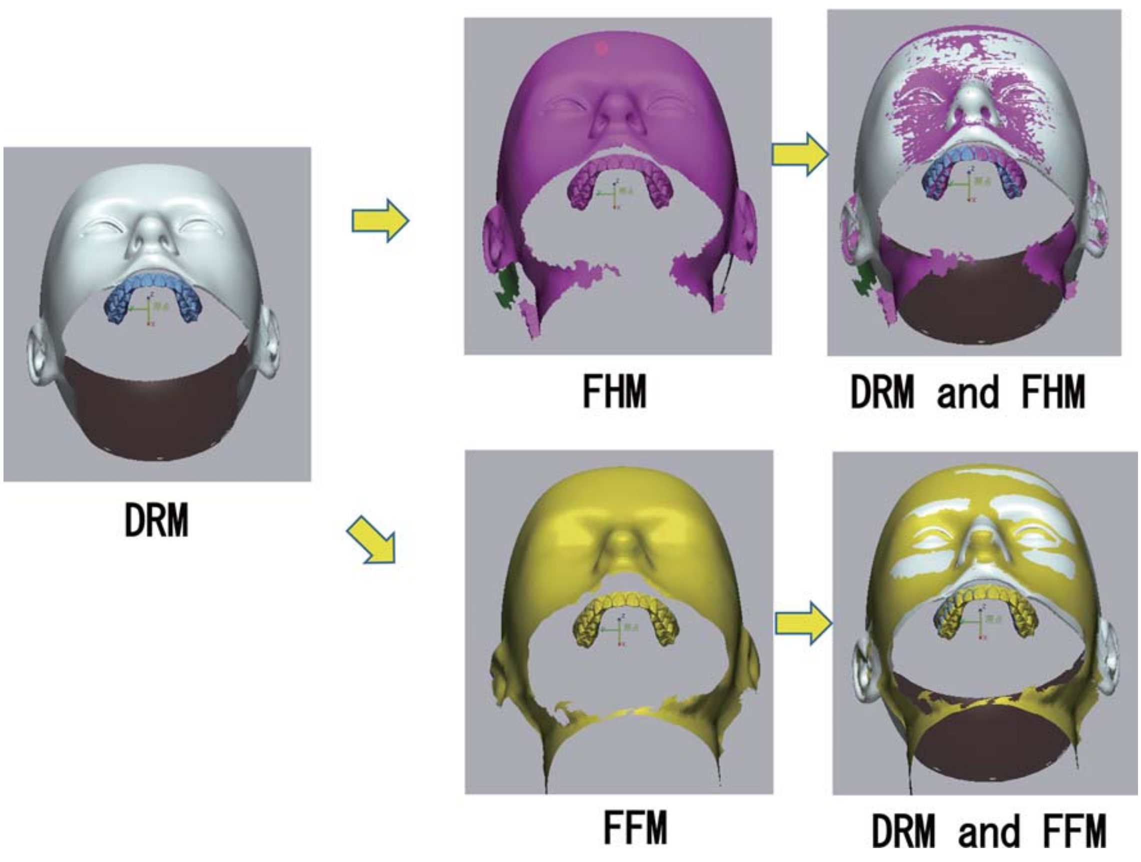

Fig. 5 Matching of DRM and two digital models and calculation of deviation distance between maxillary dentition.

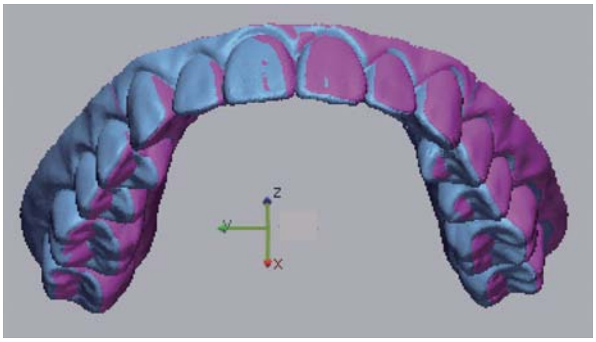

Fig. 6 Deviation of the full maxillary arch.

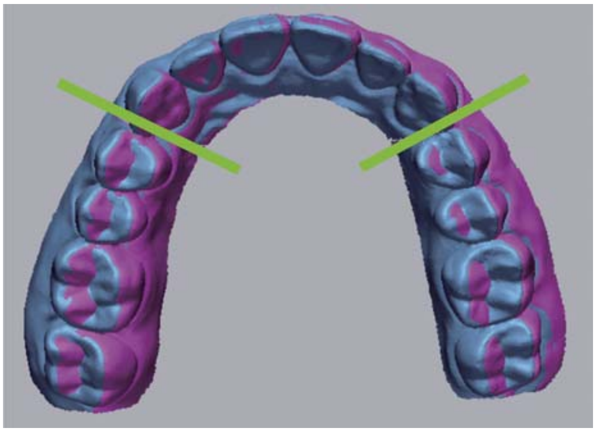

Fig. 7 Deviation of the three regions of the maxillary arch.

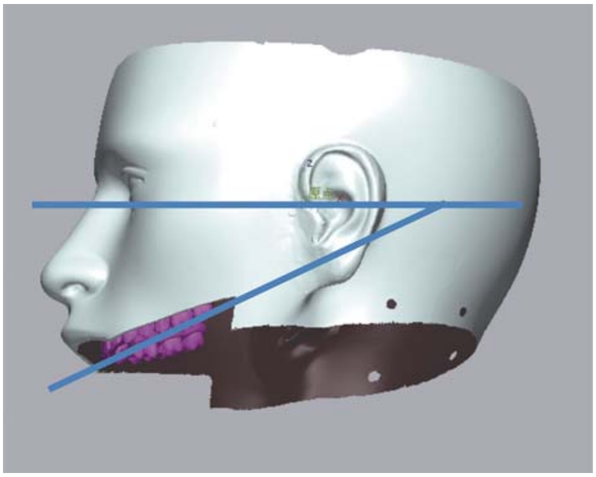

Fig. 8 Reference planes with measured dihedral angle.

Mean deviation distance of the three regions of the maxillary arch (MDD3R)

We calculated the mean deviation distance (trueness) (Fig. 7) for each of the three regions, the anterior teeth and the left and right molars.

Angular difference in the maxillary reference plane (ADMR)

The maxillary dentition reference plane was set such that it connected the midpoint between the mesial angles of the left and right central incisors of the maxilla and the distobuccal cusp of the left and right first molars. Regarding the dihedral angle with respect to the Frankfurt plane, we calculated the difference (trueness and precision) between DRM and FHM and between DRM and FFM (Fig. 8).

Statistical analysis

An unpaired Welch's t-test was performed for MDD, and an F-test was performed for the differences in variance. For MDD3D, two-way analysis of variance (ANOVA) (mixed design) was performed with the system (two levels) and the direction (three levels) as factors.[15] If a significant difference was found in the interaction, a simple main effect was tested, and the Bonferroni method was used for multiple comparisons. For MDD3R, two-way ANOVA (mixed design) was performed with the system (two levels) and the site (three levels) as factors. When a significant difference in interaction was observed, a simple main effect was tested, and the Bonferroni method was used for multiple comparisons. An unpaired Welch's t-test was performed for ADMR, and an F-test was performed for differences in variance. The statistical significance level (α) was set at 0.05. IBM SPSS Statistics for Windows, version 28 (IBM, Armonk, NY, USA) and MedCalc Ver. 20 (MedCalc Software, Ostend, Belgium) were used for statistical analyses.

Power analysis

A priori power analysis was performed using G *power Ver. 3.1 (Heinrich Heine University, Dusseldorf, Nordrhein-Westfalen, Germany).[16] A sample-based effect size was calculated from a preliminary experiment with five samples, and a sample size satisfying $\alpha = 0.05$ and statistical power $(1-\beta) = 0.8$ was obtained.[17] For MDD, the sample size for each group was calculated as 2 from the sample effect size $d = 7.459$. For MDD3D, the factor sample size was 2-3. For MDD3D, the factor sample size was

2-9. For ADMR, a sample size of 8 for each group was calculated from a sample effect size of d = 1.545. Based on the above results, we created 10 digital models for each system from the reference model in this study.

RESULTS

MDD

The trueness of MDD was 0.403 mm for FHM and 3.053 mm for FFM, indicating that FHM had good trueness. The precision was 0.120 mm for FHM and 0.568 mm for FFM, indicating that FHM had good precision (Fig. 9).

MDD3D

Two-way ANOVA of MDD3D showed differences in all factors (Table 1). The values ranged from -0.212 mm to 0.250 mm in all directions for FHM and from -0.399 mm to -2.800 mm for FFM. Simple main effects and multiple comparisons showed that FHM had greater deviation than FFM in all directions. The downward deviation of FFM was the largest (Fig. 10).

MDD3R

Two-way ANOVA revealed differences only in system factors (Table 2). FHM showed smaller values

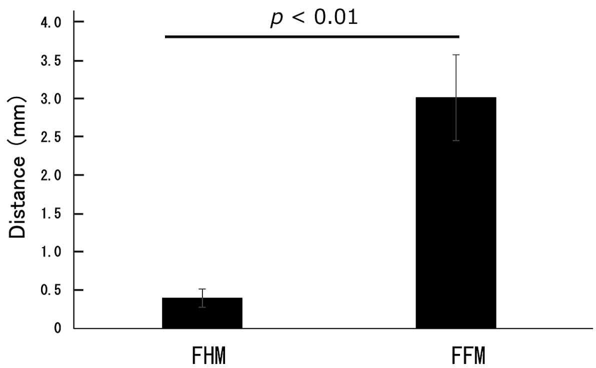

Fig. 9 Mean deviation distance of the full maxillary arch (MDD)
n = 10, Mean ± SD, Independent-samples Welch's t test, t = 14.433 ($p < 0.01$), F test: F = 22.406 ($p < 0.01$).

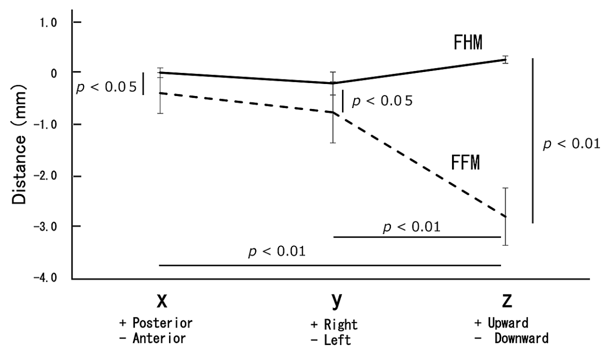

Fig. 10 Interaction plots for mean deviation for three-dimensional mean deviation distance of maxillary arch (MDD 3D) (n = 10, Mean ± SD).

Table 1 Analysis of variance table for three-dimensional mean deviation distance of maxillary arch (MDD3D)

Factor	Sum of squares	df	Mean square	F-value	η_p^2	Power
System	26.780	1	26.780	171.378*	0.905	1.000
Error	2.813	18	0.156			
Direction	12.316	2	6.158	43.065*	0.705	1.000
Interaction	22.093	2	11.046	77.252*	0.811	1.000
Error	5.148	36	0.143			

df: Degrees of freedom, η_p^2: Partial eta squared, *$p < 0.01$.

Table 2 Analysis of variance table for mean deviation distance of three regions of maxillary arch (MDD3R)

Factor	Sum of squares	df	Mean square	F-value	η_p^2	Power
System	106.171	1	106.171	207.607*	0.920	1.000
Error	9.205	18	0.511			
Region	0.328	1.171	0.280	2.044	0.102	0.295
Interaction	0.184	1.171	0.157	1.145	0.060	0.185
Error	2.891	21.084	0.137			

df: Degrees of freedom, η_p^2: Partial eta squared, *$p < 0.01$.

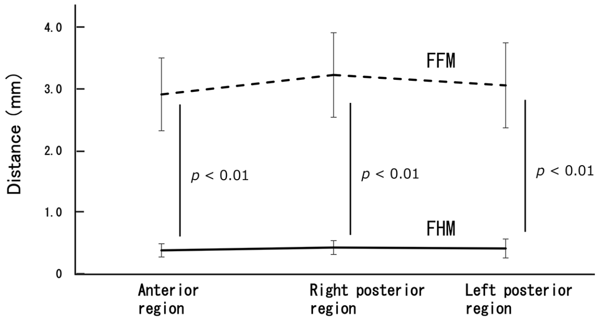

Fig. 11 Mean deviation distance of the three regions of the maxillary arch (MDD3R)
(n=10, Mean ± SD).

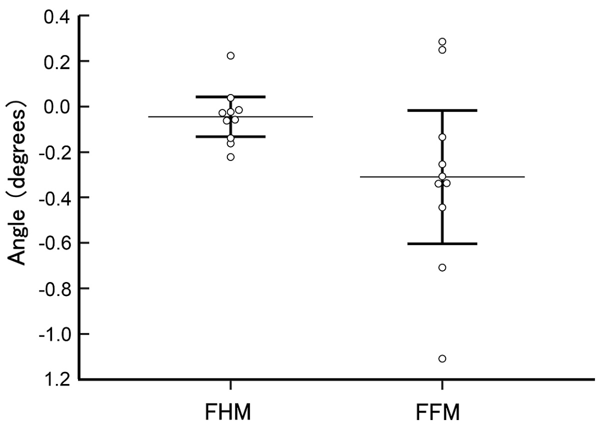

Fig. 12 Angular difference in maxillary reference plane (ADMR)
n=10, Mean ± SD, Independent-samples Welch's t test, t=1.958 ($p = 0.07$), F test: F=11.195 ($p < 0.01$).

than FFM at all sites (Fig. 11).

ADMR

The trueness of both systems was -0.045° for FHM and -0.310° for FFM, showing a tendency to approach zero for FHM. However, no significant difference was observed. In contrast, the precision was 0.123° for FHM and 0.410° for FFM, indicating a significant difference (Fig. 12).

DISCUSSION

This study investigated the accuracy of three-dimensional virtual models of the face using two types of dental face scanning systems currently available in Japan. A significant difference was noted in trueness and precision between the three-dimensional facial models obtained using the two tested systems, and the null hypothesis was rejected.

Creation of the DRM and digital model

The Design Scan Arm 2.0 line laser scanner, which was used to create the DRM, records 600,000 data points per second with a trueness of 0.075 mm.[7] In addition, the maxillary dentition model was scanned using the S300 ARTI scanner, which has trueness of 0.010 mm or less.[8] The data from the dental arch portion of the reference model, scanned within the mannequin head, was integrated with the data obtained from the maxillary dentition model to evaluate DRM, FHM and FFM using common three-dimensional data.

The two types of face scanning systems tested in this study employ a measurement method that uses structured light. Structured light scanning involves the use of a projector to project a pattern of light onto a subject, which is captured by a camera and processed by a computer to obtain a three-dimensional shape of the subject's facial surface. It records light from various angles and calculates a three-dimensional mesh from the displacement of the light pattern. The advantage of this technology is its high speed and accuracy compared with other methods.[18] However, the accuracy of this scanning method is said to be easily affected by illumination. Thongma-Eng *et al.*[19] reported that ambient light affects the accuracy of facial scans. Therefore, in this study, the lighting environment was unified with only a ceiling light in a room that was shielded from outside light.

As a means of integrating facial data and maxillary model data, a method of directly matching the labial side of the maxillary anterior teeth captured during facial scanning with the labial side of the maxillary anterior teeth of the digital dental model,[20, 21] and a method[2] using a scan body have been proposed. Using a laser scanner, Nagao *et al.*[2] measured the three-dimensional morphology of the tooth mold and face structures and integrated the facial data with the maxillary dentition model data to devise a method of attaching an extraoral marker plate to the maxillary dentition model as an interface. Revilla-León *et al.*[22] compared the accuracy of three-dimensional virtual models of the face using these two methods and the scan body system and achieved better trueness and precision than that achieved with the method that did not use it. The two types of face scanning systems tested in this study employed a method that used a scan body.

Accuracy measurements

Many studies have reported on the accuracy of face scanners. Most of them focused only on morphological data of the facial surface.[1, 23-28] In the dental field, clinical applications of three-dimensional facial virtual models that integrate facial data and three-dimensional dentition models are increasing.[29] However, the accuracy of the three-dimensional virtual facial model created by the dental face scan system available in Japan has not been examined. Using FH, Pellitteri *et al.*[27] and Sato *et al.*[1] examined the accuracy of facial topography data. In addition, Sato *et al*[1] and Watarai *et al.*[30] conducted research on FF. Previous *in vivo* and *in vitro* studies[1, 31] have reported that accuracy was higher in the midface than in other areas. In this study, this region was used as reference for superimposing the DRM and DM of each system.

Considering the results of the comparison experiment between FH and FF in this study, MDD showed higher accuracy in FHM than FFM. In terms of the direction of maxillary dentition deviation, FFM was more forward shifted to the left, and shifted downward than FHM. The results for MDD3 R showed the same degree of displacement in all three sites, indicating that the maxillary dentition was not rotated in the horizontal plane. Although a significant difference was observed in ADMR precision, there was no significant difference in trueness, indicating that the FFM maxillary dentition model deviated antero-inferiorly along the maxillary dentition reference plane compared to FHM. The reason why FH generated a three-dimensional virtual facial model with higher accuracy than FF is associated with the higher accuracy of the facial morphology data of FH.[1] In addition, FH had a stationary scanner body, and the shooting time was short. Additionally, there may be differences in the performance of the software algorithms used to integrate scanned facial, dentition, and scan body data.

The trueness of the entire dentition of FHM was 0.403 mm and the precision was 0.120 mm, whereas these values for FFM were 3.053 mm and 0.568 mm, respectively. When compared with studies investigating the accuracy of physical facebow transfers traditionally used in clinical practice, Choi *et al.*[32] reported that the trueness ranged from 1.5 mm to 6.7 mm for maxillary central incisors and for left and right lateral maxillary first molars. Lam *et al.*[33] calculated a trueness of 3.66 $\pm$ 2.94 mm. FH using digital technology showed higher accuracy than conventional methods.

Amezua *et al.*[34] measured the trueness as 0.138 mm and precision as 0.022 mm for the accuracy of the technology that applies digital technology to create a three-dimensional virtual facial model using the scan body. Revilla-León *et al.*[22] reported trueness ranging from 0.244 mm to 0.346 mm. Due to methodological heterogeneity, strict quantitative comparisons between studies are challenging. However, the results of this experiment indicated a higher accuracy compared to FHM. According to the results of Sato *et al.*[1] who examined the accuracy of only facial surface shape data regarding FH, the trueness was 0.117 mm and precision was 0.004 mm, indicating that the deviation may have increased in the process of positioning the maxillary dentition data to the facial data using the scan body data. Factors that affect accuracy, such as the software involved in data integration and the skill of operators, must be considered as future issues.

Kokich *et al.*[35] conducted an experiment in which two-dimensional photographs of the upper anterior teeth when smiling were presented, and test photographs were presented in which the vertical distance from the upper lip to the gingival margin of the upper anterior teeth was changed in increments of 2 mm. Orthodontists can recognize a change when the tooth is moved by 2 mm from the reference point. In this experiment, the three-dimensional virtual facial model of FF, in which the maxillary dentition was deviated downward by 2.800 mm, may be associated with challenges in the aesthetic inspection/diagnosis of the anterior teeth or in fabrication of prosthesis.

This study has some limitations, including the use of a static mannequin head; therefore, the results should be interpreted with caution. This indicates a need for clinical trials that evaluate the accuracy of a three-dimensional virtual facial model and the clinical validity of this model in a workflow. Moreover, studies that consider all variables that may influence the final results must be conducted.

Conflicts of interest

There are no conflicts of interest for the authors of this article.

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REFERENCES

1. Sato M, Kashiwagi K, Nishibori K, Itoda S, Shinozaki Y, Fujii T, Tanaka J. An *in vitro* study of the three-dimensional accuracy of facial measurements by two dental face scanners. *J Osaka Dent Univ* 2022; **56**: 175-181.
2. Nagao M, Sohmura T, Kinuta S, Kojima T, Wakabayashi K, Nakamura T, Takahashi J. Integration of 3-D shapes of dentition and facial morphology using a high-speed laser scanner. *Int J Prosthodont* 2001; **14**: 497-503.
3. Grayson B, Cutting CB, Bookstein FL, Kim HC, McCarthy JG. The three-dimensional cephalogram: Theory, technique, and clinical application. *Am J Orthod Dentofac Orthop* 1988; **94**: 327-37.
4. Bookstein FL, Grayson B, Cutting CB, Kim HC, McCarthy JG. Landmarks in three dimensions: Reconstruction from cephalograms versus direct observation. *Am J Orthod Dentofac Orthop* 1991; **100**: 133-140.
5. Jacobson A, Jacobson RL. The role of radiographic cephalometry in diagnosis and treatment planning. Radiographic cephalometry: from basics to 3-d imaging. 2nd ed. Chicago: Quintessence Pub, 2006; 10-12.
6. Lee JD, Nguyen O, Lin Y, Luu D, Kim S, Amini A, Lee SJ. Facial scanners in dentistry: an overview. *Prosthesis* 2022; **4**: 664-678.
7. FARO. ENGRISH US. https://downloads.faro.com/index.php/s/LRgxRPQgYSApkL6: accessed on July 10 2023.
8. Zirkonzahn S300 ARTI SCANNER-COMPACT WITH ARTICULATOR SCAN. https://zirkonzahn.com/en/cad-cam-systems/scanner-s300-arti: accessed on July 10 2023.
9. Yang S, Feng N, Li D, Wu Y, Yue L, Yuan Q. A Novel Technique to align the intraoral scans to the virtual articulator and set the patient-specific sagittal condylar inclination. *J Prosthodont* 2022; **31**: 79-84.
10. Hoffmann L, Sabbagh H, Wichelhaus A, Kessler A. Bracket transfer accuracy with two different three-dimensional printed transfer trays vs silicone transfer trays. *Angle Orthod* 2022; **92**: 364-371.
11. Besl P J, McKay ND. A method for registration of 3-D shapes. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 1992; **14**: 239-256.
12. Polymetric GmbH. Polymetric Competence in Optical 3D Measuring. https://www.polymetric.de/fileadmin/content_images/handouts/PolymetricHandout2014en.pdf: accessed on July 10 2023.
13. DOF Inc. Face Scanner FREEDOM F. https://doflab.com/freedomf/: accessed on July 10 2023.
14. International organization for standardization. Accuracy (trueness and precision) of measurement methods and results —part 4: Basic methods for the determination of the trueness of a standard measurement method. ISO 5725-4. 1994; 1-17.
15. Kirk, R. E. Experimental design: procedures for the behavioral sciences. 4th ed. California, Los Angeles. Sage Publications Inc. 2013; 541-620.
16. Faul F, Erdfelder E, Lang AG, Buchner A. G*power 3: a flexible statistical power analysis program for the social, behavioral and biomedical sciences. *Behav Res Methods* 2007; **39**: 175-191.
17. Cohen J.Statistical power analysis for the behavioral sciences 2nd ed. NJ: Hillsdale: Erlbaum 1988; 273-406.
18. Tzou CH, Artner NM, Pona I, Hold A, Placheta E, Kropatsch WG, Frey M. Comparison of three-dimensional surface-imaging systems. *J Plast Reconstr Aesthet Surg* 2014; **67**: 489-497.
19. Thongma-Eng P, Amornvit P, Silthampitag P, Rokaya D, Pisitanusorn A. Effect of ambient lights on the accuracy of a 3-dimensional optical scanner for face scans: an *in vitro* study. *J Healthc Eng* 2022; **2022**: 2637078.
20. Rangel FA, Maal TJ, Bergé SJ, van Vlijmen OJ, Plooij JM, Schutyser F, Kuijpers-Jagtman AM. Integration of digital dental casts in 3-dimensional facial photographs. *Am J Orthod Dentofacial Orthop* 2008; **134**: 820-826.
21. Rosati R, De Menezes M, Rossetti A, Sforza C, Ferrario VF. Digital dental cast placement in 3-dimensional, full-face reconstruction: a technical evaluation. *Am J Orthod Dentofacial Orthop* 2010; **138**: 84-88.
22. Revilla-León M, Zeitler JM, Barmak AB, Kois JC. Accuracy of the 3-dimensional virtual patient representation obtained by using 4 different techniques: An *in vitro* study. *J Prosthet Dent* 2022; **128**: 984-993.
23. Weinberg SM, Naidoo S, Govier DP, Martin RA, Kane AA, Marazita ML. Anthropometric precision and accuracy of digital three-dimensional photogrammetry: comparing the Genex and 3dMD imaging systems with one another and with direct anthropometry. *J Craniofac Surg*; 2006; **17**: 477-483.
24. Fink M, Medelnik J, Strobel K, Hirschfelder U, Hofmann E, Lombardo L. Metric precision via soft-tissue landmarks in three-dimensional structured-light scans of human faces. *J Orofac Orthop* 2014; **75**: 133-143.
25. Pokpong A, Sasiwimol S. The accuracy of digital face scans obtained from 3d scanners: an *in vitro* study. *Int J Environ Res Public Health* 2019; **16**: 5061. doi:10.3390/ijerph16245061 (13 pages).

26. Federica P, Luca B, Giorgio Alfredo S, Giuseppe S, Luca L. Comparison of the accuracy of digital face scans obtained by two different scanners An *in vivo* study. *Angle Orthod* 2021; **91**: 641-649.
27. Pellitteri F, Brucculeri L, Spedicato GA, Siciliani G, Lombardo L. Comparison of the accuracy of digital face scans obtained by two different scanners. *Angle Orthod* 2021; **91**: 641-649.
28. Wang C, Shi YF, Xiong Q, Xie PJ, Wu JH, Liu WC. Trueness of one stationary and two mobile systems for three-dimensional facial scanning. *Int J Prosthodont* 2022; **35**: 350-356.
29. Joda T, Brägger U, Gallucci G. Systematic literature review of digital three-dimensional superimposition techniques to create virtual dental patients. *Int J Oral Maxillofac Implants* 2015; **30**: 330-337.
30. Watarai Y, Koide K, Ota S, Mizuhashi F. Examination of facial measurement on the image using a noncontact three-dimensional measurement device. *J Family Med Prim Care* 2022; **11**: 7776-7782.
31. Zhao YJ, Xiong YX, Wang Y. Three-dimensional accuracy of facial scan for facial deformities in clinics: a new evaluation method for facial scanner accuracy. *PLoS One* 2017; **12**: e0169402.
32. Choi DG, Bowley JF, Marx DB, Lee S. Reliability of an ear-bow arbitrary face-bow transfer instrument. *J Prosthet Dent* 1999; **82**: 150-156.
33. Lam WYH, Hsung RTC, Choi WWS, Luk HWK, Cheng LYY, Pow EHN. A clinical technique for virtual articulator mounting with natural head position by using calibrated stereophotogrammetry. *J Prosthet Dent* 2018; **119**: 902-908.
34. Amezua X, Iturrate M, Garikano X, Solaberrieta E. Analysis of the influence of the facial scanning method on the transfer accuracy of a maxillary digital scan to a 3D face scan for a virtual facebow technique: An *in vitro* study. *J Prosthet Dent* 2022; **128**: 1024-1031.
35. Kokich VO Jr, Kiyak HA, Shapiro PA. Comparing the perception of dentists and lay people to altered dental esthetics. *J Esthet Dent* 1999; **11**: 311-324.