copyright by
all rights reserved
Quintessenz

Effect of the Spatial Position of Transfer Fork Markers on the Accuracy of Digital Virtual Patient Registration

Shi Rui QIU[1,#], Rui Tao CAO[2,#], Sheng Han GAO[2,#], Dan Ni GUO[2,#], Shao Xia PAN[2]

Objective: *To investigate the impact of spatial positions of the transfer fork registration markers on the accuracy of generating a virtual dentofacial patient.*

Methods: *An in vitro study was conducted using a mannequin head with a standard maxillary dentition model. Radiopaque gauge markers were fixed on the face and dentition of the mannequin head. CBCT was performed and the distance and angle between the dentition and facial markers were measured in the CBCT as reference values. Intraoral scanners were used to obtain 3D morphological data of the maxilla. Two types of transfer fork were designed and fabricated. The registration markers on transfer fork A were positioned in the midline area, while those on transfer fork B were located at the corners of the mouth on both sides. The transfer forks were digitised and connected to the maxillary dentition within the mannequin head, and facial scanning was performed using a facial scanner five times in each group. A virtual dentofacial patient was built through matching and integration of digital dentition, face and transfer fork data using 3D reverse engineering software (Geomagic Wrap 2021, 3D Systems, Rock Hill, SC, USA). Measurement values including feature lengths and feature angles between six facial gauge markers and three dentition gauge markers were obtained in the virtual patients.*

Results: *The mean trueness and precision of linear difference for virtual patients established using transfer fork A were −1.00 ± 0.11 mm and 0.27 ± 0.02 mm and the angle deviation was −1.88 ± 0.27 degrees, whereas for transfer fork B, the mean trueness and precision of linear difference were 2.66 ± 0.25 mm and 0.83 ± 0.06 mm, and the angle deviation was 3.74 ± 0.87 degrees. There is an overall significant difference in the trueness values of feature lengths (t = −13.963, P = 0.000) and angles (t = −5.985, P = 0.004) between transfer fork groups A and B, with group A showing better trueness and precision.*

Conclusion: *Linear and angular errors will be introduced in the process of building up a virtual dentofacial patient using a transfer fork. The trueness and precision of the transfer fork with the matching markers at the centre of the lips are more precise than the transfer fork, with matching markers on both sides of the mouth.*

Keywords: *digital virtual patient, spatial position, transfer fork*

Chin J Dent Res 2026;29(2):175–184; doi: 10.3290/j.cjdr.b7044063

The shape and arrangement of teeth should be in harmony with the face, making dental prostheses closely related to personalised facial modality recognition and analysis. 3D facial scanning (FS) provides a technical foundation for the digital workflow of prosthesis fab-

1 Peking University School and Hospital of Stomatology & National Center for Stomatology & National Clinical Research Center for Oral Diseases & National Engineering Research Center of Oral Biomaterials and Digital Medical Devices & Beijing Key Laboratory of Digital Stomatology & NHC Key Laboratory of Digital Stomatology & NMPA Key Laboratory for Dental Materials. Beijing, P.R. China.

2 Department of Prosthodontics, Peking University School and Hospital of Stomatology Beijing,100081, P.R. China.

\# Equal contribution.

Corresponding author: Dr Shao Xia PAN, Department of Prosthodontics, Peking University School and Hospital of Stomatology, #22 Zhongguancun South Avenue, Haidian District, Beijing 100081, P.R. China. Email: panshaoxia@vip.163.com

This study was supported by the Program for New Clinical Techniques Therapies of Peking University and School and Hospital of Stomatology (PKUSSNCT-25A02), and by the Beijing Natural Science Foundation Haidian Original Innovation Collaborative Fund (no. L232146), and by the Program for Health Technologies Promotion of National Center for Stomatology (2024NCSHTP05), and by the Peking University School of Stomatology Innovation Experiment Program for University Students (grant number: 2023-SSCD-39).

copyright by all rights reserved Quintessenz

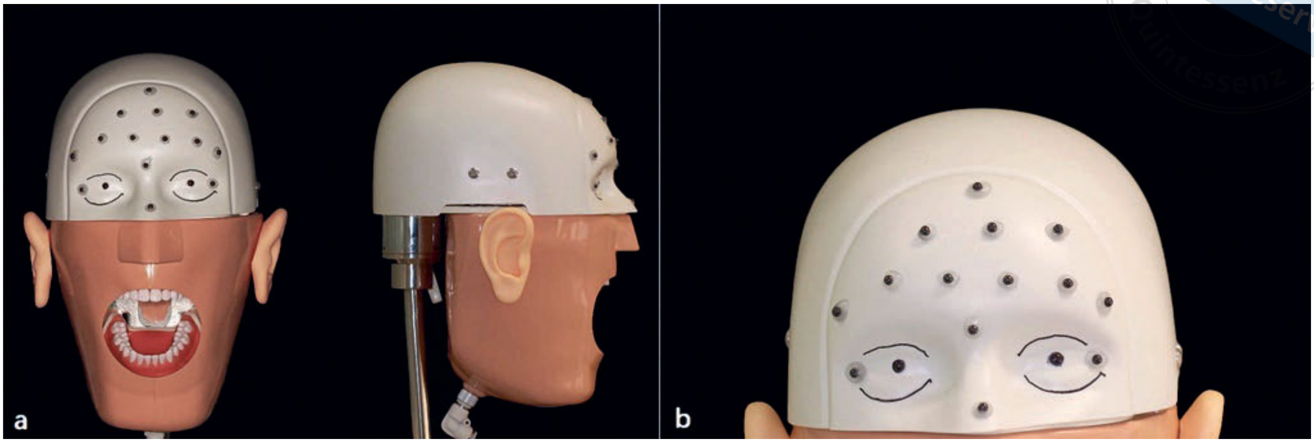

Fig 1a and b Fiducial markers on the mannequin head with dentition. Front and side of the mannequin head **(a)**. Fiducial markers on the key facial anatomical structure points and the forehead **(b)**.

rication,[1-6] and is now widely used in prosthodontics. At present, prosthodontists and technicians can complete the virtual design,[7] artificial teeth arrangement,[8,9] partial realisation of try-in[10] and production[11] of dental prostheses using a digital workflow, and this also facilitates communication between doctors, technicians and patients.[12]

The digital workflow offers many advantages over the conventional workflow, such as a non-invasive, faster impression process,[13] simplified treatment procedure,[14] better clinical efficiency[13,15-17] and reduced treatment cost.[18] To build a "virtual dentofacial patient", a key element is used to register the FS data with intraoral scanning (IOS) data to obtain the relative position of the dentition and the face.[24,25] This element consists of two parts. The intraoral part is connected with patient's dentition and can be digitalised and superimposed with their IOS data. The extraoral part was scanned and registered with the FS data. The element was named differently in various previous studies, such as virtual facebow,[20-22] extraoral registration geometries,12 geometric occlusal registration prototype device,[26] intraoral marker,[27] intraoral transfer element (IOTE),[28,29] intraoral scan body[30-34] and transfer fork.[35,36] In this study, a transfer fork was used.

The transfer fork is key to the integration of FS data and IOS data, and its design will affect the accuracy of integration. Although the use of a variety of transfer forks had been reported in digital workflows, most of them were case reports.[9,22,27,28,32,34,35] There are only a limited number of studies investigating the accuracy of registration between FS and IOS.[20] Raffone et al[37] designed a transfer fork consisting of a bite fork and a scanning plate with several letters and a circle on it. They conducted an in vitro study to evaluate the accuracy of registration, without comparison with other transfer forks. Lam et al[20] made a transfer fork using a tray and LEGO bricks (LEGO Group, Billund, Denmark) and evaluated the accuracy of registration in an in vivo study. The registration error was 0.26~1.70 mm.[20] However, the design of the transfer fork was not compared with another type of fork. Moreover, the heterogeneity of these studies prevented comparison of different designs among the transfer forks.

This study aims to investigate the impact of different spatial positions of the registration markers of the transfer fork on the accuracy of generating a virtual dentofacial patient. The study hypothesis is that the position of the registration markers on the transfer fork has no significant effect on the accuracy of generating a virtual dentofacial patient.

Materials and methods

CBCT (NewTom VGi, NewTom, Imola, Italy), a 3D facial scanner (SHINING 3D, Hangzhou, China), an intraoral scanner (3Shape TRIOS 4, 3Shape, Copenhagen, Denmark), a 3D dental model scanner (3Shape D2000, 3Shape) and a 3D resin printer (HeyGears chairside pro, HeyGears Technology, Guangzhou, China) were used in this study, along with 3D reverse engineering software Geomagic Wrap 2021 (3D Systems, Rock Hill, SC, USA), medical imaging software Quotation Mimics 23.0 (Materialise, Leuven, Belgium) and SPSS 27.0 (IBM, Armonk, NY, USA).

A virtual dentofacial patient with a mannequin head and a standard dentition model was created using the IOS and FS data. Fourteen zirconia spheres with a diameter of 4 mm were fixed in the facial forehead of the mannequin as fiducial markers (Fig 1). Key facial

copyright by all rights reserved

anatomical structure points such as the glabella and the outer canthus points were chosen as the key sites for fixing zirconia spheres. Other zirconia spheres were evenly distributed on the forehead.

Transfer fork was composed of the extraoral and the intraoral parts. The extraoral part was a printed rectangular plate-type structure using a 3D resin printer and LEGO bricks were fixed on the extraoral part as the registration markers. The intraoral part, a resin impression tray, was connected with the extraoral part to complete the transfer fork. Two types of transfer fork were made. The registration markers on transfer fork A were positioned in the middle of the lips and those on transfer fork B were positioned on the bilateral mouth corners (Fig 2).

Fiducial markers were also prepared on the maxillary dentition. Holes with a diameter of 1 mm were prepared at the mesio-buccal cusps of the bilateral first molars and the mesio-incisal angle of the right central incisor.[37,38] Radiopaque material (Coltosol F zinc oxide temporary sealing material, Coltène, Altstätten, Switzerland) was used to fill in the holes.

IOS was performed to obtain 3D data of the maxilla (Fig 3a). The mannequin's face was digitalised using a facial scanner.

The intraoral impression tray of the transfer fork was connected with the maxillary dentition in the mannequin head with silicone rubber material. FS was then performed five times with the transfer fork connected rigidly to the maxillary dentition (Fig 3b). The transfer fork was then removed and scanned using a 3D dental model scanner (Fig 3c). The same steps were performed for transfer fork B to obtain 3D images (Fig 3b and c). A total of 10 groups of 3D facial images were obtained.

Intraoral scans, facial scans, facial scans taken with the transfer fork and corresponding transfer fork data were imported into Geomagic Wrap 2021. The "Alignment - Best fit" function was used. Intraoral and facial scans with the transfer fork were respectively superimposed on the intraoral and extraoral part of the transfer fork to obtain a digital mannequin head with transfer fork, then the facial scans were superimposed on it. Thus, the virtual dentofacial patient was built (Fig 3d, 4 and 5).

Standard values were measured on CBCT scans. CBCT was performed for the mannequin head. DICOM data were extracted and a 3D model was reconstructed. Three zirconia spheres attached to the facial anatomical structure (the glabella and the outer canthus points), two spheres on the forehead and one sphere on the bridge of the nose, were selected as facial fiducial markers. The "feature point" function in Geomagic

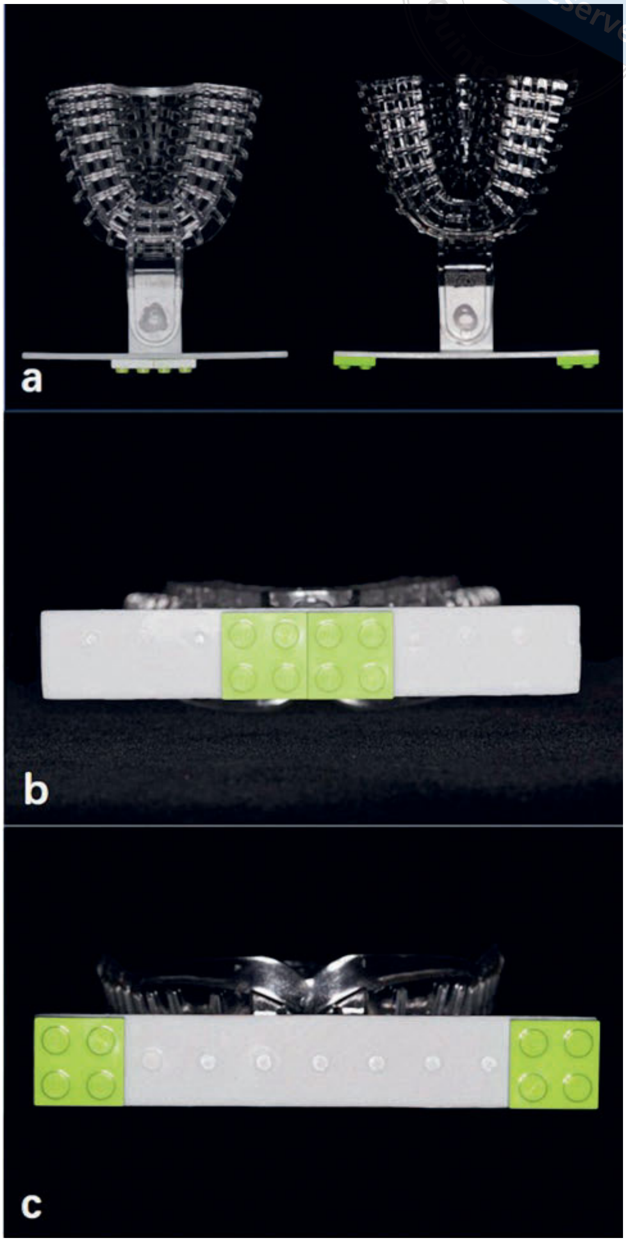

Fig 2a to c Transfer forks. Two types of transfer fork **(a)**. Transfer fork A: The registration markers were positioned in the middle of the lips **(b)**. Transfer fork B: The registration markers were positioned on the bilateral mouth corners **(c)**.

Wrap 2021 was used to pick up these markers named points 1~ 6 (Fig 6). The buccal cusps of the bilateral first molars and the mesio-incisal angle of the right central incisor were selected, namely LM (left molar), RM (right molar) and RI (right incisor), as fiducial markers on the dentition (Fig 7). The axial, coronal and sagittal planes of CBCT images of facial fiducial markers are presented in Fig 8. The distances between dentition markers (LM, RM and RI) and facial fiducial markers (points 1~ 6)

copyright by all rights reserved Quintessenz

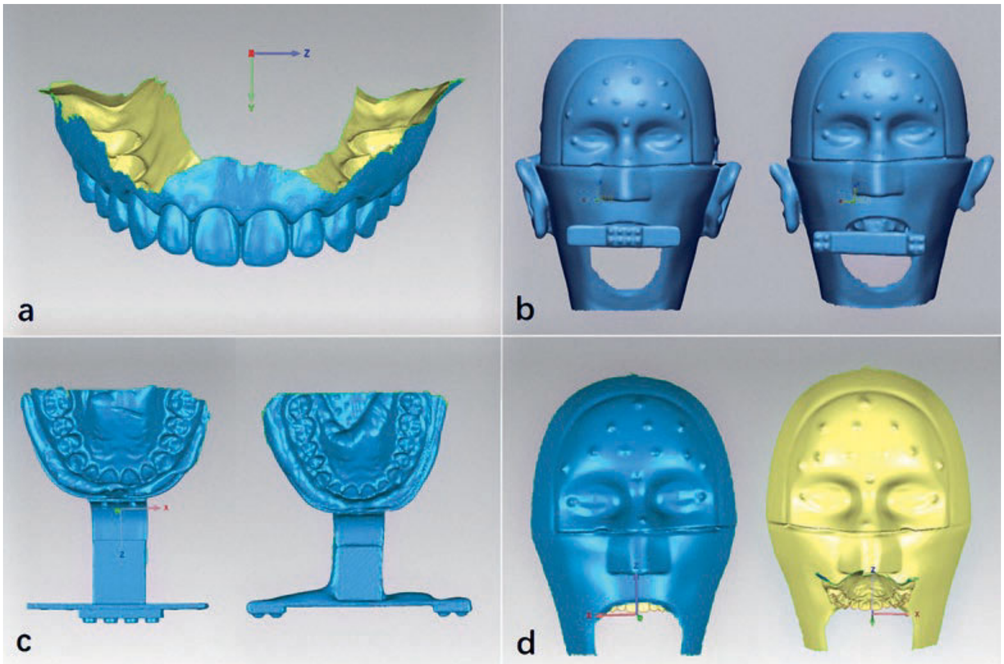

Fig 3a to d Digital images in the workflow. 3D image of the maxillary dentition **(a)**. FS data of transfer forks A and B **(b)**. 3D images of transfer fork A and B **(c)**. 3D images of the virtual dentofacial patient **(d)**. On transfer fork A, the registration markers were positioned in the middle of the lips; on transfer fork B, they were positioned on the bilateral mouth corners.

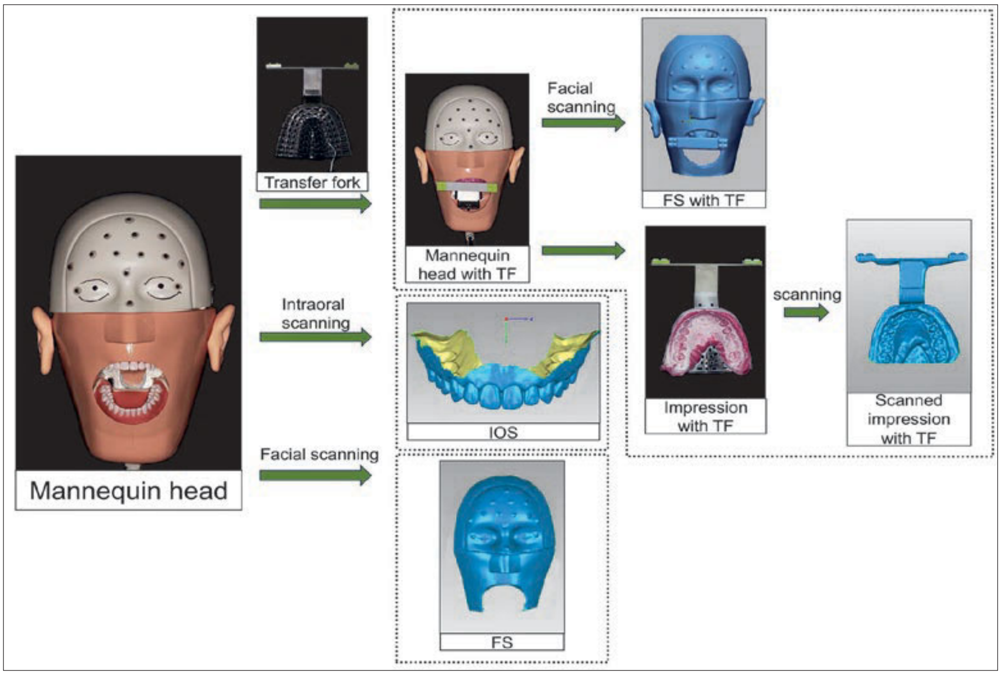

Fig 4 The workflow of obtaining digital information. TF, transfer fork.

copyright
all rights reserved
Quintessenz

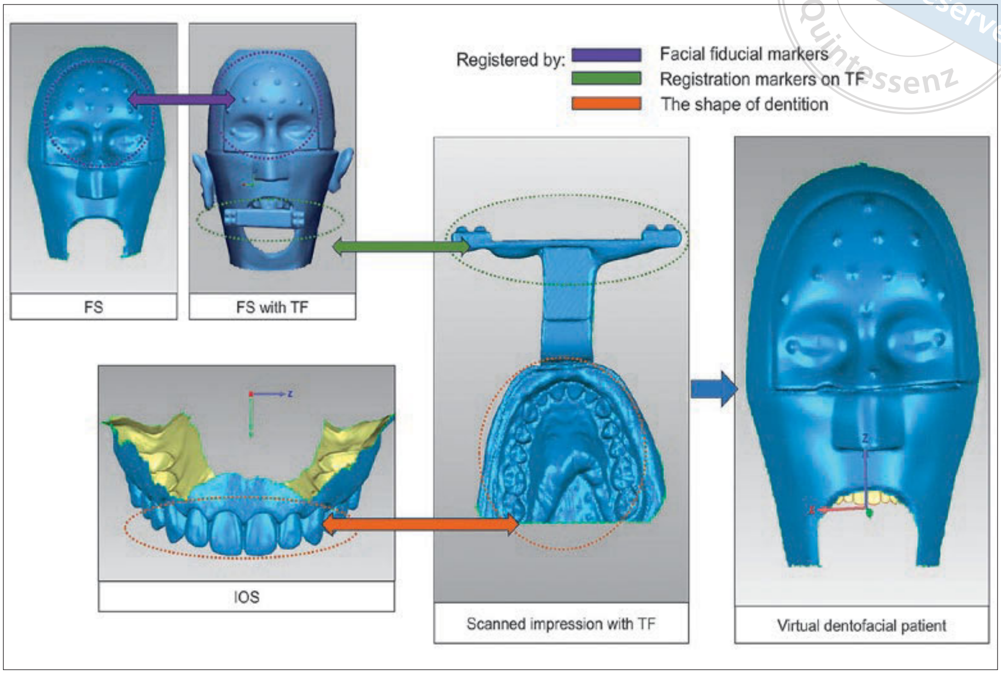

Fig 5 Registration of building up virtual dentofacial patient.

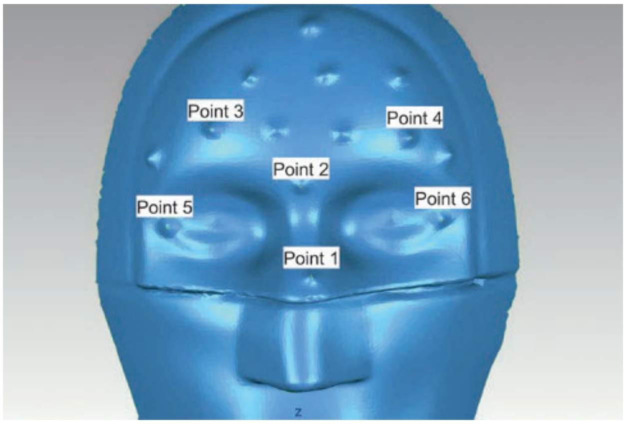

Fig 6 Six facial fiducial markers (points 1~6).

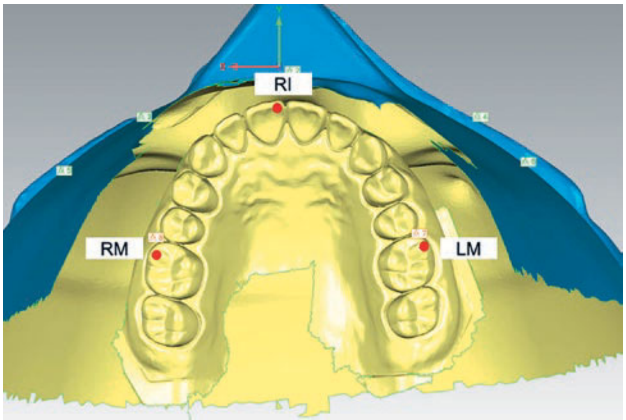

Fig 7 Three dentition fiducial markers (points LM, RM and RI). LM, the dental fiducial marker on the left molar; RM, the dental fiducial marker on the right molar; RI, the dental fiducial marker on the right incisor.

were measured as the feature lengths,[39] and 18 feature lengths (Table 1) were obtained as standard values. The feature angle formed by the connection between the glabella (point 2) and RI and the occlusal plane (defined by LM, RM and RI) was measured, and one feature angle was obtained as the standard value.[20,37,38]

The registration accuracy of the transfer fork was evaluated by comparing the standard values of feature lengths and angles measured in CBCT with the corresponding measurements in the virtual dentofacial patient.

The 18 feature lengths between six facial markers and three dental fiducial markers in each transfer fork, with five in the transfer fork A group and 5 in the transfer fork B group. The feature angles between the line defined by point 2 (glabella point) and point RI (right incisor) and the occlusal plane of each group were obtained, with a total of 10 groups. The errors between the 180 feature lengths and 10 feature angles and the standard values were calculated.

The differences between feature lengths and angle measured in the two transfer fork groups and those

copyright by all rights reserved Quintessenz

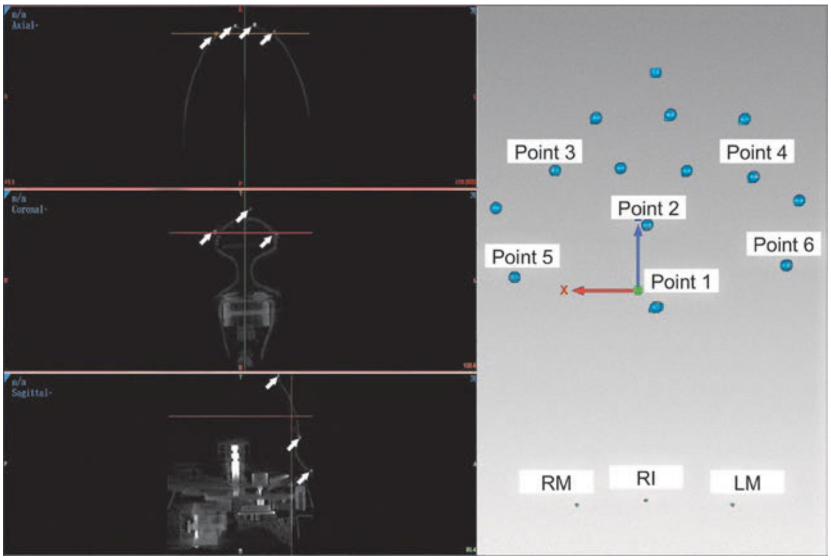

Fig 8 The feature points in the CBCT image of the mannequin head and the 3D reconstruction image.

Table 1 One-sample *t* test of each feature lengths errors and ideal error (0.000) (mm).

Measurement of feature lengths		Transfer fork A, mean ± SD	*P* value	Transfer fork B, mean ± SD	*P* value
Starting point	End point				
Point 1	LM	−1.73 ± 0.27*	0.003	3.47 ± 0.86*	0.016
	RM	−2.47 ± 0.29*	0.001	0.91 ± 0.73	0.279
	RI	−2.03 ± 0.21*	0.001	0.53 ± 0.60	0.425
Point 2	LM	0.23 ± 0.32	0.511	5.94 ± 1.05*	0.005
	RM	−0.49 ± 0.37	0.261	3.14 ± 0.95*	0.030
	RI	0.75 ± 0.24*	0.035	3.09 ± 0.65*	0.009
Point 3	LM	−1.67 ± 0.29*	0.005	4.34 ± 0.95*	0.010
	RM	−1.29 ± 0.33*	0.018	2.75 ± 1.25	0.092
	RI	−0.64 ± 0.17*	0.019	2.14 ± 0.34*	0.003
Point 4	LM	−1.73 ± 0.36*	0.009	3.86 ± 1.10*	0.025
	RM	−1.90 ± 0.40*	0.009	0.80 ± 0.90	0.429
	RI	−1.36 ± 0.27*	0.007	0.60 ± 0.61	0.385
Point 5	LM	−0.81 ± 0.22*	0.020	4.65 ± 0.85*	0.005
	RM	−0.71 ± 0.32	0.094	3.64 ± 0.98*	0.021
	RI	0.28 ± 0.14	0.112	2.25 ± 0.55*	0.015
Point 6	LM	−1.04 ± 0.28*	0.021	4.08 ± 1.11*	0.021
	RM	−0.92 ± 0.25*	0.021	0.81 ± 0.87	0.407
	RI	-0.41 ± 0.17	0.071	0.96 ± 0.64	0.205

*P < 0.05.

LM, the dental fiducial marker on the left molar; RI, the dental fiducial marker on the right incisor; RM, the dental fiducial marker on the right molar; SD, standard deviation.

measured in the CBCT (standard values) were compared. The standard values were subtracted from the measurement values to obtain feature lengths and angle errors. SPSS 27.0 was used for data analysis, and the measurement data were expressed as mean ± standard deviation (SD). The errors between the transfer fork groups were analysed and their trueness and precision were compared. A one-sample t test was used to test the differences between feature length error, feature angle error and ideal error 0.000 in both groups. The length and angle errors between transfer forks A and B were tested with a paired t test. Bilateral tests were used in all tests, and P < 0.05 was considered statistically significant.

Results

The registration error of the two types of transfer fork was analysed. The feature length and angle errors for each group were tested using a K-S normality test, and

copyright by all rights reserved Quintessenz

Table 2 One-sample *t* test of measurement errors of transfer fork groups and ideal error (0.000)

Group	Feature lengths		Feature angles	
	t	*P* value	t	*P* value
Transfer fork A	−9.247	0.000	−6.852	0.002
Transfer fork B	10.722	0.000	4.291	0.013

the results were statistically significant. The data all followed the normal distribution.

The trueness and precision of transfer forks A and B were analysed. For transfer fork A registration, the trueness was 1.00 ± 0.11 mm and the precision was 0.27 ± 0.02 mm. For transfer fork B, the registration trueness was 2.66 ± 0.25 mm and precision was 0.83 ± 0.06 mm.

A total of 36 groups of feature length errors and two groups of feature angle errors for the two transfer forks were analysed, and a one-sample t test was carried out with an ideal error of 0.000 (Table 1). The angular registration error of transfer fork A was 1.88 ± 0.27 degrees. The angular registration error of the transfer fork B was 3.74 ± 0.87 degrees. In the transfer fork A group, the feature length errors of five groups (point 2-LM, point 2-RM, point 5-RM, point 5-RI and point 6-RI) showed no statistical difference from the ideal error of 0.000 ($P > 0.05$). In the transfer fork B group, the feature length errors of seven groups (point 1-RM, point 1-RI, point 3-RM, point 4-RM, point 4-RI, point 6-RM and point 6-RI) showed no statistical difference from the ideal error of 0.000 ($P > 0.05$). The facial markers near the midline performed better and the dentition markers performed equally.

The difference between the mean feature length and angle errors and ideal error of 0.000 of transfer forks A and B were respectively tested by a one-sample *t* test. The results are shown in Table 2. The feature length and angle errors of transfer forks A and B were significantly different from the standard values ($P < 0.05$).

The mean feature length error of transfer forks A and B was 1.00 ± 0.11 mm and 2.66 ± 0.25 mm, respectively. The difference in feature length between transfer forks A and B was statistically significant ($P = 0.000$). The angular registration error of transfer fork A was 1.88 ± 0.27 degrees, and that for transfer fork B was 3.74 ± 0.87 degrees. The difference in angle error between transfer forks A and B was statistically significant ($P = 0.004$).

Discussion

The length and angular relationship between the occlusal plane and the FS indicates the deviation of the dentition position.[37,38] In this study, the registration trueness of transfer fork A was 1.00 ± 0.11mm, and the precision was 0.27 ± 0.02 mm, and the angle deviation was −1.88° ± 0.27 degrees. The registration trueness and precision of transfer fork B were 2.66 ± 0.25 mm and 0.83 ± 0.06 mm, respectively, and the angle deviation was 3.74 ± 0.87 degrees. The registration trueness and precision of transfer fork A were significantly better than those for transfer fork B. A significant difference in feature length ($t = -13.963$, $P = 0.000$) and feature angle ($t = -5.985$, $P = 0.004$) was found between the two groups, which negated H0.

Choi et al[40] used the traditional articulator to determine the relative position of the maxillary dentition and the craniofacial area. The error for the maxillary central incisor was ± 1.2 mm, while the difference between groups reached 6.7 mm.[40] Lam et al[21] established the virtual patient using the traditional articulator with an accuracy of 3.66 ± 2.94 mm. Their protocol improved the precision and simplified the workflow but decreased the trueness.[21] Revilla-Leon et al[39] used different scanning devices to carry out FS, and a transfer fork was employed for registration. The length trueness was 0.50~1.64 mm, and precision was 0.04~0.14 mm.[39] The transfer fork in their study was designed with a curvature that fit closer to the face contour, because the shape of the transfer fork may affect the registration accuracy. Raffone et al[37] designed a special shaped transfer fork and evaluated the length and angle errors of the virtual patient established by it. They registered the CBCT image and the virtual patient and measured the distance in-between corresponding tooth surfaces. The length deviation of different fiducial markers was 0.18~1.07 mm, and the angle deviation was 2.17 ± 0.46 degrees. However, the influence of the registration marker position of the transfer fork on the accuracy of the virtual patient was not investigated. Moreover, different scanning equipment was used in previous studies and the scanning environment was different, so the results from previous studies could be affected by the resolution of the scanning instrument, light, operator experience and other factors and therefore could not be compared quantitatively.

In the two transfer fork groups in this study, the feature length error of the posterior dental area was around

copyright by all rights reserved Quintessenz

twice that in the anterior dental area. The length from the registration points on the transfer fork to the posterior dental area in the sagittal direction was also about twice as that from the anterior area. In the transfer fork A group, the feature lengths and angles between facial and dental fiducial markers were generally decreased compared to the standard values on CBCT. It is possible that the registered dentition position shifted in a straight line in addition to rotation along the coronal axis. By contrast, in the transfer fork B group, the feature lengths between facial and dental fiducial markers were generally increased, which indicated that the position of the registered dentition changed downwards.

The registration point deforms to a certain extent in scanning, which is more prominent on transfer fork B (the registration markers were positioned on bilateral mouth corners), thus influencing the fit of feature points and registration. This might be one of the reasons why the registration trueness and precision of transfer fork A were better than those of transfer fork B. In view of the possible rotation in the registration, whether the use of asymmetric shaped registration points can solve this problem is worthy of further exploration.

By placing the registration markers of the transfer fork in the middle position, the registration accuracy can be improved and the data volume obtained during transfer fork-dentition joint scanning can be reduced, which is convenient for subsequent registration and other data processing. The deviation of feature length and angle in the transfer fork A group was similar to that of clinical cases reported in the literature,[39] which met the accuracy requirement of establishing a virtual patient.

In previous studies, various types of transfer fork have been used for registration, and most studies were clinical cases of complete denture restoration, implant restoration and other treatments.[22,26,27,29-35] Even though several studies quantitatively evaluate the accuracy of the registration results,[20,37-39] few studies investigated the influence of registration markers positions. The morphology of the transfer fork used in different studies varied greatly.

It has been reported that the application of a mannequin head to establish virtual patients is feasible.[28] In this study, the mannequin head was used for registration, which eliminated the influence of small changes and slight movements of real human beings on the test results. In the same place at the same time, the same operator scanned the model, reducing the impact of factors such as light and operator experience. By using the mannequin in this study, CBCT imaging can be performed to obtain accurate standard values while there is no real human exposure in the radiographic examination.

The sources of error in the registration of the virtual dentofacial patient mainly include dentition scanning, FS and registration.

Affected by the intraoral brightness, the amount of saliva, the breathing of the patient and the reflective characteristics of teeth surface, the actual scanning accuracy of the intraoral 3D scanner is always different from the standard accuracy, and the accuracy of single-crown scanning is better than that of full-arch scanning.[41] Thus, there are some differences between the dental 3D morphological data obtained by IOS and the actual form, which leads to incomplete fitting of dental feature points and affects the registration.

The nominal accuracy of commonly used 3D facial scanners is 0.024~0.2 mm.[42] It is also affected by environmental light, reflective characteristics, background interference and other factors, resulting in length and angle deviation. The present study showed that the closer the registration markers on the transfer fork to the midline, the higher the accuracy of FS. The most obvious deformation can be observed in the outermost scanning part, and this will have an impact on the accuracy of registration. The facial fiducial markers also deformed to some extent and affected the fit of feature points.

The registration included dentition-transfer fork registration and face-transfer fork registration. The transfer fork was scanned by a 3D dental model scanner. It was considered that the 3D scanning data were consistent with the real shape of the transfer fork. Due to the errors introduced in the dentition and face scanning, there are some differences between the scanning shape and the real shape. While best-fit alignment reduces the impact of such differences on the registration, it cannot resolve them completely.

In subsequent studies, optimisation of the above error can further improve the accuracy of establishing virtual dentofacial patients.

The limitation of this study is the need for multiple scanning devices to complete the establishment of the virtual dentofacial patient. The production of the transfer fork was complex, requiring 3D printing technology and the bonding of three parts. As an in vitro study, the result may not fully reflect the situation of a clinical scenario. The dental and facial reflection degree, mobility and other characteristics were different from those recorded in real patients. Further in vivo studies are needed to explore the factors that influence the registration accuracy of the transfer fork.

copyright
all rights reserved
Quintessenz

Conclusion

Registration using a transfer fork will introduce certain linear and angular errors in the process of creating a virtual dentofacial patient. The trueness and precision of the virtual patient created using a transfer fork with midline registration markers are significantly better than those using a transfer fork with bilateral registration markers.

Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Drs Shi Rui QIU, Rui Tao CAO, Sheng Han GAO and Dan Ni GUO contributed to the study experiment, data collection, analysis and manuscript draft; Dr Shao Xia PAN designed and supervised the study and revised the manuscript. All the authors read and approved the final version of the manuscript.

(Received Sep 04, 2025; accepted Jan 09, 2026)

References

1. Wong JY, Oh AK, Ohta E, et al. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. Cleft Palate Craniofac J 2008;45:232–239.
2. Sforza C, de Menezes M, Ferrario V. Soft- and hard-tissue facial anthropometry in three dimensions: What's new. J Anthropol Sci 2013;91:159–184.
3. Secher JJ, Darvann TA, Pinholt EM. Accuracy and reproducibility of the DAVID SLS-2 scanner in three-dimensional facial imaging. J Craniomaxillofac Surg 2017;45:1662–1670.
4. Ozsoy U, Demirel BM, Yildirim FB, Tosun O, Sarikcioglu L. Method selection in craniofacial measurements: Advantages and disadvantages of 3D digitization method. J Craniomaxillofac Surg 2009;37:285–290.
5. Knoops PG, Beaumont CA, Borghi A, et al. Comparison of three-dimensional scanner systems for craniomaxillofacial imaging. J Plast Reconstr Aesthet Surg 2017;70:441–449.
6. Artopoulos A, Buytaert JAN, Dirckx JJJ, Coward TJ. Comparison of the accuracy of digital stereophotogrammetry and projection moiré profilometry for three-dimensional imaging of the face. Int J Oral Maxillofac Surg 2014;43:654–662.
7. Liu YS, Ye HQ, Gu M, et al. Application of patient-participated digital design in esthetic rehabilitation of anterior teeth [in Chinese]. Beijing Da Xue Xue Bao Yi Xue Ban 2014;46:90–94.
8. Hassan B, Gimenez Gonzalez B, Tahmaseb A, Greven M, Wismeijer D. A digital approach integrating facial scanning in a CAD-CAM workflow for complete-mouth implant-supported rehabilitation of patients with edentulism: A pilot clinical study. J Prosthet Dent 2017;117:486–492.
9. Amin SA, Hann S, Elsheikh AK, Boltchi F, Zandinejad A. A complete digital approach for facially generated full arch diagnostic wax up, guided surgery, and implant-supported interim prosthesis by integrating 3D facial scanning, intraoral scan and CBCT. J Prosthodont 2023;32:90–93.
10. Coachman C, Calamita MA, Coachman FG, Coachman RG, Sesma N. Facially generated and cephalometric guided 3D digital design for complete mouth implant rehabilitation: A clinical report. J Prosthet Dent 2017;117:577–586.
11. Hassan B, Greven M, Wismeijer D. Integrating 3D facial scanning in a digital workflow to CAD/CAM design and fabricate complete dentures for immediate total mouth rehabilitation. J Adv Prosthodont 2017;9:381–386.
12. Ritschl LM, Wolff KD, Erben P, Grill FD. Simultaneous, radiation-free registration of the dentoalveolar position and the face by combining 3D photography with a portable scanner and impression-taking. Head Face Med. 2019;15:28.
13. Guo DN, Liu YS, Pan SX, et al. Clinical efficiency and patient preference of immediate digital impression after implant placement for single implant-supported crown. Chin J Dent Res 2019;22:21–28.
14. Guo D, Mühlemann S, Pan S, Zhou Y, Jung RE. A double-blind randomized within-subject study to evaluate clinical applicability of four digital workflows for the fabrication of posterior single implant crown. Clin Oral Implants Res 2023;34:1319–1329.
15. 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.
16. Javaid M, Haleem A, Kumar L. Current status and applications of 3D scanning in dentistry. Clin Epidemiol Glob Health 2019;7:228–233.
17. Pan S, Guo D, Zhou Y, Jung RE, Hämmerle CHF, Mühlemann S. Time efficiency and quality of outcomes in a model-free digital workflow using digital impression immediately after implant placement: A double-blind self-controlled clinical trial. Clin Oral Implants Res 2019;30:617–626.
18. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J 2008;204:505–511.
19. 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.
20. Lam WY, Hsung RT, Choi WW, Luk HW, Pow EH. A 2-part facebow for CAD-CAM dentistry. J Prosthet Dent 2016;116:843–847.
21. 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;119:900–908.
22. Solaberrieta E, Garmendia A, Minguez R, Brizuela A, Pradies G. Virtual facebow technique. J Prosthet Dent 2015;114:751–755.
23. Ye H, Ye J, Wang S, et al. Comparison of the accuracy (trueness and precision) of virtual dentofacial patients digitized by three different methods based on 3D facial and dental images. J Prosthet Dent 2024;131:726–734.
24. Yang S, Wu L, Alabkaa B, Lepidi L, Yue L, Li J. Intraoral scanner-based virtual facebow transferring: A chairside dental technique [epub ahead of print 10 July 2024]. J Prosthodont doi: 10.1111/jopr.13897.

copyright by all rights reserved Quintessenz

25. Petre A, Drafta S, Oancea L. A new technique to transfer the upper maxillary arch position using a facebow, a transfer table, and a reference block with a CAD application. J Prosthodont 2024;33:195–200.
26. Granata S, Giberti L, Vigolo P, Stellini E, Di Fiore A. Incorporating a facial scanner into the digital workflow: A dental technique. J Prosthet Dent 2020;123:781–785.
27. Revilla-León M, Raney L, Piedra-Cascón W, Barrington J, Zandinejad A, Özcan M. Digital workflow for an esthetic rehabilitation using a facial and intraoral scanner and an additive manufactured silicone index: A dental technique. J Prosthet Dent 2020;123:564–570.
28. 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.
29. Amezua X, Iturrate M, Garikano X, Solaberrieta E. Analysis of the impact of the facial scanning method on the precision of a virtual facebow record technique: An in vivo study. J Prosthet Dent 2023;130:382–391.
30. Pérez-Giugovaz MG, Mosier M, Revilla-León M. An additively manufactured intraoral scan body for aiding complete-arch intraoral implant digital scans with guided integration of 3D virtual representation. J Prosthet Dent 2022;127:38–43.
31. Pérez-Giugovaz MG, Mostafavi D, Revilla-León M. Additively manufactured scan body for transferring a virtual 3-dimensional representation to a digital articulator for completely edentulous patients. J Prosthet Dent 2022;128:1171–1178.
32. Pérez-Giugovaz MG, Park SH, Revilla-León M. 3D virtual patient representation for guiding a maxillary overdenture fabrication: A dental technique. J Prosthodont 2021;30:636–641.
33. Pérez-Giugovaz MG, Park SH, Revilla-León M. Three-dimensional virtual representation by superimposing facial and intraoral digital scans with an additively manufactured intraoral scan body. J Prosthet Dent 2021;126:459–463.
34. Pérez-Giugovaz MG, Sadeghpour M, Revilla-León M. Virtual 3-dimensional representation of a completely edentulous patient for computer-aided static implant planning. J Prosthet Dent 2023;129:384–390.
35. Sun A, Yang Y, Gao H, Lin WS, Chen L, Tan J. Integrating facial and intraoral scans for digital esthetic and occlusal design: A technical report. J Prosthodont 2021;30:729–733.
36. 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.
37. Raffone C, Gianfreda F, Antonacci D, Pompeo MG, Bollero P, Canullo L. Chairside virtual patient protocol. Part 3: In vitro accuracy of a digital facebow. J Dent 2023;137:104622.
38. Li J, Chen Z, Decker AM, et al. Trueness and precision of economical smartphone-based virtual facebow records. J Prosthodont. 2022;31:22–29.
39. Revilla-León M, Zandinejad A, Nair MK, Barmak AB, Feilzer AJ, Özcan M. Accuracy of a patient 3-dimensional virtual representation obtained from the superimposition of facial and intraoral scans guided by extraoral and intraoral scan body systems. J Prosthet Dent 2022;128:984–993.
40. Choi DG, Bowley JF, Marx DB, Lee S, Choi DG, Bowley JF, et al. Reliability of an ear-bow arbitrary face-bow transfer instrument. J Prosthet Dent 1999;82:150–156.
41. Diker B, Tak Ö. Accuracy of six intraoral scanners for scanning complete-arch and 4-unit fixed partial dentures: An in vitro study. J Prosthet Dent. 2022;128:187–194.
42. Zhao YJ, Xiong YX, Yang HF, Wang Y. Evaluation of measurement accuracy of three facial scanners based on different scanning principles [in Chinese]. Beijing Da Xue Xue Bao Yi Xue Ban. 2014;46:76–80.