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DENTAL TECHNIQUE

A clinical technique for virtual articulator mounting with natural head position by using calibrated stereophotogrammetry

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ABSTRACT

Accurate articulator-mounted casts are essential for occlusion analysis and for fabrication of dental prostheses. Although the axis orbital plane has been commonly used as the reference horizontal plane, some clinicians prefer to register the horizontal plane with a spirit level when the patient is in the natural head position (NHP) to avoid anatomic landmark variations. This article presents a digital workflow for registering the patient's horizontal plane in NHP on a virtual articulator. An orientation reference board is used to calibrate a stereophotogrammetry device and a 3-dimensional facial photograph with the patient in NHP. The horizontal plane can then be automatically registered to the patient's virtual model and aligned to the virtual articulator at the transverse horizontal axis level. This technique showed good repeatability with positional differences of less than 1 degree and 1 mm in 5 repeated measurements in 1 patient. (J Prosthet Dent 2017;■:■-■)

A semiadjustable articulator (SA) is an instrument that simulates mandibular movements by using averages or mechanical equivalents for all or part of the motion.[1] An SA is often used when fixed prostheses involving more than 5 units or removable prostheses are being planned.[2] The first step in mounting dental casts to a SA is to use a facebow to transfer the relationship between the maxilla and the transverse horizontal axis (THA), an imaginary rotation axis of the condyle in the sagittal plane.[3,4] Because the maxillary member of the SA to which the maxillary cast is attached is designed to be horizontal, the axis orbital plane is commonly used to transfer the horizontal plane of the patient to the articulator.[5,6] However, the axis orbital plane is not always truly horizontal when the patient's head is in the natural head position (NHP), particularly in individuals with facial asymmetry. Ethnic variation has also been found.[7-11] A study has also shown that the orientation of maxillary casts mounted by using the axis orbital plane can be too steep for clinical use.[5]

Natural head position is a standardized position of the head in an upright posture looking to a distant point at eye level.[12,13] It is reproducible[12-15] and has been used extensively in anthropomorphic studies as a standard orientation of the skull for reference. Its use as the horizontal reference plane can avoid individual and ethnic variations[16-19] and has been recommended for facebow registration by using a spirit level.[20-22]

The advent of digital technology has revolutionized the prosthodontic workflow. Digital tooth images obtained by intraoral scanning, can be merged with 3-dimensional (3D) facial images such as cone beam computed tomography (CBCT) or stereophotogrammetry (SP) to generate a virtual patient model (VPM).[23,24] In order to simulate jaw movements, virtual articulators have been developed in computer software for computer-aided design and computer-aided manufacturing (CAD-CAM) dentistry.[25] By identifying a number of facial

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landmarks in the VPM, the relationship between the maxilla and the THA can be transferred to the virtual articulator.[26] However, the authors are unaware of an established protocol for the registration of the patient's horizontal plane in the NHP for virtual articulators, which this article describes.

TECHNIQUE

Orientation calibration of the stereophotogrammetry device

1. Arrange a plane mirror behind the stereophotogrammetry (SP) device (3dMDface; 3dMD Inc) (Fig. 1). Fix the mirror's upper edge to the wall first so that its mass will align it in the true vertical plane.
2. Position the orientation reference board in the field of view of the SP device by by using a tripod. Arrange two 3D leveling and alignment lasers, I and II (Line laser GLL 3-80 P; Bosch), on 2 tripods and align them perpendicularly to the plane mirror so that their sagittal and horizontal laser beams are directly reflected. Align the green and red disk patterns of the board (Fig. 2) to the sagittal and horizontal laser beams of alignment laser I and align the upper and lateral edge of the reference board to the vertical laser beam of alignment laser II. The board is now parallel to the plane mirror and to the true vertical plane.[27,28]
3. After removing alignment lasers I and II, make an SP scan of the orientation reference board and import the data into a simulation program (Matlab R2012b; Mathworks), which can automatically detect the axes and orient subsequent 3D facial scans.[28]

Create an oriented virtual patient model

4. Instruct the patient to sit comfortably, look straight into the mirror image of the eyes, and tilt the head forward and backward with decreasing amplitude until a comfortable position of natural balance is found.[12,14] Make a 3D facial scan by using the SP device and apply the automatic orientation correction.
5. Scan the teeth and their maxillomandibular relationship with an intraoral scanner (True definition scanner; 3M ESPE).
6. Make another 3D facial scan of the patient with a virtual facebow in place.[24,26] The patient does not need to be in NHP in this scan. Scan the virtual facebow with a structured light 3D scanner (DAVID SLS-3, Hewlett-Packard) and the buccal relationship of the maxillary teeth and virtual facebow with

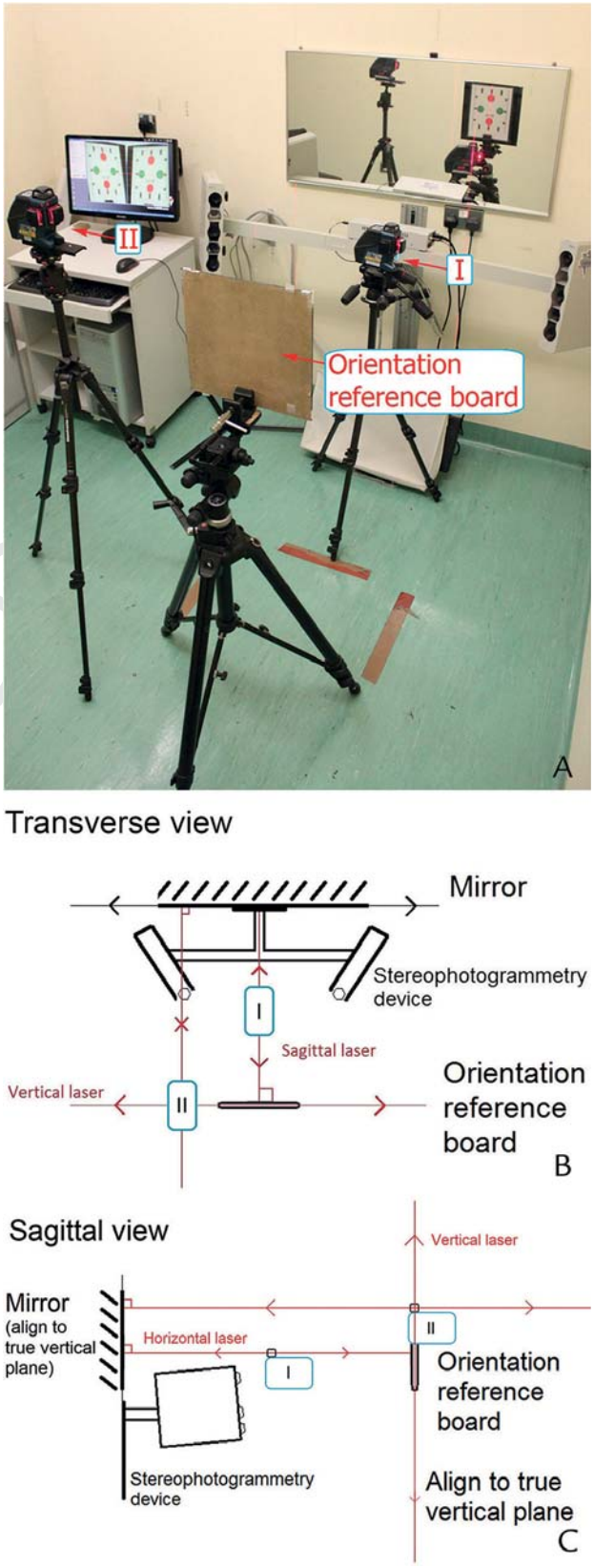

Figure 1. A, Arrangement of stereophotogrammetry device, alignment lasers, and orientation reference board. B, Reference board aligned parallel to plane mirror with alignment lasers. C, Reference board aligned to true vertical plane. I and II, lasers.

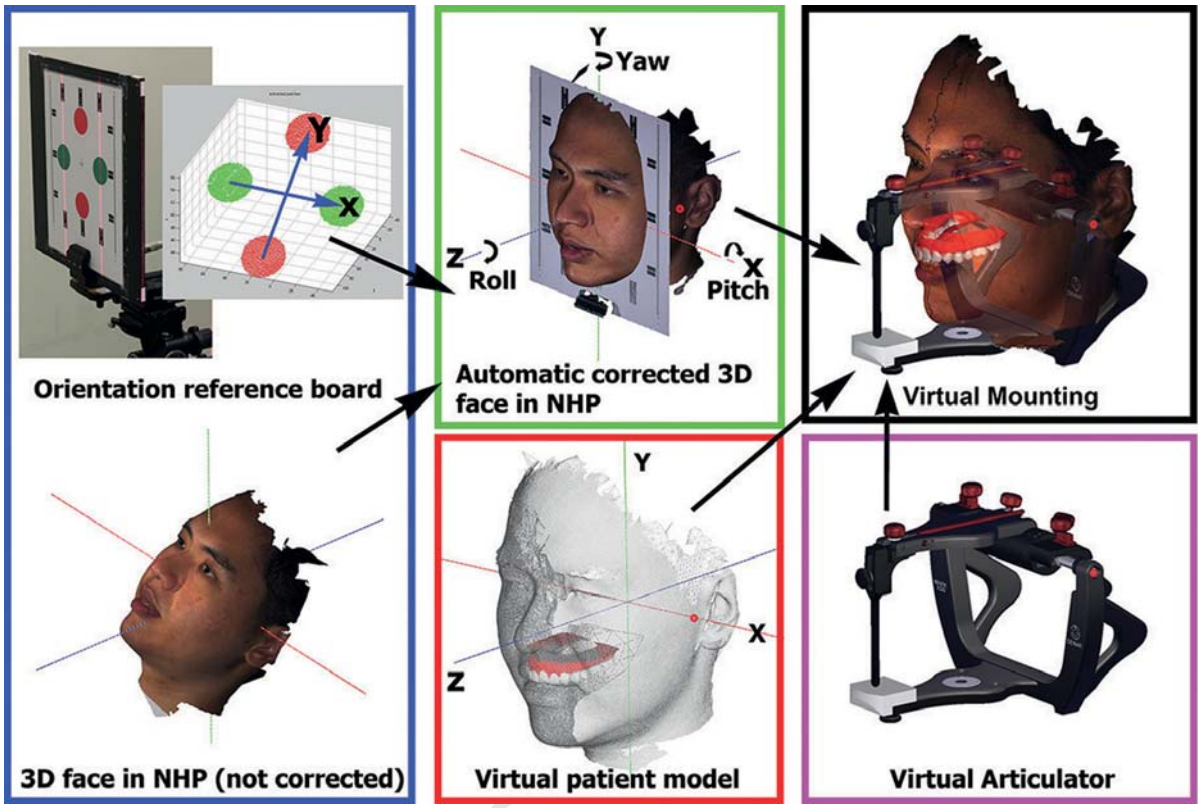

Figure 2. Red and green disk patterns of orientation reference board define x-axis (horizontal plane) and y-axis (true vertical plane) in computer environment. When patient was in natural head position during 3D facial scan, resultant virtual patient model and maxillary teeth automatically aligned to horizontal plane (z-plane) for mounting to virtual articulator. NHP, natural head position.

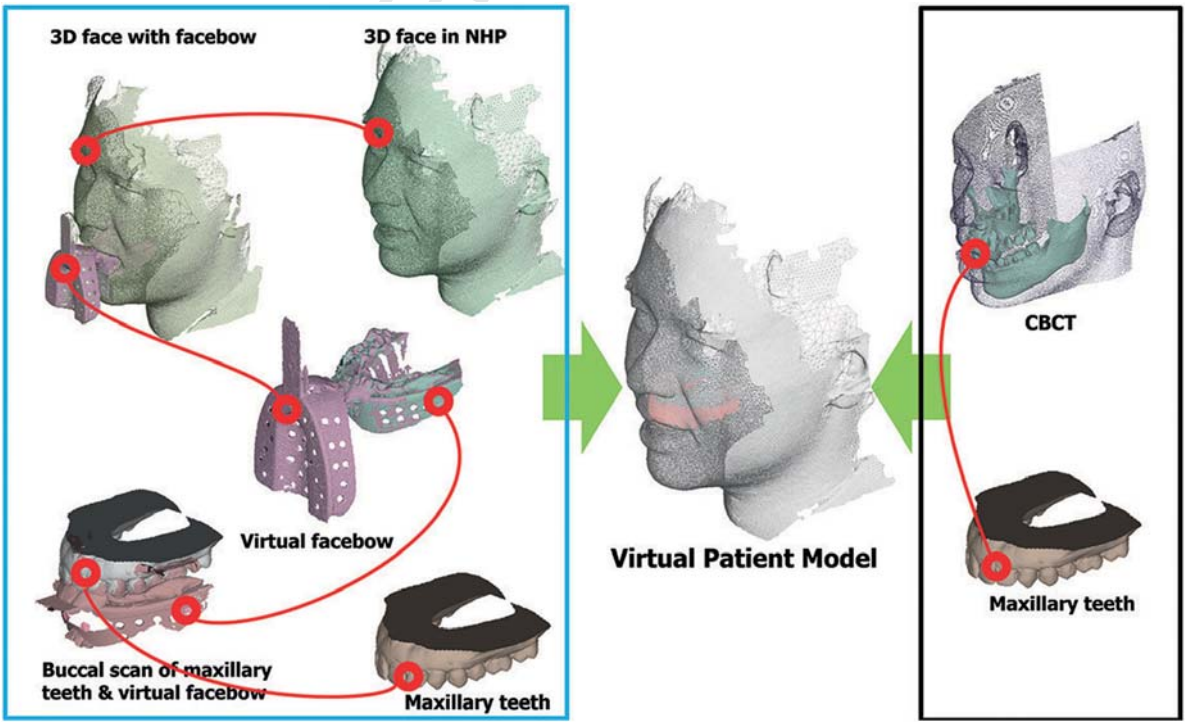

Figure 3. Creation of virtual patient model by using digitized teeth, 3D facial photography or full-face skull CBCT. Virtual facebow[25] medium for fusing digitized teeth into 3D facial photography. Alternatively, CBCT provides 3D virtual model with teeth and face. CBCT, cone beam computed tomography.

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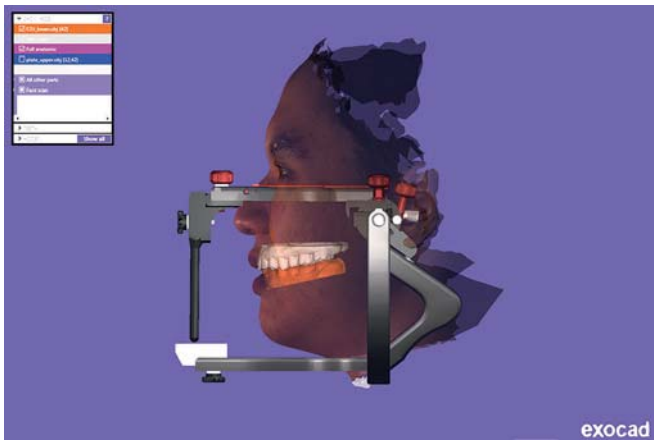

Figure 4. Transfer oriented maxillary teeth to virtual articulator and fitting THA to condylar element of articulator. Virtual articulator oriented horizontally by default. THA, transverse horizontal axis.

an intraoral scanner. Align the patient's digital teeth to the 3D facial photographs by using an iterative closest point algorithm (MeshLab v1.3.3; Visual Computing Lab of the ISTI-CNR) and a virtual facebow as a medium (Fig. 3).

7. As an alternative to step 6, make a full-face CBCT image (Planmeca ProMax 3D Mid; Planmeca). Align the patient's digital teeth, CBCT, and 3D facial photograph in NHP by using the iterative closest point algorithm.

Mounting maxillary and mandibular teeth to the virtual articulator

8. Load the oriented VPM into CAD/CAM software (Exocad; Exocad GmbH) (Fig. 4). Match the patient's THA to the condylar element of the virtual articulator.[26,29,30] Transfer the mandibular teeth to the articulator according to its maxillomandibular relationship with maxilla.

DISCUSSION

A technique for mounting digitized teeth to a virtual articulator is presented. Virtual facebows[24,26] have been proposed to transfer patient's digitized maxillary teeth to a 3D facial photograph for the creation of a VPM. Alternatively, CBCT provides a VPM with face and teeth. This model contains useful information such as face-and-teeth relationship for smile design[31] as well as the axis orbital plane for transferring maxillary teeth to the virtual articulator.[26] The present SP NHP technique automatically orients the VPMs and provides an alternative horizontal plane for articulator mounting.

Stereophotogrammetry is one of the commonly used methods of capturing the 3D face to create VPMs[23] and

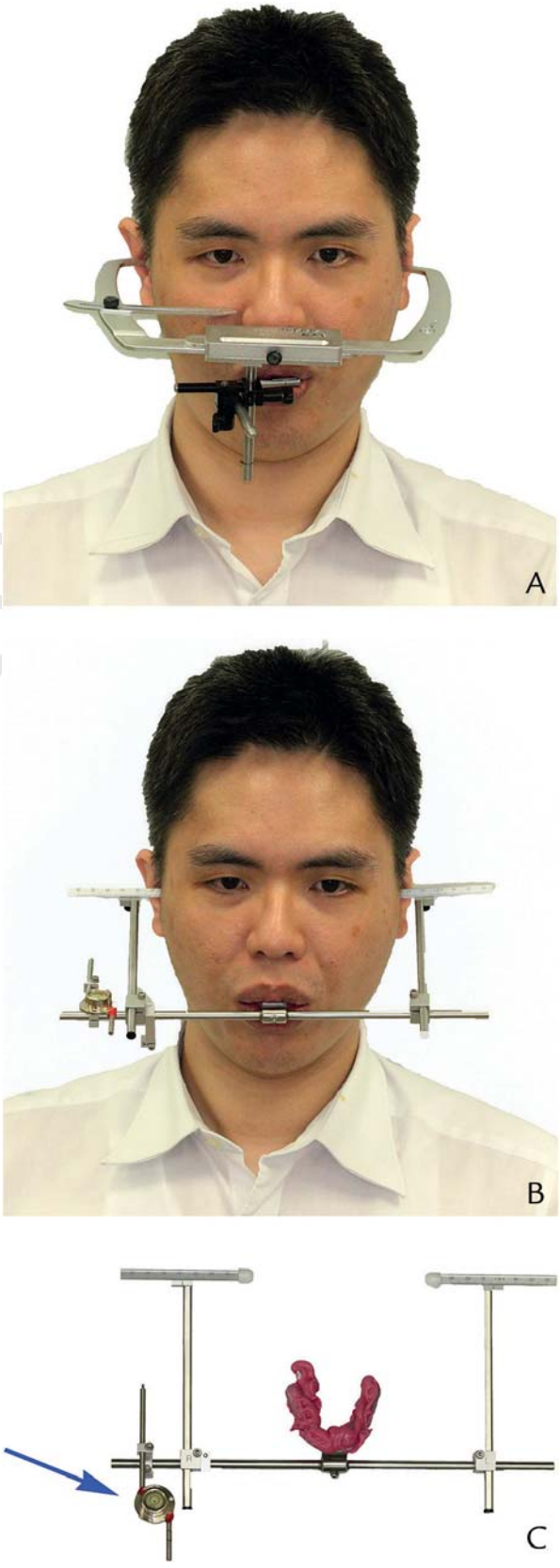

Figure 5. A, Anatomic facebow. B, Natural head position facebow. C, Bull's eye spirit level (arrow) attached to facebow to determine horizontal plane when patient in natural head position.

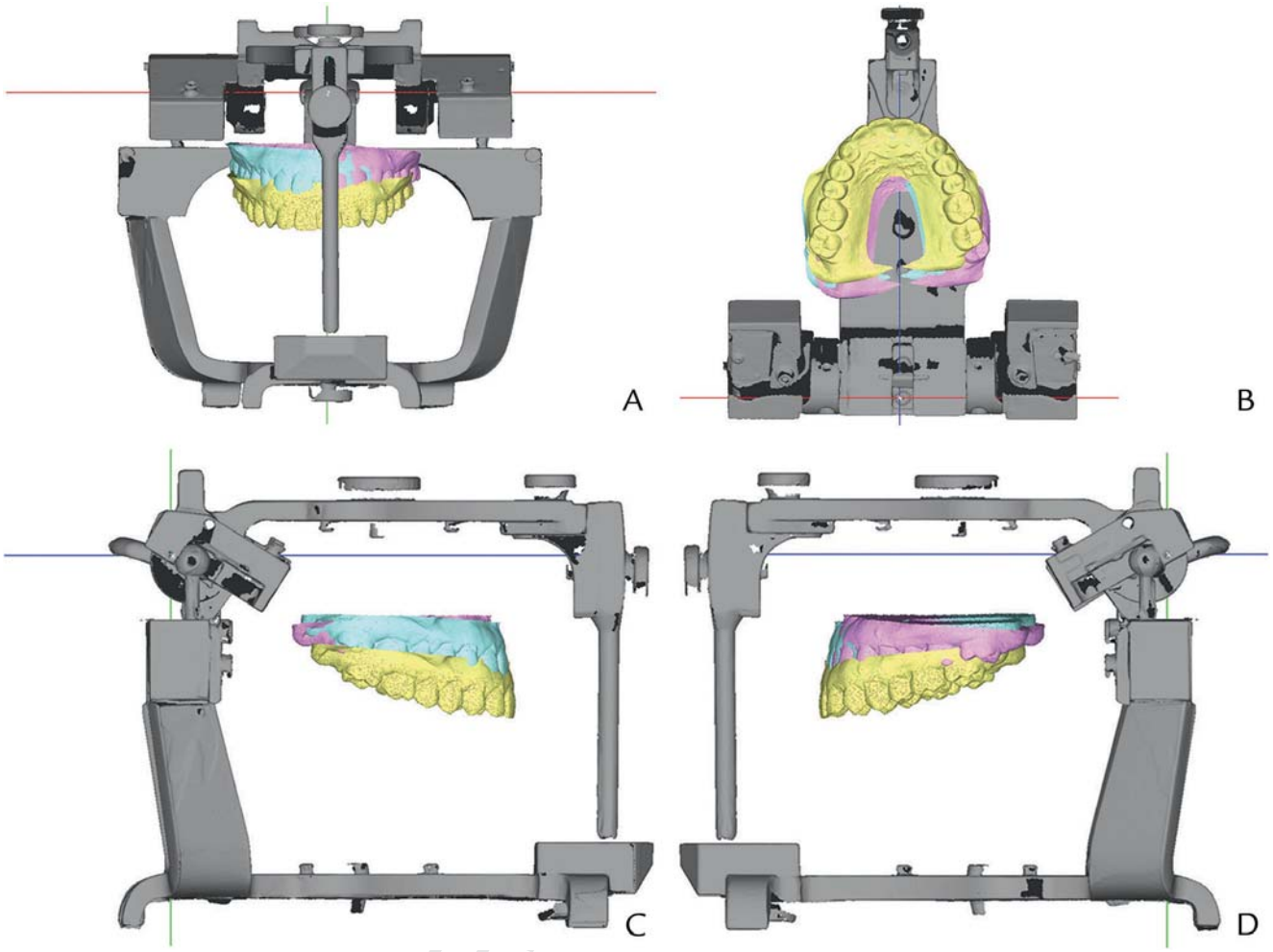

Figure 6. Alignment of maxillary casts mounted with stereophotogrammetric (purple), natural head position facebow (blue), and anatomic facebow (yellow) techniques by using iterative closest point algorithm with articulator as alignment reference. A, Frontal view. B, Occlusal view. C, D, Lateral views.

to record NHPs.[32] It is radiation free, and the image acquisition can be done within 1 second, minimizing patient movement. In this proposed technique, only 1 calibration is required for multiple facial scans and the equipment for the calibration is inexpensive. This method does not need any facial markings, and the laser lines will not appear in the 3D photograph. Automatic detection of orientation can reduce human error, although training in the calibration process and the virtual mounting procedure is needed. However, patients with craniofacial disorders[33,34] may have difficulty in achieving NHP reproducibly. In addition, THA may not be truly horizontal,[35] particularly for patients with facial asymmetry, and a virtual articulator that allows adjustment of the position of the condylar components should be developed.[22]

The repeatability and validity of this SP NHP technique were measured in 1 patient. Our hypotheses were that the technique should be reproducible and that the resultant mountings should be similar to those of the spirit level NHP facebow technique. Five 3D facial scans were made when the patient was in the NHP on separate occasions, and 5 oriented VPMs were created. For the sake of comparison, the maxillary cast was scanned and incorporated into these VPMs. Five facebow records each were made by using anatomic landmarks (Denar Slidematic facebow; Whip Mix Corp) and NHP by an experienced prosthodontist (Fig. 5). The horizontal plane when the patient was in the NHP was determined by attaching a bull's eye spirit level (CL1508M; RS Pro) to the facebow (Denar D31AB facebow/earbow; Whip Mix Corp).[21,22] The external auditory meatuses were used as a reference for determining the THA location for all 3 techniques,[30] and maxillary casts were mounted onto an articulator with external auditory meatus reference (Denar Mark II articulator; Whip Mix Corp). The articulator-mounted casts were scanned with a structured light 3D scanner. Scanned casts were aligned by using an iterative closest point algorithm in MeshLab with the articulator as the alignment reference (Fig. 6). For each technique, 1

Table 1. Repeatability of 3 mounting techniques in this study*

Technique	Angular Displacement			Linear Displacement			
	Pitch (degree)	Roll (degree)	Yaw (degree)	x-Axis (mm)	y-Axis (mm)	z-Axis (mm)	Square Root Distance (mm)
Stereophotogrammetric NHP technique							
First	-0.15	0.62	0.25	0.50	0.19	0.56	0.78
Second	-0.04	0.94	0.20	1.29	-0.01	0.28	1.32
Third	0.15	0.10	0.58	-0.04	-0.17	0.27	0.32
Fourth	0.13	0.17	-0.44	-0.12	-0.46	-0.93	1.05
Mean ±SD	0.02 ±0.14	0.46 ±0.40	0.15 ±0.43	0.41 ±0.65	-0.11 ±0.27	0.04 ±0.66	0.86 ±0.42
NHP facebow technique							
First	0.50	-1.52	0.72	0.58	-0.63	-0.09	0.86
Second	2.08	-0.78	0.59	1.76	-1.03	1.23	2.38
Third	-0.02	0.09	-0.07	0.12	0.12	-0.06	0.19
Fourth	1.82	-1.51	1.15	-0.86	-1.13	0.62	1.55
Mean ±SD	1.10 ±1.01	-0.93 ±0.76	0.60 ±0.51	0.40 ±1.09	-0.67 ±0.57	0.43 ±0.63	1.24 ±0.94
Anatomic facebow technique							
First	-0.72	-0.73	1.39	0.90	-1.02	-.70	1.53
Second	1.87	0.13	2.52	7.10	1.37	3.47	8.02
Third	0.32	1.69	0.64	1.39	-0.69	1.92	2.47
Fourth	-0.41	-0.84	0.91	1.81	-1.02	1.63	2.64
Mean ±SD	0.26 ±1.16	0.06 ±1.17	1.36 ±0.83	2.24 ±2.80	-0.27 ±1.00	1.58 ±1.72	3.66 ±2.94

NHP, natural head position. *One mounting from each group was arbitrarily selected as reference for comparison.

Table 2. Validity of SP NHP mounting technique when compared with cast mounted by using NHP facebow technique*

Technique	Angular Displacement			Linear Displacement			
	Pitch (degree)	Roll (degree)	Yaw (degree)	x-Axis (mm)	y-Axis (mm)	z-Axis (mm)	Square Root Distance (mm)
SP NHP							
First	-4.84	-0.38	0.65	4.14	-6.29	-4.02	8.54
Second	-4.51	-0.07	0.79	5.28	-5.62	-4.07	8.72
Third	-5.06	0.18	0.95	4.61	-6.14	-3.51	8.44
Fourth	-4.90	0.52	0.95	5.43	-6.31	-3.74	9.13
Fifth	-4.62	-0.38	1.23	4.06	-6.33	-3.72	8.38
NHP facebow							
First	0.28	0.31	-0.07	0.11	0.54	0.22	0.60
Second	1.89	-0.84	0.53	2.52	0.98	0.50	2.75
Third	0.45	-1.54	0.68	1.75	-0.17	-0.23	1.78
Fourth	1.81	-1.50	1.04	0.69	0.83	0.19	1.10

NHP, natural head position; SP, stereophotogrammetric. *One NHP facebow mounting selected as standard for comparison.

mounting was arbitrarily selected as the reference for measuring its repeatability. Because NHP has been validated to lateral cephalograms by Walker et al,[21] an NHP facebow mounting was arbitrarily selected as the standard for measuring the validity of SP NHP. Deviations in the reference/standard mountings were derived from the alignment matrices. The SP NHP technique was reliable, with deviations of less than 1 mm/1 degree in 5 attempts (Table 1). The pitch angle between SP NHP and NHP facebow mountings (Table 2) lies within the range (from -5.2 to 4.2 degree) observed in Walker et al's study.[21] Casts mounted with NHP techniques have a higher position in the articulator than those mounted with the anatomic facebow technique. Further studies are needed to verify this observation.

SUMMARY

A clinical technique using calibrated stereophotogrammetry was presented for transferring the true horizontal plane when the patient is in natural head position.

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