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Virtual Coordinate System in Unicoronal Synostosis

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Background: We propose a landmark-based, virtual coordinate system, specifically designed for assessment of asymmetrical craniofacial anatomy associated with unicoronal synostosis.

Method: CT scans of 33 patients with nonsyndromic unicoronal synostosis were included. Proposed mid-sagittal plane was compared with commonly used sagittal planes: (1) nasion, sella, and basion (N-S-BA); (2) midplane of bilateral frontozygomatic sutures (midFZ); and (3) the skull gravity center plane, to evaluate reliability and validity in the assessments of the anterior and posterior skull base.

Results: The proposed midplane is similar to the midFZ plane in describing the direction of the anterior skull base. However, it has less bias than the N-S-BA ($P < 0.001$), and the gravity center planes ($P < 0.001$). The proposed midplane measures the direction of the posterior skull base plane, similar to the midFZ and gravity center planes, but it has less measurement deviation than the N-S-BA plane ($P < 0.001$). The most protrusive point on the frontal bone in unicoronal patients is contralateral to the fused suture and distant from the mid-sagittal plane by 13.93 ± 4.01 mm. In addition, it is more anteriorly positioned, by 5.32 mm ($P < 0.001$), when compared with the corresponding point on the synostotic side. The uppermost point of the supraorbital rim on the synostotic side is cephalic to that of the contralateral side by 4.09 mm ($P < 0.001$).

Conclusions: Prioritized orientation of an averaged Frankfort horizontal plane, followed by the location of the mid-sagittal and coronal planes, can generate a reliable and valid coordinate framework for the assessment of asymmetric skull shape in unicoronal synostosis. *(Plast Reconstr Surg Glob Open 2021;9:e3616; doi: 10.1097/GOX.0000000000003616; Published online 20 July 2021.)*

INTRODUCTION

Asymmetry is the most noticeable characteristic of patients with unicoronal synostosis (UCS), involving all the craniofacial skeleton.[1] Balancing structures on the synostotic and contralateral sides is one of the primary goals of surgical intervention.[2,3] A reliable coordinate system is essential in surgical planning, especially for distraction osteogenesis.[4,5] However, defining the mid-sagittal plane is highly controversial for this group of patients because there is no exact mid-sagittal plane in the UCS skull. Therefore, a more representative vertical plane needs to be defined. Here, we propose a landmark based, virtual coordinate system, specifically designed for the assessment of asymmetrical craniofacial anatomy resulted from UCS.

METHODS

With institutional human investigation committee approval (no. 1101007932), preoperative CT scans of 33 nonsyndromic UCS patients (age: 5.08 ± 4.13 months, 11 men) were included. Three-dimensional cephalometrics were performed using Mimics (version 19.0; Materialise, Leuven, Belgium).

TECHNIQUE

The orientation of the Frankfort horizontal (FH) plane, for this study purpose, was defined as an averaged plane of four established FH planes, using three of the four landmarks for each plane (ie, bilateral orbitales and bilateral porions). Thereafter, a mid-sagittal plane, which is perpendicular to the averaged FH planes, parallels to a

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line between nasion and basion, and passes through the sella, was orientated. Lastly, a coronal plane passing the sella and simultaneously perpendicular to mid-sagittal plane and averaged FH plane was defined (Fig. 1).

Reliability and Validity Evaluation

Craniofacial landmarks, including the most protrusive point of the frontal bone, lateral and posterior skull, and the relative position of landmarks on synostotic and contralateral side, were measured. The proposed mid-sagittal plane was compared with commonly used middle skull planes: (1) nasion, sella, and basion (N-S-BA); (2) middle plane of bilateral frontozygomatic sutures (midFZ); and (3) the skull gravity center plane, in describing the anterior and posterior skull base deviation (**See figure 1, Supplemental Digital Content 1,** which displays relative position of proposed mid-sagittal plane, N-S-BA plane, bilateral frontozygomatic sutures defined midplane, and gravity center plane, along with the relative position of skull and intracranial gravity centers with skull base. **http://links.lww.com/PRSGO/B664**).

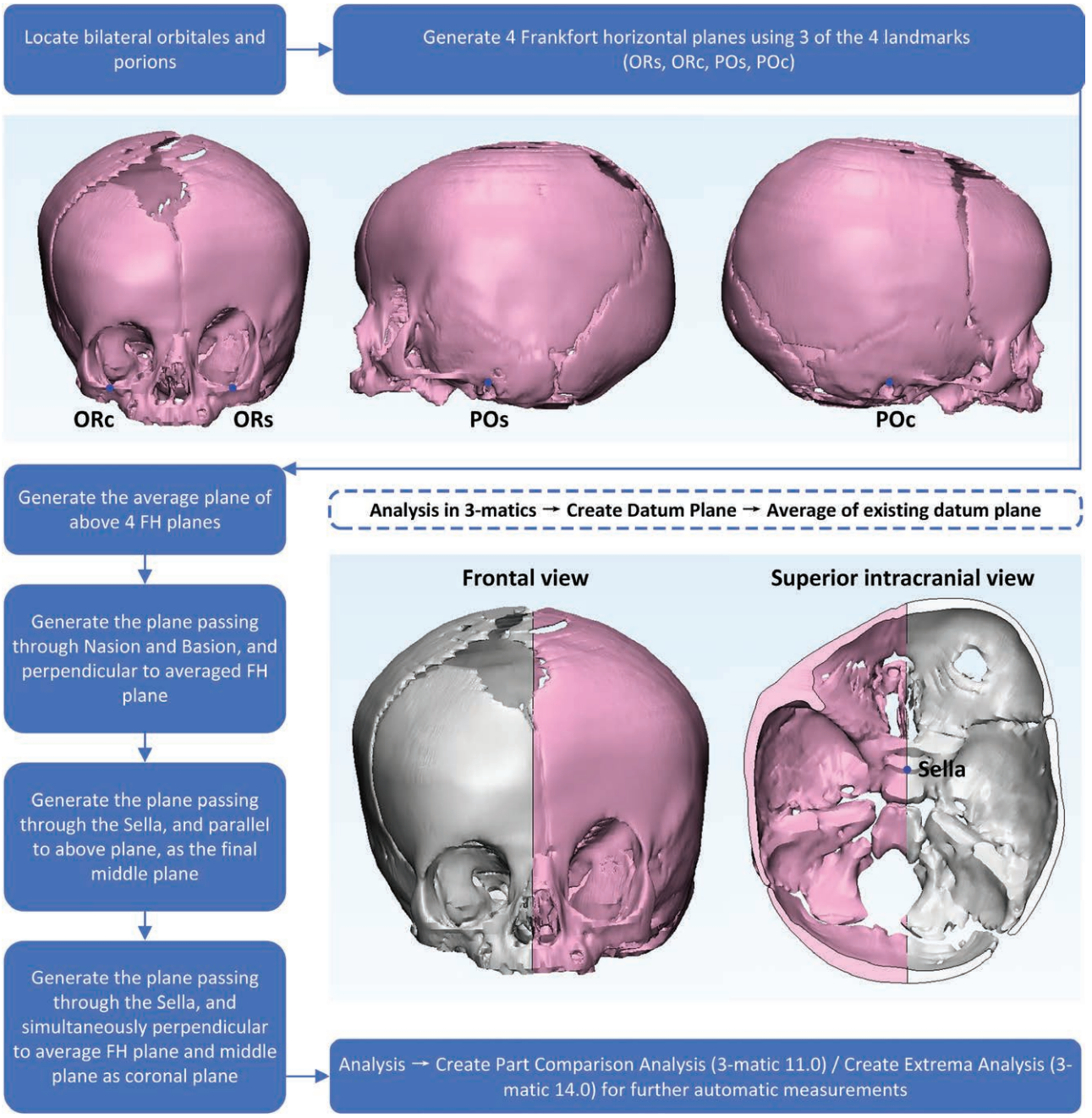

Fig. 1. Flow chart of establishing coordinate system. Briefly, generating the averaged Frankfort horizontal plane is the initial step to establish this coordinate system, followed by orientating the mid-sagittal plane, while locating the coronal plane is the last step.

Statistical Analysis

Bland-Altman method comparison was used to evaluate the agreements between different middle skull planes (Prism, v.8.4.3, GraphPad Software Inc, San Diego, Calif.). One-way ANOVA and type 3 *t*-test was used for the comparison of the measurements. Statistical significance was set at a *P* value less than 0.05.

RESULTS

Reliability and Validity

The deviation of four individual FH planes relative to the averaged FH plane is 1.75 ± 1.28 degrees ($P = 0.666$). The anterior skull base deviates 11.69 ± 3.87 degrees from the posterior skull base. The proposed midplane has a similar bias (systematic error, 3.42 ± 1.10 degrees) as the midFZ plane in describing the direction of the anterior skull base. However, it has less bias than N-S-BA (13.00 ± 4.68 degrees, $P < 0.001$) and the gravity center planes (13.57 ± 16.66 degrees, $P < 0.001$). Proposed midplane is similar to the midFZ and gravity center planes, in describing the direction of the posterior skull base, while it has less bias than the N-S-BA plane ($P < 0.001$). (**See figure 2, Supplemental Digital Content 2,** which displays a Bland-Altman plot between proposed coordinate system and midplane between bilateral frontozygomatic sutures [midFZ plane]. The midFZ plane was chosen due to its bias statistically second only to the proposed method, and its frequent use in published studies. **http://links.lww.com/PRSGO/B665**.)

Application

Based on the proposed coordinate system, the most protrusive point of frontal bone is contralateral to the fused coronal suture, and distant from the mid-sagittal plane by 13.93 ± 4.01 mm. It is more anteriorly displaced by 5.32 mm ($P < 0.001$), when compared with the corresponding point on the synostotic side. The uppermost point of the supraorbital rim on the synostotic side is 14.72 ± 4.84 mm lower than the frontal bone protruding point level, whereas the uppermost point of supraorbital rim on the contralateral side is 18.81 ± 3.95 mm lower. Therefore, the uppermost point of supraorbital rim on synostotic side is higher than that of contralateral side by 4.09 mm ($P < 0.001$) (Figs. 2, 3). (**See tables, Supplemental Digital Content 3,** which displays (a) Definition of landmarks, distances, angles, and planes (b) Results of Bland-Altman method comparison. No deviation (zero degree) was set as golden standard. (c) Results of application of proposed coordinate system in craniofacial feature evaluation. **http://links.lww.com/PRSGO/B666**.)

The orbitale on the synostotic side is higher than the averaged FH plane, and higher than that on contralateral side by only 0.56 mm ($P < 0.001$). However, the porion on synostotic side is lower than the FH plane, and it is 0.86 mm ($P < 0.001$) lower than the porion on contralateral side.

The most lateral points of the skull on the synostotic (Ts) and contralateral sides (Tc) have a similar distance away from the mid-sagittal plane ($P = 0.255$). However, the Ts point is lower and more anteriorly positioned compared with Tc point ($P < 0.001$). The most posterior point of the skull is 79.21 ± 8.69 mm posterior to the sella, and is not significantly deviated from midplane.

DISCUSSION

The mid-sagittal plane is usually the first dimension that is chosen for orientation in craniofacial cephalometrics. The midplane between bilateral frontozygomatic suture landmarks is frequently used to define it. Subsequently, the skull base plane, facial relationship planes, and the occlusal plane are defined in the orthogonal direction of the mid-sagittal plane.[6,7] However, in UCS, the asymmetric development of orbitofrontal morphology renders this method inapplicable.[8] A plane that simultaneously passes through the nasion, basion, and sella could represent the

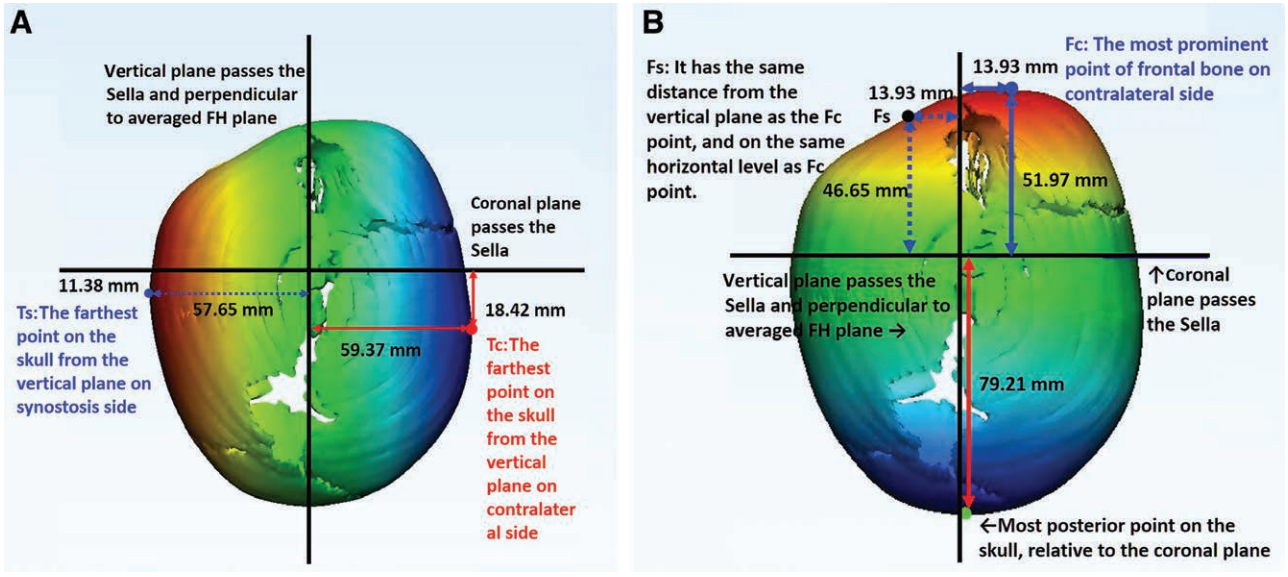

Fig. 2. Relative position of proposed mid-sagittal plane, Nasion-Sella-Basion plane, bilateral frontozygomatic sutures defined midplane, and gravity center plane, along with the relative position of skull and intracranial gravity centers with skull base.

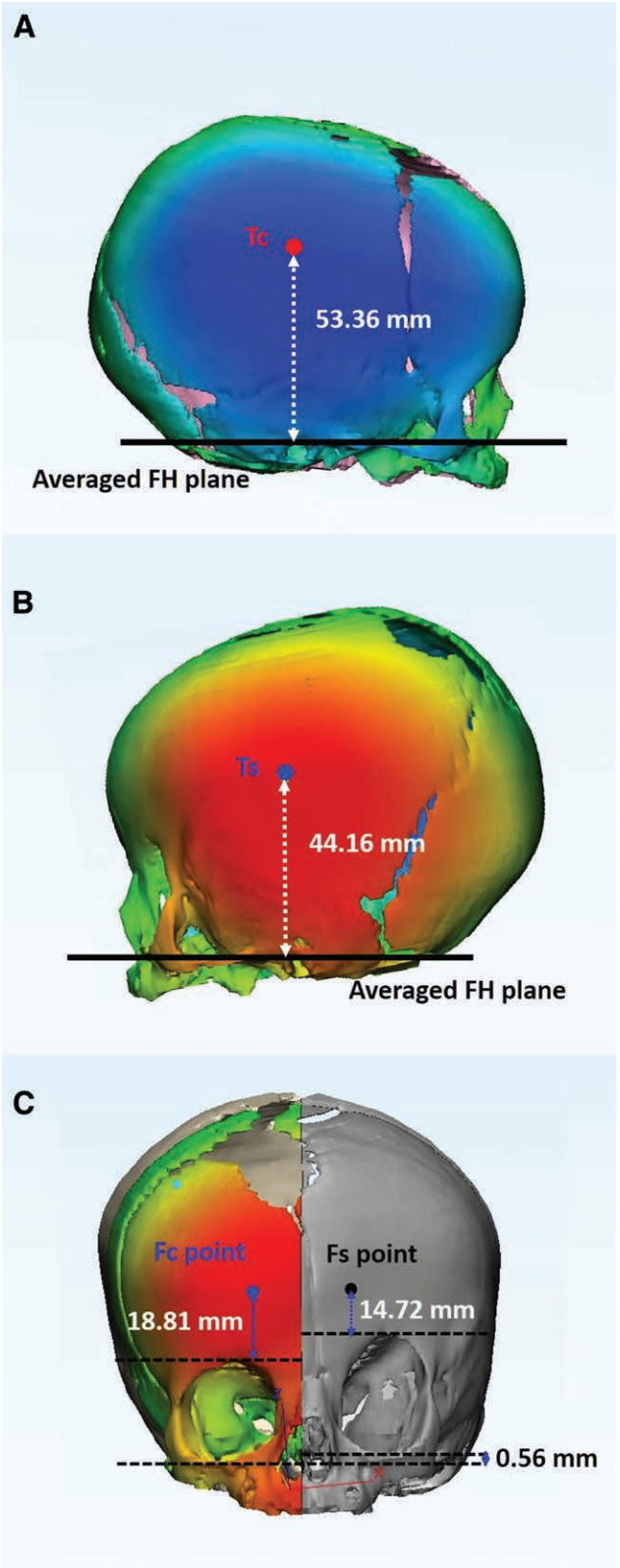

Fig. 3. Illustration of applying proposed coordinate system in craniofacial feature evaluation.

comprehensive structure of the skull base. However, in UCS, the consistently twisting relationship between anterior and posterior skull base results in an oblique vertical plane.[9] A middle plane based on the gravity centers of the skull and intracranial contents also has been recommended for unicoronal cases.[10,11] However, skull deformation and the heavier weight of the skull than the brain has limited the application of this method.

Here, we changed the sequence to build a coordinate system of a skull, starting from the FH plane, given its reliability in the vertical direction.[12] Conventionally, the right porion, right orbitale, and left orbitale are used to locate the FH plane.[13] However, the actual direction of this plane is influenced by the variation in height imposed by the UCS. Coronal synostosis increases the depth of middle cranial fossa.[14] Consequently, the porion on the synostotic side is lower (as observed in this study). A higher positioned orbitale on the synostotic side has been observed as well. However, the proposed coordinate system takes the *average* of FH planes, to balance the asymmetric skull. This coordinate system also enables evaluation of the extreme values of skull shape, such as the distance of the prominence and retrusion of frontal bone on contralateral and synostotic sides. This may be needed information for optimal frontal shape correction.

CONCLUSION

Prioritized orientation of the averaged FH plane, then locating the mid-sagittal plane and the coronal plane, can generate a reliable and valid coordinate system for the assessment on asymmetric skulls resulting from unicoronal synostosis.

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