

Novel method of constructing a stable reference frame for 3-dimensional cephalometric analysis

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Introduction: Three-dimensional (3D) cephalometric analysis has provided the ability to overcome the limitations of 2-dimensional cephalometrics. However, there is no international standard method for 3D cephalometric analysis yet. Determining the position of the midsagittal plane (MSP) practically is the most important step when constructing a 3D cephalometric reference frame. Recent studies have used several approaches to construct the MSP. In this study, we aimed to determine the true MSP of the skull to establish a stable reference frame for 3D cephalometric analysis. **Methods:** Cone-beam computed tomography data of 12 adult patients were divided into 2 groups: symmetry ($n = 6$) and asymmetry ($n = 6$). The anterior cranial base region model and its mirror model were registered and used to determine the MSP to prevent any influence of the degree of symmetry on the registration of other parts of the skull, particularly for subjects with severe facial or cranial asymmetry. Intraclass correlation coefficients were used to assess intraexaminer and interexaminer reliabilities of the x, y, and z coordinates of all landmarks measured by 2 investigators. **Results:** The intraclass correlation coefficient values were greater than 0.9, indicating almost perfect agreement. **Conclusions:** The candidate reference planes constructed using this novel method were thought to be reliable for 3D cephalometric analysis and may expand its clinical applicability in patients with cranial asymmetry. (Am J Orthod Dentofacial Orthop 2018;154:397-404)

Two-dimensional (2D) cephalometric analysis has played a crucial role in clinical measurements in orthodontics and craniofacial surgery since its introduction in 1931.¹ However, there are many disadvantages of 2D cephalometric analyses^{2,3}: (1) blurred images by overlapped anatomic structures, (2) image distortion by rotation of the head and regional magnification, (3) limited parameters that can be measured, and (4) distortion of most measurements with facial asymmetry. Even cone-

beam computed tomography (CBCT) synthesized cephalograms are difficult to accurately superimpose because of differences between the right and left sides, such as differences in scaling ratios, variations in head positioning, and overlapping of various cranial structures.⁴ Three-dimensional (3D) cephalometric analysis has provided the ability to overcome the limitations of 2D cephalometrics and has also enabled a more accurate analysis of asymmetric structures, segmental movements using 3D digital operations, and comparisons of preoperative and postoperative facial profiles.⁵ However, there is no international standard method for 3D cephalometric analysis; recent studies have focused on the identification of 3D cephalometric landmarks and the construction of 3D cephalometric reference frames.^{2,3,6-8}

Determining the position of the midsagittal plane (MSP) practically is the most important aspect of 3D construction of a cephalometric reference frame. Recent studies have proposed several approaches to construct or determine the MSP. Most studies that used 3D computed tomography software have suggested the construction of the MSP by appointing 3 reference points: nasion, sella turcica, and basion,⁹ or 2 midline structure points and making them perpendicular to a plane such as the

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Frankfort horizontal plane.¹⁰ Grummons and Kappeyne van de Coppello¹¹ used a midsagittal line through crista galli and anterior nasal spine. Tuncer et al¹² used a plane through nasion, sella, and anterior nasal spine as the MSP for 3D analysis. Baek et al¹³ used the most superior edge of the crista galli and the midpoint of the anterior clinoid processes to construct the MSP perpendicular to the Frankfort horizontal plane. These 3D cephalometric analyses relied on MSPs determined on the basis of midline structures; however, midline structures such as anterior nasal spine can deviate from the true plane of symmetry when there is asymmetry of the upper and midfacial skull regions. Nevertheless, all of these approaches have certain drawbacks and some kind of bias and cannot be applied to patients with skewed bones.² Three-dimensional analysis was selected because of its familiarity or feasibility based on traditional 2D cephalometric analyses; however, it is not yet known whether these planes are useful or accurate enough for 3D assessments of symmetry and patterns of dysmorphism.^{14,15} Damstra et al¹⁶ valued 6 frequently used cephalometric MSPs described in the literature and concluded that these planes based on midline structures must be used extremely carefully for clinical diagnosis and treatment planning of craniofacial asymmetry because they might differ from the true plane of symmetry. Gateno et al² proposed a 3D external reference system, called the “global coordinate system,” because these planes are easy to define and not altered by facial deformities or asymmetry. However, these planes are reliable only if the head is oriented in natural head posture, and it is difficult to ensure that each patient is in natural head posture during the CBCT scan. Damstra et al¹⁶ used a morphometric method to determine the MSP, with visible facial anatomic landmarks in the supraorbital and nasal bridge regions as references for partial ordinary Procrustes analysis. Thus, the construction of the MSP for patients with orbital malformation may not be accurate.

The iterative closest point procedure, a 2-step algorithm wherein candidate correspondences and rotation and translation are updated until no change is observed in either, is a popular image registration algorithm¹⁷ and is one of the most accurate methods for superimposition in the cranial base (excluding the peripheral zone).¹⁸ For every point on a reference surface, the candidate correspondence is defined as the closest point on the target surface.¹⁷ The iterative closest point is a perfect algorithm for a symmetric image. The normal human face and head have a rough symmetry. However, clinically, many patients exhibit facial bone asymmetry or even neurocranial bone asymmetry, and there is no consensus regarding the most symmetrical region of skull.¹³ Most

(>85%) of the cranial base growth is completed by about 5 to 6 years of age.^{19,20} Hence, cranial base structures are good candidates to be used as reference points, and crista galli has generally been accepted as the midpoint of the cranium.^{11,21} In traditional 2D analysis, superimposition using the anterior cranial base is used to visualize growth changes or changes due to orthodontic treatment.²² Kwon et al²³ studied patients with dentofacial deformities; they reported no differences in the cranial base between the symmetric and asymmetric groups and concluded that structures of the cranial base were not the predominant factors that determined facial asymmetry.

Accordingly, this study was conducted to determine a more accurate MSP based on the anterior cranial base for visible facial asymmetry so that a stable reference frame of 3D cephalometric analysis can be constructed to assist orthodontic and orthognathic diagnosis and treatment.

MATERIAL AND METHODS

CBCT scans (NewTom 3G volumetric scanner; Aperio Services, Verona, Italy), with a field of view of 15 cm transversal × 15 cm anteroposterior × 15 cm height, and 0.3-mm slice thickness, from 12 adult patients were selected from past orthodontic records at the department of orthodontics of Peking University of Stomatology School in Beijing, China. They were divided into 2 groups: symmetry (n = 6) and asymmetry (n = 6). Cranial asymmetry was defined as greater than a 4-mm deviation in the chin (menton and pogonion) from the cranial midline.²¹

The study protocol was approved by the ethics committee for human experiments at the Peking University School and Hospital of Stomatology (PKUSSIRB-201520027).

Step 1: Construction of the MSP

After we obtained the CBCT images from the raw study data, the images were converted into DICOM format. Mimics (version 17.0; Magterialise, Leuven, Belgium), a commercially available third-party software, was used to obtain primary reconstructed images on multiplanar reconstruction (axial, coronal, and sagittal) views as well as 3D reconstructions of images for landmark recognition and location. Orientation of the head was reset by using interactive multiplanar reconstruction online reslicing. The anterior cranial base region (anterior wall of sella, anterior clinoid processes, planum sphenoidale, lesser wings of the sphenoid, superior aspect of the ethmoid and cribriform plates, cortical ridges on the medial and superior surfaces of the orbital roofs, and inner cortical layer of the frontal bones) was

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