Int. J. Oral Maxillofac. Surg. 2017; xxx: xxx–xxx
http://dx.doi.org/10.1016/j.ijom.2017.06.030, available online at http://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Clinical Paper
Orthognathic Surgery

Cone beam computed tomography-based cephalometric norms for Brazilian adults

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R. M. G. Santos, J. M. De Martino, F. Haiter Neto, L. A. Passeri: Cone beam computed tomography-based cephalometric norms for Brazilian adults. Int. J. Oral Maxillofac. Surg. 2017; xxx: xxx–xxx.

Abstract. This study established cone beam computed tomography (CBCT)-based cephalometric norms for Brazilian adults, including the assessment of sexual dimorphism. An observer performed McNamara's cephalometric analysis twice on 60 CBCT datasets acquired from patients with a normal dental occlusion, divided equally into two groups by sex. Welch's *t*-test was applied to assess differences between the sexes in hard tissue cephalometric measurements, and Dahlberg's formula was used to calculate measurement error introduced by the observer. The cephalometric measurements of effective mandibular length, effective midfacial length, maxillomandibular differential, and lower anterior facial height presented sexual dimorphism. Linear measurements had error $\leq$0.78 mm, and angular measurements had error $\leq$1.24°. The results show that (1) the CBCT-based cephalometric norms established in this study are reliable for use by researchers and clinicians, and (2) Brazilian adult males and females have similar craniofacial morphology, with males possessing larger jaws than females.

Key words: orthodontics; cephalometry; three-dimensional imaging; dental occlusion; reference values.

Accepted for publication 6 June 2017

Since its introduction by Broadbent in 1931, cephalometric radiography has been the standard craniofacial imaging technique used by clinicians for evaluating and planning the treatment of orthodontic and orthognathic surgery patients[1]. However, its position has been increasingly challenged by cone beam computed tomography (CBCT), the state-of-the-art imaging technique in the field of oral and maxillofacial surgery, introduced by Mozzo et al. in 1998[2]. CBCT has been gaining acceptance over radiography, since the latter produces undesirable effects inherently related to perspective projection, such as size and shape distortion, superimposition, and misrepresentation of anatomical structures, which can jeopardize cephalometric analysis[3]. These effects affect cephalometric measurement outcomes, mainly because they amplify values and distort the correct location of cephalometric landmarks[4,5]. Besides overcoming these problems, CBCT provides an accurate and reliable three-dimensional (3D) image of the patient's skull[5–7]. Among other advantages, CBCT allows clinicians to virtually orient the head after the image acquisition process, obtain the 3D position of cephalometric landmarks virtually identified on anatomical structures of the head, and perform 3D cephalometric measurements[8].

Prior studies have shown that cephalometric measurements performed on craniofacial images acquired from cephalometric radiography and CBCT present statistically significant and clinically relevant differences[9–11]. Consequently, cephalometric norms derived from the traditional radiographic analyses are not adequate for CBCT-based cephalometric analyses. Additionally, the ever-increasing use of CBCT imagery in routine clinical practice has also pushed the need for cephalometric norms based on CBCT technology[12].

Cephalometric norms are of paramount importance from a clinical point of view, as they provide useful guidelines for clinicians in planning orthodontic and surgical treatments. CBCT-based cephalometric norms have been established for Chinese[13–15], Indian[16], Korean[17], and Turkish[18] populations. However, CBCT-based cephalometric norms for Brazilians appear to be lacking. This study aimed to contribute to the establishment of such norms. In summary, the well-known method of cephalometric analysis developed by McNamara in 1984 was applied to a database of CBCT images acquired from adult male and female Brazilian subjects[19]. Furthermore, sexual dimorphism was assessed statistically.

Materials and methods

This study conformed to the ethical standards and procedures for biomedical research involving human subjects of the National Health Council of Brazil. The study was reviewed and approved by the Human Research Ethics Committee of the School of Medical Science at the University of Campinas.

Data collection

A total of 60 CBCT datasets acquired from Brazilian adults of European descent (30 male and 30 female) were obtained from the clinical archive of the Division of Oral Radiology, Piracicaba Dental School, University of Campinas. Inclusion criteria were the following: CBCT datasets from patients with a normal dental occlusion, age 18–35 years, and presence of all teeth (wearing or not dental braces or implants); the CBCT datasets had to have a large field of view (16 cm in diameter and 13–22 cm in height) and voxel size $\leq$0.4 mm^3. The following exclusion criteria were applied: CBCT datasets from patients who had undergone surgery of the facial bones or who had an abnormal facial asymmetry, and CBCT datasets with severe noise.

Procedure

The four steps described below were performed on each CBCT dataset by one observer. The last two steps were performed twice for the estimation of the technical error of measurement (TEM)[20]. The second observation was done almost 2 years after the first observation. A graphics software toolkit was developed by the first author specifically for these steps. The Python programming environment (version 2.7.7; Python Software Foundation, Beaverton, OR, USA) and its NumPy (version 1.7.1; NumFOCUS, Austin, TX, USA), PyQt (version 4.11; Riverbank Computing Ltd, Wimborne, Dorset, UK), and VTK (version 6.1.0; Kitware Inc., Clifton Park, NY, USA) extension packages were used to produce the toolkit.

In step 1, the patient's skull was virtually reconstructed (Fig. 1). The marching cubes algorithm was applied to the CBCT dataset to build a high-resolution 3D geometric model representing the hard tissue surface of the head[21]. For greater precision, different contour values were considered for bones and teeth since both have different radiodensitiy values.

In step 2, the reconstructed skull was precisely placed in a standardized position oriented to the Frankfort horizontal (FH) and midsagittal reference planes (Fig. 1). To accomplish this, the left and right porion, left and right orbitale, basion, and nasion hard tissue cephalometric landmarks were first marked on the reconstructed skull (Table 1, Fig. 2). Next, the FH, midsagittal, and transporionic planes were created (Fig. 1). The FH is the least-squares best-fit plane to the left and right porion and left and right orbitale[22]. The midsagittal plane intersects the basion and nasion landmarks and is orthogonal to the FH plane. The transporionic plane intersects the midpoint between the left and right porion, and is mutually orthogonal to the other two planes. Finally, the three planes were used to set up a 3D Cartesian coordinate system, where the origin is the intersection point between these planes. The x-axis is a leftward vector normal to the midsagittal plane, the y-axis is a frontward vector normal to the transporionic plane, and the z-axis is a downward vector normal to the FH plane.

In step 3, the hard tissue cephalometric landmarks required to perform McNamara's cephalometric analysis were marked on the reconstructed skull (Fig. 2). The 3D definition shown in Table 1 was used, where unpaired landmarks are located in the midsagittal plane and paired landmarks lie on either side of this plane.

In step 4, McNamara's cephalometric analysis was performed on the midsagittal plane by orthogonally projecting the landmarks. For paired landmarks, the midpoint between the two was projected orthogonally onto the midsagittal plane. Cephalometric reference lines and planes used in McNamara's cephalometric analysis are

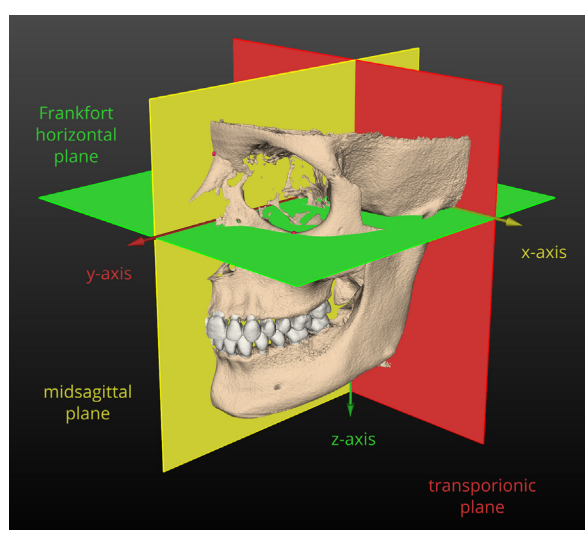

Fig. 1. A reconstructed skull placed in a standardized position oriented to the midsagittal, transporionic, and Frankfort horizontal planes. Three-dimensional hard tissue cephalometric landmarks are represented by magenta spheres of 1-mm radius; only the nasion and left porion are visible in this view of the skull.