Reliability of three-dimensional measurements of the upper airway on cone beam computed tomography images

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Objectives. The aim of this study was (1) to assess intra- and interobserver reliability of the localization of anatomic landmarks of the upper airway on cone beam computed tomography (CBCT) images; and (2) to assess intra- and interobserver reliability of the three-dimensional measurements of the upper airway based on these landmarks.

Study Design. Fifteen NewTom 5G (QR systems, Verona, Italy) CBCT data sets were randomly selected from the archives of the Department of Oral Radiology, Academic Centre for Dentistry (ACTA) at University of Amsterdam and VU University, Amsterdam, The Netherlands. Three observers localized six anatomic landmarks that are relevant for upper airway analysis twice, with a 10-day interval, using 3Diagnosys software (v5.3.1, 3diemme, Cantu, Italy). Subsequently, the observers performed upper airway volume measurement based on those landmarks twice as well, again with a 10-day interval, using Amira software (v4.1, Visage Imaging Inc., Carlsbad, CA). The upper airway measurements also included the minimum cross-sectional area (CSA_{min}), location of the CSA_{min}, and anteroposterior and lateral dimensions of the CSA_{min}.

Results. Both intraobserver reliability and interobserver reliability were excellent for the localization of the anatomic landmarks of the upper airway (intraclass correlation coefficients = 0.97-1.00) as well as for the three-dimensional upper airway measurements (intraclass correlation coefficients = 0.78-1.00).

Conclusions. The methodology of landmark localization and upper airway measurements, as used in this study, showed an excellent reliability and can thus be recommended for upper airway analysis on CBCT images. (Oral Surg Oral Med Oral Pathol Oral Radiol 2016;122:104-110)

The upper airway is an important and complex anatomic structure in respiratory medicine. It is suggested that anatomic and functional abnormalities of the upper airway play an important role in the pathogenesis of obstructive sleep apnea.[1] Recently, the use of cone beam computed tomography (CBCT) in dentistry has increased considerably. Because of its high spatial resolution, adequate contrast between the soft tissue and empty space, and the relatively low radiation dose compared with computed tomography, CBCT has been used to analyze the upper airway anatomy in three dimensions.[2]

Based on CBCT data sets, previous studies have shown a high reliability of the localization of some anatomic landmarks[3-5]; however, there are some limitations. For example, most of the anatomic landmarks chosen in these studies were cephalometric, using only the hard tissue landmarks and excluding soft tissue landmarks related to the upper airway.[3,6,7] It has been suggested that the reliability of the soft tissue landmarks based on CBCT data sets needs to be investigated.[8]

After landmark localization, the upper airway can be segmented on the basis of these landmarks for further analysis. To date, several studies have tested the reliability of upper airway measurements.[9-13] Most studies showed a good reliability,[9-12] but one study

Statement of Clinical Relevance

The methodology of landmark localization and upper airway measurements based on cone beam computed tomography images, as used in this study, is recommended for analysis of the upper airway of breathing disorders, such as obstructive sleep apnea.

This study was presented as an oral presentation at the 20th International Congress of Dento-Maxillo-Facial Radiology, 2015, in Santiago, Chile.

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Received for publication Jan 25, 2016; returned for revision Mar 10, 2016; accepted for publication Apr 13, 2016.

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2212-4403/$ - see front matter
http://dx.doi.org/10.1016/j.oooo.2016.04.005

Table I. Definitions of the anatomic landmarks in three dimensions

Landmark	*Definition*	*Sagittal (X)*	*Coronal (Y)*	*Axial (Z)*
Posterior nasal spine (PNS)	Tip of the sharp posterior end of the nasal crest of the hard palate	Most posterior point	First slice to show PNS (from posterior to anterior)	Midposterior point
Anterior nasal spine (ANS)	Tip of bony projection formed by the union of the two premaxillae	Most anterior point	First slice to show ANS (from anterior to posterior)	Midanterior point
Anteroinferior aspect of the vertebral body of the second cervical vertebra	Middle inferior point of the second cervical vertebra	Most inferior point	Midinferior point	First slice to show second cervical vertebra (from inferior to superior)
Tip of the uvula	Inferior point of caudal margin of the uvula at the mid-sagittal plane	Inferoanterior point	Midinferior point	Midposterior point
Tip of the epiglottis	Midsuperior point of the epiglottis	Most superior point	Midsuperior point	First slice to show epiglottis (from superior to inferior)
Base of epiglottis	Bottom of epiglottis crypt	Most inferior point	Midinferior point	First slice to show epiglottis crypt (from inferior to superior)

demonstrated that certain upper airway measurements are unreliable.[13] Moreover, many of these studies only focused on the reliability of the volume of the upper airway, without testing the reliability of the area measurement of the upper airway or that of the linear measurement of the upper airway.[9,11,12] Therefore, the aims of our study were (1) to assess the intra- and interobserver reliability of the localization of both hard tissue and soft tissue landmarks of the upper airway on CBCT images; (2) and to assess the intra- and interobserver reliability of the three-dimensional measurements of the upper airway based on these landmarks.

METHODS AND MATERIALS

Power calculation

The power calculation recommended by Walter et al. for reliability studies was followed.[14] The null hypothesis was defined as H_0: $\rho_0 \leq 0.6$ and the alternative hypothesis was defined as H_1: ρ_1: ≥ 0.8. The rate of type I error (α), which equates to the criterion for significance, was set at 0.05. The rate of type II error (β), which is related to the power of a test (1-β), was set at 0.2. After checking Table II in Walter et al.'s study, the proposed sample size was set at 15 patients.

CBCT images

CBCT images of 15 patients were randomly and retrospectively selected from scans available at the Department of Oral and Maxillofacial Radiology of the Academic Centre for Dentistry Amsterdam (ACTA), The Netherlands. These patients had been referred to the Department of Oral Kinesiology for an examination of the temporomandibular joints between April 1, 2013, and July 1, 2014. The study was approved by the Medical Ethics Committee of VU University, Amsterdam; protocol number: NL18726.029.07.

The inclusion criteria were as follows: age >18 years and CBCT images covering the entire upper airway from the level of the hard palate to the base of the epiglottis (BEP). The exclusion criteria were presence of a palatal cleft, presence of a craniofacial syndrome, or craniofacial surgery in the past.

The procedure of randomization was as follows: (1) 36 CBCT data sets of the patients who fulfilled the inclusion criteria were gathered; (2) the patients were grouped in random order by using the Excel (Microsoft, Redmond, WA) "RAND" function; and (3) the first 15 data sets of the random list were selected in this study.

The CBCT data sets used in this study were obtained by using the NewTom 5G (QR systems, Verona, Italy), according to the department's standard imaging protocol. During the imaging procedure, the patients were positioned in the supine position, with the Frankfort horizontal (FH) plane perpendicular to the floor. They were instructed to maintain maximum intercuspation and to avoid swallowing and other movements during the scanning period. The exposure settings were 110 kV, 4 mA, 18 × 16-cm field of view, 0.3-mm voxel size, 3.6 seconds exposure time (pulsed radiation), and 18 to 36 seconds scanning time, depending on the size of the patient. For further analysis, the images were saved as digital imaging and communications in medicine (DICOM) files, and these data sets were imported into 3Diagnosys software (v5.3.1, 3diemme, Cantu, Italy) for anatomic landmark localization and into Amira software (v4.1, Visage Imaging Inc., Carlsbad, CA) for upper airway measurements.

Procedure of measurements

Two maxillofacial radiologists and an orthodontist were trained as observers, using two data sets that were not included in this study. After training, each observer

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