AJO-DO

Imaging software accuracy for 3-dimensional analysis of the upper airway

André Weissheimer,[a] Luciane Macedo de Menezes,[b] Glenn T. Sameshima,[c] Reyes Enciso,[d] John Pham,[e] and Dan Grauer[f]

Porto Alegre and Rio Grande do Sul, Brazil, and Los Angeles, Calif

Introduction: The aim of this study was to compare the precision and accuracy of 6 imaging software programs for measuring upper airway volumes in cone-beam computed tomography data. **Methods:** The sample consisted of 33 growing patients and an oropharynx acrylic phantom, scanned with an i-CAT scanner (Imaging Sciences International, Hatfield, Pa). The known oropharynx acrylic phantom volume was used as the gold standard. Semi-automatic segmentations with interactive and fixed threshold protocols of the patients' oropharynx and oropharynx acrylic phantom were performed by using Mimics (Materialise, Leuven, Belgium), ITK-Snap (www.itksnap.org), OsiriX (Pixmeo, Geneva, Switzerland), Dolphin3D (Dolphin Imaging & Management Solutions, Chatsworth, Calif), InVivo Dental (Anatomage, San Jose, Calif), and Ondemand3D (CyberMed, Seoul, Korea) software programs. The intraclass correlation coefficient was used for the reliability tests. A repeated measurements analysis of variance (ANOVA) test and post-hoc tests (Bonferroni) were used to compare the software programs. **Results:** The reliability was high for all programs. With the interactive threshold protocol, the oropharynx acrylic phantom segmentations with Mimics, Dolphin3D, OsiriX, and ITK-Snap showed less than 2% errors in volumes compared with the gold standard. Ondemand3D and InVivo Dental had more than 5% errors compared with the gold standard. With the fixed threshold protocol, the volume errors were similar (–11.1% to –11.7%) among the programs. In the oropharynx segmentation with the interactive protocol, ITK-Snap, Mimics, OsiriX, and Dolphin3D were statistically significantly different ($P < 0.05$) from InVivo Dental. No statistical difference ($P > 0.05$) was found between InVivo Dental and OnDemand3D. **Conclusions:** All 6 imaging software programs were reliable but had errors in the volume segmentations of the oropharynx. Mimics, Dolphin3D, ITK-Snap, and OsiriX were similar and more accurate than InVivo Dental and Ondemand3D for upper airway assessment. (Am J Orthod Dentofacial Orthop 2012;142:801-13)

For the last century, the gold standard method for analysis of craniofacial development was cephalometry, with linear and angular measurements performed on lateral headfilms. However, as a 2-dimensional representation of 3-dimensional (3D) structures, lateral headfilms offer limited information about the airways.[1] Information regarding axial cross-sectional areas and overall volumes can only be determined by 3D imaging modalities.[2-9] Medical computed tomography is a 3D imaging modality used in medicine but not as a routine method for airway analysis because of its high cost both financially and in terms of radiation. These drawbacks were overcome with the introduction of cone-beam computed tomography (CBCT). CBCT is becoming a popular diagnostic method for visualizing and analyzing upper airways. Since its introduction in 1998, CBCT technology has been improved, with lower costs, less radiation exposure to patients, and better accuracy in identifying the boundaries of soft tissues and empty spaces (air).[7] Furthermore, CBCT allows for the

[a]Postgraduate student, Department of Orthodontics, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil; visitor scholar, Graduate Orthodontics, Ostrow School of Dentistry, University of Southern California, Los Angeles.
[b]Associate professor, Department of Orthodontics, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil.
[c]Associate professor and director, Graduate Orthodontics, Ostrow School of Dentistry, University of Southern California, Los Angeles.
[d]Assistant professor, Clinical Dentistry, Division of Dental Public Health and Pediatric Dentistry, Ostrow School of Dentistry, University of Southern California, Los Angeles.
[e]Biomedical and computer engineer and resident, Graduate Orthodontics, Ostrow School of Dentistry, University of Southern California, Los Angeles.
[f]Assistant professor, Clinical Dentistry, Graduate Orthodontics, Ostrow School of Dentistry, University of Southern California, Los Angeles.
The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.
Supported by the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES Foundation, process number BEX 5335-11-6).
Reprint requests to: André Weissheimer, Pontifícia Universidade Católica do Rio Grande do Sul, Avenida Ipiranga, 6681, Faculdade de Odontologia, Prédio 6 sala 209, Porto Alegre, RS, Brazil CEP 90619-900; e-mail, andre5051@hotmail.com.
Submitted, April 2012; revised and accepted, July 2012.
0889-5406/$36.00

http://dx.doi.org/10.1016/j.ajodo.2012.07.015

assessment of axial cross-sectional areas and volumes of the upper airways. The accuracy and reliability of CBCT for upper airway evaluation have been validated in previous studies,[2,6,8,10-12] and the use of CBCT for airway evaluation has been reported in a systematic review of the literature.[1]

The evaluation of the size, shape, and volume of the upper airway starts by defining the volume corresponding to the airway passages, a process called segmentation. In medical imaging, segmentation is defined as the construction of 3D virtual surface models (called *segmentations*) to match the volumetric data.[13] In other words, it means to separate a specific element (eg, upper airway) and remove all other structures of noninterest for better visualization and analysis. Upper airway segmentation can be either manual or semiautomatic. In the manual approach, the segmentation is performed slice by slice by the user. The software then combines all slices to form a 3D volume. This method is time-consuming and almost impractical for clinical application. In contrast, semiautomatic segmentation of the airway is significantly faster than manual segmentation.[14] In the semiautomatic approach, the computer automatically differentiates the air and the surrounding soft tissues by using the differences in density values (grey levels) of these structures. In some programs, the semiautomatic segmentation includes 2 user-guided interactive steps: placement of initial seed regions in the axial, coronal, and sagittal slices, and selection of an initial threshold.

Image thresholding is the basis for segmentation. When the user determines a threshold interval, it means that all voxels with grey levels inside that interval will be selected to construct the 3D model (segmentation). Lenza et al[7] reported the use of a single threshold value to segment the airway in each patient's CBCT scan. This approach can generate errors, especially in volume analysis, but it is certainly more reproducible than the use of a dynamic threshold. However, there are few studies comparing the results of threshold filtering with different imaging software programs for airway assessment.

A growing number of software programs to manage and analyze digital imaging communications in medicine (DICOM) files are introduced in the market every year. Many of these have incorporated tools to segment and measure the airway. A systematic review of the literature reported 18 imaging software programs for viewing and analyzing the upper airway in CBCT.[1] However, validation studies with a clear study design were performed in only 4 software programs.[10,14] The systematic review suggested that studies assessing the accuracy and reliability of current and new software programs must be conducted before these imaging software programs can be implemented for airway analysis.[1]

The aim of this study was to compare the precision and accuracy of 6 imaging software programs for measuring the oropharynx volume in CBCT images. The primary null hypothesis, that there are no significant differences in airway volume measurements among the 6 imaging software programs, was tested.

MATERIAL AND METHODS

This study was approved by the ethical committee of Pontifical Catholic University of Rio Grande do Sul in Brazil. The records we used were obtained from the patient database of the Department of Orthodontics and consisted of the pretreatment CBCT scans of a preexisting rapid maxillary expansion sample.[15] The sample included 33 growing patients (mean chronologic age, 10.7 years; range, 7.2-14.5 years) with transverse maxillary deficiency and no congenital malformations. Additionally, a custom-made oropharynx acrylic phantom with a known volume was used as the gold standard (Fig 1). The oropharynx acrylic phantom consisted of an air-filled plastic rectangular prism surrounded by water. Water was the medium of choice because it has a similar attenuation value to soft tissue. The dimensions of the outer surface of the phantom were created to simulate the dimensions of a growing patient's neck, and the rectangular prism to simulate the dimensions of the oropharynx. The oropharynx acrylic phantom's dimensions were measured to the nearest 0.01 mm by using digital calipers (model 727; Starret, Itú, São Paulo, Brazil), and the volume was calculated multiplying the base area by the height. Additionally, the oropharynx acrylic phantom's volume was confirmed by using the water weight equivalent. The oropharynx acrylic phantom was filled with distilled water, at 20°C, and the water weight was determined by using a digital scientific scale (model BG1000; Gehaka, São Paulo, São Paulo, Brazil).

Patients and the phantom were scanned with the i-CAT scanner (Imaging Sciences International, Hatfield, Pa) set at 120 kVp, 8 mA, scan time of 40 seconds, and 0.3-mm voxel dimension. The images were reconstructed with a 0.3-mm slice thickness and exported as DICOM files. Any CBCT scans with artifacts distorting the airway borders were excluded from this study. CBCT scans were imported into OsiriX software (version 4.0; Pixmeo, Geneva, Switzerland) for head orientation and definition of the oropharynx's region of interest. The head orientation was performed by using the palatal plane as a reference (ANS-PNS parallel to the global horizontal plane in the sagittal view and perpendicular to the global horizontal plane in the axial view). After head orientation, a tool in OsiriX (Vol cutter) was used