Correlation and reliability of cone-beam computed tomography nasopharyngeal volumetric and area measurements as determined by commercial software against nasopharyngoscopy-supported diagnosis of adenoid hypertrophy

Camila Pachêco-Pereira,[a] Noura Alsufyani,[b] Michael Major,[a] Sandra Palomino-Gómez,[c] José Roberto Pereira,[a] and Carlos Flores-Mir[a]

Edmonton, Alberta, Canada, Riyadh, Saudi Arabia, and Lima, Peru

Introduction: The aim of this study was to evaluate the diagnostic correlation and reliability of Dolphin Imaging fully automated segmentation (Dolphin Imaging and Management Solutions, Chatsworth, Calif) for assessing adenoid hypertrophy. This was investigated through 3 modes: (1) intraobserver and interobserver agreement of repeated airway auto-segmentation procedures, (2) correlation between auto-segmentation measures of volume and minimal cross-sectional airway against nasopharyngoscopy, and (3) optimum diagnostic cutoff thresholds for volume and minimal cross-sectional airway identified and tested with sensitivity and specificity analyses. **Methods:** Cone-beam computed tomography scans of 38 patients with suspected upper airway obstruction were analyzed. Two calibrated evaluators applied a previously validated method to quantify nasopharyngeal minimal cross-sectional airway and volume using Dolphin Imaging. Assessments were compared against grades of obstruction provided by otolaryngologists' diagnoses. **Results:** The reliability between the 2 assessments by the same evaluator on the Dolphin automatic segmentation function for volume (ICC, 0.97; 95% CI, 0.95, 0.98) and minimal cross-sectional airway (ICC, 0.84; 95% CI, 0.69, 0.91) was excellent. The interoperator reliability for volume was also excellent (ICC, 0.97; 95% CI, 0.95, 0.98), but only good (ICC, 0.701; 95% CI, 0.44, 0.85) for minimal cross-sectional airway. In contrast, the Spearman rank correlation test demonstrated weak associations between the values of the automatic measurements for both volume (4.9%; $\rho = -0.22$) and minimal cross-sectional airway (3.7%; $\rho = 0.19$). Assessments of accuracy via Receiver Operating characteristic analysis, sensitivity, specificity, negative predictive values, positive predictive values, and likelihood ratios demonstrated the poor clinical applicability of volume and minimal cross-sectional airway numbers provided by Dolphin Imaging. **Conclusions:** The evaluators were reliable at manipulating the selected software, achieving consistent volume and minimal cross-sectional airway measurements, However, Dolphin Imaging volumetric and minimal cross-sectional airway measurements did not correlate well with the nasopharyngoscopy-supported reference standard for adenoid hypertrophy assessment. Under these study conditions, volume and minimal cross-sectional airway used to assess localized adenoid hypertrophy with cone-beam computed tomography

[a]School of Dentistry, Faculty of Medicine and Dentistry, School of Dentistry, University of Alberta, Edmonton, Alberta, Canada.
[b]School of Dentistry, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada; College of Dentistry, King Saud University, Riyadh, Saudi Arabia.
[c]Department of Pediatric Dentistry, Universidad Nacional Mayor de San Marcos, Lima, Peru.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.

Address correspondence to: Camila Pachêco-Pereira, School of Dentistry, Faculty of Medicine and Dentistry, University of Alberta, 5-533 Edmonton Clinic Health Academy, 11405-87 Av NW, Edmonton T6G 1C9, AB, Canada; e-mail, cppereir@ualberta.ca.
Submitted, January 2016; revised and accepted, November 2016.
0889-5406/$36.00

http://dx.doi.org/10.1016/j.ajodo.2016.11.024

imaging based on automated measurements may not yield high-quality clinically relevant information about upper airway constriction related to adenoid hypertrophy. (Am J Orthod Dentofacial Orthop 2017;152:92-103)

A common cause of an upper airway dysfunction in children and adolescents is adenoid or tonsil hypertrophy. Chronic adenoid hypertrophy can cause partial or total airway obstruction.[1] In chronic cases, adenotonsillar hypertrophy is considered an important risk factor for obstructive sleep apnea development.[2-4]

The diagnosis of obstructive dysfunction is primarily made on the basis of the medical history, as well as the physical findings.[5] Chronic snoring, breathing interruption during sleep, diminished growth rate, tendency to fall asleep during the day, behavioral difficulties, and chronic runny nose are common symptoms.[3] An indicative medical history with associated physical findings will support an imaging request to provide a definitive diagnosis. In such cases, nasopharyngoscopy is considered the reference standard of imaging; it is a noninvasive and radiation-free technique that facilitates the assessment of the adenoids without sedation.

Among dental professionals, 2-dimensional (2D) lateral skull radiographs have been the traditional tool to screen for adenoid hypertrophy.[6] The advent of cone-beam computed tomography (CBCT) imaging has expanded the screening capability of the upper airway area by allowing simultaneous assessment of cross-sectional areas and volumetric portrayals. Three-dimensional (3D) imaging compensates for the downside of 2D views by refining the image definition, eliminating structural superimpositions, and improving the overall diagnostic accuracy.[7-11] Simultaneously, CBCT is becoming the imaging tool of choice for diagnosis and treatment planning of complex orthodontic cases.[7] However, the high percentage of CBCT incidental findings in the upper airway area (42.3%) has raised the attention of researchers.[12,13]

Several software companies have developed specific applications to analyze and display the DICOM reconstructions of complex airway space and anatomy.[11] Some of these craniofacial reconstruction softwares propose that their computer algorithms could efficiently replace the time-demanding manual segmentation of the upper airway space in 3D reconstructions. These software programs were designed to offer automatically or semiautomatically upper airway CBCT segmentation for limited or no operator control and knowledge of anatomy while transforming the data into a 3D volume.[14]

A previous study questioned the accuracy of Dolphin Imaging automated software (Dolphin Imaging and Management Solutions, Chatsworth, Calif); the authors found that observers' effects influenced the segmentation and volume when the method was not standardized and the numbers were compared with manual segmentation.[15] To our knowledge, no study has evaluated the airway volume and minimal cross-sectional airway area calculated from this software against the reference standard assessment for adenoid hypertrophy by an otolaryngologist head and neck surgeon through nasopharyngoscopy. Therefore, the aims of this study were (1) to test the reliability of CBCT volumetric and cross-sectional area measurements of the nasopharynx using Dolphin Imaging and (2) to test the correlation of CBCT volumetric and cross-sectional area measurements of the nasopharynx with an otolaryngologist head and neck surgeon's nasopharyngoscopy-supported adenoid hypertrophy diagnosis.

MATERIAL AND METHODS

The Research Ethics Board at the University of Alberta in Canada (Pro00044649) approved this retrospective cross-sectional study protocol.

The study sample consisted of CBCT imaging from 39 subjects between 6.3 and 15.8 years of age (mean, 11.5 years $\pm$ 2.8). This prospective sample was selected from a pool of patients' records from the Interdisciplinary Upper Airway Clinic at the University of Alberta. Consecutively examined patients were previously selected as explained in a previous study.[16] No CBCT images were taken specifically for this study, according to the ALARA principle and the standards of care of the American[17] and European[18] guidelines.

The inclusion criteria were (1) children from 6 to 16 years old and (2) referrals for significant upper airway concerns. Patients with (1) previous active treatment of upper airway dysfunction or sleep disorders, (2) previous orthodontic treatment, or (3) developmental craniofacial disorders such as syndromes and cleft palate were excluded.

All subjects had the CBCT and nasopharyngoscopy obtained during a 2-hour appointment. The same technician using the same scan parameters followed a CBCT imaging protocol. The images were taken using an ICat Classic (cone beam 3D dental imaging system; Imaging Sciences International, Hatfield, Pa) at 110 kV,