AJO-DO

When static meets dynamic: Comparing cone-beam computed tomography and acoustic reflection for upper airway analysis

Ioannis A. Tsolakis,[a] Divya Venkat,[b] Mark G. Hans,[c] Aurelio Alonso,[d] and J. Martin Palomo[e]
Athens, Greece, and Cleveland, Ohio

Introduction: Upper airway measurement can be important for the diagnosis of breathing disorders. Acoustic reflection (AR) is an accepted tool for studying the airway. Our objective was to investigate the differences between cone-beam computed tomography (CBCT) and AR in calculating airway volumes and areas. **Methods:** Subjects with prescribed CBCT images as part of their records were also asked to have AR performed. A total of 59 subjects (mean age, 15 ± 3.8 years) had their upper airway (5 areas) measured from CBCT images, acoustic rhinometry, and acoustic pharyngometry. Volumes and minimal cross-sectional areas were extracted and compared with software. **Results:** Intraclass correlation on 20 randomly selected subjects, remeasured 2 weeks apart, showed high reliability (r >0.77). Means of total nasal volume were significantly different between the 2 methods (P = 0.035), but anterior nasal volume and minimal cross-sectional area showed no differences (P = 0.532 and P = 0.066, respectively). Pharyngeal volume showed significant differences (P = 0.01) with high correlation (r = 0.755), whereas pharyngeal minimal cross-sectional area showed no differences (P = 0.109). The pharyngeal volume difference may not be considered clinically significant, since it is 758 mm^3 for measurements showing means of 11,000 ± 4000 mm^3. **Conclusions:** CBCT is an accurate method for measuring anterior nasal volume, nasal minimal cross-sectional area, pharyngeal volume, and pharyngeal minimal cross-sectional area. (Am J Orthod Dentofacial Orthop 2016;150:643-50)

The measurements of the upper airway can be significantly important for the diagnosis of breathing disorders. A partial or complete collapse of the upper airway during sleep is the hallmark of sleep apnea. Sleep-disordered breathing was defined as weekly occurrences of loud snoring; gasping, choking, or snorting; awakening with gasping or choking; or momentary periods of stopped or abnormal breathing.[1] More than 20% of adolescents snore at least a few nights per month, 6% snore every night or nearly every night, and apnea-like symptoms affect from 2.5% to 6.1% of adolescents.[1] Even though sleep studies are still the official method to diagnose sleep-disordered breathing conditions, using imaging techniques, the clinician can assess potential risk factors of patients for a more complete pretreatment diagnosis.

[a]Orthodontist, PhD candidate, Laboratory of Experimental Surgery and Surgical Research School of Medicine, University of Athens, Greece.
[b]Pulmonary and Critical Care Fellow, School of Dental Medicine, Case Western Reserve University, Cleveland, Ohio.
[c]Professor and chairman, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, Ohio.
[d]Assistant professor, Department of Comprehensive Care, School of Dental Medicine, Case Western Reserve University, Cleveland, Ohio.
[e]Professor and program director, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, Ohio.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Address correspondence to: Ioannis A. Tsolakis, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, 10900 Euclid Ave, Cleveland, OH 44106; e-mail, tsolakisioannis@gmail.com.
Submitted, November 2015; revised and accepted, March 2016.
0889-5406/$36.00

http://dx.doi.org/10.1016/j.ajodo.2016.03.024

Airway analysis usually consists of nasal passage and oropharynx volumes and assessment of areas of maximum constriction. Acoustic reflection (AR), first described over 25 years ago, has been used in many industries and is probably one of the most accepted tools for studying the airway.[2-4] This noninvasive technique uses sound waves that go through the airway and back, collecting data and calculating volumes and areas of maximum constriction. Its accuracy and reliability have been examined with special focus on the anterior nasal passage and the most constricted areas in both the nasal passage and the oropharynx. AR encounters some limitations when the airway becomes narrower, and the sound waves have difficulty getting back to the sensor.[2-5] The acoustic pharyngometry technique has been validated against computed tomography scans and experimental models. Hoffstein and Fredberg[6] reported that using the acoustic reflective method can accurately measure the upper airway and is highly reproducible.

Cone-beam computer tomography (CBCT) was created by Robles RA in 1982 for angiography purposes.[7] CBCT captures different images while rotating around the patient's head and creates a 3-dimensional (3D) volume, in a similar way as computed tomography, but in a volumetric way that allows a single rotation, resulting in a much lower radiation dose. Further changes in the capturing methods used by CBCT have recently allowed for less radiation to the patient than traditional 2-dimensional radiographs.[8]

Aboudara et al[9] reported one of the first studies that tried to measure the volume of the nasopharynx with CBCT and concluded that airway measurements with CBCT can be accurately achieved by segmentation of the image. In medical imaging, segmentation is defined as the construction of 3D virtual surface models to match the volumetric data.[10] Upper airway segmentation can be either manual or semiautomatic. In the manual approach, the segmentation is performed slice by slice by the user. This method is time-consuming and almost impractical for clinical applications. On the contrary, semiautomatic segmentation of the airway is significantly faster than manual segmentation.[11] Ghoneima and Kula[12] suggested that CBCT measurement of the upper airway is an accurate and reliable technique to quantify airway volume and minimal cross-section area; their result is consistent with the previous findings by Tso et al.[13] El and Palomo[11] tested manual segmentation compared with different methods of semiautomatic segmentation and found that different software programs gave different values, but showed great correlations, suggesting systematic error. Weissheimer et al[14] confirmed those conclusions and reported that upper airway measurements using Mimics, Dolphin3D, ITK-Snap, and OsiriX were similar and more accurate than InVivo Dental and Ondemand 3D.

The question of how useful and complete is the CBCT airway assessment is still controversial, since it is based on a static capture, whereas the airway is a dynamic structure.

The aim of this study was to compare CBCT upper airway analysis with the dynamic AR method.

MATERIAL AND METHODS

Institutional review board approval was obtained from Case Western Reserve University before this study. Subjects were recruited from the Craniofacial Imaging Center at Case Western Reserve University in Cleveland, Ohio. Inclusion criteria consisted of subjects seeking orthodontic treatment who were referred for CBCT imaging at the craniofacial imaging center. No CBCT image was taken for research purposes only. The subjects' records included CBCT images and AR. All CBCT images were taken using a custom low-dose scanner, CB MercuRay (Hitachi Medical Systems of America, Twinsburg, Ohio), using 2 mA, 120 kV(p), resulting in a voxel size of 0.37.[15] The patients were instructed to close their eyes, swallow once, bite down, and hold still during the acquisition of the CBCT images. Subjects with intraoral appliances, congestion, or asthmatic conditions were excluded. A sample size calculation was performed using a pilot study with 10 subjects, suggesting that 39 subjects was necessary for a confidence level of 95%. A sample of 59 subjects was recruited and used in this project.

AR consists of 2 separate analyses with separate sensors, acoustic rhinometry, and acoustic pharyngometry. Acoustic rhinometry is used to measure the nasal cavity and requires a nasal mask, whereas acoustic pharyngometry is for pharyngeal areas and uses a mouthpiece (Fig 1). For all AR imaging, the Eccovision system (Sleep Group Solutions, Hollywood, Fla) was used.

For all subjects, the CBCT image, acoustic rhinometry, and acoustic pharyngometry were taken on the same day by 1 operator (I.A.T.) with the patient sitting on the same chair, with the same head orientation. Calibration and orientation of the acoustic techniques were performed before each measurement. Patients were instructed to breathe normally during the measurement, and 4 separate measurements were taken for each acoustic rhinometry, and acoustic pharyngometry (Fig 2).

The graphs generated by acoustic rhinometry and acoustic pharyngometry show different areas of constriction on the x-axis and y-axis, giving the distance that sound has traveled. The areas under the graphs represent the volume at a certain distance. For acoustic rhinometry, we calculated the area under the graph to the first most constricted area, which is often identified as the nasal valve. Acoustic rhinometry reported the area in this region and is recorded as the anteriormost constricted area.

All CBCT images were imported into the Dolphin 3D Imaging program (version 11.0; Dolphin Imaging and Management Solutions, Chatsworth, Calif), where they were oriented according to the technique of Wu et al[16] (Fig 3). Data collected from the CBCT images included total nasal volume, anterior nasal valve volume, nasal minimal cross-sectional area, pharyngeal volume, and pharyngeal minimal cross-sectional area (Fig 4).

For all nasal data, after orientation of the skull, a vertical plane was constructed perpendicular to the horizontal border. The vertical plane was then used

Fig 1. *Left*, Rhinometry: mask and orientation; *right*, pharyngometry: mouthpiece.

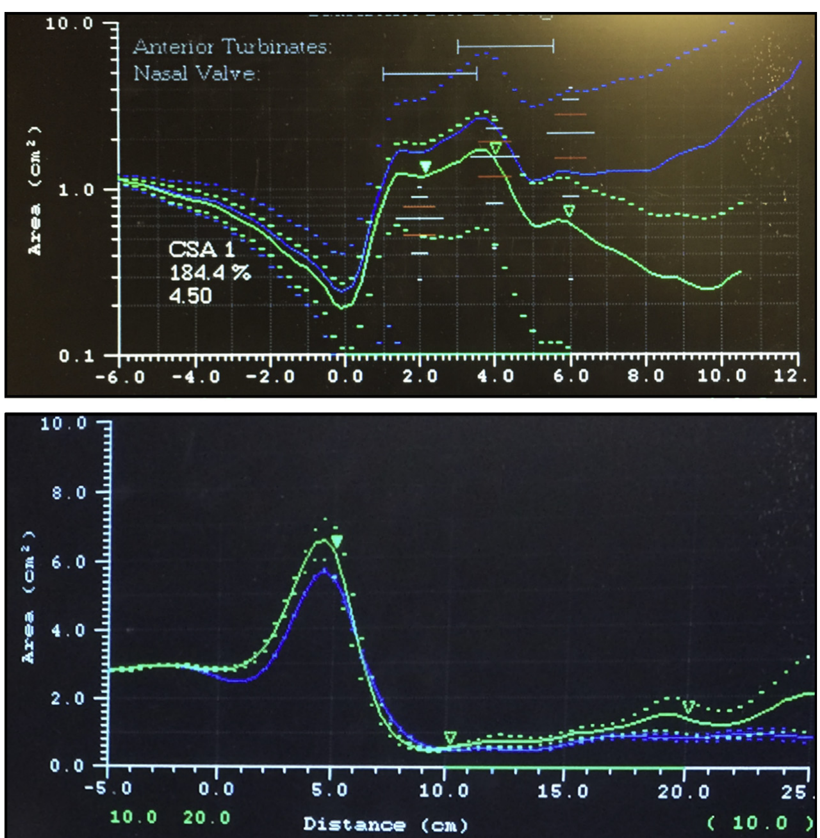

Fig 2. *Top*, Graph illustrating cross-sectional area and distance from the nostrils into the nasal cavity by acoustic rhinometry; *bottom*, graph illustrating cross-sectional area and distance from the oral cavity into the pharynx generated by acoustic pharyngometry.

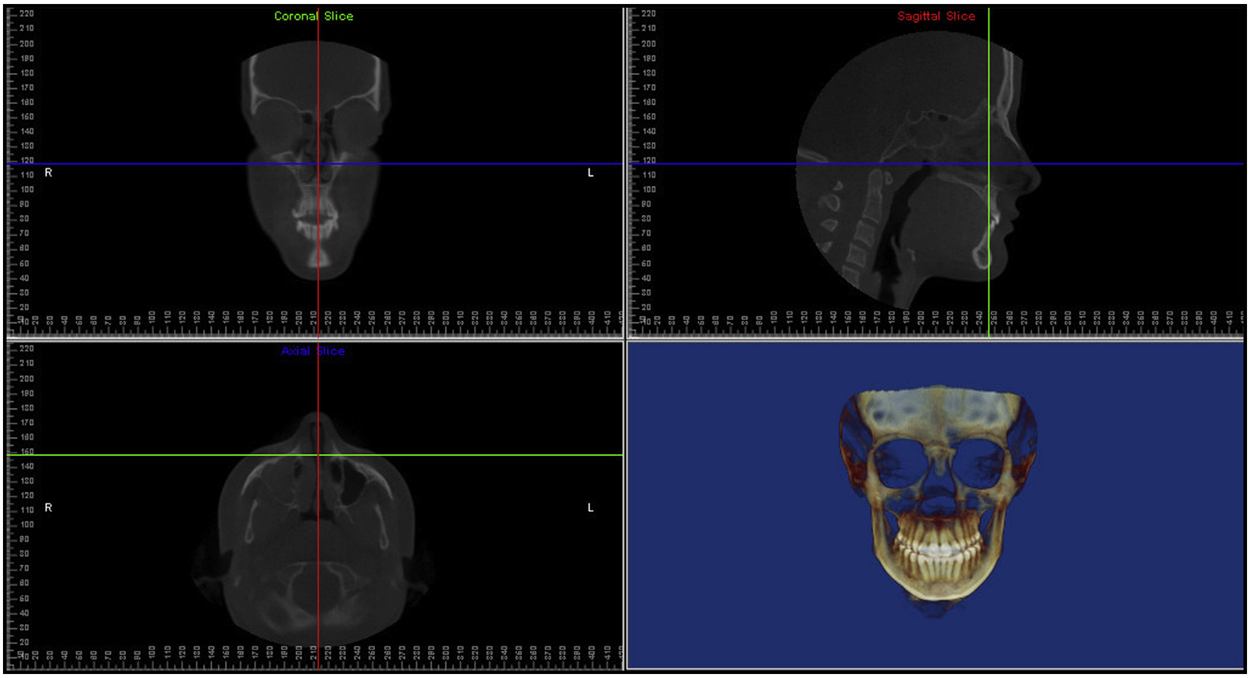

Fig 3. CBCT orientation: orient the subject in the coronal view so that the axial plane is aligned with the optic foramen, and in the axial view so that the coronal plane is aligned with the left and right foramen ovale. Orientation of the sagittal plane with foramen cecum in the coronal view and the axial plane with McRae's line in the sagittal view.

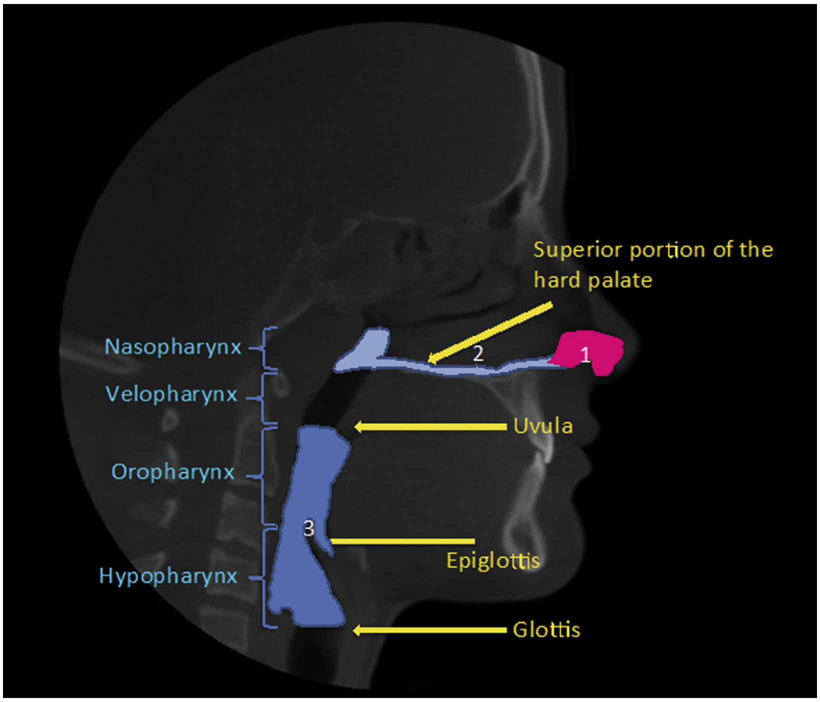

Fig 4. Radiographic anatomy of the upper airway: *1*, anterior nasal valve volume; *2*, total nasal volume; *3*, pharyngeal volume.

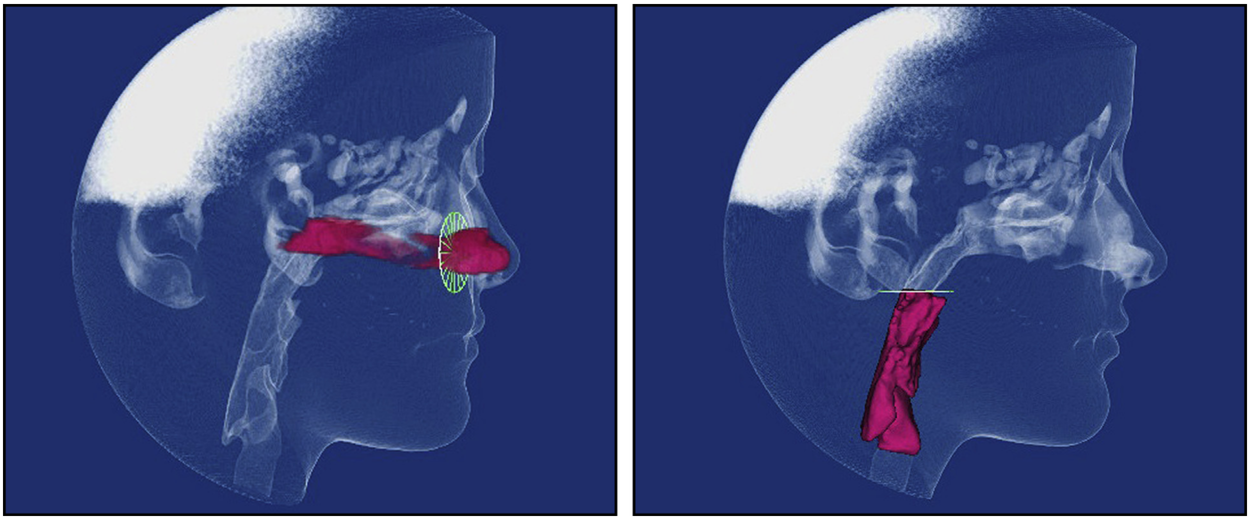

Fig 5. *Left*, CBCT total nasal volume and minimal cross sectional area; *right*, CBCT pharyngeal volume and minimal cross sectional area.

to rotate the axial slice by 90°, making it parallel to the horizontal line. After the skull was properly oriented, borders of the nasal passage were drawn on all 3 slices: axial, coronal, and sagittal. The nasopharyngeal volume was defined as the pharyngeal volume located between the palatal plane and a parallel plane passing through the last axial slice before the nasal septum fused with the posterior pharyngeal wall. The effects of paranasal sinuses and acoustic resonances in the nasal cavity are not accounted for in our AR algorithms; therefore, the CBCT measurements will not include the sinus and parasinus areas.[17] The minimum cross-sectional area for that volume was also calculated. The nasal valve was identified using the cross-sectional slices right before the passage was slit into several narrow pathways (Fig 5).

All pharyngeal data were collected from a predetermined pharyngeal area. The superior border started by moving downward parallel to the palatal plane (ANS to PNS) until it reached the end of the uvula in the axial plane. The glottis marked the most inferior point in this cavity, which has a prominent notch after the epiglottis. The volume in this cavity was generated with its minimal cross-sectional area (Fig 5).

Statistical analysis

All CBCT, acoustic rhinometry, and acoustic pharyngometry data were imported into an Excel spreadsheet (Microsoft, Redmond, Wash), and statistical analysis was performed using SPSS software (version 22; IBM, Armonk, NY). Normal distribution of the data was tested using the Shapiro-Wilk test. The only variables showing normal distributions were total nasal volume, anterior nasal valve volume, and anterior nasal cavity. Paired *t* tests were used for variables showing normal distribution, and the Wilcoxon signed rank test was used for data not normally distributed.

RESULTS

The sample included 59 subjects (34 female) with a mean age of 15.4 ± 3.8 years (Table I).

The operator's reliability was calculated using intraclass correlation on 20 randomly selected subjects, whose data were remeasured 2 weeks apart. All measurements with both the CBCT and the AR methods were highly reliable (Table II).

The mean total nasal passage volumes were 10,462 ± 2726 mm^3 for CBCT and 9194.7 ± 4224.7 mm^3 for acoustic rhinometry. There was a significant difference between the 2 methods ($P = 0.035$). The CBCT images had slightly higher volumes than did the acoustic rhinometry method. The 2 measurements showed a low correlation ($r = 0.274$) (Table III).

Anterior nasal valve volume measured by CBCT had a mean of 2787.02 ± 845.59 mm^3 and acoustic rhinometry had a mean of 2544.2 ± 1045.3 mm^3. There was no significant difference between these 2 methods ($P = 0.532$) (Table III).

The means of the minimal area cross-section of the nasal valve between CBCT and acoustic rhinometry had no statistically significant difference ($P = 0.066$) with respective means of 125.7 ± 44.6 mm^2 and 128.6 ± 47.3 mm^3. The 2 methods were highly correlated ($r = 0.974$).

Table I. Demographic data

Sex (n)	*Age (y)*	*Race (n)*	
Male (25)	15.12 ± 2.57	White	20
		Asian	2
		Hispanic	2
		African American	1
Female (34)	15.61 ± 4.5	White	30
		Asian	1
		Hispanic	0
		African American	3
Total (59)	Mean 15.41 ± 3.8	Mode white	

Table II. Reliability performed on 20 randomly selected subjects remeasured 2 weeks apart

Variable	*Cochran alpha*
Volume	
CBCT—total nasal cavity	0.833
Acoustic rhinometry—total nasal cavity	0.807
CBCT—anterior nasal cavity	0.859
Acoustic rhinometry—anterior nasal cavity	0.777
CBCT—pharyngeal cavity	0.984
Acoustic pharygometry—pharyngeal cavity	0.964
Minimal cross-sectional area	
CBCT—nasal valve	0.871
Acoustic rhinometry—nasal valve	0.917
CBCT—pharyngeal cavity	0.809
Acoustic pharygometry—pharyngeal cavity	0.981

Pharyngeal volume measured by CBCT had a mean of 12,062 ± 4471.36 mm^3, and acoustic pharyngometry showed a mean of 11,303.63 ± 6325.034 mm^3. There was a significant difference between the 2 methods (P = 0.01). The CBCT images tended to show higher values than the acoustic pharyngometry method. The 2 methods were highly correlated (r = 0.755) (Table III).

The mean minimal cross-sectional area of the pharyngeal space between CBCT (78.23 ± 44.96 mm^2) and acoustic pharyngometry (75.11 ± 49.04 mm^3) showed no statistically significant difference (P = 0.109). The 2 methods were also highly correlated (r = 0.944) (Table III).

DISCUSSION

In this study, we compared the CBCT and AR methods for the measurement of nasal and pharyngeal volumes and cross-sections.

Previous studies have validated the AR method for the measurement of anterior nasal volume and minimal cross-sectional areas in the anterior part of the nasal cavity.[18-20] Our study showed no significant differences for those measurements when using either CBCT or AR; this validates the CBCT method. Hilberg et al[21] compared magnetic resonance imaging (MRI) measurements of the anterior nasal volume with AR measurements and found MRI to be accurate, with differences less than 15%. We found CBCT and AR differences for those same measurements to be less than 7.8%. Terheyden et al[22] found that when comparing computed tomography scans in the nasal minimal cross-sectional area with AR, the differences between the 2 measurements were around 4.5%. We found CBCT and AR differences for the same measurements to be less than 3.2%. Corey et al[23] compared MRI measurements with AR and found the 2 methods to be highly correlated when measuring the minimal cross-sectional area of the nasal cavity (0.95). Our study shows an even higher correlation between CBCT and AR (r = 0.974).

Table III. Results for all variables measured, with means, standard deviations, and ranges

Method	*Mean volume (mm^3) and MCA (mm^2)*	*SD*	*Minimum and maximum*	*P value*	*Correlation*
CB Rh	10,462	2726	5440-17,820	0.035	0.274
AR Rh	9194	4424	3510-18,648		
CB ant nasal	2787	845.6	1300-4750	0.532	0.786
AR ant nasal	2544	1045	794-4903		
CB N MCA	125	44	44-213	0.066	0.974
AR N MCA	128	47	45-228		
CB Ph	12,062	4471	5985-29,650	0.01	0.755
AR Ph	11,304	6325	3999-35,050		
CB Ph MCA	78.2	44.9	34-245	0.109	0.944
AR Ph MCA	75.1	49.0	28-251		

Methods were compared by using t tests for parametric values and the Wilcoxon signed rank test for nonparametric values. The last column shows the Pearson correlations comparing both methods.
MCA, Minimal cross-sectional area; *CB*, cone-beam computed tomography; *Rh*, rhinometry (total nasal); *AR*, acoustic reflection; *ant nasal*, anterior nasal volume; *N*, nasal; *Ph*, pharyngometry.

A difference between the CBCT and the AR methods was found when measuring the total nasal volume, but those same articles point out that AR is not accurate in the posterior nasal cavity and the epipharynx.[21,22] It is reported that the accuracy of AR decreases as the distance from the nares increases, with the best accuracy in the first 5 cm, which was our anterior nasal area.[24] Based on how the capturing method works, it makes sense for CBCT measurements to be accurate in the posterior nasal region, but further studies may be needed to confirm this finding. The difference, even though statistically significant, was 1268 mm^3, which is less than half of the standard deviations (2726 for CBCT, and 4424 for AR).

Acoustic pharyngometry was found to provide accurate measurements for airway volumes and cross-sectional areas.[25] In our findings, the CBCT values of the pharyngeal volume were slightly higher than the acoustic measurements. Even though significant, this difference may be considered not clinically significant, since it is only 758 mm^3 for measurements showing means of over 11,000 ± 4000 mm^3. Because there was a high correlation between the 2 methods, a possible explanation may be that the slight overestimation resulted from the operator's (I.A.T.) adjustment of the automatic segmentation sensitivity when calculating the volume. In 1993, Marshall et al[25] found that when compared with MRI scans, AR showed differences of less than 10% for pharyngeal volume calculation and deemed MRI accurate. The CBCT volume measurement showed less than a 6.3% difference against the AR; this suggests equivalent accuracy. Alves et al[26] suggested that overestimation of CBCT was found, but it had no clinical significance and was highly reliable. This agrees with our findings.

Kamal[27] reported that the AR technique has been used to assess pharyngeal cross-sectional areas because of its accuracy. The pharyngeal minimal cross-sectional area measured by CBCT and AR was found to be same, with a mere 3 mm^2 difference, validating the CBCT method. D'Urzo et al[28] suggested that the minimal cross-sectional area measured by both AR and computed tomography scan are accurate with differences of less than 4.3%, showing a high correlation of 0.92. Our results showed that CBCT and AR had a difference of less than 4% for that same pharyngeal minimal cross-sectional area, with an even higher correlation of 0.94.

Accurate upper airway measurements can play a pivotal role in identifying patients with breathing or sleep disorders. The airway in an apneic person has a thinner lateral wall and a significantly smaller retropalatal area.[29] Two-dimensional images from lateral cephalograms are not an adequate tool for analyzing those important regions; thus, it is essential to use 3D imaging techniques. The most common 3D imaging techniques used are CBCT, computed tomography, and MRI. With recent low-dose CBCT options, this imaging technique may become more common. It may be in the patients' best interests when a CBCT volume is taken for the airway to be properly studied, that we now know that such measurements are accurate.

CONCLUSIONS

CBCT is an accurate method for measuring anterior nasal volume, nasal minimal cross-sectional area, pharyngeal volume, and pharyngeal minimal cross-sectional area. A difference was found for total nasal volume, but because AR is not considered accurate in this measurement, the CBCT accuracy can only be implied at this moment. Further research may be needed to confirm this finding.

REFERENCES

1. Marcus CL. Sleep-disordered breathing in children. Am J Respir Crit Care Med 2001;164:16-30.
2. Numminen J, Dastidar P, Heinonen T, Karhuketo T, Rautiainen M. Reliability of acoustic rhinometry. Respir Med 2003;97:421-7.
3. Cakmak O, Coskun M, Celik H, Buyuklu F, Ozluoglu LN. Value of acoustic rhinometry for measuring nasal valve area. Laryngoscope 2003;113:295-302.
4. Wang DY, Raza MT, Goh D, Lee B, Chan Y. Acoustic rhinometry in nasal allergen challenge study: which dimensional measures are meaningful. Clin Exp Allergy 2004;34:1093-8.
5. Cakmak O, Celik H, Cankurtaran M, Buyuklu F, Ozgirgin ON, Ozluoglu LN. Effects of paranasal sinus ostia and volume on acoustic rhinometry measurements: a model study. J Appl Physiol 2003;94:1527-35.
6. Hoffstein V, Fredberg JJ. The acoustic reflection technique for non-invasive assessment of the upper airway. Eur Respir J 1991; 4:602-11.
7. Govila S, Gundappa M. Cone beam computed tomography—an overview. J Conserv Dent 2007;10:53-8.
8. Ludlow JB, Walker C. Assessment of phantom dosimetry and image quality of i-CAT FLX cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2013;144:802-17.
9. Aboudara CA, Hatcher D, Nielsen IL, Miller A. A three-dimensional evaluation of the upper airway in adolescents. Orthod Craniofac Res 2003;6(Suppl 1):173-5.
10. Grauer D, Cevidanes LSH, Proffit WR. Working with DICOM craniofacial images. Am J Orthod Dentofacial Orthop 2009;136:460-70.
11. El H, Palomo JM. Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofacial Orthop 2010;137(Suppl 4):S50.e1-9.
12. Ghoneima A, Kula K. Accuracy and reliability of cone-beam computed tomography for airway volume analysis. Eur J Orthod 2013;35:256-61.
13. Tso HH, Lee JS, Huang JC, Maki K, Hatcher D, Miller AJ, et al. Evaluation of the human airway using cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:768-76.
14. Weissheimer A, Macedo de Menezes L, Sameshima G, Enciso R, Pham J, Grauer D. Imaging software accuracy for 3-dimensional analysis of the upper airway. Am J Orthod Dentofacial Orthop 2012;142:801-13.
15. Palomo JM, Rao PS, Hans MG. Influence of CBCT exposure conditions on radiation dose. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:773-82.
16. Wu R, Palomo JM, Landers M, et al. Anatomically based cranial landmarks for three-dimensional superimposition [thesis]. Cleveland, Ohio: Case Western Reserve University; 2012.
17. Tarhan M, Coskun M, Cakmak O, Celik H, Cankurtaran M. Acoustic rhinometry in humans: accuracy of nasal passage area estimates, and ability to quantify paranasal sinus volume and ostium size. J Appl Physiol (1985) 2005;99:616-23.
18. Gilain L, Coste A, Ricolfi F, Dahan E, Marliac D, Peynegre R, et al. Nasal cavity geometry measured by acoustic rhinometry and computed tomography. Arch Otolaryngol Head Neck Surg 1997; 123:401-5.
19. Hilberg O, Jackson AC, Swift DL, Pedersen OF. Acoustic rhinometry: evaluation of nasal cavity geometry by acoustic rhinometry. J Am Physiol 1989;66(295):303.
20. Corey JP, Nalbone VP. Anatomic correlates of acoustic rhinometry as measured by rigid nasal endoscopy. Otolaryngol Head Neck Surg 1999;121:572-6.

21. Hilberg O, Jensen FT, Pedersen OF. Nasal airway geometry: comparison between acoustic reflections and magnetic resonance scanning. J Appl Physiol (1985) 1993;75:2811-9.
22. Terheyden H, Maune S, Mertens J, Hilberg O. Acoustic rhinometry: validation by three-dimensionally reconstructed computer tomographic scans. J Appl Physiol (1985) 2000;89:1013-21.
23. Corey JP, Gungor A, Nelson R, Fredberg J, Lai V. A comparison of the nasal cross-sectional areas and volumes obtained with acoustic rhinometry and magnetic resonance imaging. Otolaryngol Head Neck Surg 1997;117:349-54.
24. Hilberg O, Pedersen OF. Acoustic rhinometry: recommendations for technical specifications and standard operating procedures. Rhinol Suppl 2000;16:3-17.
25. Marshall I, Maran NJ, Martin S, Jan MA, Rimmington JE, Best JJ, et al. Acoustic reflectometry for airway measurements in man: implementation and validation. Physiol Meas 1993; 14:157-69.
26. Alves M Jr, Baratieri C, Mattos CT, Brunetto D, Fontes RC, Santos JR, et al. Is the airway volume being correctly analyzed? Am J Orthod Dentofacial Orthop 2012;141:657-61.
27. Kamal I. Test-retest validity of acoustic pharyngometry. Otolaryngol Head Neck Surg 2004;130:223-8.
28. D'Urzo AD, Lawson VG, Vassal KP, Rebuck AS, Slutsky AS, Hoffstein V. Airway area by acoustic response measurements and computerized tomography. Am Rev Respir Dis 1987;135:392-5.
29. Schwab RJ, Gupta KB, Gefter WB, Metzger LJ, Hoffman EA, Pack AI. Upper airway and soft tissue anatomy in normal subjects and patients with sleep-disordered breathing. Significance of the lateral pharyngeal walls. Am J Respir Crit Care Med 1995;152(5 Pt 1):1673-89.