Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography

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Introduction: Changes in the normal pattern of nasal respiration can profoundly affect the development of the craniofacial skeleton in both humans and experimental animals. The orthodontist is often the first clinician to notice that a child is breathing primarily through the mouth, either at the initial examination or later during treatment. The lateral headfilm, part of the patient’s normal records, might show increased adenoid masses, suggesting that these could be part of the problem. Previous studies have, however, questioned the validity of the information from lateral headfilm. Methods: Our aim was to compare imaging information about nasopharyngeal airway size between a lateral cephalometric headfilm and a 3-dimensional cone-beam computed tomography scan in adolescent subjects. The nasopharyngeal airway area and volume were measured in 35 subjects (8 boys, 27 girls; average age, 14 years). Results: Volumetric measurement errors ranged from 0% to 5% compared with known physical airway phantoms used to calibrate. A moderately high (r = 0.75) correlation was found between airway area and volume; the larger the area, the larger the volume. However, there was considerable variability in the airway volumes of patients with relatively similar airways on the lateral headfilms. Nine of the 35 patients had over 25% of the potential nasopharyngeal airway volume occupied by inferior turbinate protuberances, leading to significant airway restriction in some patients. Conclusions: The cone-beam 3-dimensional scan is a simple and effective method to accurately analyze the airway. (Am J Orthod Dentofacial Orthop 2009;135:468-79)

R espiration through the upper airway is a vital functional process that can have a profound impact on normal craniofacial development.1-9 Changes in normal airway function during the active facial growth period can have had a profound influence on facial development by the time a patient comes for orthodontic treatment. This makes early diagnosis imperative to ensure normal facial development. At the initial clinical examination, the orthodontist usually notes enlarged tonsils and breathing patterns.10 Normally, only limited and subjective evaluations of possible airway problems are completed by the clinician, usually from a lateral cephalometric headfilm.11-13 Clinically, the orthodontist might notice an obstructive airway on the headfilm. If this obstruction is judged to be severe enough, the patient might be referred for an ear, nose, and throat (ENT) evaluation. Most of these referrals result in a recommendation by the ENT specialist for continued observation, rather than removal of the obstructing tissue.14 These recommendations are motivated by 2 issues. ENT specialists question the validity of using conventional headfilms for evaluation of possible airway obstruction.13,15 ENT specialists also believe that the lymphoid tissue will decrease after the adolescent years.16,17 Current pediatric guidelines for tonsillectomy and adenoidectomy require a specific number of recurrent throat infections per year, sleep apnea, or severe difficulty with respiration as medical indications for the removal of these lymphoid tissues.14 Unfortunately, even though airway restrictions can clear

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spontaneously over time, their effects during periods of rapid facial growth can have serious and long-lasting influence on dentition, speech, and craniofacial development. Orthodontists need to develop credible diagnostic tools that provide data acceptable to both themselves and the medical specialists.13

Clinical reports and studies in humans and experimental animals have indicated a link between mouth breathing and craniofacial development. Children with enlarged adenoids that obstruct nasal breathing also exhibit certain changes in their craniofacial development, including narrow maxillary arch, posterior crossbite, anterior open bite, retroclination of maxillary and mandibular incisors, and short mandibular arch.18 These patients also have increased anterior face height, lower tongue posture, and increased mandibular plane angles when compared with control subjects with normal-sized adenoids.18 In animal studies, morphologic effects of induced nasal occlusion increase anterior face height, increase the occlusal and mandibular plane angles, lower the mandibular posture, increase the posterior dental eruption, lead to forward tongue posture, induce anterior crossbites, and can modify interdental relationships.2,4 Removing the nasal obstruction can partially reverse the palatal, occlusal, and mandibular plane angles toward those of controls.4,19

Airway investigations have attempted to quantify airway restriction and function by functional or morphologic measurements.11,15,18,20,21 Most morphometric investigations of the upper airway in orthodontics have used lateral cephalometric headfilms, with specific skeletal and soft-tissue landmarks to characterize the airway.22 The nasopharyngeal region was selected because the lymphatic tissue outline is easy to identify. Some investigations have shown that airway measurements of the same patient can be different as a result of variations in head posture.23,24 The posture and the position of the head can also modify the airway space. The airway decreases in retropalatal width between radiographs taken in supine and upright positions of the same adult. We also believe that a 2-dimensional (2D) view of the airway space does not give an accurate indication of the complexity of this structure or its true size.

Our aim in this study was to compare imaging information about nasopharyngeal airway size between a lateral headfilm and a 3-dimensional (3D) cone-beam computed tomography (CBCT) scan in adolescent subjects.

**MATERIAL AND METHODS**

Our sample included all consecutive adolescents at 1 dental imaging center (Diagnostic Digital Imaging, Sacramento, Calif) for either orthodontic, temporomandibular joint (TMJ), or possible pathology evaluation over 18 months. The project was approved by the Committee on Human Research at the University of California, San Francisco (CHR approval #H893-22337-01). The subjects were between 6 and 17 years of age (Table I). All subjects had a CBCT scan and a lateral cephalometric headfilm taken within 1 week. Subjects were excluded if they wore a bite splint, or had a documented craniofacial anomaly or previous orthognathic surgery. We examined 123 possible subjects, and 35 met the inclusion criteria. The most common reason for exclusion of a subject was that the 2 sets of images were not taken within 1 week of each other. The most common reason for imaging referral was TMJ evaluation (Table II).

Lateral headfilm studies of the airway have included both linear and area measurements based on specific cephalometric landmarks and subjective classification of airway restriction based on an ordinal scale. Using the lateral headfilm leads to certain problems. The landmarks are assumed to be located in the midline of the craniofacial lateral view.11 Some landmarks are difficult to identify accurately because of superimposition of lateral structures on the headfilm. Also, a lateral headfilm often outlines the contours of bony objects that are not anatomically related. The most significant disadvantage of headfilm measurements for airway size is the inability to quantify the transverse dimension, as evident in the frontal plane.

One factor from this study limited the region of comparison between the 2 methods. The CBCT scans were taken in the supine position, whereas all lateral headfilms were taken in an upright position. Previous studies by other investigators indicated that head position can modify the airway space. Because of postural differences in airway dimensions,23,24 measurements...
were made above the level of the soft palate and posterior to the maxilla, because this airway region is best visualized on the lateral headfilm for direct comparison. This area is termed the nasopharyngeal airway (Fig 1).

The anatomy of the nasopharynx is complex, with the posterior border bound superiorly by the basilar portion of the occipital bone and inferiorly by the first 2 cervical vertebrae. Overlying these bones is the pharyngobasilar fascia and the superior pharyngeal constrictor muscle. These structures pass laterally and attach to the pterygoid hamulus and the medial pterygoid plate composing the lateral borders of this space. The levator and tensor veli palatini muscles as well as the entrance of the eustachian tube pass through the lateral borders. The superior border of the pharynx consists of the vomer and sphenoid bones. Adenoid tissue usually extends from the bony recess at the region of the sphenoid bone. Adenoid tissue usually extends from the bony recess at the region of the sphenoid bone. The lateral bony border of the nasopharynx is the medial plate of the pterygoid process of the sphenoid bone. The medial pterygoid muscle attaches along its lateral aspect. The anterior border of this potential space is the entrance to the nasal cavity, or the choanae, which represents the posterior aspect of the maxilla and the palatine bones. These skeletal structures seen on a lateral cephalometric headfilm are the pterygomaxillary fissure. The confluence of the outline of the pterygomaxillary fissure continues inferiorly to the posterior nasal spine.

The following anatomic structures as seen on the lateral headfilm were used as boundaries of the nasopharyngeal airway for all subjects: (1) the axial (horizontal) CBCT reconstruction plane passing through the posterior nasal spine (PNS), (2) the plane perpendicular to the axial reconstruction plane from PNS extending to the superior aspect of the pterygomaxillary fissure, and (3) the soft-tissue contour of the posterior pharyngeal wall extending from the superior aspect of the pterygomaxillary fissure inferiorly to the axial reconstruction plane. These same planes were transferred into the 3D scan to measure airway volume over the same anatomic boundaries.

Lateral 2D cephalometric headfilms were taken under standardized conditions with a magnification of 9.8%. The headfilms were then scanned at 150 to 300 dpi for analysis. All image measurements were made with a software program, 3-D Doctor (Able Software, Lexington, Mass).

Three-dimensional CBCT volume scans were obtained by using the same NewTom-9000 computed
Tomography machine (Quantitative Radiology, Verona, Italy). This 3D conical scanner uses a cone-shaped x-ray beam centered on an x-ray area detector (Table III). The tube-detector system performs a complete 360° rotation around the subject’s head, during which a series of exposures (1°) are made, providing digital images. The digital images provide the raw data for the reconstruction of the examined volume (9 cm high, 9 cm in diameter). The x-ray beam is pulsed and synchronized with both the acquisition system and the scanner. The x-ray area detector is a special image intensifier (6 in) coupled with a solid-state (CCD) TV camera. Digital radiographs are acquired in 512 × 512 pixel format, with the resulting spatial resolution of 0.3 mm in the x, y, and z directions. Digital image files were exported in DICOM (digital imaging and communications in medicine) format for analysis and measurement in 3-D Doctor. The resulting image slice thickness was 0.8 to 1 mm with an in-plane resolution of 0.3 × 0.3 mm.

All physical measurements were performed with 3-D Doctor by the primary author (C.A.). Two airway phantoms were used to test the accuracy of volumetric measures and validate the segmentation method (Fig 2). The phantoms consisted of an air-filled plastic tube of known volume surrounded by water as a soft-tissue equivalent. The simulated airway tube in 1 phantom was placed parallel to the long (vertical) axis of the CBCT scan. In the other phantom, the tube was placed at an angle (35°) to the long (vertical) axis of the scan. The total phantom circumference was approximately that of a human head. Phantom dimensions were measured to the nearest 0.1 mm with digital calipers. The phantoms were imaged in the same CBCT machine. The extent of the air-filled tube in each slice was delineated in the scan by setting gray-scale threshold limits. Phantom volumes were determined from the summation of the airway area by using 1-mm axial CBCT slices.

Lateral headfilms were calibrated for size. Each boundary line was manually placed, and all measurements were corrected for magnification. The CBCT axial reconstruction plane was transferred to the lateral headfilm by measurement of the angle between the axial reconstruction plane and the palatal plane (from anterior nasal spine to PNS) on a lateral scout view of the CBCT scan. The average angle between the axial reconstruction plane and the palatal plane was 2.5° ± 2.7°. The vertical height of the airway was determined as the distance from PNS to the height of the pterygomaxillary fissure along a line perpendicular to the axial (horizontal) reconstruction plane. The soft-tissue outline of the posterior pharyngeal wall was traced to complete the nasopharyngeal area. Airway volumes were determined from the summation of the airway area by using 0.8 to 1 mm axial CBCT slices over the vertical height of the nasopharyngeal airway determined from the lateral headfilm. The extent of the airway in each axial section was delineated by setting gray-scale threshold limits (Fig 3). Protuberances of the inferior turbinate into the nasopharyngeal potential space posterior to the plane...
corresponding to the posterior aspect of the maxilla were manually outlined and then sectioned.

The following measurements of the nasopharyngeal airway space were made: (1) subjective airway classification (1-5) from the lateral headfilm performed by an author (I.N.); (2) airway area of the region of interest from the lateral cephalometric headfilm; (3) airway volume over the same of region of interest from the CBCT scan (Fig 4), with all segmented 3D volumes in this study at the same scale and magnification for comparison; and (4) volume of the soft- and hard-tissue components of the inferior turbinates that protruded into the nasopharyngeal potential space.

The subjective airway classification of airway restriction, defined by Linder-Aronson, was used with a scale of 1 through 5, with 5 the most restricted.

Statistical analysis

The Lin concordance and Pearson product correlations were used to assess the reliability of duplicate measurements. Although the Pearson correlation estimates only the degree of linear association (ie, as one increases, the other tends to increase), the Lin concordance correlation estimates the degree that the duplicates are coincident (ie, exactly the same compared with a 45° reference line of equality). The Bland-Altman method of comparing the mean of the duplicates to the differences between the duplicates graphically, with 95% confidence intervals, was also used to assess reliability. Intraexaminer error measurements of airway area, airway volume, and turbinate volume were determined by using 10 repeated measurements. A linear regression of the area to the volume was determined to discern associations and correlation coefficients. Age and airway classification were added alone and together to the regression analysis to determine their effects on associations. Descriptive statistics for airway dimensions and turbinate protuberances were determined. All statistical analyses were done with Statview (version 5.0.1, SAS Institute, Cary, NC).

RESULTS

Evaluating the CBCT with the 2 phantoms showed that there was some imaging noise at either end of the scan. Applying a range of values for the airway space was not as effective as visually evaluating each transverse image and designating the airway volume.
Volume measurement through variable threshold segmentation showed half the error of constant threshold segmentation when compared with the known volume. Therefore, in each axial section, the gray-scale threshold value was adjusted so that the entire internal portion of the air-filled tube or airway was selected for both the phantoms and the subjects. This defined the extent of the airway in each axial section.

Six repeated measures of each airway phantom were assessed. The average error between the known volumes and the volumes determined through variable threshold segmentation of the CBCT scan for the 6 repeated measures are shown in Table IV. Two times the standard deviation of the repeated measures made up less than 0.5% of the absolute mean volumes calculated for the vertical and angled phantoms, showing that the segmentation procedure was repeatable.

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Evaluation of the duplicate measures produced Lin concordance and Pearson product correlations above 0.9, indicating excellent reliability for measurements of airway area, airway volume, and turbinate volume. The Bland-Altman method for airway volume indicated excellent reliability, with all measurements within the 95% confidence intervals and close to zero with no evident error trends. The Bland-Altman method for the 2 measures of airway area and turbinate volume showed only 1 measurement outside the 95% confidence intervals. Measurements were close to zero with no evident error trends, indicating very good to excellent reliability. The mean percentage error and mean absolute error were relatively small for airway area, 2.0% (6.7 ± 7.6 mm²); airway volume, 1.6% (48.7 ± 41.1 mm³); and turbinate volume, 5.7% (49.2 ± 50.1 mm³).

The orthodontically derived subjective airway scale was applied to all subjects who had the lateral headfilm and CBCT analysis. No significant sex differences were found for any measurement, so all data were combined. Most subjects had airway classifications that were low on the scale, indicating many airways without large adenoid restrictions. The average airway classification was 1.7 ± 0.8. No subjects were in the most severe airway classification of 5 in our sample, and only 1 had a classification of 4.

The area measurements with the lateral cephalometric approach and volume measurements with the CBCT indicated a distinct difference between the 2 approaches. There was more variability in volume than in area as a percentage of the means. There was also a much wider range in the volume determined as a percentage of the means. The overall area-to-volume linear regression (Fig 5) shows a positive association between the measurements with a moderately high correlation coefficient value (r = 0.75, P <0.001). Age and airway classification did not have a high correlation coefficient with volume. When age and airway classification were added to the regression model either together or alone, no significant increase in the regression coefficient was determined.

**Table IV.** Percentage of error in the repeated CBCT evaluation (n = 6) of the known volume of the air-filled space in the 2 types of phantoms

<table>
<thead>
<tr>
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<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Vertical phantom error (%)</td>
<td>5.0</td>
<td>0.23</td>
<td>4.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Angled phantom error (%)</td>
<td>0.2</td>
<td>0.22</td>
<td>-0.5</td>
<td>0.2</td>
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</table>

Fig 4. Three-dimensional volume of the nasopharyngeal airway of a subject: A, lateral view and B, at an angle.
Although the regression plot of the area to volume shows a moderately high correlation, when the individual data were viewed and sorted by airway classification severity (Table V), much airway volume variability could be seen over small changes in airway area. Over the midrange of the sample, there was much variability in airway volume measured from the CBCT scans for similar airway areas measured from the lateral headfilm (Fig 6). The area varied over a narrow range, between 325 and 375 mm$^2$, for many patients, yet the volume varied from 1000 to 5000 mm$^3$, with most in the range of 2000 to 4000 mm$^3$.

All subjects except 1 had some soft and hard tissue of the interior turbinate protruding into the nasopharyngeal airway space. The total nasopharyngeal potential space was determined as the measured airway volume plus the volume of the inferior turbinate protuberance, and the percentage of the inferior turbinate protuberance was calculated. We found considerable variability in the actual volume of the tissue that protruded into the space (Table VI). Nine of the 35 subjects had inferior turbinate protuberances into this space that occupied more than 25% of the total potential volume. These subjects included 9 of the 11 overall smallest volumes measured.

Although the lateral headfilm of the subject in Figure 7 shows no obvious nasopharyngeal airway restriction, the 3D scan shows severe restriction caused by the inferior turbinates. This subject had the largest turbinate

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**Table V.** Descriptive statistics of the nasopharyngeal area and volume in subjects classified by subjective scale of 1 through 5

<table>
<thead>
<tr>
<th>Classification</th>
<th>Measurement</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>r</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Area (mm$^2$)</td>
<td>35</td>
<td>358.3</td>
<td>± 74.2</td>
<td>185.7</td>
<td>528.0</td>
<td>0.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>All</td>
<td>Volume (mm$^3$)</td>
<td>35</td>
<td>3667.8</td>
<td>± 1414.3</td>
<td>877.2</td>
<td>7839.3</td>
<td>0.60</td>
<td>0.01</td>
</tr>
<tr>
<td>1</td>
<td>Area (mm$^2$)</td>
<td>16</td>
<td>398.0</td>
<td>± 54.8</td>
<td>312.2</td>
<td>528.0</td>
<td>0.60</td>
<td>0.01</td>
</tr>
<tr>
<td>1</td>
<td>Volume (mm$^3$)</td>
<td>16</td>
<td>4176.4</td>
<td>± 1419.4</td>
<td>1389.2</td>
<td>7839.3</td>
<td>0.79</td>
<td>0.001</td>
</tr>
<tr>
<td>2</td>
<td>Area (mm$^2$)</td>
<td>12</td>
<td>339.6</td>
<td>± 75.5</td>
<td>244.8</td>
<td>453.9</td>
<td>0.79</td>
<td>0.001</td>
</tr>
<tr>
<td>2</td>
<td>Volume (mm$^3$)</td>
<td>12</td>
<td>3614.7</td>
<td>± 1344.6</td>
<td>1753.1</td>
<td>6261.5</td>
<td>0.74</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>Area (mm$^2$)</td>
<td>6</td>
<td>318.3</td>
<td>± 49.4</td>
<td>246.2</td>
<td>361.5</td>
<td>0.74</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>Volume (mm$^3$)</td>
<td>6</td>
<td>2883.1</td>
<td>± 670.2</td>
<td>1837.7</td>
<td>3889.0</td>
<td>0.74</td>
<td>0.10</td>
</tr>
<tr>
<td>4</td>
<td>Area (mm$^2$)</td>
<td>1</td>
<td>185.7</td>
<td>NA</td>
<td>185.7</td>
<td>185.7</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4</td>
<td>Volume (mm$^3$)</td>
<td>1</td>
<td>877.2</td>
<td>NA</td>
<td>877.2</td>
<td>877.2</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>Area (mm$^2$)</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>5</td>
<td>Volume (mm$^3$)</td>
<td>0</td>
<td>NA</td>
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protuberance measured. The patient in Figure 8 had the most restricted airway, with a classification of 4. The 3D view shows that the airway space has a small anteroposterior dimension with significant inferior turbinate protuberances.

**DISCUSSION**

This is one of the first studies that has attempted to use CBCT to evaluate the airway. The study involved developing a method to complete the analysis of the same region that is depicted on the lateral view of the head in a full headfilm. Validation of the volumetric measurement method used in this study was essential because of the lower resolution and increased noise of this first-generation maxillofacial scanner. Although computed tomography scans are not usually indicated for soft-tissue imaging, the significant contrast gradient between air and any other soft- or hard-tissue structure allowed development of accurate segmentation procedures to quantify airway and turbinate volumes. The differential error seen in our methodology test between the angled and vertical phantoms can be attributed to over-estimation of the in-plane volume over the slice thickness along the angled border. The nasopharyngeal airway volume borders can be thought of as angled on the posterior and lateral surface, and vertical along the

**Fig 6.** The area of the nasopharynx (green diamonds) ranked in increasing order for subjects with the same subjective restriction scale (1-5) and compared with the volume (blue bars) of the same nasopharyngeal region.

**Table VI.** Descriptive statistics for the inferior turbinates

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<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Volume of inferior turbinate protuberance into potential nasopharyngeal airway space (mm³)</td>
<td>706.5</td>
<td>593.3</td>
<td>0</td>
<td>2896.4</td>
</tr>
<tr>
<td>Percentage of potential nasopharyngeal airway space taken up by inferior turbinate protuberance (%)</td>
<td>16.9</td>
<td>14.7</td>
<td>0</td>
<td>67.6</td>
</tr>
</tbody>
</table>
anterior and inferior surfaces. The borders of the airway are, however, less discrete than the phantom because of the variability in the soft-tissue lining of the airway. There were some imaging artifacts caused by the denser skeletal elements of the skull. The percentage error of our measurements compared with the true volume was between 0% and 5%, and probably closer to 5%. The increased error with the turbinate measurements was probably higher because they were manually outlined, instead of using the systematic variable gray-scale threshold method.

The influence of airway function on facial morphology takes place over a long time. Although there is still some controversy about airway function and its effect on facial morphology, almost every study found increased anterior face height in persons with impaired nasal breathing. This can have adverse consequences on dental function and esthetics.\(^3,5,9,22,32,33\) No functional information on breathing pattern, tongue posture, or mandibular posture was available on the subjects in our study. Since our data were retrospective, cross-sectional, and predominately comprising female patients referred for temporomandibular disorder problems, no attempt was made to correlate the subjects’ facial morphology with individual airway size. This study was primarily designed to evaluate the clinical value of cephalometric headfilms as a tool for nasopharyngeal airway assessment, compared with quantification of the 3D morphology of the nasopharyngeal airway with CBCT scans.

The airway in adolescents changes rapidly; therefore, the CBCT scan and the lateral headfilm needed to be taken at the same time for accurate comparison. Even though the cutoff point for the images was 1 week, most subjects had images taken at the same time. In 30 of the 35 subjects, the images were taken within 2 days.

The cephalometric headfilm provided a good general overall indicator for nasopharyngeal airway

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**Fig 7.** Subject with the largest turbinate protuberance: **A,** lateral headfilm view of region of interest; **B,** rendered airway volume at off-angle view; **C,** CBCT axial sections at levels of maximum constriction caused by the inferior turbinates.
Fig 8. Subject with a large adenoid contour and severe airway restriction: A, lateral headfilm with nasopharyngeal region of interest outlined in green and a red line at the height of contour of the adenoids; B, CBCT axial sections corresponding to those at and surrounding the red line in the lateral headfilm view with the airway outlined in green; C, rendered airway volume from lateral view; D, rendered airway volume at an off-angle view.
patency. The subject with the smallest airway area viewed on the lateral cephalometric headfilm had the smallest corresponding airway volume; thus, the headfilm can provide valuable information about severe restrictions in this portion of the airway. Unfortunately, this point cannot be generalized because only 1 subject had a severe airway restriction classification as shown on the lateral headfilm. However, the purpose of this study was to compare airway size measured in 2 ways, not to determine adenoid volume. For airway classifications 1 and 2—the least restricted—there was considerable volume variability and range between subjects with similar airway areas. The correlation coefficient was the weakest for the least restricted airways; thus, predicting volumes from airways that appear wide open on the headfilm might be difficult. These facts make accurate volumetric nasopharyngeal airway estimates from the lateral headfilm questionable because there could be a small volume that is not detected in a patient.

In our subjects, we observed the inferior turbinate protruding significantly into the nasopharyngeal potential space. This anatomic variation is not accounted for in cephalometric airway analysis and most clinical evaluations of orthodontic patients. Our subjective classification system did not take this into account. Our finding with the CBCT is contrary to what most anatomy textbooks depict: the inferior turbinates are shown ending at the posterior aspects of the maxilla. In our group of older adolescents, the turbinates appeared to contribute as much to airway obstructions as did the adenoids. The lack of significant adenoid tissue was expected because most subjects were beyond their peak development of hypertrophic adenoid tissue.

All CBCT scans were done with the patient in the supine position, whereas the headfilms were taken with the patient standing upright. This difference in position was solved by evaluating only the nasopharynx. In future studies, it would be preferable to record the patient sitting upright for the CBCT studies. It was not our purpose to compare the anatomic definition of the airway to the airway dynamics and the physiologic parameters of airflow. Future studies need to address this association. One question this study design did not address was the quantification of a threshold for airway restriction severe enough to affect nasal airflow function. Because functional tests were not performed in our subjects, we cannot answer this question, and further studies are needed. Considerable volumetric size and shape variability was seen in our adolescent sample. Resistance to airflow is not only related to airway size, but also to airway shape. Airway volume could be large, but, if the airflow passageway is tortuous, the effective airway resistance could be great enough to affect function. Future research with 3D imaging might provide better evaluation of the size and 3D form of all parts of the airway to better understand and discriminate patients with potential airway problems and their consequences. With more discriminating diagnosis of those with true airway restrictions, irrespective of the location, better research can be done to discern the associations between facial morphology and respiratory pattern.

CONCLUSIONS

1. In adolescents, there is a significant positive relationship between nasopharyngeal airway size on a headfilm and its true volumetric size from a CBCT scan.
2. Accurate determination of airway volume for a patient from a headfilm is difficult because of the great variability in the 3D airway.
3. The inferior turbinates can protrude significantly into the nasopharyngeal airway space and cause severe airway restrictions for some patients.

REFERENCES