Published in final edited form as:

Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007 January ; 103(1): 102–108.

Evaluation of Cross-section Airway Configuration of Obstructive Sleep Apnea

Takumi Ogawa, DDS, PhD[a], **Reyes Enciso, BS, PhD**[b], **Werner H. Shintaku, DDS, MS**[c], and **Glenn T. Clark, DDS, MS**[d]

a *Visiting Scholar, Orofacial Pain/Oral Medicine Center, Division of Diagnostic Sciences, School of Dentistry, University of Southern California Los Angeles, CA 90089-0641*

b *Clinical Assistant Professor, Division of Craniofacial Sciences and Therapeutics, School of Dentistry, University of Southern California Los Angeles, CA 90089-0641*

c *Clinical Assistant Professor, Oral Radiology Clinic, Division of Diagnostic Sciences, School of Dentistry, University of Southern California Los Angeles, CA 90089-0641*

d *Professor and Program Director, Orofacial Pain and Oral Medicine Center, Division of Diagnostic Sciences, School of Dentistry, University of Southern California Los Angeles, CA 90089-0641*

Abstract

Upper airway imaging techniques can be useful to identify the exact location and nature of the obstruction in obstructive sleep apnea (OSA) patients.

Methods—Ten OSA patients and ten non-OSA control subjects were imaged using cone-beam computed tomography (Newtom QR-DVT9000) to compare their upper airway structure.

Results—The OSA subjects presented higher BMI (OSA: 29.5 ± 9.05 kg/m^2; Non-OSA: 23.1 ± 3.05 kg/m^2 [p=0.034]), lower total volume (mm^3) of the airway (OSA: 4868.4 ± 1863.9; Non-OSA: 6051.7 ± 1756.4 [p =0.054]), statistically significantly smaller anterior-posterior dimension (mm) of the minimum cross-section segment (OSA: 4.6 ± 1.2; Non-OSA: 7.8 ± 3.31 [p =0.009]), and smaller minimum cross-section area (OSA: 45.8±17.5 mm^2; Non-OSA: 146.9±111.7 mm^2 [p=0.011]) positioned below the occlusal plane in 70% of the cases (OSA:7 out of 10; Non-OSA: 5 out of 10 [p=0.030]). The OSA group presented a concave or elliptic shaped airway and the non-OSA group presented a concave, round or square shaped airway. (156 words)

Keywords

Obstructive sleep apnea; airway configuration; cone-beam computed tomography; airway volume; 3D imaging

---

Reyes Enciso, PhD, School of Dentistry, University of Southern California, 925 West 34th Street, Room DEN312, Los Angeles, CA 90089-0641, USA, Phone (Office): (213)821-6730, Fax number: (213)740-5715, E-mail: renciso@usc.edu.

Source of funding: This research was partially funded by the University of Southern California and the NIDCR grant # 1 K25 DE016391-01A1.

1. Introduction

Obstructive sleep apnea (OSA) is a disorder characterized by repetitive upper airway collapse during sleep. Identifying the exact location of the obstruction is important to obtain an effective treatment. For many years two-dimensional (2D) cephalometric images have been used to look for anatomic differences between OSA patients and normal subjects (non-OSA), and researchers have reported significant craniofacial differences such as size and position of the mandible, posterior airway space enlargement and in the size of the tongue and soft palate.[1–5] While 2D imaging is valuable, the complex shape of the airway is not fully appreciated except with 3D images.

For example, soft-tissue collapse under conditions of negative airway pressure has been described [6] but the exact location and anatomic risk factors that determine the site of collapse are still debated. Answering this question will require 3D imaging techniques including static imaging (MRI, CT, cone-beam CT)[5,7–10] and dynamic imaging (cine-CT, EBCT, cine MRI).[11–14] The most common measurements used to compare the static morphology of the upper airway between OSA patients and healthy subjects (non-OSA) are the minimum surface area of the oropharyngeal region[15] and the anterior-posterior (AP) and lateral (L) dimensions of this area.[10–11, 16] Other authors correlated OSA with the body mass index (BMI = kg/m^2) and many of them found a positive relationship between these two factors.[1,16–18] In addition to BMI it is also possible that the shape of the airway is a predictor of collapse. Mayer et al[16] were one of the first to relate the airway shape with the BMI when they reported that it tends to be more spherical secondary to a decrease in the lateral dimension of the pharynx in patients with a higher BMI. They concluded that in patients with higher BMI, the shape appeared to be more dependent on the BMI than on the presence of OSA condition, but such a conclusion requires longitudinal data. Cosentini et al[15] examined 28 obese severe OSA patients with MRI imaging during wakefulness. They report that these subjects had a very small minimal cross-sectional area (35±16 mm^2) which was usually positioned retropalatally. They also measured airway shape and did not find a strong correlation between the shape and the severity of OSA using the Apnea Hypopnea Index.

Using cine MR images, Donnelly et al[13] and Abbott et al [14] both reported significant differences in the patterns of airway dynamic when they compared young OSA with subjects without OSA. In particular, Donnelly et al, noticed greater changes in diameter of the hypopharynx (posterior of tongue to posterior pharyngeal wall below the soft palate but above the epiglottis) in their OSA cases.

Another interesting sub-product of 3D imaging is the possibility to compute 3D volume of the oropharyngeal area as well as describe the upper airway form. With the advent of cone-beam CT technology, 3D images can be obtained exposing the patient to a lesser radiation than conventional CT. For example, using a measure of the effective absorbed dose (E), a traditional medical CT exposes the patient to a radiation dose of 124.9 to 528.4 μSv for the mandible and 17.6 to 656.9 μSv for the maxilla (depending on the volume imaged and operational settings of the CT). In contrast the cone-beam CT (NewTom 9000) used in this study needs 36 μSv[19] to 50.3 μSv[20] to provide a good amount of information. With an electron bean medical CT imaging system, as was used by Tom et al.[21] to image the vocal cords, they report 0.17 rem which is equivalent to a 1700 μSv exposure.

The study described in this report correlated the information collected from OSA patients and a non-OSA control group, reconstructed three-dimensional (3D) surfaces using the CBCT technology to assess the oropharyngeal volume and compare the anatomy of the narrowest cross-sectional area of the upper airway of these two groups. Our null hypothesis was that there would be no difference in their airways configuration.

2. Materials and Methods

This retrospective study included ten OSA patients (2 female and 8 male) and ten controls (4 female and 6 male). All patients had been seen at the Orofacial Pain/Oral Medicine Center at the Division of Diagnostic Sciences, School of Dentistry, University of Southern California. The control subjects were patients presenting for TMJ related purposes and had been imaged for non-OSA related purposes. Data such as age, gender and BMI had been recorded. This retrospective study was approved by the Institutional Review Board of the University of Southern California #04C022.

All subjects had polysomnography proven OSA and the mean Apnea/Hypopnea Index or AHI was 23.4 with a standard deviation of 9.59. The controls were diagnosed as non-OSA subjects based on clinical criteria, which means they did not present a medical history of snoring or sleep apnea symptoms. All subjects were radiographically evaluated in supine position with Frankfort plane perpendicular to the floor during their awake periods. This study evaluated the 3D images obtained by a dentomaxillofacial volumetric imaging system. This system was a cone-beam CT (Newtom QR-DVT 9000; QA sri, Via Silvestrini 20, 37135 Verona, Italy) and it acquires 360 images at 1-degree intervals, with a resolution of 512*512 pixels and 8 bits per pixel (256 grey scale). The reconstruction volume size is 150*150 mm and the imaging takes 75–77 seconds. The pixel size is 0.25mm*0.25mm and the slice thickness is 1 mm.

The reconstructed axial tomographic images were imported into Amira software (Mercury Computer Systems/3D Viz group, San Diego, CA). To define the volumetric region of interest (VOI), we first selected a midsagittal image of the airway and used the following planes as our upper and lower VOI borders: The upper border was defined by a plane drawn parallel to the Frankfort plane and going through the most distal point of the bony hard palate; the lower border was set by a plane drawn parallel to the Frankfort plane and going through the most anterior-inferior point of the second cervical vertebrae (see Fig. 1.a). To define the anterior-posterior and lateral borders of our VOI we used the following convention: as shown in Fig. 1.b, we selected in an axial view of the airway a large enough square area that will always contain the airway within its borders (the software allows the user to display up and down the axial images to check that the airway is always contained in the square area). Between the upper and lower borders and within the limiting axial square borders the airway VOI was determined. The actual limits of the segmented airway involved one of the authors (TO) manually tracing the soft tissue-air interface for each 1 mm axial slice using the Amira software segmentation tool. From the segmented airway images, Amira automatically computed the surface mesh shown in Fig. 2 and the volume of the oropharyngeal region in mm^3.

In order to compute the cross-sectional area a program written in Matlab counted the labeled/segmented pixels and multiplied by the pixel’s size in millimeters. The program automatically reported the axial slice with the minimum airway locus. Once we identified the slice with the smallest computed cross-section area, we measured its antero-posterior (AP) and lateral (L) dimensions (Fig. 3).

To report the location of the narrowest place in the airway some researchers use the retropalatal (RP) and retroglossal (RG) regions as intraoral landmarks.[9, 11] All our subjects presented the smallest caliber in the retropalatal region and presented soft palates with different sizes, so in this study we used the occlusal plane (CO) to define a third intraoral reference allowing to classify the airway in the upper occlusal (UO) and the lower occlusal (LO) regions.

Using these data we were able to verify:

- the total airway volume of the oropharyngeal region (Fig. 2),

- the smallest cross-section area,
- the anteroposterior (AP) and lateral (L) dimensions of the smallest cross-section area (Fig. 3),
- the relationship between AP and L (AP/L),
- the localization of the smallest cross-section area in the upper (UO) or lower (LO) oropharyngeal region,
- the configuration of the smallest cross-section area in the upper airway as rounded, elliptic, square or concave.

We then compared the information collected from both groups. Descriptive results are expressed as mean ± one standard deviation. Statistical significance of any differences between OSA and non-OSA groups were determined using a non-parametric Mann-Whitney U test with significance defined as $p \leq 0.05$, using SPSS software (SPSS Inc., Chicago, IL). The Spearman correlation coefficient was also calculated between BMI and the volume, the minimum cross-section area, AP and L with significance defined as $p \leq 0.05$.

3. Results

Table 1 presents the subjects' gender and mean age, BMI, and CT variables (airway volume, smallest cross-sectional area and location, AP, L and the ratio AP/L measures). The two groups did not match perfectly, however the median age was not statistically significantly different between the cases and the controls (P=0.496). The median BMI was statistically significantly different between the two groups (P=0.034) and it is a potential confounder. As would be expected the OSA patients did have a BMI close to the obesity criteria of 30 (29.5±9.05) and the controls presented with a lower BMI (23.1±3.05). The smallest cross-section area (P=0.011) and the AP dimension (P=0.009) showed statistically significant group differences. There were no statistically significant group differences in median total volume (P=0.054) and median lateral dimension (P=0.104).

The location of the smallest cross-section area as UO or LO showed significant differences (P=0.030) being found in the OSA patients more often (70% of the time) below the occlusal plane than above it. In contrast, the non-OSA subjects presented the smallest cross-sectional area equally in both locations (50% above and 50% below the occlusal plane). These data suggest that there is a difference in the length of the soft palate between cases and controls. Considering the AP and L relationship of the narrowest slice of the airway, the OSA patients presented a slightly more elliptical shape (AP/L=0.39±0.26) than the non-OSA subjects (AP/L=0.48±0.49). Fig. 2 represents the 3D models of a case and a control. The AP dimension is also noticeably smaller in the OSA case and this difference can be seen in 2.

Table 2 graphically represents the typical shape and dimensional differences seen in our OSA and non-OSA smallest cross-section area computed from the mean AP and L for all the subjects.

There was no correlation between BMI and the volume of the airway ($r = -0.39$, p=0.09), or BMI and AP (−0.32, p=0.17) using the Spearman correlation coefficient. However there was significant correlation between BMI and the minimum cross-section area (−0.48, p=0.034), and BMI and lateral dimension (0.50, p=0.03).

4. Discussion

The primary focus of this investigation was to examine for differences in airway shape and size between two subject groups (those with PSG confirmed OSA and those without clinical manifestations of this disease). The total volume of the oropharyngeal area (p=0.054) and the lateral dimension at the smallest cross-sectional area of the airway (p=0.104) did not show statistically significant differences between groups. Considering the relationship between AP and L, our OSA patients presented a lateral or transverse dominant axis, agreeing with Mayer et al[16].

The minimum cross-sectional area (min. area) and AP showed significant group differences. Statistically, the AP dimension and the minimum area of the OSA group were significantly smaller than the values found in the non-OSA group. Based on these data we can reject our null hypothesis that there was no difference in the airways of these two groups. Essentially this study demonstrates that the AP dimension of the airway of OSA patients and the cross-sectional area of the narrowest airway slice in the oropharynx were significantly smaller than non-OSA subjects. Our results agree with the results reported by cephalometric based studies, fluoroscopy imaging studies, as well as other CT and MR imaging studies.[7,8,11,22] In particular it correlates with data found by Cosentini et al[15] who examined 28 obese severe OSA patients with MRI imaging during wakefulness and reported that the subjects had a very small minimal cross-sectional area (35±16 mm^2) which was usually positioned retropalatally.

Several researchers have speculated that the collapse of the airway is caused by tissue hypertrophy, swelling/inflammation of oropharynx, uvula and tongue, by narrowing of the lateral wall of the airway during inspiration or by mandible retrusion causing tongue relapse.[7, 22] Using cine MR images, Donnelly et al[13] and Abbott et al [14] both reported significant differences in the patterns of airway dynamic when they compared young OSA with subjects without OSA. In particular, Donnelly et al, noticed greater changes in diameter of the hypopharynx (posterior of tongue to posterior pharyngeal wall below the soft palate but above the epiglottis) in their OSA cases. Other studies have suggested that low resistance of airway tissue to collapse is due to changes associated with obesity. [16, 18, 23, 24] Our study did not test these specific ideas, but now that the CBCT method has been shown to be useful to measure and distinguish the two groups and with large data sets taken overtime, the effect of weight gain on airway can be studied. The potential for longitudinal studies is incredible due to the relatively low radiation exposure needed to collect such data.[19, 20] As in the studies by Ferini-Strambi et al[17] and Vgontzas et al[18] our cases had a BMI near the obesity definition (29.5 ±9.05), while the control group had a lower BMI (23.1±3.05). This means it is not possible with our data to determine if the airway shape seen in the OSA patients was acquired in conjunction with the obesity or whether the airway change was present pre-obesity. This question would require an examination of airway of adolescents (e.g. snorers and non-snorers with equivalent BMI). It would also require a longitudinal based study where multiple 3D images of the airway will be gathered over time. It is reasonable to speculate that the airway of potential OSA patients is abnormal or different in size or shape before they develop apnea and it is the loss of pharyngeal muscle tone or fascial rigidity or the accumulation of fat that shifts a non-OSA subject to an OSA diagnosed condition. If so then there is a possibility that abnormal airway form and shape may be a risk factor for OSA that is evident in younger non-OSA subjects.

Finally, despite the fact that CBCT does not have the highest resolution and is not the most sophisticated airway imaging method, this technology has been continuously developed, has a lower radiation exposure dose compared to conventional CT imaging and EBCT systems and data are being routinely taken from a young cohort of patients receiving orthodontics treatment, with TMJ disfunction issues or seeking dental implants.[9] We speculate that the observed difference in shape and size of the airway seen in our two groups is predictive of lower resistance and/or susceptibility to collapse during sleep. In the future we will explore this application and test our concept.

5. Conclusion

The following conclusions were provided about the OSA patients: (1) we demonstrate the utility of diagnosis of anatomy with the 3D airway imaging with cone-beam computed tomography in awake patients in supine position; (2) we show the characteristics of OSA airway that may contribute to distinguishing OSA cases from non-OSA cases.

References

1. Ferguson KA, Ono T, Lowe AA, Ryan CF, Fleetham JA. The relationship between obesity and craniofacial structure in obstructive sleep apnea. Chest 1995;108:375–81. [PubMed: 7634870]
2. Lowe AA, Fleetham JA, Adachi S, Ryan CF. Cephalometric and computed tomographic predictor of obstructive sleep apnea severity. Am J Orthod Dentofacial Orthop 1995;107:589–95. [PubMed: 7771363]
3. Lyberg T, Krogstad O, Djupesland G. Cephalometric analysis in patients with obstructive sleep apnea syndrome: Skeletal morphology. J Laryngol Otol 1989;103:287–92. [PubMed: 2703770]
4. Lyberg T, Krogstad O, Djupesland G. Cephalometric analysis in patients with obstructive sleep apnea syndrome: 2 Soft tissue morphology. J Laryngol Otol 1989;103:293–7. [PubMed: 2703771]
5. Li HY, Chen NH, Wang CR, Shu YH, Wang PC. Use of 3-dimensional computed tomography scan to evaluate upper airway patency for patients undergoing sleep-disordered breathing surgery. Otolaryngol Head Neck Surg 2003;129:336–42. [PubMed: 14574286]
6. Masumi S, Nishigawa K, Williams AJ, Yan-Go FL, Clark GT. Effect of jaw position and Posture On forced Inspiration Airflow. Chest 1996;109:1484–9. [PubMed: 8769498]
7. Schwab JR, Pasirstein M, Pierson R. Identification of upper airway anatomic risk factors for obstructive sleep apnea with volumetric magnetic resonance imaging. Am J Respir Crit Care Med 2003;168:522–30. [PubMed: 12746251]
8. Faber CE, Grymer L. Available techniques for objective assessment of upper airway narrowing in snoring sleep apnea. Sleep Breath 2003;7:77–86. [PubMed: 12861487]
9. Chen NH, LI KK, Li SY, Wong CR, Chuang ML, Hwang CC, Wu YK. Airway Assessment by Volumetric Computed Tomography in Snorers and Subjects With Obstructive Sleep Apnea in a Far-East Asian Population(Chinese). Laryngoscope 2002;112:721–6. [PubMed: 12150529]
10. Rodenstein DO, Dooms G, Thomas Y, Liistro G, Stanescu DC, Culee C, Aubert-Tulkens G. Pharyngeal shape and dimensions in healthy subjects, snorers and patients with obstructive sleep apnea. Thorax 1990;45:722–7. [PubMed: 2247861]
11. Schwab JR, Gefter WB, Hoffman EA, Gupta KB, Pack AI. Dynamic upper airway imaging during awake respiration in normal subjects and patients with sleep disorder breathing. Am Rev Respir Dis 1993;148:1385–400. [PubMed: 8239180]
12. Choi JK, Kee WC, Lee JM, Ye MK. Variable site of oropharyngeal narrowing and regional variations of oropharyngeal collapsibility among snoring patients during wakefulness and sleep. Cranio 2001;19:252–9. [PubMed: 11725849]
13. Donnelly LF, Surdulescu V, Chini BA, Casper KA, Poe SA, Amin RS. Upper airway motion depicted at Cine MR Imaging performed during sleep: comparison between young patients with and those without Obstructive Sleep Apnea. Radiology 2003;227(1):239–245. [PubMed: 12616001]
14. Abbott MB, Donnelly LF, Dardzinski BJ, Poe SA, Chini BA, Amin RS. Obstructive Sleep Apnea: MR Imaging Volume Segmentation Analysis. Radiology 2004 Sept;232(3):889–895. [PubMed: 15333801]
15. Cosentini T, Le Donne R, Mancini D, Colavita N. Magnetic resonance imaging of the upper airway in obstructive sleep apnea. Radiol Med 2004;108:404–416.
16. Mayer P, Pépin J-l, Bettega G, Veale D, Ferretti G, Deschaux C, Lévy P. Relationship between body mass index, age and upper airway measurements in snorers and sleep apnoea patients. Eur Respir J 1996;9:1801–9. [PubMed: 8880094]
17. Ferini-Strambi L, Fantini ML, Castronovo C. Epidemiology of obstructive sleep apnea syndrome. Minerva Med 2004;95:187–202. [PubMed: 15289748]

18. Vgontzas AN, Bixler EO, Chrousos GP. Sleep apnea is a manifestation of the metabolic syndrome. Sleep Med Rev 2005;9:211–24. [PubMed: 15893251]

19. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: Newtom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac Radiol 2003;32:229–34. [PubMed: 13679353]

20. Mah J, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental CT. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96:508–13. [PubMed: 14561979]

21. Tom K, Titze I, Hoffman E, Story B. 3-D vocal tract imaging and formant structure: varying vocal register, pitch and loudness. J Acoust Soc Am 2001;109:742–7. [PubMed: 11248978]

22. Rama NA, Tekwani HS, Kushda AC. Site of obstruction in Obstructive Sleep Apnea. Chest 2002;122:1139–47. [PubMed: 12377834]

23. Lam B, Ip MSM, Tench E, Ryan CF. Craniofacial profile in Asian and white subjects with obstructive sleep apnea. Thorax 2005;60:504–10. [PubMed: 15923252]

24. Martin SE, Marthur R, Marshall I, Douglas NJ. The effect of age, sex, obesity and posture on upper airway size. Eur Respir J 1997;10:2087–90. [PubMed: 9311508]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

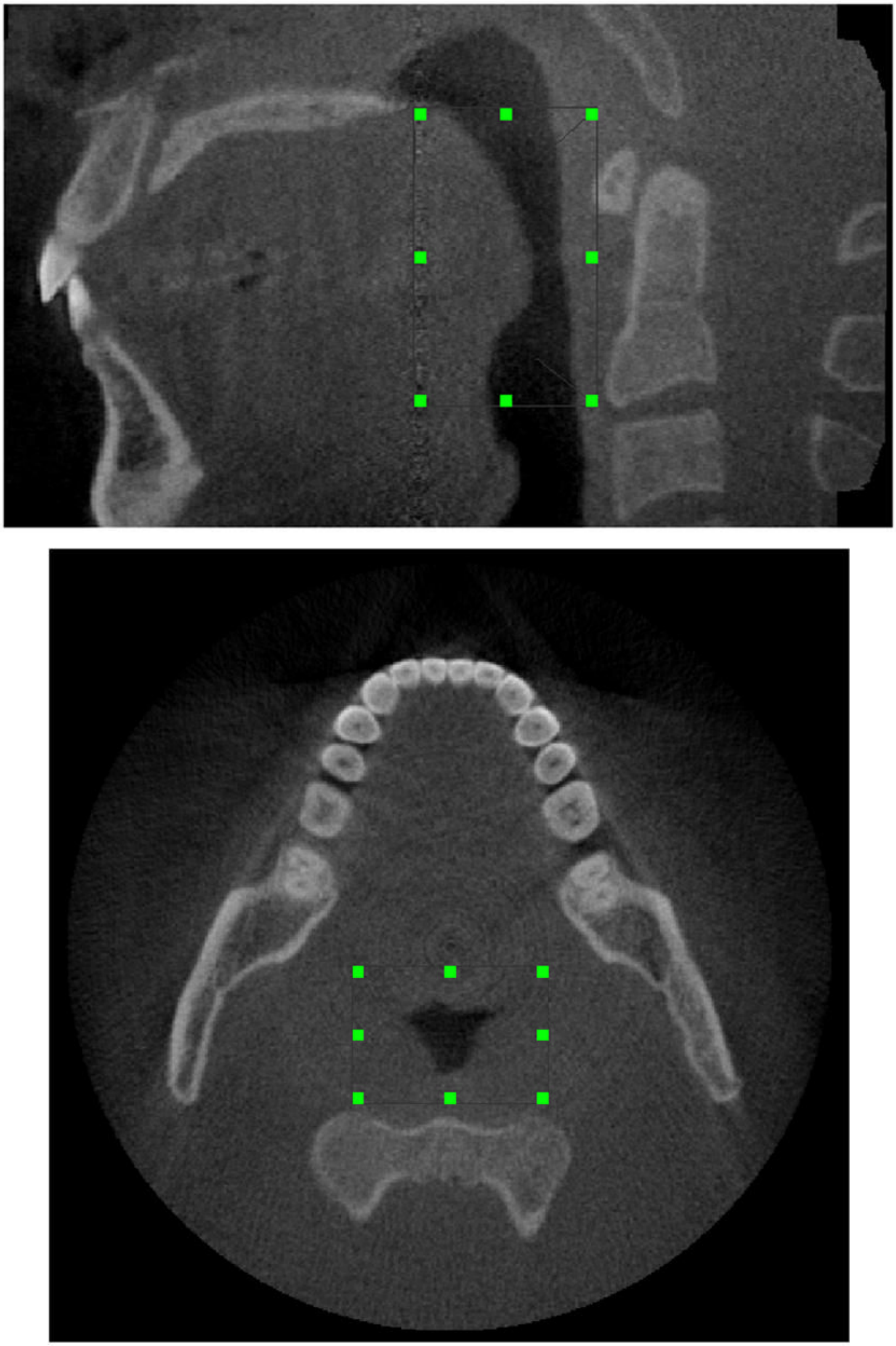
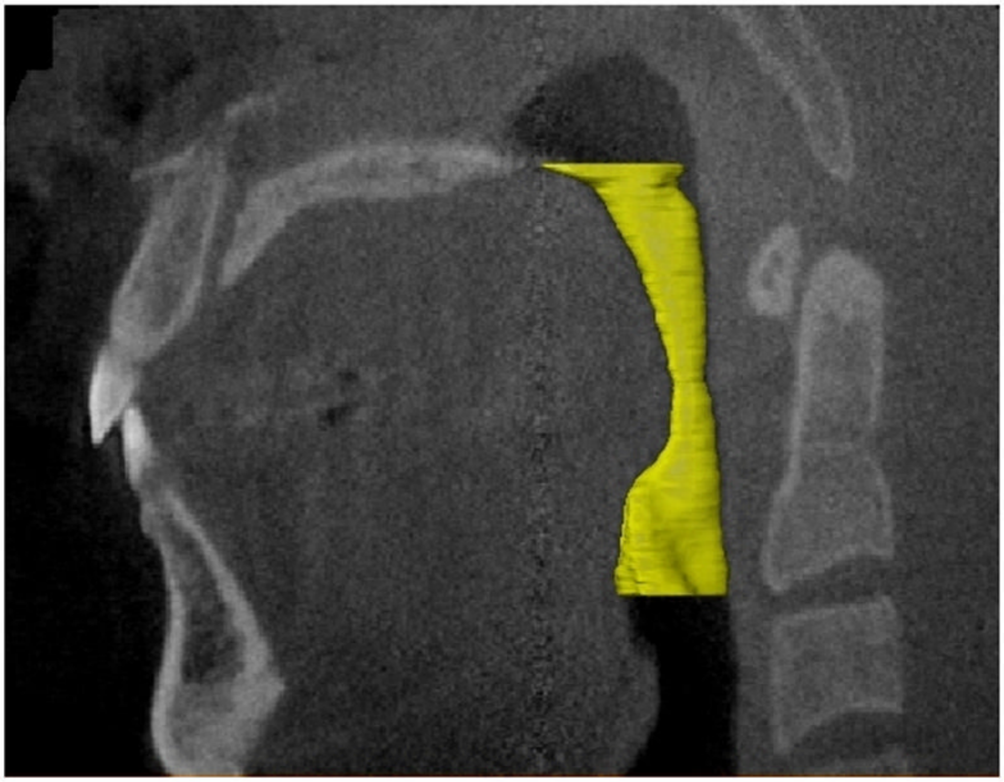
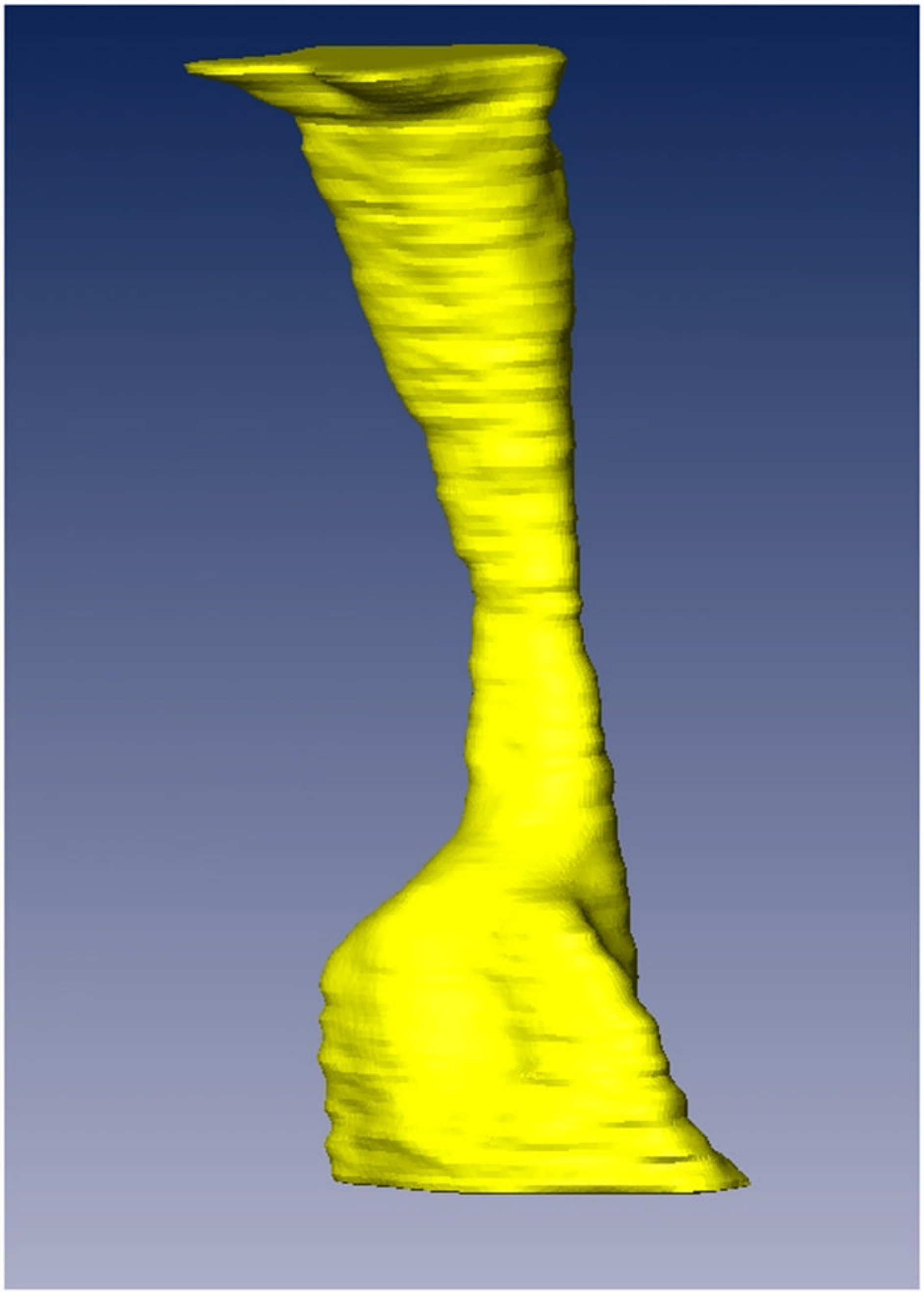
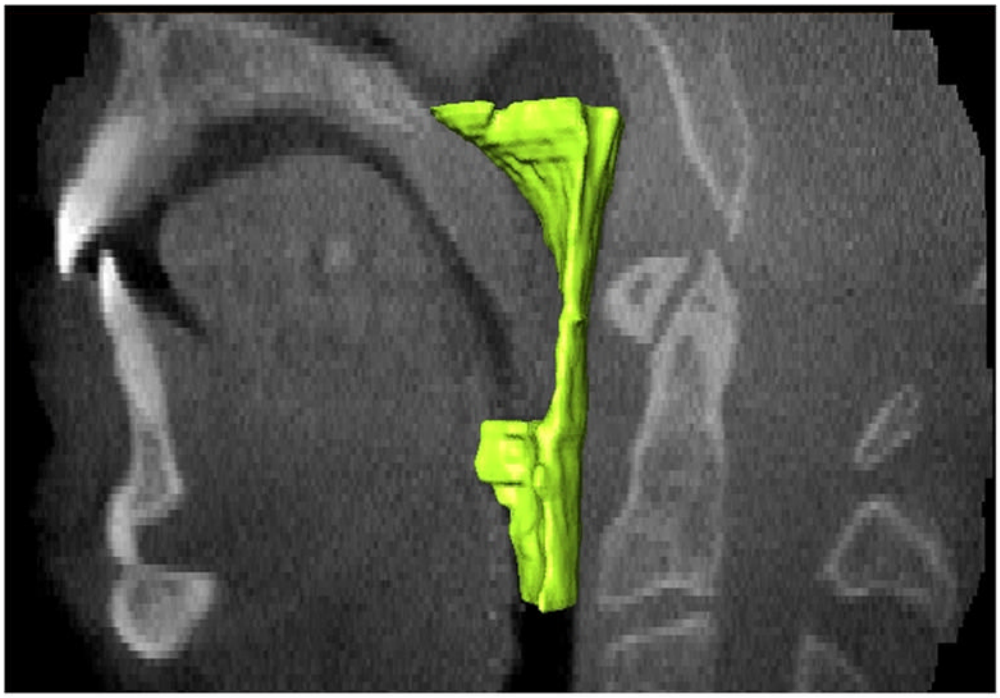


Fig. 1.

The region of interest selected by the operator as the oropharyngeal region defined in two planes: the mid-sagittal image of the airway (a) and the axial image (b).







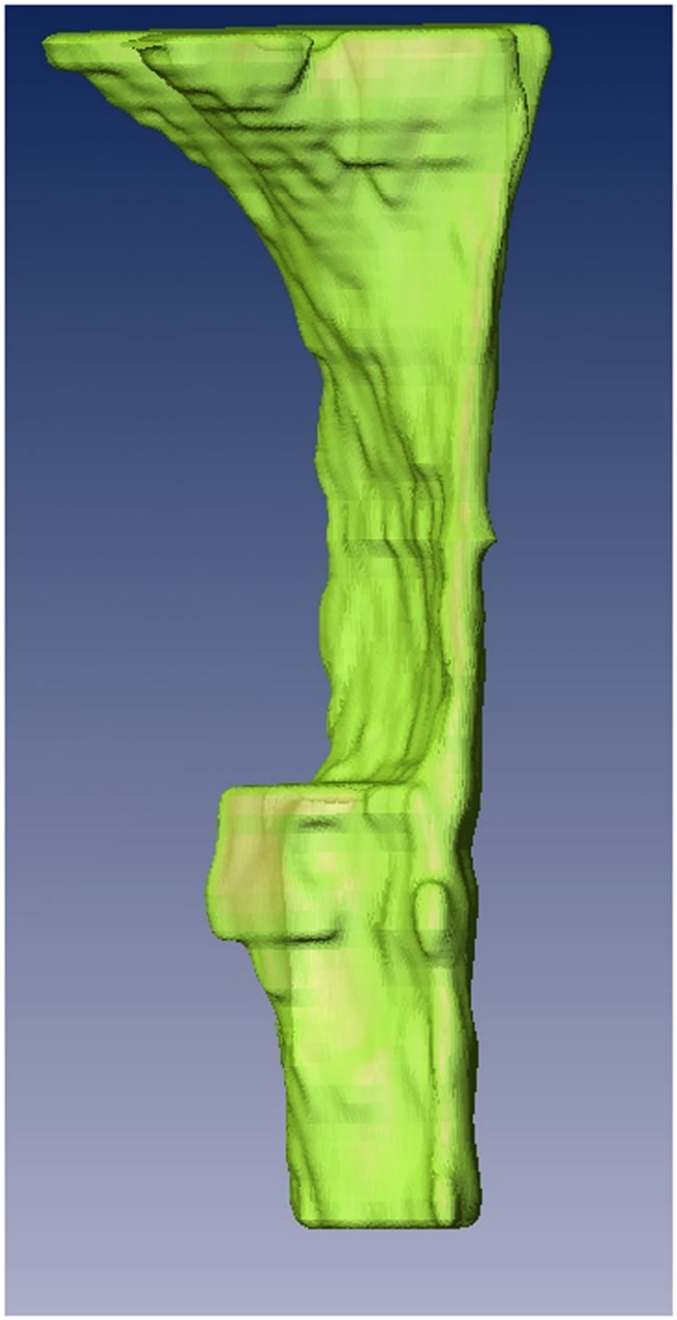


Fig. 2.
The volume computed of the oropharyngeal region for a control (a and b) and an OSA case (c and d).

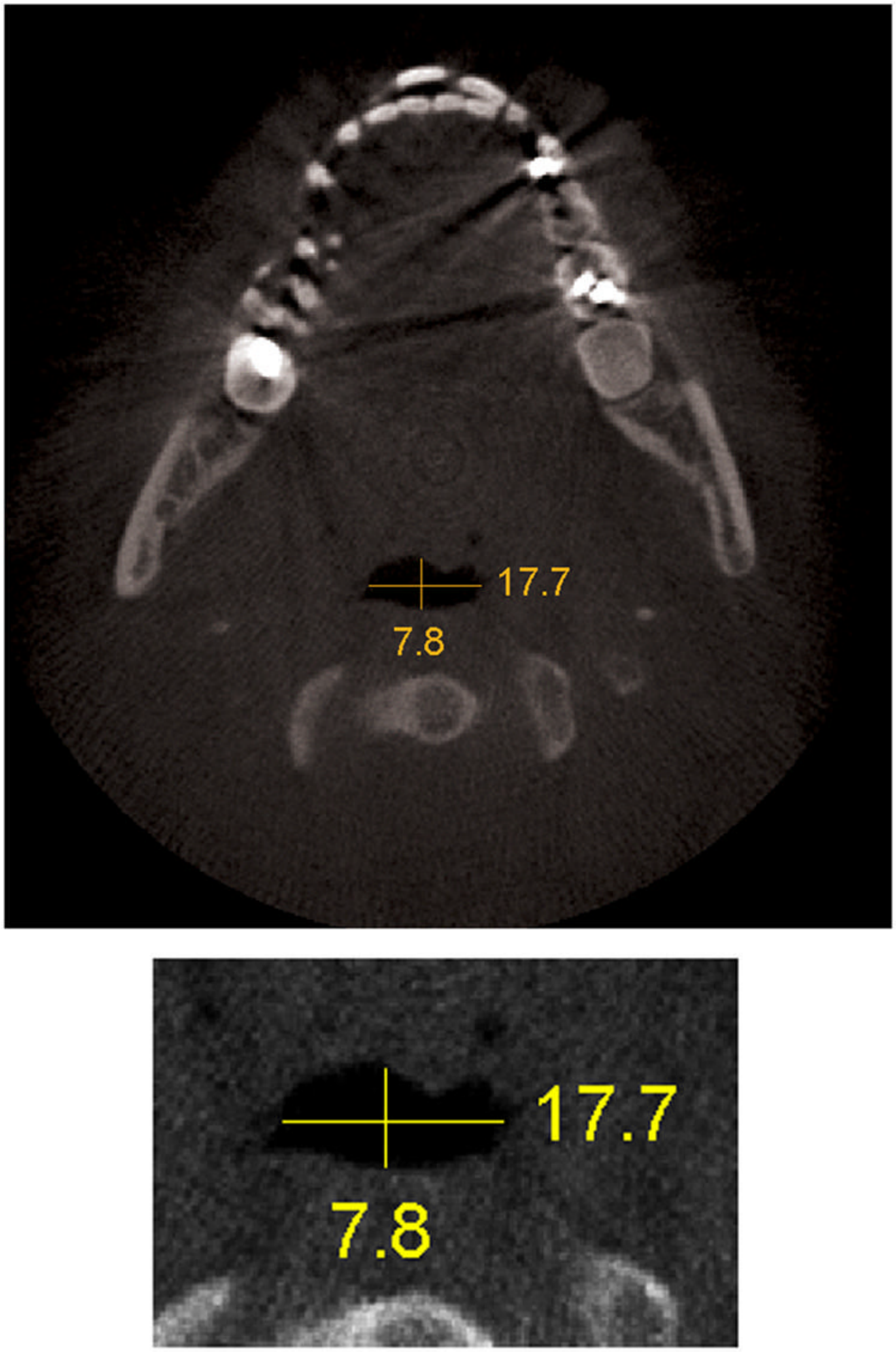


Fig. 3.
Axial NewTom image of the smallest cross-section area (a); the anteroposterior (7.8mm) and lateral dimensions (17.7mm) of the same area (b).

Table 1

Comparison between OSA and Non-OSA subjects (Mann-Whitney U test with statistical significance defined by a p-value ≤.05)

	OSA AVE. SD	Non-OSA AVE. SD	P value
Gender	F=2, M=8	F=4, M=6	---
Age	52.9±14.7	45.4±19.5	0.496
BMI (kg/m^2)	29.5±9.05	23.1±3.05	**0.034**
Volume (mm^3)	4868.4±1863.9	*6051.7±1756.4*	**0.054**
Smallest Area (mm^2)	45.8±17.5	146.9+111.7	**0.011**
AP (mm)	4.6±1.2	*7.8±3.31*	**0.009**
L (mm)	11.6±4.5	16.2±6.8	0.104
AP/L	0.39±0.26	0.48±0.49	0.940
Location	UO=3, LO=7	UO=5, LO=5	**0.030**

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Comparison of airway shape and size at the smallest cross-section: We used the mean values of AP and L for cases and controls to draw the oval shape, so the mean area reported in mm^2, may not correspond exactly to the area drawn here.

OSA	non-OSA
 AP = 4.6 ± 1.2 mm L = 11.6 ± 4.5 mm Area = 45.8 ± 17.5 mm^2 AP/L = 0.39	 AP = 7.8 ± 3.31 mm L = 16.2 ± 6.8 mm Area = 146.9 ± 111.7 mm^2 AP/L = 0.48