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Evaluation of upper airway volume and craniofacial volumetric structures in obstructive sleep apnoea adults: A descriptive CBCT study

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Keywords
Cone beam computed tomography
Upper airway volume
Craniofacial volumetric structures
Obstructive sleep apnea

Summary

Objective > The aim of this investigation was to assess, with a descriptive three-dimensional evaluation, the volume of upper airway (UAWV) and the volume of craniofacial structures in adult patients suffering from obstructive sleep apnoea (OSA) and compare them to the corresponding findings in adults with no sleep disorders.

Materials and methods > The sample consisted of 54 adult males, 27 suffering from OSA diagnosed by means of the Apnoea Hypopnea Index and 27 with no history of sleep disorders. All subjects had a cone beam computerized tomography scan performed with the same head position. UAWV was assessed with the Amira® software, and craniofacial volumes by means of a specially developed data-processing program, which allowed the construction of tetrahedrons using anatomical landmarks. Assessed volumes were naso-maxillary, cranium upper anterior, oral cavity, post-oral cavity, hyoid to mandible, and post-hyoid. SPSS (version 19.0) was used for the statistical analysis. The Levene's test for Equality of Variance, the t-test for Equality of Means and the Mann-Whitney test were used to evaluate the variables. The level of significance was set at $P \leq 0.05$.

Results > The mean value of UAWV was smaller in the OSA group. The post-hyoid volume, the calculated posterior volume, and the ratio of posterior to total volume showed differences between the groups.

Conclusions > Craniofacial structures did not show significant differences between the groups, but in the OSA group the posterior space released for upper airway was significantly bigger and UAWV was significantly smaller.

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Mots clés
Tomographie volumique par faisceau conique
Volume des voies respiratoires supérieures
Structures volumétriques crâniofaciales
Apnée obstructive du sommeil

Résumé

Évaluation du volume des voies respiratoires supérieures et des structures volumétriques crâniofaciales chez les adultes atteints d'apnée obstructive du sommeil : étude descriptive tridimensionnelle

Objectif > *Mesurer, à l'aide d'une évaluation descriptive tridimensionnelle, le volume des voies respiratoires supérieures (UAWV) et le volume des structures crâniofaciales de patients adultes souffrant d'apnée obstructive du sommeil (OSA) pour les comparer aux résultats correspondants chez les adultes sans troubles du sommeil.*

Matériels et méthodes > *L'échantillon se composait de 54 hommes adultes, parmi lesquels 27 souffraient d'OSA diagnostiquée à l'aide de l'indice d'apnée-hypopnées et 27 n'avaient pas d'antécédent de troubles du sommeil. Tous les sujets ont subi une tomographie volumique par faisceau conique avec la même position de tête. L'UAWV a été mesuré avec le logiciel Amira® et les volumes crâniofaciaux ont été évalués au moyen d'un programme informatique spécialement développé qui a permis de construire des tétraèdres à partir de repères anatomiques. Le volume nasomaxillaire, le volume crânien antérosupérieur, le volume de la cavité buccale, le volume de la cavité pharyngale, le volume allant de l'os hyoïde à la mandibule et le volume postérieur à l'os hyoïde ont été mesurés. Le logiciel SPSS (version 19.0) a été utilisé pour l'analyse statistique. Le test de Levene pour l'égalité de variance, le test* t *pour l'égalité des moyens et le test de Mann-Whitney ont été utilisés pour évaluer les variables. Le seuil de signification a été fixé à* $p \leq 0{,}05$.

Résultats > *La valeur moyenne de l'UAWV était plus faible dans le groupe OSA. Le volume postérieur à l'os hyoïde, le volume postérieur calculé et le rapport du volume postérieur au volume total ont montré des différences entre les groupes.*

Conclusions > *Les structures crâniofaciales ne présentaient pas de différences significatives entre les groupes, mais dans le groupe OSA, l'espace postérieur libéré pour les voies respiratoires supérieures était significativement plus grand et l'UAWV était significativement plus petit.*

Introduction

According to the Adult Obstructive Sleep Apnoea Task Force of the American Academy of Sleep Medicine, obstructive sleep apnoea (OSA) is clinically defined by the occurrence of daytime sleepiness, loud snoring, witnessed breathing interruption or awakening due to gasping or chocking in the presence of at least 5 obstructive respiratory events per hour of sleep [1]. The available general population-based studies indicate that the prevalence of OSA associated with accompanying daytime sleepiness is approximately 3 to 7% for adult men and 2 to 5% for adult women [2].

Several studies attempted to establish a relation between oropharyngeal dimensions and craniofacial structures in subjects with sleep disorders and in particular with OSA, through cephalometric radiographic measurements [3–6], or by using magnetic resonance imaging [7,8]. The use of three-dimensional (3D) craniofacial reconstruction imaging approaches led to the widespread use of 3D imaging techniques for calculating volumes of facial bones and air cavities [9,10] and for the assessment of diagnosis and treatment of OSA [11,12]. Relevant 3D studies are mainly focusing on airway volume [13,14], its relationship to skeletal and facial morphology [15–18] and on changes that occur with orthognathic surgery [19–21]. A 3D study assessing orbits, maxillary sinuses and oral cavity volumes in non-growing subjects with different vertical skeletal patterns suggested that a compensatory phenomenon might exist between the vertical, sagittal and frontal dimensions equilibrating an excess or a deficit of the vertical dimension thus maintaining constant the volume of facial cavities [22].

The aim of this investigation was to assess by means of descriptive 3D imaging, the volume of upper airway (UAWV) and the volume of craniofacial structures in adult patients suffering from OSA and compare them with the corresponding findings of adults with no sleep disorders. The null hypothesis was that

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there are no differences in the UAWV and the volume of craniofacial structures, between patients with OSA and subjects without respiratory disorders.

Materials and methods

Study samples

Adult subjects of the OSA group were recruited from the Otolaryngology and Pulmonary Departments of hospitals located in Beirut, Lebanon. The diagnosis of OSA was performed by means of the apnoea-hypopnea index (AHI = number of apnoeas plus hypopneas per hour of sleep) after nocturnal polysomnography. Twenty-seven consecutive males participated in the study (mean age: 49y 4 m) with mild, moderate or severe AHI. Inclusion criteria were no contraindications for CBCT examination of their head, presence of at least 20 healthy or replaced teeth supporting the occlusion and no history of upper airway surgery. CBCT records of 27 adult males (mean age: 44y 4 m) were selected from a dental imaging centre located in Ashrafieh, Lebanon among patients who had undergone this radiographic examination of their head for dental or orthodontic purposes. In addition to the age this selection attempted to have both group characteristics regarding body mass index (BMI) as close as possible (OSA group: mean value 32.83; non-OSA group: mean value 28.02) and with the same number of teeth requirements. Twenty-three subjects of the OSA group had positive scoring in the Berlin questionnaire, while 13 showed daytime sleepiness on the Epworth sleepiness scale. In the control group, all subjects had negative scores in both questionnaires. The medical records showed no history of allergies or respiratory infections in either groups. The CBCT-scans of the second group were taken in the same way as with the OSA group.

All patients provided their informed consent, and control subjects were contacted to explain and inform them about the study and get their approval for using their records. The investigation received approval by the Ethical Committee of the Faculty of Dentistry, Aristotle University of Thessaloniki, Greece.

Data collection

CBCT-scan approach

All subjects included in the study had their head CBCT-scans performed with a Kodak 9500 Cone Beam 3D System (Carestream Health, Inc., Rochester, New York, USA) in their natural head position and the occlusion in maximal intercuspal position with the same cuts' thickness of 300 μ. The numerical data were recorded in DICOM format (Digital Imaging for COmmunication in Medicine).

Procedure of segmentation

The Amira® software version 5.0 (Visage Imaging Inc., Carlsbad, California, USA) was used for the assessment of the UAWV. UAWV

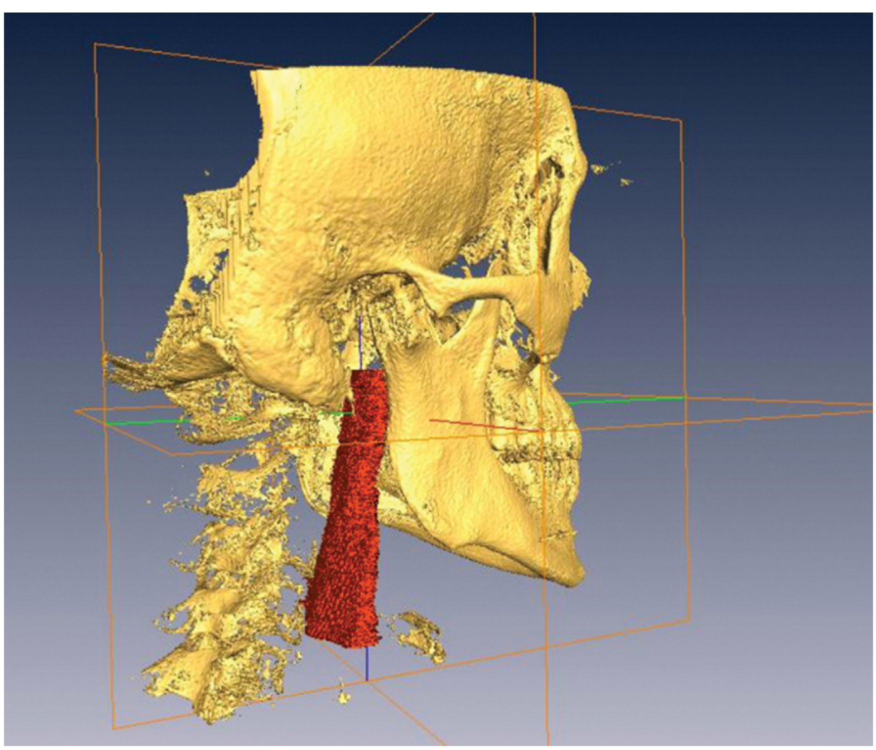

FIGURE 1

Computed volume of upper airway (UAWV)

was defined by the projection of the hard palate on the pharyngeal posterior wall for the upper limit; the projection of the epiglottis base on the pharyngeal posterior wall for the lower limit, the soft palate; the base of the tongue joined by the line dropped from the edge of the soft palate to the tongue base for the anterior and the superior limits; the middle and inferior pharyngeal constrictor muscles for the posterior and lateral limits. UAWV was manually traced on each slice using the Amira® software segmentation tool, from the slice of the upper limit till the slice defining the lower limit, and from the segmented airway images. The Amira® software automatically computed and calculated the UAWV in cm^3 (*figure 1*).

Identification of landmarks and craniofacial volume calculation

The isosurface 3D reconstruction extracted from the CBCT-scan slices using Amira® software allowed visualization of anatomical reference landmarks on the cranium base, cervical vertebrae, maxilla, mandible and hyoid bone. The software defines the coordinates of each anatomical point (*figure 2*). Each landmark was labelled and then verified on the xy, yz and xz orientation axes. All landmarks were defined by the first author, and in the same sequential order, for the subjects in both groups, and a data-processing program, developed for the study allowed the construction of tetrahedrons for calculating, in cm^3 the volumes of the craniofacial structures (*figure 3*). Thus, naso-maxillary volume (A), cranium upper anterior volume (B), oral cavity volume (C), post-oral cavity volume (D), hyoid to mandible volume (E), and post-hyoid volume (F) were evaluated using the landmarks listed in *table I* [23–25].

- Naso-maxillary volume (A): defined by Nasion (N), anterior nasal spine (ANS), right and left maxillary tuberosity points (MtR, MtL) and right and left articular points (ArtR, ArtL) using three tetrahedrons.

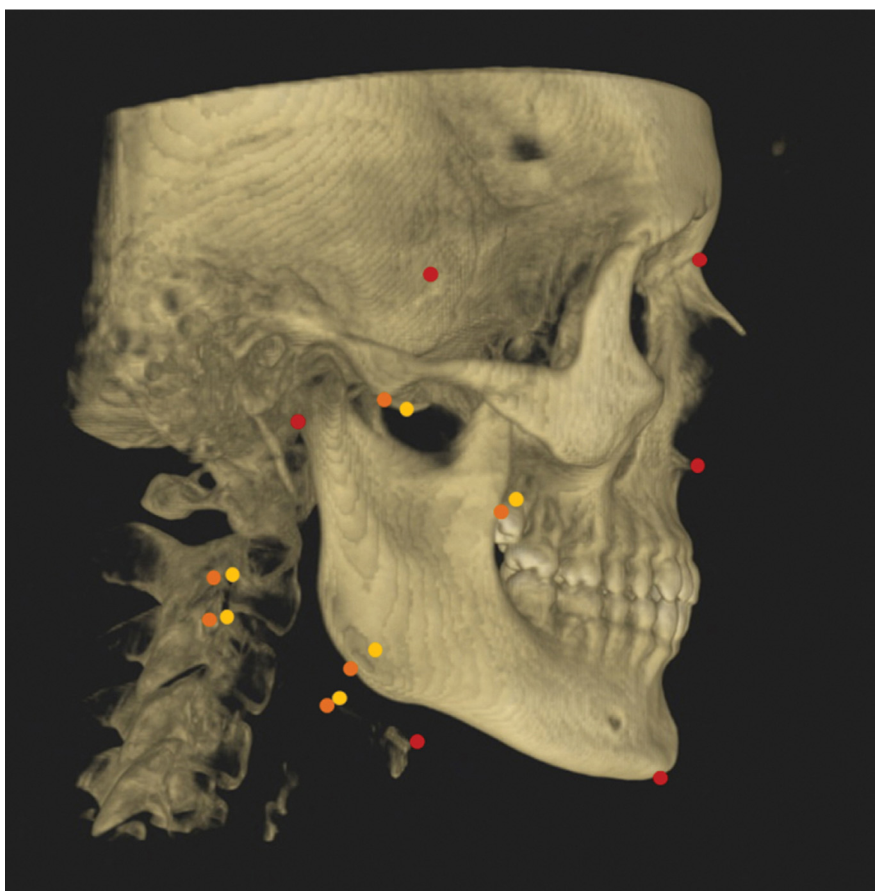

FIGURE 2

Craniofacial landmarks used for calculation of naso-maxillary volume, cranium upper anterior volume, oral cavity volume, post-oral cavity volume, hyoid to mandible volume, and post-hyoid volume. Red dots are for midline landmarks, orange dots for right landmarks and yellow dots for left landmarks

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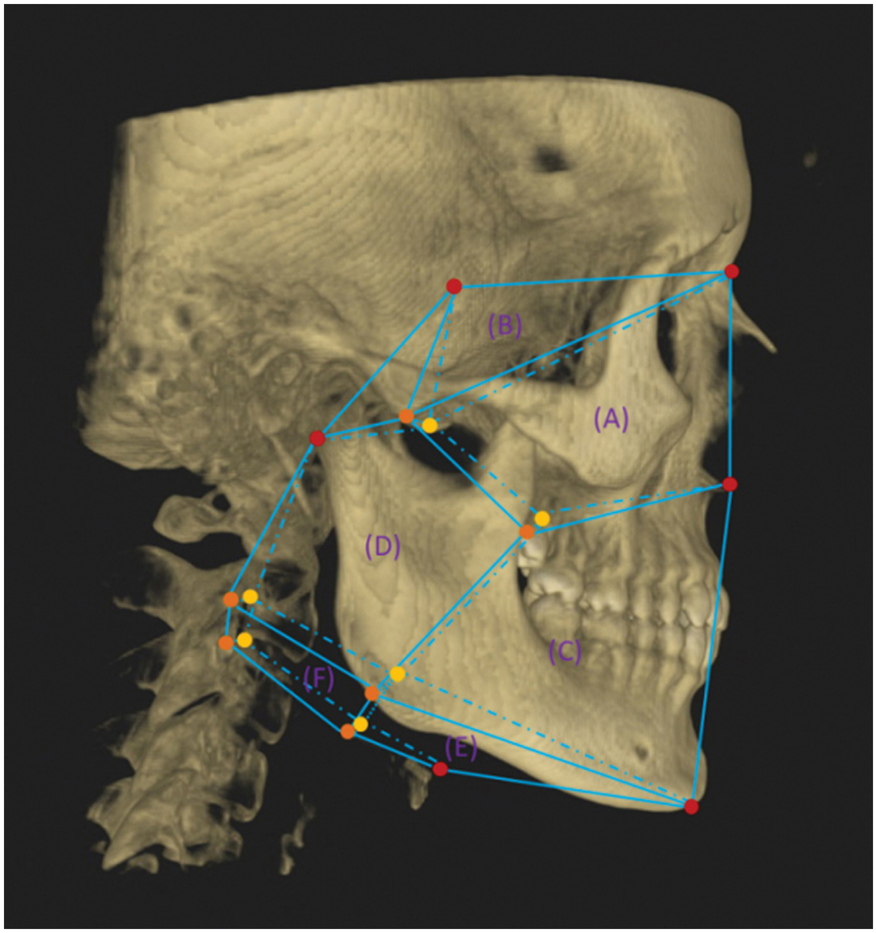

FIGURE 3

Volumes calculated in the study: A: naso-maxillary volume; B: cranium upper anterior volume; C: oral cavity volume; D: post-oral cavity volume; E: hyoid to mandible volume; F: post-hyoid volume

- Cranium upper anterior volume (B): defined by Nasion (N), right and left articular points (ArtR, ArtL), Basion (Ba) and pituitary point (Sc) using two tetrahedrons.
- Oral cavity volume (C): defined by anterior nasal spine (ANS), right and left maxillary tuberosity points (MtR, MtL), Gonion right and left (GoR, GoL) and Menton (Me) using three tetrahedrons.
- Post-oral cavity volume (D): defined by right and left maxillary tuberosity points (MtR, MtL), right and left articular points (ArtR, ArtL), Basion (Ba), right and left transverse process of second cervical vertebrae (C2R, C2L) and Gonion right and left (GoR, GoL) using eight tetrahedrons.
- Hyoid to mandible volume (E): defined by Menton (Me), Gonion right and left (GoR, GoL), right and left greater cornea points of hyoid bone (HCR, HCL) and hyoid point (H) using three tetrahedrons.
- Post-hyoid volume (F): defined by right and left Gonion (GoR, GoL), right and left transverse process of second cervical vertebrae (C2R,C2L), right and left transverse process of third cervical vertebrae (C3R, C3L) and right and left Gonion (GoR, GoL) using six tetrahedrons.

The following variables were also calculated:

- The anterior volume defined as the sum of the naso-maxillary volume, the oral cavity volume and the hyoid to mandible volume (AV = A + C + E).
- The posterior volume defined as the sum of the post-oral cavity volume and the post-hyoid to mandible volume (PV = D + F).
- The total volume defined as the sum of anterior and posterior volumes (TV = AV + PV).
- The ratios of cranium upper anterior volume R1, anterior volume R2 and posterior volume R3 over total volume.

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TABLE I
Craniofacial landmarks used in the study for calculation of studied volumes.

Landmarks	Sequence	Description of landmarks
Basion (BA)	5	Most anterior point of the foramen magnum
Nasion (N)	1	Midpoint of the fronto-nasal suture
Pituitary point (Sc)	6	Most posterior point on the contour of the anterior clinoid of pituitary fossa
Articular tubercles, Right ArtR	9	Most inferior midpoint of right articular tubercle
Articular tubercles, Left ArtL	10	Most inferior midpoint of left articular tubercle
Anterior nasal spine ANS	2	Most anterior point of anterior nasal spine of the maxilla
Maxillary tuberosity points, Right MtR	7	Most posterior point of right maxillary tuberosity
Maxillary tuberosity points, Left MtL	8	Most posterior point of left maxillary tuberosity
Gonion, Right GoR	3	Junction between mandible corpus and right ramus
Gonion, Left GoL	4	Junction between mandible corpus and left ramus
Menton Me	11	Most inferior midpoint of the chin, on the outline of the mandibular symphysis
Hyoid H	12	Most superior midpoint on hyoid bone corpus
Greater cornu of hyoid bone, Right HCR	13	Most superior point of greater right cornu
Greater cornu of hyoid bone, Left HCL	14	Most superior point of greater left cornu
Transverse process of second cervical vertebra, Right C2R	15	Most external point of right process
Transverse process of second cervical vertebra, Left C2L	16	Most external point of left process
Transverse process of third cervical vertebra, Right C3R	17	Most external point of right process
Transverse process of third cervical vertebra, Left C3L	18	Most external point of left process

TABLE II
Intra-Class Correlation Coefficient (ICC).

		OSA Group		Control Group	
		ICC	Sig	ICC	Sig
UAWV	Single measures	.990	.000	.996	.000
	Average measures	.995	.000	.998	.000
A	Single measures	.827	.002	.714	.002
	Average measures	.905	.002	.833	.002
B	Single measures	.803	.000	.919	.000
	Average measures	.891	.000	.958	.000
C	Single measures	.862	.000	.939	.000
	Average measures	.926	.000	.969	.000
D	Single measures	.704	.002	.926	.000
	Average measures	.816	.002	.962	.000
E	Single measures	.974	.000	.993	.000
	Average measures	.987	.000	.997	.000
F	Single measures	.930	.000	.974	.000
	Average measures	.964	.000	.987	.000

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Statistical analysis

The normal distribution of variables was evaluated with the Shapiro-Wilk test. The Levene's test for Equality of Variances and the t-test for Equality of Means were used for variables normally distributed, while the non-parametric Mann-Whitney test was used for the other variables, in order to check if the null hypothesis will be rejected or not. The statistical analysis was performed using the statistical software SPSS 19.0 for Windows (SPSS, Chicago, Illinois, USA). The level of significance for all tests was set at $P \leq 0.05$.

Error of the method

The procedure of point localisation and the segmentation for the UAWV, were performed a second time after a four-week interval by the first author on 14 randomly chosen CBCT-scans from each group, in order to assess the intra-operator reliability, by using the Intra-Class Correlation Coefficient (ICC). The ICC values indicated a very good reliability for the measurements assessed (*table II*).

Results

The null hypothesis was rejected for upper airway volume and post-hyoid volume between patients with OSA and subjects without respiratory disorders. UAWV and post-hyoid volume showed significant differences with a mean value smaller for the first and larger for the second in the OSA group, respectively.

For the calculated volumes, the posterior volume showed a significant difference with a larger value in the OSA group and a significant difference of its ratio over the total volume in this group (*table III*).

Discussion

This study evaluated 3D characteristics of UAWV and craniofacial volumetric structures in OSA adults and compared them with corresponding findings in adults with no sleep disorders. The use of the Epworth sleepiness scale and the Berlin questionnaires were reliable enough to ensure that the control group subjects were free of OSA [26]. Ideally, this study should have used supine position for taking the CBCT-scans, where OSA usually occurs during sleep. However, ethical limitations on the control group did not permit extra unnecessary X-rays exposure for these individuals, thus both groups were assessed in standing position. A recent study, analysing differences in pharyngeal airway dimensions and head posture in OSA patients with and without morphological deviations in the upper cervical spine, did not find an association between head posture and pharyngeal airway volume [27]. In this investigation all subjects in both groups had their CBCT-scans performed in the same head position. This investigation utilized volumetric measurements for assessing maxilla, mandible and hyoid spatial positions, whereas other studies so far evaluated these structures with

Table III
Results of the comparisons of means of volumetric variables between the two groups.

	OSA group		Control group		Levene's test for equality of variances		*t*-test for equality of means		
	Mean	Std. deviation	Mean	Std. deviation	F	Sig	*t*	Sig. (2-tailed)	Mean Difference
UAWV[1]	17.72	5.14	22.68	9.23				0.034	4,96
A	102.65	12.07	105.23	11.60	0.041	0.840	0.799	0.428	2.57
B	50.39	8.64	50.66	10.40	1.454	0.233	0.102	0.919	0.26
C	105.68	10.30	99.89	12.96	1.714	0.196	−1.814	0.075	−5.78
D[1]	120.46	18.69	111.59	18.05				0.071	−8,86
E	49.09	15.88	46.34	14.23	0.356	0.553	−0.669	0.506	−2.74
F	30.74	8.01	24.59	9.12	0.426	0.517	−2.630	0.011	−6.14
AV	257.43	27.44	251.47	22.88	1.475	0.230	−0.866	0.391	−5.95
PV	151.20	21.90	136.19	22.40	0.791	0.378	−2.490	0.016	−15.01
TV	459.03	41.77	438.33	43.63	0.092	0.763	−1.781	0.081	−20.70
R1	0.110	0.018	0.114	0.016	0.008	0.929	0.995	0.324	0.00
R2	0.560	0.030	0.575	0.037	2.030	0.160	1.548	0.128	0.01
R3	0.329	0.031	0.309	0.030	0.149	0.701	−2.269	0.027	0.01

[1]Variable tested with non-parametric Mann-Whitney test.

linear and angular measurements, and by using magnetic resonance imaging [28]. A systematic review and a meta-analysis of cephalometric studies regarding craniofacial and upper airway morphology in adult OSA patients showed strong evidence for reduced pharyngeal airway space, inferiorly placed hyoid bone and increased anterior facial heights in adult OSA patients compared to control subjects [29]. These 2D conclusions tend to support the findings of this 3D investigation. According to the results of this study, the mean value of UAWV for the control group was larger than the one in the OSA group. This finding is similar to the one found in a validation study defining the anatomical sub-regions of the upper airway with 3D CBCT using slightly different variables [30]. In another study, where also slight differences in the upper and lower borders of the pharyngeal airway were observed, the average volume was 20.3 cm^3 in non-growing subjects with no gender specification [13]. Until present there has been no strict norm for airway volume, probably because it is extremely variable, and depends on head posture, skeletal pattern, breathing stage and the volumetric region of interest used [13,17]. Regarding the mean values of UAWV for OSA subjects, the findings in the 3D studies are disparate depending on the boundaries used to define upper airway or the methods used to measure the volume [10]. The results are often discussed in terms of cross-sectional areas and/or length of the upper airway [28,31,32] as well as treatment effects on airway volume after use of oral appliances or maxillo-mandibular advancement surgery [12,33,34]. In this investigation, the significant differences between the means of volumetric variables in both groups were found for UAWV and post-hyoid volume, where UAWV was found to be significantly smaller and post-hyoid volume significantly bigger in the OSA group. These findings highlight the role of hyoid bone spatial position, which defines post-hyoid volume and the explanation might be related to the fact that the tetrahedrons defining the craniofacial structures in this study did not take into consideration the soft tissues that might be obstructing the airway.

When searching existing literature, it is not possible to compare the present craniofacial volumetric results with similar findings. A few years ago, Perri et al., defined two 3D mandibular enclosure spaces:

- a mandibular volume (MV) defined by the mandible and maxilla and contained within the bony craniofacial landmarks of the subnasion, lateral condyle, gonion and gnathion;
- a retro-mandibular volume (RMV) defined as a soft tissue volume extending posteriorly from the mandibular ramus to the base of the skull and contained within the bony craniofacial landmarks of the lateral condylion, gonion and mastoid process [16].

These two volumes, even though similar in their construction with tetrahedrons to the method used in the present study, are not comparable to its findings since they correspond to different craniofacial surfaces. Nevertheless, both MV and RMV values were approximately 7.5% larger in OSA patients when compared to the control group, while in the present report only the posterior volume and its ratio over the total volume showed a significant difference between both groups, with posterior volume means 136.19 cm^3 for the control group and 151.20 cm^3 for the OSA group, respectively (approximately 10% larger in the OSA group). On the other hand, a recent 3D analysis of craniofacial bones and soft tissue in OSA highlighted the role of soft tissue in obstructing airway volume supporting our findings regarding post-hyoid volume [35]. In this study, the hyoid bone distance to mandibular plane showed significant differences between the OSA and non-OSA groups. Furthermore, this long distance was also noted in another report in which a longer distance between post nasal spine and second cervical vertebrae was also found in OSA subjects when compared to a control group [36]. These findings tend to corroborate the results of our study regarding the posterior volume, which was found bigger in the OSA group.

With the advances in CBCT technology regarding reduced cost and radiation exposure, 3D data is being widely available thus enabling better understanding of the relationship between UAWV and its bony enclosure. Nevertheless, in a CBCT study regarding the sagittal jaw relationship, no correlations were found between airway morphology and skeletal patterns in patients with no obvious signs of respiratory problems [37]. The findings of our investigation would be useful for better understanding the volumetric craniofacial structures of OSA patients, since the 3D form truly represents the anatomical structures with no overlapping or distortion. However, future study design should integrate other known parameters relevant in OSA patients such as neck circumference and lingual volume [38].

Conclusion

The mean value of UAWV in the OSA group was smaller than in the control group while post-hyoid volume, posterior volume and its ratio over total volume were larger than in the control group. These volume differences between both groups suggest an obstruction of the upper airway in the OSA group.

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