Comparison between anatomy and resistance of upper airway in normal subjects, snorers and OSAS patients

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Abstract

Upper airway (UA) anatomical abnormalities are frequently observed in obstructive sleep apnea syndrome (OSAS). The correspondence between UA anatomical modifications and UA resistance (UAR) had not been studied. We aimed to determine if cephalometric characteristics could be related to segmental UAR. In twenty-five patients (21 males) (15 OSAS patients, 10 snorers) and 10 control subjects (8 males), segmental UAR were measured in supine position and cephalometry was performed. Inspiratory and expiratory UAR were calculated at peak flow. Length of the soft palate (LP), posterior airway space (PAS), distance from hyoid bone to mandibular plane and to posterior pharyngeal wall were different between the groups ($P < 0.01$). Inspiratory and expiratory, total and segmental, UAR were higher in OSAS ($P < 0.001$). Segmental UAR were correlated with PAS and distance from hyoid bone to mandibular plane and to pharyngeal posterior wall ($P < 0.05$). In conclusion, OSAS patients had higher UAR depending on anatomical variables, especially the place of the hyoid bone. © 2002 Elsevier Science B.V. All rights reserved.

1. Introduction

During sleep, in obstructive sleep apnea syndrome (OSAS), upper airway (UA) instability leads to airflow obstruction (Remmers et al., 1978; Schwartz et al., 1988, 1991, 1992). The mechanical characteristics of UA largely depend

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on its structural and functional properties. The nasal and the hypopharyngeal segments are supported by bony and cartilaginous structures, and thus are relatively stiff while the pharyngeal tissues are not supported by such rigid structures. These characteristics account for the fact that resistance of the nasal and laryngeal segments is roughly linear (Hudgel, 1986), in spite of the pharyngeal segment which is a collapsible structure.

Recent studies have demonstrated that UA anatomical abnormalities were frequently observed in OSAS and could explain such UA instability. Specific craniofacial characteristics, detected using cephalogram (Pracharktam et al., 1994) or magnetic resonance imaging (Rodenstein et al., 1990) may be related to the risk of developing sleep related disordered breathing. Nevertheless, the correspondence between these UA anatomical properties and UA mechanic alterations had not been extensively studied. Only one study had demonstrated that critical pressure was correlated with anatomical alterations in OSAS (Sforza et al., 2000), but the relationship between segmental UA resistance (UAR)s and UA anatomic characteristics have not been studied. It could be hypothesised that craniofacial morphology could influence UA mechanic. Therefore, the aim of this study was to determine if cephalometric characteristics could be related to segmental UARs.

2. Method

2.1. Subjects

Twenty-five patients (21 males) and 10 control subjects (eight males) participated in the study. Subjects volunteered to participate gave their informed consent prior to participate. Each subject underwent UARs measurements in supine position, cephalometric measurements and polygraphic sleep recording. Control subjects had no clinical evidence of sleep apnea syndrome, were non-snorers, and did not have sleep recording measurements.

2.2. Measurements

2.2.1. Upper airway resistance

2.2.1.1. Nasal flow. A tightly fitting translucent mask (continuous positive airway pressure mask, Respironics, Murrisville, PA) was placed over the nose, connected to a Fleish number 3 pneumotachograph (Hans Rudolph, Kansas City, MO) to measure instantaneous flow.

2.2.1.2. Nasal, palatal and supralaryngeal pressure (Hudgel, 1986). Nasal, palatal and supralaryngeal pressures were measured with three catheters (XRO feeding tube, 50 cm length, external diameter = 2.4 mm; internal diameter = 1.4 mm, Vygon, Ecouen, France) connected to Valydine MP 45-1 differential pressure transducers (± 100 cmH$_2$O, Valydine, Northridge, CA). They were passed through the mask and introduced into one nostril, after topical anaesthesia (lidocaine spray 5%) and lubrication of the catheters (lidocaine gel 2%). Supralaryngeal pressure, the tip was inserted into the lower part of the pharynx, as far down as the patient could tolerate without gag or discomfort in swallowing (18 ± 2 cm from the nostrils). In this position, it was posterior to the epiglottis. The tip of the palatal pressure catheter was placed visually in the palatal segment of the UA, at 14 ± 2 cm from the nares and the catheter measuring the nasal pressure was placed at 7 ± 2 cm from the nares. The side of each catheter were perforated with two holes near its sealed tip. To assure UA catheter patency and keep the catheters free of secretion, equal bias flow of 0.1 L/min of compressed air was passed through each catheter. Nasal pressure was referenced to mask pressure, palatal pressure was referenced to nasal pressure, and supralaryngeal pressure was referenced to palatal pressure. Pressure and flow were recorded on an electrostatic system Gould ES 2000 (Gould instrument system, Valley View, OH).

2.2.1.3. Upper airway resistance. Inspiratory and expiratory resistances were calculated at peak flow by ratio of pressure to flow at peak inspiratory and expiratory flow. They were, respectively,

called transnasal resistance (TNR), transpalatal resistance (TPR) and supralaryngeal resistance (SLR), preceded with the suffix i or e for inspiratory or expiratory resistance, and represented segmental UARs. Total inspiratory or expiratory UARs (iUAR and eUAR) were calculated using the sum of TNR, TPR and SLR. For each subject, ten reproducible consecutive respiratory cycles were selected for subsequent analysis.

2.2.2. Cephalometric measurements

Lateral cephalometric radiographs were obtained for each subject with the technique described by Riley et al. (Riley et al., 1983), in sitting position. The conventional landmarks were determined with the subject's head in neutral position, eyes looking directly forward at a film tube distance of exactly 152 cm. The same investigator (XB), who did not know the results of sleep recording, interpreted all radiographs. The length of the soft palate (LP), the posterior airway space (PAS), angle measurement from sella to nasium to point A (SNA), to point B (SNB) and ANB, distance from hyoid bone to the mandibular plane (H-Mp) or to posterior wall of the pharynx (H-Ph) (using a line parallel to the orbito-meatal plane), were measured.

2.2.3. Polygraphic sleep recordings

Cardio respiratory polygraphy was performed using a CID 102P device (Cidelec, Saintes Gemmes sur Loire, France) (Van Surell et al., 1995). Tracheal sound, nasal pressure, thoracic and abdominal movements, O_2 saturation (SaO_2), heart rate, body position were recorded and permitted to recognise and to characterise apneas or hypopneas. In all cases, automatic analysis was corrected by visual analysis, and number of apneas, apnea index, number of hypopneas, hypopnea index, apnea hypopnea index (AHI), and number of desaturations were measured or calculated.

2.3. Procedures

UA catheters were first introduced under local anaesthesia (lidocaïne spray 5%). Then all the subjects underwent cephalogram, neck in upright position, which also permit to control the catheter place. Secondary, UAR were measured. Subjects were placed in a supine position, on a bed, the head on a pillow inclined with a 20° angle, and were asked not to breathe through the mouth. A 30-min period was allowed between the setting of the catheters and the beginning of the test to accustom the subject and for lidocaine clearance. During the night following these measurements, patients underwent sleep recording study. The polygraphic results were used to class subjects as snorer or OSAS patient (AHI > 15 n/h).

2.4. Statistical analysis

Data were expressed as mean $\pm$ S.D. Statistical analysis was performed using the SUPERANOVA® 4.5 software (Abacus Concept, Berkeley, CA) running on an Apple Macintosh computer. Cephalometric measurements, inspiratory and expiratory resistances (TNR, TPR, SLR) were compared between each group using an analysis of variance (ANOVA) for repeated measures with a post-hoc protected least-square difference Fisher's test analysis of variance (Fisher test) lysis of variance (Fisher test).. Linear regression between cephalometric measurements and UARs were made using least square method.

3. Results

All the subjects underwent the challenge without any discomfort. Ten patients were classed snorers without OSAS, and 15 patients had OSAS. Anthropometric characteristics of the different group are given in Table 1, age, body mass index (BMI), and neck size were statistically higher in OSAS patients than in snorers than in control subjects ($P < 0.05$).

3.1. Cephalometric measurements

Results of the cephalogram are presented in Table 2 and showed that craniofacial data were not statistically different between the different groups. Soft tissue variables as the LP, the PAS, the distance from the hyoid bone to mandibular

plane and to the posterior pharyngeal wall were different between normal subjects or snorers and OSAS patients.

3.2. Upper airway measurements

Inspiratory, total and segmental (Fig. 1, Table 3), UAR were not different between normal subjects and snorers, but higher in OSAS. Expiratory resistance were higher in OSAS than in control subjects. Nasal resistance (TNR) represented $36 \pm 10\%$ of iUAR and $37 \pm 9\%$ of eUAR in all the population. Inspiratory or expiratory TNR were positively correlated with TPR ($P < 0.05$), SLR ($P < 0.0001$) and UAR ($P < 0.0001$) (Fig. 2).

3.3. Correlation between cephalometric measurements and UA resistance

Inspiratory and expiratory UAR (iUAR and eUAR) were positively correlated with soft tissue variables but not with craniofacial characteristics (Fig. 3). Positive correlations between segmental UAR and cephalogram results are presented in Table 4. It could be seen that TNR were strongly correlated with PAS and H-Ph, TPR with H-Mp, and SLR with PAS and H-Ph.

4. Discussion

Our results shown that anatomical characteristics in UA were different between OSAS patients, snorers and normal subjects, especially regarding the LP and the position of the hyoid bone. These anatomical characteristics were correlated with segmental UARs.

Before these results can be fully interpreted, several methodological procedures need to be considered. In our study UA pressures were measured with three bias-flow catheters. This method has been previously described by Hudgel (Hudgel, 1986) and appears to be accurate in determining UA pressures. Topical anaesthesia could have

Table 1
Anthropomorphic data of the three populations (mean $\pm$ S.D.)

Patients	Sex	Age (years)	BMI (kg/m^2)	NS (cm)	AHI (n/h)	mSa$_{O_2}$ (%)
Control subjects	8 M; 2 F	34 ± 8	22 ± 2	36 ± 3	–	–
Snorers	10 M	44 ± 12	29 ± 5	40 ± 4	6 ± 4	95 ± 2
OSAS patients	11 M; 4 F	60 ± 9	34 ± 3	46 ± 5	36 ± 14	92 ± 2

BMI, body mass index; NS, neck size; AHI, apnea hypopnea index; mSa$_{O_2}$, mean oxygen saturation during the sleep recording study.

Table 2
Cephalometric data in control subjects, snorers and OSAS patients

	Control subjects	$P1$	Snorers	$P2$	OSAS	$P3$
SNA (°)	83 ± 5	ns	84 ± 6	ns	84 ± 4	ns
SNB (°)	82 ± 4	ns	81 ± 5	ns	81 ± 4	ns
ANB (°)	2 ± 2	ns	3 ± 4	ns	3 ± 3	ns
H-MP (mm)	12 ± 5	<0.05	18 ± 3	<0.01	24 ± 7	<0.0001
H-Ph (mm)	35 ± 4	ns	39 ± 6	<0.05	46 ± 1	<0.01
LP (mm)	36 ± 4	ns	38 ± 5	<0.01	41 ± 7	<0.001
PAS (mm)	13 ± 4	ns	13 ± 3	<0.05	18 ± 5	<0.05

SNA, position of the maxilla; SNB, position of the mandible; H-MP, distance from the hyoid bone to the mandibular plane; H-Ph, distance from the hyoid bone to the posterior pharyngeal wall; LP, length of the soft palate; PAS, posterior airway space. $P1$, comparison between normal subjects and snorers; $P2$, comparison between snorers and OSAS patients; $P3$, comparison between normal subjects and OSAS patients
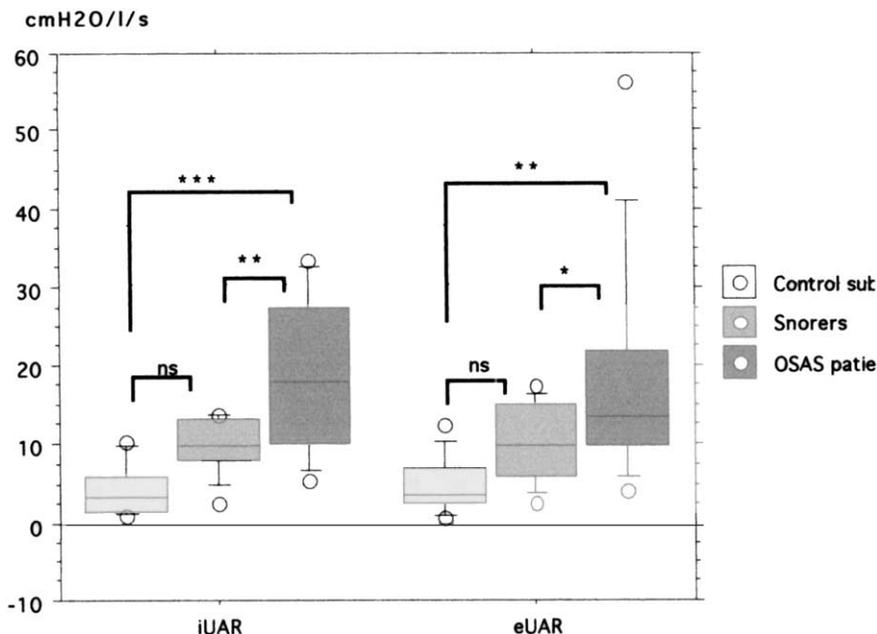
Fig. 1. Total inspiratory and expiratory upper airway resistance (respectively, iUAR and eUAR) in control subjects, snorers and OSAS patients. Resistance were significantly different between the three populations. The black box represented 25–75 percentile of the median and the black line the 10th and 90th percentile. Ns, non significant; $*P < 0.05$; $**P < 0.01$; $***P < 0.0001$.

Table 3
Segmental upper airway resistance (cmH$_2$O/L per sec) in control subjects, snorers and OSAS

	Control subjects	$P1$	Snorers	$P2$	OSAS	$P3$
iTNR	1.5 ± 1.2	ns	3.8 ± 1.3	<0.01	6.5 ± 4.4	<0.001
iTPR	0.9 ± 0.6	ns	1.9 ± 1.6	<0.01	4.6 ± 2.9	<0.001
iSLR	1.7 ± 1.6	ns	4.0 ± 1.7	<0.05	6.8 ± 4.7	<0.001
eTNR	1.6 ± 1.1	ns	3.9 ± 1.8	ns	6.7 ± 6.2	<0.01
eTPR	0.8 ± 0.7	ns	1.9 ± 1.7	ns	4.5 ± 5.2	<0.05
eSLR	2.1 ± 2.2	ns	4.2 ± 2.1	ns	7.3 ± 6.4	<0.01

i, inspiratory; e, expiratory; TNR, transnasal resistance; TPR, transpalatal resistance; SLR, supralaryngeal resistance. $P1$, comparison between normal subjects and snorers; $P2$, comparison between snorers and OSAS patients; $P3$, comparison between normal subjects and OSAS patients.

modified UAR, since it provides an UA mecanoreceptor blockade, and modifies UA behaviour. In our study, only the nostrils were anaesthetised, but the subjects did not stop swallowing and a part of their pharynx could have been anaesthetised. Therefore, we chose to begin the experiment 30 min after the anaesthesia to eliminate a potential lidocaine effect. The pressure/flow ratio was used to calculate UAR at peak inspiratory or expiratory flow because it has

been demonstrated that pressure/flow relationship is roughly linear in OSAS (Tamisier et al., 2000). In this study, correlation between UAR measured using hyperbolic equation (Hudgel et al., 1988) or pressure/flow ratio was highly significant, confirmed by a Bland and Altman analysis.

UAR were measured in supine position, on a bed, nearest physiological situation which provoke apneas or hypopneas during sleep. Nevertheless, cephalometric measurements have been made

in sitting position, because of radiological constraint and used of standardised method. Such a situation was nevertheless studied because we wanted to be as near as possible of reality, even if comparison between cephalometry and UAR should be influenced by those two different positions.

Our groups were not matched for age and BMI. Age (Young et al., 1993) and BMI (Sforza et al., 1994) increase the prevalence of sleep apnea syndrome, and are correlated with AHI, as the anatomical or mechanical alterations of the UA (Anch et al., 1982). We are confident that age and fat infiltration of the neck could influence UA properties, but dissociating these factors seems not to be possible in study using control subjects, especially for BMI.

Inspiratory and expiratory UAR (total or segmental resistance) are higher in OSAS patients than in snorers or normal subjects, during wakefulness or asleep (Anch et al., 1982; Hudgel,

1986). We did not remark any difference in the behaviour of inspiratory and expiratory UAR. In sleep apnea syndrome, airway abnormalities occur both during expiratory and inspiratory phases of ventilation. Recent studies have demonstrated that narrowing of the UA can also occur during expiration. Increased expiratory resistance (Sanders and Moore, 1983) and prolonged expiratory air flow (Stanescu et al., 1996) are associated with the breath preceding the initial occluded inspiratory effort in occlusive apnea. Lofaso et al. (Lofaso et al., 1998) have demonstrated that an increase in expiratory resistance is of a similar magnitude as the increase in inspiratory resistance. It also promotes dynamic hyperinflation, increases inspiratory work and could participate in CO_2 retention or O_2 deprivation during sleep.

Surprisingly, in our study, nasal resistance of OSAS patients (and not in healthy subjects (Hudgel, 1986; Lorino et al., 2001; Series et al., 1989)) were higher compared with literature (Se-
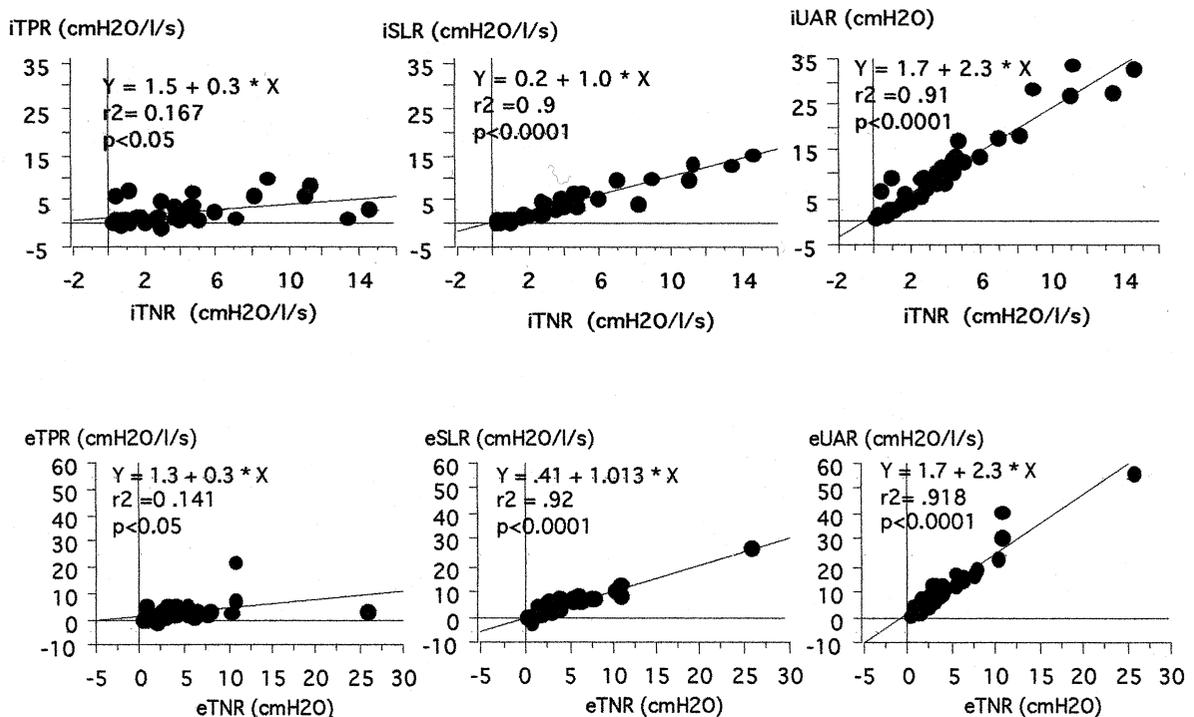

Fig. 2. Correlation between inspiratory (top) and expiratory (bottom) nasal resistance (iTNR and eTNR) and inspiratory or expiratory transpalatal (left, TPR), supralaryngeal (middle, SLR) and total upper airway resistance (right, UAR).
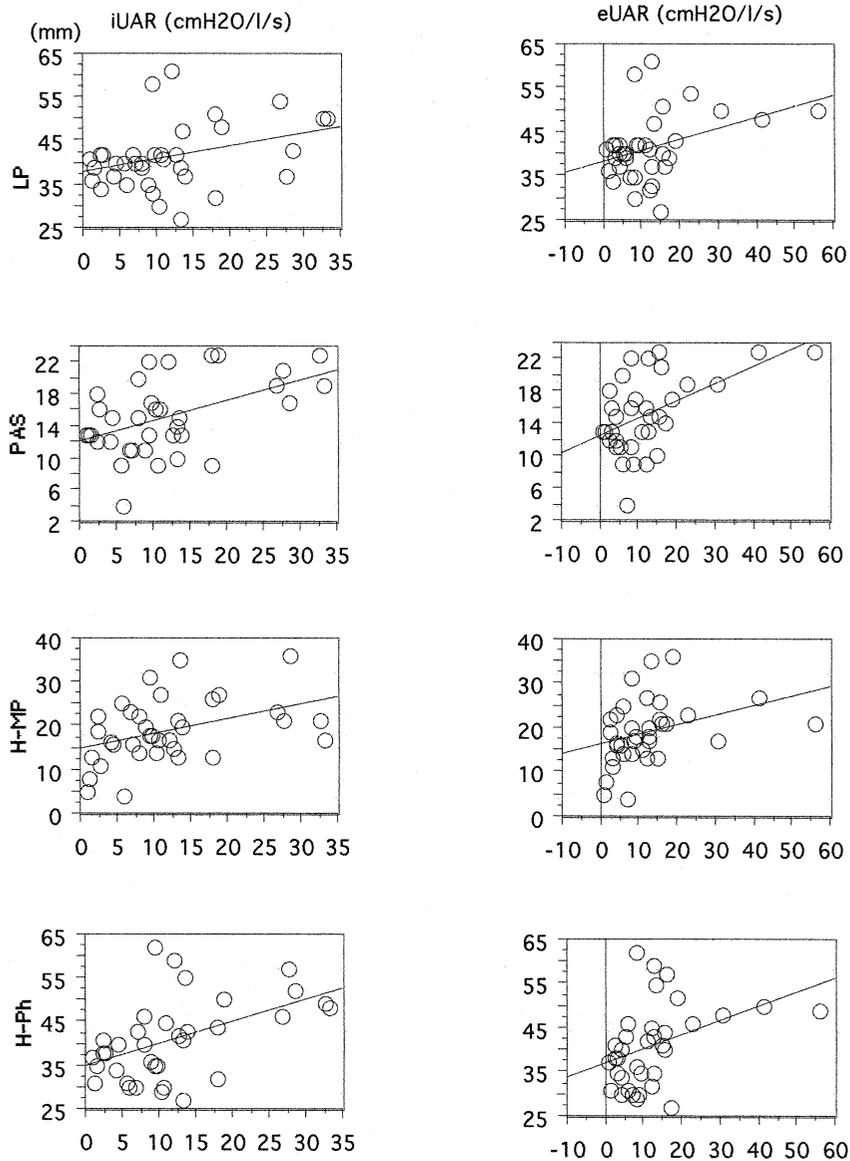
Fig. 3. Linear correlation between total inspiratory and expiratory upper airway resistance (respectively, iUAR and eUAR) and soft tissue variables in the whole population (LP, length of the soft palate, PAS, posterior airway space, H-Mp, distance from hyoid bone to mandibular plane, H-Ph, distance from hyoid bone to posterior pharyngeal wall). All the correlations were significant ($P < 0.05$).

ries et al., 1992). Rhinomanometry had recently be evaluated in OSAS and snorers (541 patients) (Lofaso et al., 2000). Patients with OSAS had higher nasal resistance than patients without OSAS (2.6 ± 1.6 vs. 2.2 ± 1.0 cmH$_2$O/L per sec). In this study, nasal resistance appeared to be an independent risk factor for OSAS. Those results

are closely related with precedent studies (Cole et al., 1982; Cole, 1989, 1992). The higher nasal resistance measured in our study compared with literature could be explained by the method used to measure nasal resistance, because three catheters (one catheter had 2.4 mm external diameter) were passed through the nare, and must

increase nasal resistance, compared with rhinomanometry. Another point could influence results is that in OSAS group, four patients had nasal obstruction, with nasal resistance > 10 cmH$_2$O.

UA anatomical modifications had been shown in OSAS or snoring using cephalogram, acoustic reflection (Huang et al., 1998) or MRI (Rodenstein et al., 1990). Cephalometric measurements differed in OSAS patients and in snorers from control subjects, especially the place of the hyoid bone (Maltais et al., 1991). Our results shown that segmental and total UAR (TNR, TPR and SLR) were highly correlated with PAS and the place of the hyoid bone. PAS and distance from hyoid bone to posterior pharyngeal wall were linked in our study, and the PAS depended of the hyoid bone position and of the tongue thickness. These results indicated that the place of the hyoid bone is a crucial determining in UAR, and that the segmental resistances were associated with local anatomical modifications in the concerned UA segment. Such importance of the hyoid bone position on UA mechanic had already been demonstrated (Sforza et al., 2000). In this study, critical pressure was correlated with the place of the hyoid bone. It position seems to be crucial to pharyngeal patency, because it is determined by an imbalance between the suprahyoid and infrahyoid muscles activity, especially UA dilators muscles. The consequent changes in contractile properties and the progressive loss in the compensatory muscular mechanisms maintaining UA patency and influencing hyoid position may determine a greater UAR. In our study, if it is obvious to observe a correlation between SLR and soft tissue variables, it is less clear to observe correlations between nasal resistance and these soft tissue variables. It could be suggest that nasal resistance may influence or may be influenced by the tongue position. The cephalometric results (no difference in craniofacial data between the different groups and decreasing of PAS and of the distance between hyoid bone and pharyngeal wall) suggest that area of the tong is increase in the OSAS group, and could be responsible of the increase in nasal resistance. Those nasal resistances were highly correlated with the other segmental resistances, especially SLR and UAR. Such correlations indicate that nasal resistances are determinant in UA mechanic, or UA mechanic alterations highly influence nasal resistance.

Nevertheless, some considerations need to be evoked before concluding. First, cephalogram was obtained in seated position, as resistance, were measured in supine position, and could explain why the soft palate was not correlated with nasal resistance, because soft palate and tongue thickness increase in supine position. Second, cephalogram provides information for anterio-posterior but not lateral pharyngeal structures that could be implicated in pharyngeal narrowing. Third, the three catheters to measure segmental pressures

Table 4
Correlation between segmental upper airway resistance and soft tissue measurements obtained with cephalogramm

Resistance	LP		PAS		H-Mp		H-Ph	
	r	P	r	P	r	P	r	P
iTNR	0.29	ns	0.52	0.001	0.12	0.04	0.49	0.003
eTNR	0.34	0.042	0.51	0.001	0.31	ns	0.39	0.02
iTPR	0.42	0.01	0.25	ns	0.44	0.008	0.28	ns
eTPR	0.3	ns	0.35	0.03	0.34	0.04	0.25	ns
iSLR	0.26	ns	0.45	0.006	0.31	ns	0.48	0.003
eSLR	0.31	ns	0.43	0.009	0.22	ns	0.35	0.03
iUAR	0.36	0.03	0.49	0.002	0.41	0.01	0.5	0.002
eUAR	0.38	0.02	0.52	0.001	0.34	0.04	0.41	0.01

ns, non significant; See text for legend.

passed throughout the oropharynx and could increase nasal resistance.

In conclusion, OSAS patients had higher UAR depended on anatomical variables, especially the place of the hyoid bone. It could be quite correctly argued that changes in soft tissue and body facial anatomy may interfere with UAR. Further study in sleeping condition would provide more information on the influence of anatomical variables on UA mechanic.

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