Acoustic pharyngometry patterns of snoring and obstructive sleep apnea patients

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OBJECTIVE: **Anatomic narrowing of the pharyngeal airway increases the relative negative pressure generated during inspiration, thus affecting the dynamic behavior of the upper airway. The aim of this work was to measure pharyngeal area in snoring patients with and without obstructive sleep apnea (OSA), as categorized by polysomnography and by acoustic pharyngometry, and to analyze the different curve patterns obtained from patients of both groups.**

METHODS: **We examined 50 snorers who were divided into 2 groups matched for age, gender, and body mass index.**

RESULTS: **Mean Apnea Index (AI) in nonapneic snorers (group 1) was 4, and mean pharyngeal area was 2.41 cm^2. In snoring patients with OSA (group 2), mean AI was 25.9 with a mean pharyngeal area of 1.589 cm^2 ($P < 0.001$). In both groups, the dependent variable (AI) can be predicted from a linear relation with the independent variable (pharyngeal area) with normality and constant variance tests passed. In group 1, the resulting curve can be 1 of 2 types depending on the relative area of the pharyngeal segment to the velopharyngeal area. In group 2, the curve pattern can be categorized into 3 patterns depending on the possible pathology of pharyngeal obstruction.**

CONCLUSION: **The acoustic reflection technique is reproducible, noninvasive, and free from potential side effects. The good correlation between AI and pharyngeal area adds to the potential of acoustic pharyngometry. Careful study of the pharyngeal cross-sectional area and curve topography may give a good idea about the site of upper airway obstruction.** (Otolaryngol Head Neck Surg 2004; 130:58-66.)

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Three variables are important in the development of obstruction and collapse of the upper airway in patients with obstructive sleep apnea (OSA): the decreased activity of the upper airway dilator muscles, the relative negative pressure generated in the upper airway during inspiration, and anatomic obstruction of the upper airway. All 3 interact together in what can be called "the dynamic behavior of the upper airway." Disorders producing anatomic narrowing and thereby necessitating the generation of more negative inspiratory pressure to maintain ventilation have been reported in OSA patients. Factors that may contribute to pharyngeal airway collapse include, compliance of the airway walls, and inspiratory intraluminal negative pressure, whereas compliance of the airway depends significantly on the tone of the pharyngeal muscles.[1,2]

Surgical intervention for OSA includes several procedures, with each designed to increase the patency at a specific level of the upper airway. The identification of the collapsing or stenotic site(s) of the upper airway is therefore important in selecting the appropriate procedure.[3] Pharyngeal structure is usually assessed by measurements of the pharyngeal cross-sectional area using a number of techniques, including lateral cephalometry, computed tomography (CT) scanning, magnetic resonance imaging (MRI), video fluoroscopy, and acoustic reflection.[4]

Reflections of acoustic pulse introduced at the mouth can be used to infer airway cross-sectional area of the oral cavity, pharyngeal airway down to the level of the larynx. Advances over other methods for objectively evaluating the upper airway include portability, free tidal breathing during measurement, real-time display of the airway area, and ability to simultaneously assess the entire airway.[5]

The aim of this work was to measure pharyngeal cross-sectional area in snoring nonapneic patients as well as in snoring patients with OSA by acoustic pharyngometry, as categorized by polysomnography, and to analyze the different curve patterns obtained from patients of both groups.

SUBJECTS AND METHODS

Equipment

The apparatus used for the assessment of pharyngeal cross-sectional area was the Eccovision Acoustic Pharyngometer (Hood Laboratories, USA). This device uses acoustic technology to assess cross-sectional area of the airway as a function of distance from the mouth. Graphic representation is inferred from the knowledge of the reflected spectrum arising from the subject's airway response to the incident acoustic pulse.[6]

Polysomnography studies were made using the portable SAM system sleep apnea monitor (Intercare Technologies Inc, USA).

Subjects

This study included 50 male patients divided into 2 equal groups matched in age and body mass index (BMI).

All patients were habitual snorers and had no history of chronic nasal obstruction (verified by clinical examination and acoustic rhinometry whenever needed). All patients have performed acoustic pharyngometry for assessment of pharyngeal airway obstruction. Diagnosis of OSA was verified by polysomnography using the SAM system.[7]

Acoustic Pharyngometry

Pharyngeal cross-sectional area was measured in all patients adopting the standard operating protocol; all patients were examined in the sitting position on a straight-back chair with head support during normal tidal breathing. Wave tube was placed horizontally parallel to the ground. Patients were requested to fix their gaze at a point on the opposite wall straight ahead to the gaze level and requested to think silently of the sound "oooh"; this helps to keep the tongue in a relaxed and neutral position and keeps the velum closed so preventing acoustic leak through the nose.[5,8] Four trials were performed for each patient achieving a coefficient of variance of 10% or less before the study was accepted.[9] All acoustic pharyngometry studies were performed by the same examiner before polysomnography was performed.

Polysomnography

Polysomnography studies were done using the portable SAM system (level 3 polysomnography equipment as classified by the American Sleep Association).[10] The equipment measures cardiorespiratory variables (airflow, respiratory effort, pulse rate, oxygen saturation, snoring index, apneas, desaturations, and sleeping position).

Each patient was admitted for an overnight stay, and the equipment was mounted following the operating protocol.[11] A member of the staff was always present during each test setting, regularly monitoring the patient/equipment setup and functionality of the unit. On the next morning, the base unit was disconnected from the patient and reconnected to an IBM compatible computer; patient data were transferred and analyzed by the computer. An apneic event was considered when airflow stopped for at least 10 seconds.[12] Apnea Index (AI) is defined as the number of apneas averaged per hour of sleep.[1] During patient file transfer from the base unit to the computer, the file was closely monitored for areas of possible artefacts, which were deleted from the study if found. Only those patients whose files had at least 90% of the study during a period of sleep of at least 6 hours were included.

Statistical Analysis

Statistical analysis was made using Statistica 5 software (StatSoft Inc).

RESULTS

The patient were divided into 2 groups. Group 1 included 25 patients (mean age, 41 years [$\pm$9 years]; mean BMI, 29.1 kg/mm^2 [$\pm$2.9 kg/mm^2]). According to data from sleep studies, they were diagnosed as nonapneic snorers (AI, $\leq$5).[12]

Group 2 also included 25 patients (mean age, 44 years [$\pm$7 years]; mean BMI, 31.3 kg/mm^2 [$\pm$3.2 kg/mm^2]). They were classified as snorers with OSA (according to sleep studies) (AI $>$5).[12]

Polysomnography Studies

AI in group 1 ranged from 3 to 5 episodes/hr of sleep, with a mean of 4 episodes/hr of sleep. In OSA patients (group 2), AI ranged from 11 to 47 episodes/hr of sleep, with a mean of 25.9 episodes/hr.

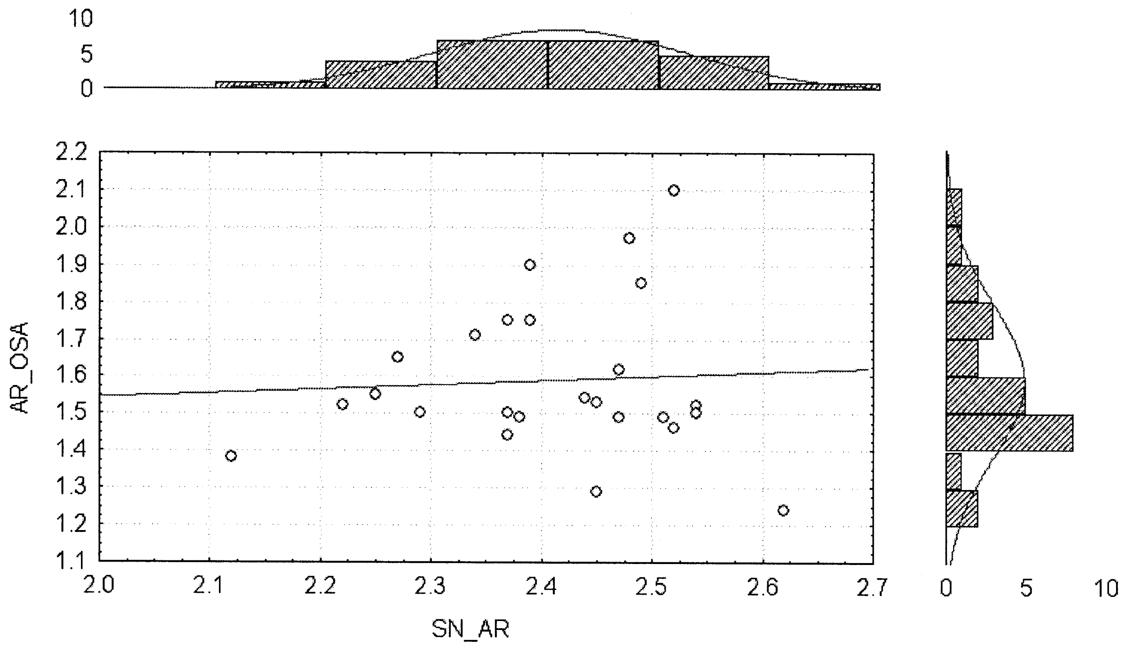

Fig 1. The horizontal axis shows pharyngeal cross-sectional area in snoring nonapneic patients with a corresponding upper histogram showing the distribution of patients of this group according to area. The vertical axis shows pharyngeal cross-sectional area in apneic patients with a corresponding histogram to the opposite side showing the distribution of patients.

Pharyngeal Cross-sectional Area

Mean pharyngeal cross-sectional area in snoring nonapneic patients ranged from 2.12 cm^2 to 2.62 cm^2 with a mean of 2.41 cm^2. In apneic patients, it ranged from 1.24 cm^2 to 2.1 cm^2 with a mean of 1.589 cm^2 (Fig 1).

Applying *t* test for independent variables showed that the difference in pharyngeal cross-sectional area between both groups is statistically significant at $P < 0.001$.

Linear regression analysis, a method by which the links between 2 variables are estimated,[13] was applied to test the relationship between the pharyngeal cross-sectional area as an independent variable and the corresponding AI as a dependent variable. In group 1, AI can be predicted from a linear relationship with pharyngeal area (normality test passed [$P = 0.395$] and constant variance test passed [$P = 0.09$]). The power of performed test was 0.305 (well below the desired power of 0.800).

In the OSA group (group 2), AI (as a dependent variable) can be predicted from a linear relationship with the pharyngeal area (independent variable), with normality test passed ($P = 0.4$) and constant variance test passed ($P = 0.103$).

Comparing the pharyngeal cross-sectional area in snoring nonapneic patients with the mean normal pharyngeal cross-sectional area,[5] using the difference between 2 independent means,[13] showed a *t* value of 12.52 ($P < 0.001$)with probability of significant difference of 99.9%.

In a previous study,[8] pharyngeal cross-sectional area was measured at inspiratory and expiratory reserve volumes to test pharyngeal compliance in normal volunteers. Comparing mean pharyngeal area in group 1 patients and mean pharyngeal cross-sectional area of normal volunteers at inspiratory and expiratory reserve volumes showed a *t* value of 1.808 and 1.467, respectively ($P <$ 0.001 in both conditions), with a probability of significant difference of 92.36% and 85.15%, respectively.

Curve Analysis (Area–Distance Function Plots)

Plots of airway cross-sectional area as a function of distance from the mouth (acoustic pharyn-

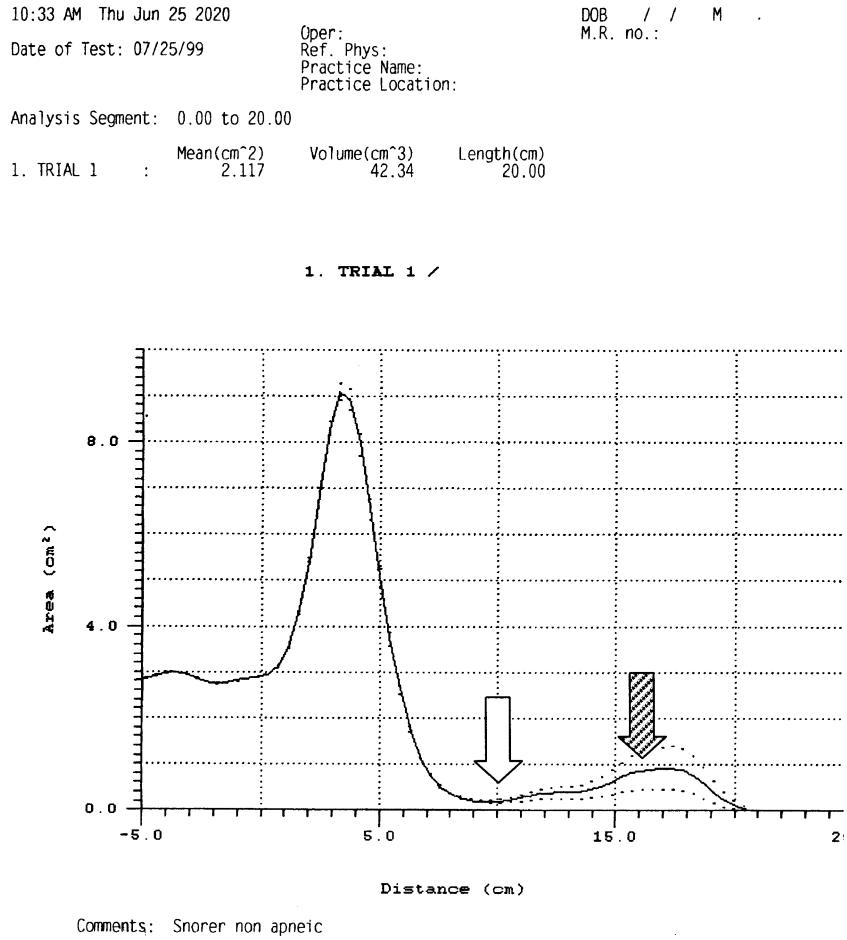

Fig 2. Snoring curve type A showing velopharyngeal junction (*white arrow*) and pharyngeal dome (*shaded arrow*). Cross-sectional area is reduced as shown in segment parameters.

gogram) showed different characteristic patterns for snoring nonapneic patients and snorers with OSA compared with the normal standard curve.[5]

Curves for Snoring Nonapneic Patients. Two patterns were identified. In the snoring curve *type A* (Fig 2), there was an elongated velopharyngeal segment with a preserved but depressed pharyngeal dome. In the snoring curve *type B* (Fig 3), there was an elongated velopharyngeal segment with a high peaked pharyngeal dome.

Velopharyngeal obstruction refers to upper airway obstruction at the region of the soft palate[9,14,15] (Fig 4).

Mean pharyngeal area in both types (as read in segment parameters) is significantly decreased compared with the normal area.

Curves for Snoring Patients with OSA. Three different curve patterns were identified. In the *type A* OSA curve (Fig 5A), the depression representing the velopharyngeal junction is in position (5- to 8-cm distance),[5] with collapse or even flattening of the pharyngeal dome. Mean pharyngeal cross-sectional area as read in segment parameters is greatly reduced compared with that of a normal or a snoring curve.

In the *type B* OSA curve (Fig 5B), there is a depressed pharyngeal dome with elongated velopharyngeal segment beyond the limit of 8-cm distance. Decrease in mean pharyngeal cross-sectional area is due to the combined decreased area in velopharynx and hypopharynx (regions A and B in Fig 4).

In the *type C* OSA curve (Fig 6), the curve shows a normal-appearing configuration and pattern regarding the distance at which the velopharyngeal segment is located on the curve and preservation of pharyngeal dome with the significantly

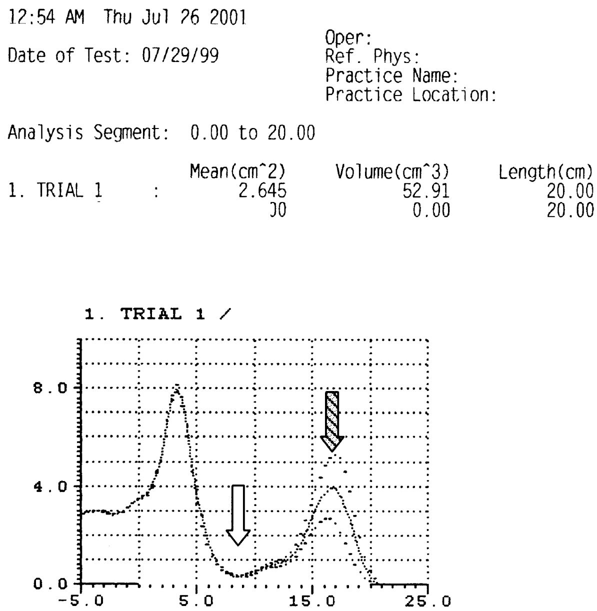

Fig 3. Snoring curve type B showing velopharyngeal junction extended (*white arrow*) and high pharyngeal dome (*shaded arrow*). Cross-sectional area is reduced as shown in segment parameters.

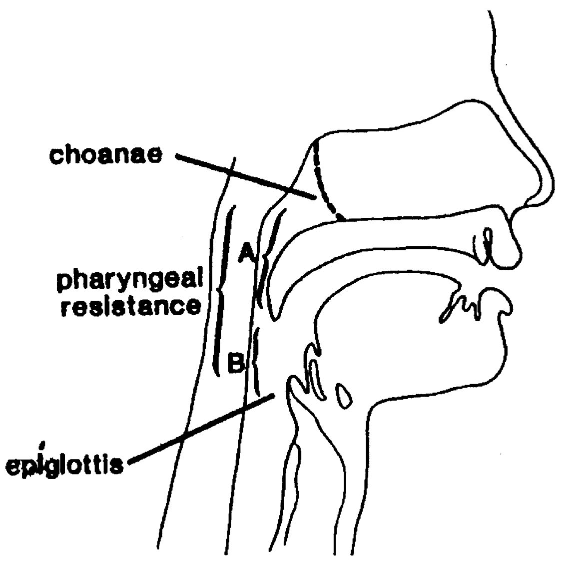

Fig 4. Upper airway segments (modified after White et al[15]). Segment A is the velopharynx, and segment B is the hypopharynx.

decreased pharyngeal area differentiating it from a normal curve.

DISCUSSION

The use of acoustic reflection technique for computing the cross-sectional area of the upper airway was developed by Fredberg et al.[16] In their technique, cross-sectional area of the airway as a function of distance from the mouth is inferred from the knowledge of the reflected spectrum arising from the subject's airway in response to an incident acoustic pulse.[6] The principle remains valid[17,18]; however, with modern equipment, 2 microphones are used for the incident and reflected waves instead of 1,[19] and the face mask is replaced by a mouth coupler to ensure an acoustic seal and to avoid malpositioning of the tongue on opening the mouth to allow acoustic impulses. In addition, a series of pulses are launched down the airway at a rate of approximately 5 pulses/s that are averaged to produce one curve by the computer software.

Brown et al[9] studied pharyngeal cross-sectional area in normal men and women and concluded that body size affects pharyngeal area and that gender differences in pharyngeal cross-sectional area can be attributed to the difference in body size between males and females. Moreover, they concluded that in males, the pharyngeal area decreases with age. In another study, White et al[15] studied the effect of gender, age, and obesity on pharyngeal resistance in normal humans. Their results suggested a relationship between obesity and pharyngeal resistance, as well as that increased age affects pharyngeal resistance. To minimize possible statistical bias in this study, these 3 factors (age, gender, and BMI) were neutralized by selecting 2 matching groups.

Nocturnal polysomnography is the gold standard for the diagnosis of OSA in snoring patients. Level III ambulatory monitoring may be the most cost-effective alternative for standard polysomnography with a reliable sensitivity and specificity.[20,21] The differentiation between nonapneic snorers and those with OSA depended primarily on the results of nocturnal polysomnography based on the criteria given by Rundell and Jones.[12]

Many studies have shown that airway obstruction in OSA patients occurs at a narrow part of the pharynx and that the width or cross-sectional area of the pharynx is an important criterion to evaluate a treatment effect.[22] Rivlin and coworkers[6] studied pharyngeal cross-sectional area in patients with OSA by acoustic reflection and found that mean pharyngeal area in those patients is signifi-

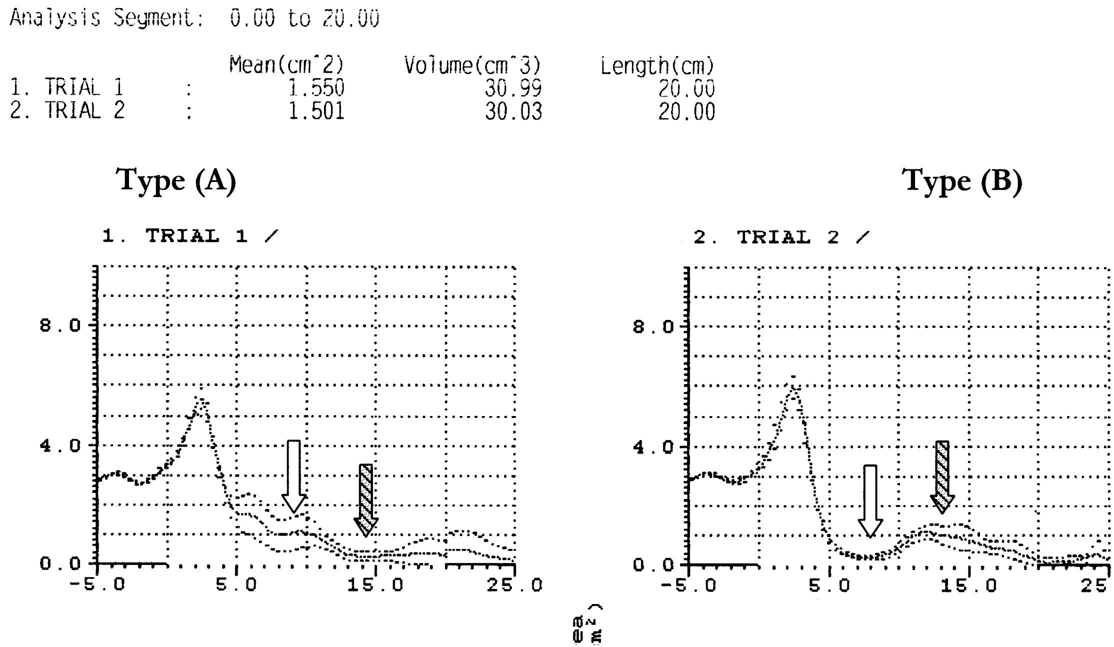

Fig 5. OSA curve pattern types A and B. *White arrows* refer to velopharyngeal junction, whereas *shaded arrows* refer to pharyngeal dome. Segment parameters show significant decrease in pharyngeal cross-sectional area.

cantly less than that in control subjects. Bradley et al[23] measured pharyngeal cross-sectional area in nonapneic snorers, patients with OSA, and control subjects by acoustic reflection. They concluded that snorers with and without OSA have a smaller cross-sectional area than do control subjects. D'Urzo et al[24] studied pharyngeal cross-sectional area with CT scanning and acoustic reflection. They concluded that pharyngeal cross-sectional area is smaller in OSA patients than in controls and that the results of both techniques are closely related so that acoustic reflection can be used reliably in clinical and physiological studies of the upper airway in humans.

Mohsenin[25] examined pharyngeal cross-sectional area by acoustic reflectometry in OSA patients and found that it is smaller than normal in both males and females.

The results of this study confirm that pharyngeal cross-sectional area in snoring nonapneic patients is significantly less than that in normal subjects and is further deceased in snoring patients with OSA. Moreover, cross-sectional area in snoring patients with or without OSA is significantly less than the normal area when the pharynx is tested for compliance by changing intrapharyngeal pressure.[8] This may indicate that structural pharyngeal obstruction plays a key role in the pathogenesis of snoring and OSA.

The relationship between pharyngeal cross-sectional area and respiratory disturbance indices during sleep was investigated. Rivlin et al[6] stated that there was a significant correlation between the number of apneas per hour sleep (AI) and pharyngeal cross-sectional area. Mohsenin[25] found a significant correlation between pharyngeal cross-sectional area and Respiratory Disturbance Index (RDI) in males and females.

The results of this work show a significant relationship between pharyngeal cross-sectional area and AI; that is, the pharyngeal cross-sectional area can be a predicting factor for the severity of OSA.

Anatomic factors favoring narrowing of the upper airway in snorers and OSA patients are 1) abnormally narrow airway, 2) increased thickness and length of the vellum palatinum, 3) facial skeletal abnormalities, 4) obesity with fat infiltration of the soft tissues particularly that of the soft palate, and 5) relatively open mandibular angle, hypertrophy, and thickness of the tongue and lowered hyoid bone.[26,27] Therefore deviations or ab-

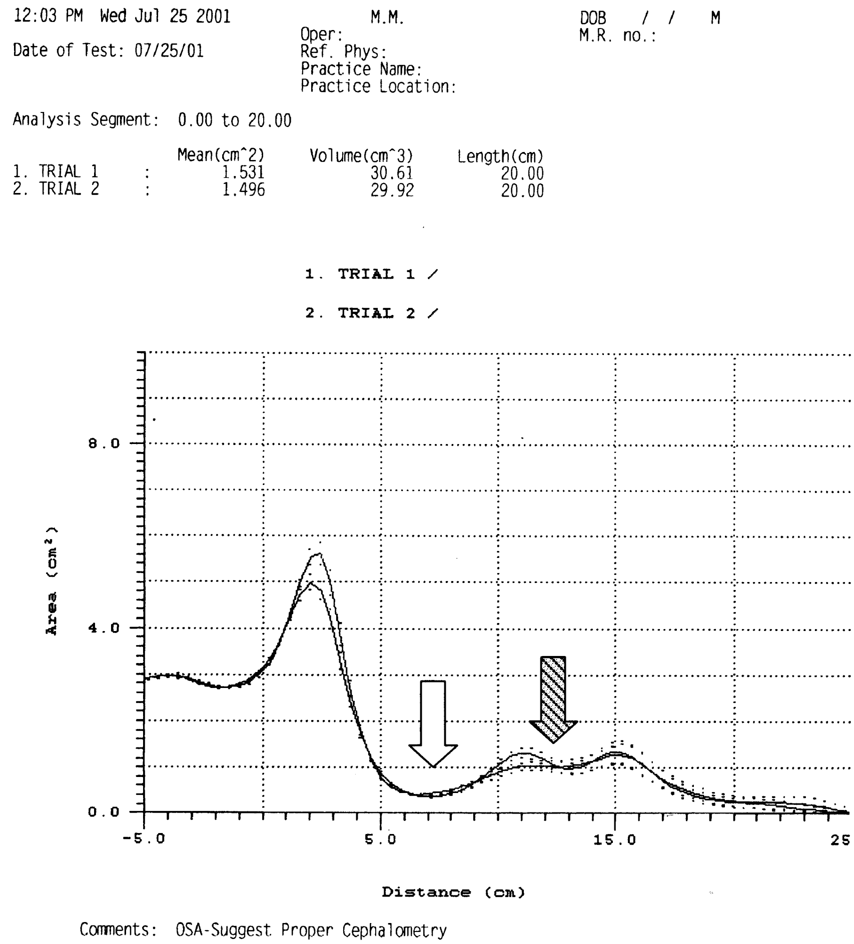

Fig 6. OSA curve pattern type C. *White arrow* refers to velopharyngeal region (occupying the distance of 5 to 8 cm as in a normal curve; the *shaded arrow* refers to the pharyngeal dome. The curve takes a normal-appearing configuration but with significant decrease in pharyngeal cross-sectional area.

erration from the curve topography as described in both groups can occur depending on which factor or factors predominate producing upper airway obstruction.

Taking into consideration that the site of upper airway obstruction varies among snoring and OSA patients, that it is not uniformly predictable in all patients,[28] and that anatomic narrowing appears to be a basic feature in those patients,[14,29] the acoustic pharyngometry curve is expected to vary according to site of obstruction. In snoring patients, airway obstruction is mainly at the velopharynx[14,27]; this is expected to be reflected in the acoustic pharyngogram as decreased pharyngeal cross-sectional area at the velopharyngeal junction (Figs 2 and 3) showing itself as increased distance occupied by this segment beyond the normal limit of 5- to 8-cm distance on the x-axis.[5]

Polo et al[30] presented an answer to the question of why not all heavy snorers have OSA. They suggested that airway collapse during sleep is favored by a narrow velopharynx associated with a large hypopharynx (Fig 3), and some heavy snorers may not have an oropharyngeal collapse because the peak inspiratory suction pressure could already be damped at the level of the narrow hypopharynx. The acoustic pharyngogram in Figure 2 can be explained on the basis of such a hypothesis.

The hypotonic pharynx of OSA patients collapses at multiple sites—oropharynx, retrolingual, or hypopharynx (Fig 5A). Alternatively, upper airway occlusion during sleep may start at the velopharynx and extend caudally[31,32] (Fig 5B) as apnea persists with pharyngeal muscle contractions and high transpharyngeal pressures modify

Table 1. Basic statistics of pharyngeal cross-sectional area and Apnea Index

	Mean	Median	SD	SE
Pharyngeal area in group 1 (cm^2)	2.410	2.420	0.124	0.025
Apnea Index in group 1	4	4	0.866	0.173
Pharyngeal area in group 2 (cm^2)	1.589	1.531	0.201	0.041
Apnea index in group 2	25.92	26	9.678	1.936

the shape of the airway caudal to the main site of occlusion.[14]

Some patients with OSA have no identifiable abnormality of the upper airway other than decreased pharyngeal cross-sectional area and have been termed "idiopathic"; investigating this category of patients may reveal some degree of facial skeletal subtype abnormality[6] such as mandibular displacement. This explains the normal-appearing configuration of the acoustic pharyngogram in Figure 6 with no abnormal topography but significantly decreased cross-sectional area of the pharynx.

The difference between snoring curve type A and OSA curve type B is in the segment parameters where the OSA curve shows much decreased cross-sectional area. Hence, interpreting the curve topography should be made in the light of pharyngeal cross-sectional area as read in the segment parameters.

Because pharyngeal narrowing contributes to snoring and sleep apnea, determination of pharyngeal area may be used as a screening procedure to suggest the severity of the condition and possibly the site of obstruction.[33] The acoustic reflection technique is reproducible, noninvasive, and free from potential side effects; the good correlation between AI and pharyngeal cross-sectional area adds to the potential of this technique. Careful study of pharyngeal cross-sectional area and curve topography may provide a good idea about the site of upper airway obstruction (Table 1).

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