Tongue shape in obstructive sleep apnea patients

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Abstract: Clinicians have long suspected that tongue shape differs between obstructive sleep apnea (OSA) patients and normal subjects. The purpose of this study was to determine whether such differences exist. Because of the difficulty in specifying reproducible homologous landmarks for the tongue, a morphometric technique—the eigenshape analysis—was used. The eigenshape analysis transforms an outline contour into a set of discrete numbers that are tangent angles of the curvature along the outline at each digitized point on the outline. Pairs of cephalograms were taken of 80 male patients in upright and supine positions. The subjects were subgrouped into four categories according to severity of symptoms. The contour of the tongue was traced, digitized, and subgrouped. When the major portion of the tongue shape variations in the supine position were graphically compared between subgroups, variations in the nonapneic group were distinguished from those in the apneic groups. The results suggest that the eigenshape analysis on cephalograms in the supine position may be a useful tool to distinguish OSA subjects from nonapneic subjects.

Key Words: Eigenshape, Morphometrics, OSA, Tongue

Angles have long been the most common tool used to quantify shapes. In order to measure an angle, landmarks are required. The configuration of the tongue is such that while homologous regions can be identified, homologous points cannot. Although the best description of a form is one-to-one mapping, it may be redundant to employ all digitized points of the outline of the form as a set of observed landmark points.

Several methods are available for dealing with closed, two-dimensional outline data for measuring shape. One method involves fitting some curves to the points sampled around the contour of an object. The parameters of the fitted mathematical function are used as descriptors of the shape of the original outlines and are used for statistical analyses. The most popular example is Fourier analysis and its cousins,[1-3] including Fourier analysis in polar coordinates, Elliptic Fourier analysis, and Fourier analysis of a contour expressed in the change of tangent angle as a function of arc length. The eigenshape analysis adopted for the current study is different from these variations of the Fourier analysis. Eigenshape analysis, first introduced by Lohmann,[4] does not fit a curve to data. Instead, it measures changes of the outline curvature *per se* in terms of angles. A series of angular measurements is expressed as an additive linear function, called a shape function. The individual outlines are collected, and variations of the outlines are analyzed algebraically. The term *eigenshape* was originally coined to call attention to this algebraic process, i.e., singular value decomposition.

Obstructive sleep apnea (OSA) is characterized by recurrent periods of cessation of breathing due to an occlusion in the upper airway for longer than 10 seconds during sleep.[5] The high prevalence of sleep apnea has recently been acknowledged.[6] Anatomical imbalance among the upper airway structures, such as a large tongue with a narrow airway, has been proposed as a significant predisposing factor for obstructive sleep apnea. However, measuring tongue and airway size to distinguish OSA patients from normals has never been proven to be efficient enough. Previous studies on the three-dimensionally reconstructed computed tomogram data of the tongue and airway show that a large person who has a large tongue also tends to have a large airway.[7] Perhaps this is the

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reason tongue size is not found among important variables of many morphometric measurements for the prediction of OSA severity.[8]

Few studies have evaluated tongue shape *per se*. The goals of the current study were twofold: First, to see if tongue shape differs between OSA patients and nonapneic patients; second, to test if the eigenshape analysis is a useful morphometric tool to study an outline form obtained from lateral headfilms.

Materials and methods

Male OSA patients were recruited from the Respiratory Sleep Disorder Clinic. Female subjects were excluded to maintain sample homogeneity. Subjects with ongoing respiratory infections, those taking long-term medications known to influence muscle activity, those with a severe orofacial skeletal disharmony, and those who were edentulous were excluded from the study as well. Eighty subjects were subclustered into four categories in accordance with OSA severity. A combination of two clinical indices was used to determine the severity of symptoms: Apnea index (AI) is the total number of apneas divided by the total sleep time; apnea-hypopnea index (AHI) is defined as the total number of apneas and hypopneas divided by the total sleep time in minutes. Hypopneas are defined as reductions in airflow of 50% accompanied by a decrease in blood oxygen saturation greater than or equal to 4%.[5] To diagnose OSA, an overnight polysomnogram study was performed in the sleep disorder clinic. Details of the sleep study and its setting are provided elsewhere.[9] The nonapneic group included 20 subjects with an AI ranging from 0 to 4 or an AHI ranging from 0 to 9. The mild group comprised 26 subjects with an AI between 5 and 15 or an AHI between 10 and 30. In the moderate group, 17 patients showed an AI of 16 to 25 or an AHI of 31 to 50. The severe group included 17 patients who showed AI values higher than 25 or AHI values above 50.

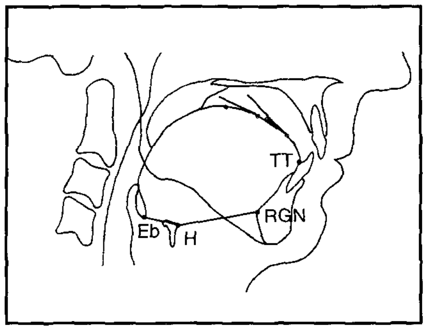

Figure 1
Outline of the tongue includes the dorsal surface of the tongue. A line connects the base of the epiglottis (Eb), hyoid (H), retrognathion (RGN), and tongue tip (TT). A series of tangent angles are measured on each digitized point, starting from TT.

Pairs of upright and supine cephalograms (Couterbalanced Cephalometer Model W-105, Wehmer Co) were taken in natural head position for each subject under identical conditions. To standardize the fluctuating pharyngeal airway size due to the lung volume changes, an X-ray exposure was made at the end of the exhalation phase. Details about the supine radiographic technique are provided elsewhere.[9]

The outline of the tongue on the cephalograms was identified and traced on acetate paper. One reproducible landmark was required to start digitization, and the direction of digitization remained the same (Digitizer, HP Model 9874). We arbitrarily started the digitization and calculation at the tongue tip, which is a reproducible anatomic landmark in a parasagittal section of the tongue. The tracing included the tongue tip, retrognathion, the hyoid, the base of the epiglottis, and the tongue dorsum; the end-point for the tracing was also the tongue tip (Figure1). Forty points with the same interval were digitized. In other words, each outline of the tongue was interpolated with 40 equally spaced points. Each point is considered to be a homologous landmark. All data acquisition processes were performed by the same investigator.

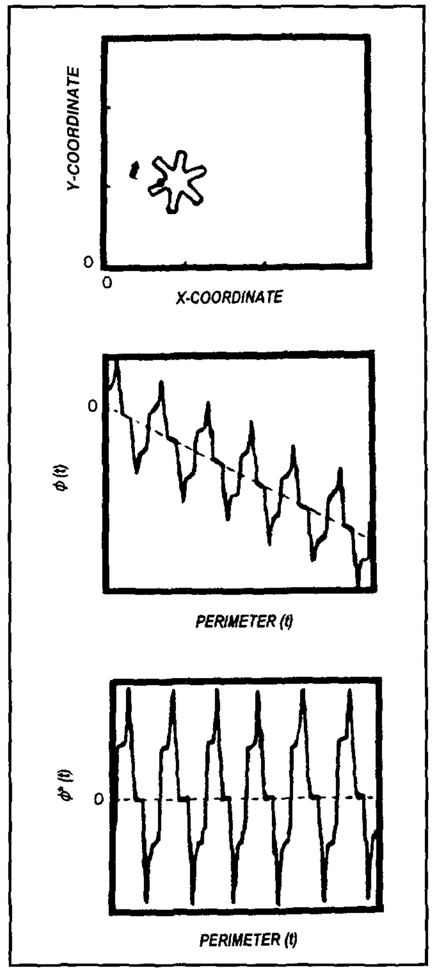

Figure 2
Obtaining a phi-star function. Starting point on the outline is indicated by a dot in the top panel. $\phi(t)$ is rendered by subtracting a tangent angle at the starting point $\phi(0)$ from the cumulative angular bend. $\phi^*(t)$ is a size-normalized $\phi(t)$, the net angular bend, by removing a circle (2Π).

Obtained data in x- and y-coordinates were fed into a custom software program to measure tangent angles at equally spaced points around the perimeter and to calculate a change of the tangent angle of the outline at each point with respect to the tangent line drawn at the point just prior to that (Figure 1). Thus, each outline was transformed into a series of numbers that were angular changes expressed in radians. Each set of numbers represents the curvature of a tongue outline. This set of numbers was transformed into a set of phi-star functions through the following process (Figure 2). The function $\phi^*(t)$ is a set of numbers, where $\phi^*(t) = \theta(t) - \theta(0) - t$, and t indicates a distance along the outline to a point. $\theta(t)$ is the angle of a tangent line at that point, and $\theta(0)$ is the angle of a tangent line at the starting point of the outline. Thus, $\phi^*(t)$ is the difference between the cumulative angular change moving along an outline and the change if the outline were a circle. A digitized tongue outline becomes a phi-star function with standardized orientation and size. Next, the sets of collected phi-star functions for each subgroup were fed into a software program (called Eigens) in a matrix format.[10] The eigenshape analysis program performed an algebraic process, which basically performs the same process as a principal components analysis.[11] The matrix was decomposed into a set of submatrices that are eigenshape functions and an associate set of weights. The eigen functions are axes of the principal components themselves. Therefore, a large degree of variation in the form measurements can be summarized by a few eigen functions. Since the first eigenshape function, i.e., the first principal components, account for most of the variance among the collection, we used it as a summary of measured shape variations.

Results

Table 1 summarizes the anthropometric data of each subgroup. Eigen analyses yielded a series of graphical outputs (Figures 3 and 4) that denote the first eigen functions of the measured tongue contours in each group. The x-axis corresponds to the perimeter of the tongue and the y-axis represents angular changes. Each of the first eigen functions were accountable for at least 65% of the total variance of the tongue outline in each group. No difference between the nonapneic group and the OSA groups was noticed in the upright position. Contrariwise, in the supine position, the characteristic outlines obtained from all apneic groups were clearly distinguished at three peaks from that of the nonapneic group (Figure 4). When the shapes of the tongue were compared between the upright and the supine positions,

Table 1
Anthropometric variables and apnea indices

	Nonapneic		Mild		Moderate		Severe	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Age (yr)	39.50	2.70	47.46	2.37	46.53	2.93	50.24	2.93
BMI	26.72	1.27	27.34	1.14	31.84	1.38	33.11	1.38
Weight (kg)	81.03	3.50	84.33	3.07	95.15	3.80	98.19	3.80
AI	0.47	2.13	6.83	1.87	13.06	2.31	28.64	2.31
AHI	1.87	2.21	18.65	1.98	32.41	2.40	63.92	2.47

BMI (body mass index) = weight (kg)/height^2 (m); SE (standard error)
AI (apnea index); AHI (apnea hypopnea index)

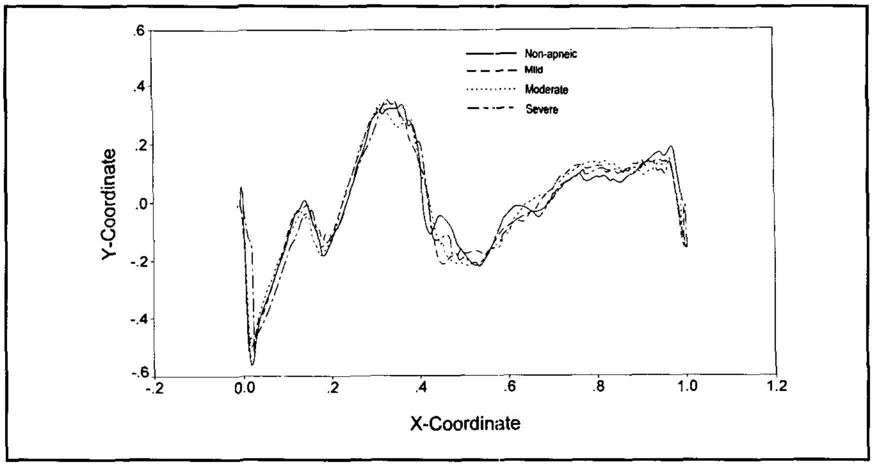

Figure 3
The first eigenshape functions calculated from each subgroup in the upright position. Four lines are almost superimposed over each other.

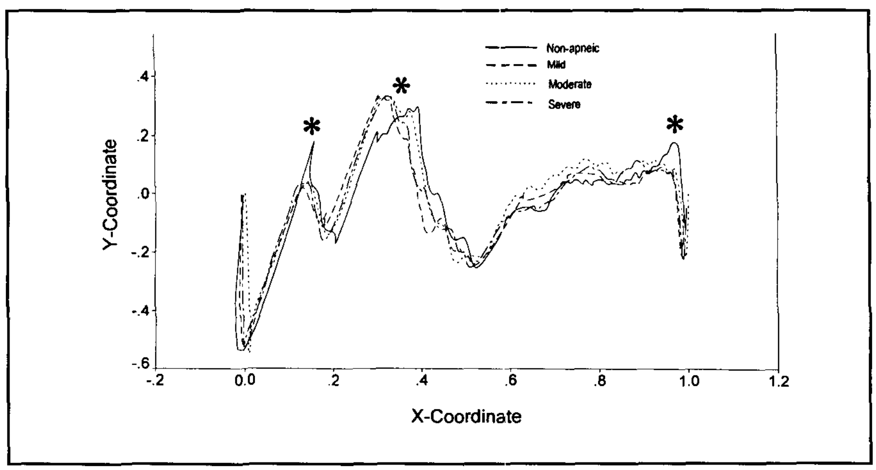

Figure 4
The first eigenshape functions in the supine position. The function represented by the nonapneic group is promptly distinguished at the three peaks.

only a slight difference was noticed (not presented here).

Discussion

Although the severity of apnea with an AHI of less than 4 is generally considered nonpathologic,[5] a significant portion of adult male snorers over 40 years of age experience some degree of apnea every night. There seems to be a wide variation in the prevalence of the disease. Recent studies suggest that OSA shows a high enough prevalence (4% to 24%) to draw public attention.[6] Due to complexity in the pathophysiology of the disorder, making a diagnosis is not simple, and treatment may be suggested in a wide range of modalities, from surgical intervention[12] to oral appliances.[13] An overnight polysomnography is too expensive for use in routine screening.[14] Despite its limitations in evaluating three-dimensional soft tissue structures, cephalometry is used for many purposes, from screening to treatment outcome evaluation, in many sleep centers mainly due to its readiness and cost-effectiveness.[15,16]

Measuring a tongue is not easy because its anatomy does not provide landmark points. The current study examined the shape of the tongue outline to demonstrate differences between OSA patients and nonapneic subjects. The eigenshape analysis employed here did not provide any method for inference testing. However, the method summarizes the data and effectively displays a difference between the apneic groups and the asymptomatic group in the shape of the tongue. It is hard to know exactly which part of the tongue is different since the outputs are a statistical summary of the tongue shape variations but not individual tongue outlines. However, the results suggest that differences in the shape of the tongue may contribute to the etiology of OSA.

Fourier analysis and its cousins may be the most widely introduced method for analysis of the outline data. Fourier decompositions are particularly good for analyzing symmetric shapes that can be easily expressed in periodic functions. Although this technique is powerful and convenient, a Fourier analysis seems to mislay its points unless harmonics are one's concern. Calculation generates many harmonic functions. However, unless one interprets, it only serves as a filtering process. Likewise, the eigenshape analysis yields several sets of shape functions that we did not attempt to present or interpret.

A principal components analysis is known to be an efficient data reduction technique summarizing main information.[11] Since this statistical technique does not require assumptions for normal distribution or homogeneity in variance as prerequisites, one does not need to worry about sample size. However, we do not know if the difference we observed between the apneic and nonapneic groups is statistically significant because the eigenshape analysis does not provide *p*-values or any numbers to compare.[2,4] This may be a critical drawback of this method. Nevertheless, if one uses the technique for graphical comparison, it may be a simple and convenient tool to demonstrate differences in outline shape.

Conclusions

To test the applicability and practicality of eigenshape analysis—a relatively novel morphometric tool in the field of OSA research—upright and supine cephalograms on OSA patients were used. The analysis successfully demonstrated that the shape of the tongue in OSA patients may be different from that of normals. This technique has proven to be applicable to any two-dimensional outline data.

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