Pharyngeal Wall Floppiness: A Novel Technique to Detect Upper Airway Collapsibility in Patients with OSAS

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Abstract
Objective. To measure pharyngeal wall floppiness (PWF) under different pressures, a novel method and technique were introduced in the present study.

Study Design. A prospective clinical study.

Subjects and Methods. Forty-seven healthy subjects (32 male; mean age, 37.9 years) and 49 patients with obstructive sleep apnea syndrome (OSAS) (46 male; mean age, 41.45 years) were recruited. The pharyngeal cavity volume was measured by acoustic reflection under positive (10 cm H2O) and negative (−10 cm H2O) pressures. The pharyngeal cavity volume was detected from the segment of 10 to 20 cm from the incisor. Moreover, PWF was calculated from the difference of pharyngeal cavity volumes under positive and negative pressures divided by the sum of the volumes under positive and negative pressures. The measurements were conducted on a group of 7 subjects weekly over 3 consecutive weeks to evaluate test-retest variability.

Results. The mean PWF was 0.19 ± 0.11 in healthy subjects and 0.24 ± 0.07 in the OSAS group, with a significant difference (P < .01). There was moderate positive correlation between PWF and age or body mass index in healthy subjects. In the 7 subjects, the mean measured interclass correlation coefficient was 0.9 (P < .05) in 3 consecutive weekly measurements.

Conclusion. The OSAS population had greater PWF compared to healthy subjects. The age dependency of PWF in healthy subjects implied which might play important roles in the development of OSAS. This noninvasive and reproducible technique might be a useful tool in OSAS clinical applications.

Keywords
upper airway, obstruction, pharyngeal wall, sleep apnea
between these techniques,\textsuperscript{25,26} which implied that acoustic pharyngometry should be informative in clinical practice.\textsuperscript{27} However, since the technique requires the cooperation of the subjects to keep the closure of the velopharyngeal space complete and relax the tongue during the measurement, it is difficult to perform for the subject and hard to keep stability and accuracy with the measurements.\textsuperscript{28,29} Also, as the measurement is carried out while being awake, it has been argued that the minimal cross-sectional areas measured might not be necessarily coordinated to the situation during sleep. All of these features limit the clinical application of the technique.

In the current study, a novel technique was developed using acoustic reflection to measure pharyngeal wall floppiness (PWF) and was performed in both healthy subjects and patients with OSAS. We hypothesized that overall PWF, including neck muscular dysfunction and soft tissue degeneration, would play important roles in upper airway collapsibility. Also, since the incidence of OSAS showed a tendency of age dependence,\textsuperscript{30} PWF should have a correlation to aging.

**Subjects and Methods**

Forty-seven healthy subjects (32 male, 15 female; mean age, 37.9 \pm 12.8 years) were recruited. All subjects were free from upper airway diseases, and an apnea-hypopnea index (AHI) of less than 10 per hour was defined by polysomnography (PSG) without daytime sleepiness.

Forty-nine patients with OSAS (46 male, 3 female; mean age, 41.45 \pm 11.35 years) from the sleep disorder clinic of Jiangsu University Affiliated People’s Hospital from January 2012 to June 2013 participated in the study. All patients were free from nasal disorders and had undergone PSG with a diagnosis of moderate to severe OSA (mean AHI, 53.8 \pm 20.56 per hour; range, 21.5-110.6 per hour).

The study was approved by the Jiangsu University Affiliated People’s Hospital Research Ethical Committee, and informed consent was obtained from all subjects and patients.

**Design of the Device and the Detective Method**

To measure the pharyngeal cavity volume under different pressures, a method and a device were invented. The acoustic reflection device employed in the study was the ECCOVISION Acoustic Pharyngometer (Sleep Group Solutions, North Miami Beach, Florida, USA). An adjustable resistance connected to a manometer was placed on the distal end of the pharyngometer wave tube (Figure 1). When the subject took a single exhalation through the wave tube, the pharyngeal cavity was inflated, and the cross-sectional area curve of the pharyngeal cavity was obtained by acoustic reflection (Figure 2A). The measurement lasts for about 10 seconds and was repeated when the pharyngeal cavity was collapsed, induced by the negative pressure of \(-10\) cm H\(_2\)O, during a single inhalation (Figure 2B). To determine the scope of the oropharyngeal and hypopharyngeal cavities from the acoustic reflection measurement, the distances from the incisor to the uvula and to the glottis were measured on 79 head and neck MRI scans in our previous study. The results showed that the mean distance from the incisor to the uvula was 8.7 cm and 15.15 cm to the glottis, respectively (unpublished data). The pharyngeal cavity volume for the analysis in the current study was accordingly taken from the segment 10 to 20 cm from the incisor (Figure 3). Pharyngeal wall floppiness was interpreted as the following formula:

\[
PWF = \frac{V_{\text{exh}} - V_{\text{inh}}}{V_{\text{exh}} + V_{\text{inh}}},
\]

where \(V_{\text{exh}}\) and \(V_{\text{inh}}\) represent the pharyngeal cavity volumes measured under positive and negative pressures, respectively.

**Measurement of Pharyngeal Cavity Volume**

The subjects kept a seated position, with one hand holding the sound wave tube horizontally and another hand holding the manometer in front. The subject was instructed to take a single exhalation through the wave tube to keep the pressure of \(10\) cm H\(_2\)O displayed on the manometer for about 10 seconds. The measurement was repeated when the subject took a single inhalation through the wave tube under the negative pressure of \(-10\) cm H\(_2\)O. The measurements were repeated 3 times for each maneuver, with differences of less than 5% from each other for further analysis.

**Reproducibility of PWF**

In a subgroup of 7 subjects (4 male, 3 female; mean age, 39.7 years), PWF was obtained weekly over 3 consecutive weeks to evaluate test-retest variability of the technique.

**Statistical Analyses**

Data were analyzed using a statistical software program (SPSS version 13.0, SPSS Inc, Chicago, Illinois, USA). Correlations between PWF and age or body mass index (BMI) in healthy subjects were performed using the Pearson rank test. Means (\pm standard deviations) of PWF were
compared between healthy subjects and patients with OSAS as well as between sexes in the healthy subject group with a Student t test. The interclass correlation coefficient (ICC) was employed to demonstrate test-retest reliability in the weekly measurements of PWF. A value of $P$ less than .05 was considered as a significant difference.

Results

The mean PWF was $0.19 \pm 0.11$ in the healthy subject group and $0.24 \pm 0.07$ in the OSAS group (Table 1). There was a significant difference between the 2 groups ($P < .01$). In the healthy subject group, the mean PWF was $0.2 \pm 0.13$ in male subjects and $0.15 \pm 0.07$ in female subjects, with no significant difference ($P > .05$).

Also, PWF had significant correlations to age ($r = 0.51$, $P < .01$) and BMI ($r = 0.57$, $P < .05$) in the healthy subject group (Figure 4). However, when the data from the male population showed a significant correlation coefficient between PWF and age or BMI ($r = 0.52$, $P < .01$ and $r = 0.36$, $P = .042$, respectively), the correlation coefficient between PWF and age or BMI in female subjects was not significant ($r = 0.27$, $P = .34$ and $r = 0.02$, $P = .91$, respectively).

In the 7 subjects, the mean measured ICC was 0.9 ($P < .05$) in PWF in 3 consecutive weekly measurements (Table 2).

Discussion

Obstructive sleep apnea syndrome is a common respiratory disorder that is characterized as repeated upper airway obstruction during sleep. The diagnosis of OSAS has been well developed by PSG and relative techniques, whereas the determination of upper airway collapse sites during sleep and the mechanism of the obstruction remain unclear.31 It is critical in clinical practice, especially for surgical treatment planning, to determine the site and degree of the upper airway obstruction. To locate the upper airway obstruction, static imaging assessments such as fluoroscopy, cephalometry, CT and MRI, and sonographic measurement along with dynamic airway/esophageal pressure measurement techniques have been introduced by previous studies.16-18 Although these techniques could offer certain information in judging the site and degree of the upper airway obstruction, the pitfalls inherent in the techniques limited the clinical application of these techniques.

Acoustic pharyngometry has been introduced to OSAS clinical practice and research over 3 decades as a noninvasive technique for assessing upper airway patency.32 Acoustic reflection may detect the minimal cross-sectional area and volume in the pharyngeal cavity, which are likely to be useful information in OSAS diagnosis and treatment guides. Unfortunately, the difficulties in performing the measurement and coordinating the results during sleep have meant that the technique is unpopular in OSAS clinical practice and research in the past. To the best of our knowledge, the current study has been the first novel technique to detect PWF, which might be a useful parameter in understanding the mechanism of the development and severity of OSAS. The core concept of the technique is that the pharyngeal cavity volumes were measured under positive and negative pressures by acoustic reflection. It has been well recognized that in patients with OSAS during sleep, the pharyngeal wall collapses, induced by negative upper airway pressure, often because of nasal airway congestion; thus, upper airway obstruction and apnea occur. It would be interesting to understand the capacity of pharyngeal wall soft tissues resisting pressure changes, PWF, and the relationship between PWF and the development of OSAS. The
technique introduced in the study demonstrated that positive pressure inflated the pharyngeal cavity, whereas negative pressure induced the collapse of it. The difference between the inflation and collapse of the pharyngeal cavity demonstrates the floppiness of the pharyngeal wall, a capacity of the pharyngeal wall soft tissues’ resistance to pressure changes, which might be an indicator of pharyngeal wall collapsibility during the development of OSAS. Because of the variation of the individual pharyngeal cavity volume, it was difficult to compare the absolute pharyngeal cavity volume in the population. Therefore, the formula to calculate the ratio of pharyngeal cavity volume changes was created. To achieve the delta of pharyngeal cavity volumes under different pressures, a positive pressure was introduced because the maneuver with a positive pressure was easy to perform and secure the closure of the pharyngeal velum compared to tidal breathing during the measurement.

In acoustic pharyngometry, one difficult feature is to keep the pharyngeal velum closed during the measurement. The opening of the velum may cause the loss of the acoustic signal and lead to a false result. It has been demonstrated in previous studies that oral respiration against resistance with pressures of 5 to 10 cm H₂O could result in pharyngeal velum closure, which was confirmed by monitoring CO₂ in the front nostril.³³,³⁴ In a preliminary study, the scope of the pressures from 10 cm H₂O to 210 cm H₂O was sufficient enough to demonstrate the changes of the pharyngeal cavity volumes and could be tolerated by most subjects without any difficulties. In the current study, the closure of the velum was an easy-to-perform maneuver for the subjects, and this could guarantee the reliable and reproducible measurement results.

It has been noticed that aging has an influence on pharyngeal collapsibility during sleep, but the underlying mechanisms remain unclear.³⁵-³⁷ In the current study, we detected PWF in

### Table 1. Number, Age, BMI, AHI, and PWF in the 2 Groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Participants (Male/Female)</th>
<th>Age, a y</th>
<th>BMI, a kg/m²</th>
<th>AHI a</th>
<th>PWF a</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSAS</td>
<td>49 (46/3)</td>
<td>41.5 ± 11.3</td>
<td>27.2 ± 2.8</td>
<td>53.8 ± 20.6</td>
<td>0.24 ± 0.07</td>
</tr>
<tr>
<td>Healthy</td>
<td>47 (32/15)</td>
<td>37.9 ± 12.7</td>
<td>22.9 ± 3.5</td>
<td>7.2 ± 2.4</td>
<td>0.19 ± 0.11</td>
</tr>
</tbody>
</table>

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index; OSAS, obstructive sleep apnea syndrome; PWF, pharyngeal wall floppiness.

*Values are expressed as mean ± standard deviation.

### Figure 4. The correlation coefficient of pharyngeal wall floppiness to age was 0.51 (P < .01) (A), and to body mass index, it was 0.34 (P < .05) (B) in the healthy subject group (n = 47).

### Table 2. Pharyngeal Wall Floppiness in 3 Consecutive Weeks.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age, y</th>
<th>Sex</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>Male</td>
<td>0.222</td>
<td>0.186</td>
<td>0.201</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>Male</td>
<td>0.076</td>
<td>0.110</td>
<td>0.081</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>Male</td>
<td>0.059</td>
<td>0.080</td>
<td>0.079</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>Female</td>
<td>0.334</td>
<td>0.172</td>
<td>0.325</td>
</tr>
<tr>
<td>5</td>
<td>51</td>
<td>Female</td>
<td>0.249</td>
<td>0.230</td>
<td>0.239</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
<td>Female</td>
<td>0.062</td>
<td>0.118</td>
<td>0.089</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>Male</td>
<td>0.376</td>
<td>0.404</td>
<td>0.398</td>
</tr>
<tr>
<td>Mean</td>
<td>39.7</td>
<td></td>
<td>0.197</td>
<td>0.186</td>
<td>0.202</td>
</tr>
</tbody>
</table>
subjects without OSAS and found that PWF had a significant correlation to age and BMI. This implied that the older pharyngeal wall might have less resistance to pressure changes in the upper airway and might contribute to the higher incidence of OSAS in middle-aged and older populations. Also, the independence of PWF to age in the female population demonstrated in the study might explain the lower incidence of OSAS in women.

**Conclusion**

1. This noninvasive and easy-to-perform technique may measure PWF with good reproducibility.
2. The OSAS population had higher PWF compared to healthy subjects.
3. The age dependence of PWF in healthy male subjects implied that aging and sex might play important roles in the development of OSAS.

**Author Contributions**

Wei Qian, data analysis, drafting, final approval, responsibility for content of article; Jun-xiang Tang, data collection, data interpretation, revising, final approval; Guo-chang Jiang, data interpretation, revising, final approval; Lin Zhao, measurement, data collection, preliminary data analysis, revising, final approval.

**Disclosures**

**Competing interests:** None.

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**References**