Effects of Continuous Positive Airway Pressure on Middle Ear Pressure and Acoustic Stapedial Reflex

Jinrang Li, MD¹, and Keliang Li, MS¹,2

Abstract

Objective. This study investigated the effects of continuous positive airway pressure (CPAP) on middle ear pressure and acoustic stapedial reflex and the correlation between CPAP and middle ear pressure.

Study Design. Prospective cohort study.

Setting. Tertiary hospitals.

Subjects and Methods. Fifty patients with obstructive sleep apnea-hypopnea syndrome were assigned to the study group, and 50 healthy volunteers were assigned to the control group. The subjects underwent standard tympanometry while wearing a CPAP device (ie, simulated CPAP treatment), which was set to 0, 5, 10, and 15 cm H₂O, respectively. Tympanometry was performed before and after swallowing at each pressure of CPAP treatment.

Results. The mean middle ear pressures were 21.2, 22.6, 22.7, and 23.4 daPa (before swallowing) and 21.6, 42.6, 81.4, and 118.6 daPa (after swallowing) in the study group and 17.6, 18.7, 19.5, and 20.8 daPa (before swallowing) and 17.7, 44.2, 85.6, and 120.5 daPa (after swallowing) in the control group at the CPAPs of 0, 5, 10, and 15 cm H₂O, respectively. While the CPAPs were at 0 and 15 cm H₂O, the stapedial muscle reflex at 1.0 kHz did not have a significant difference between the 2 groups ($\chi^2 = 0.521, P = .470$). The Pearson correlation coefficient of the CPAP pressure and the middle ear pressure after swallowing was 0.812 ($P < .001$).

Conclusion. CPAP affected middle ear pressure and was directly proportional to the pressure of the CPAP. However, CPAP treatment had no significant effect on stapedial muscle reflex.

Keywords
obstructive sleep apnea-hypopnea syndrome, continuous positive airway pressure, middle ear pressure, tympanometry, stapedial muscle reflex

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OSAHS patients both had a significant increase in their middle ear pressures.

Compared with the 2 above-mentioned studies, this research not only included a larger sample size but also used different pressure settings for CPAP therapy to further evaluate the correlation between CPAP and middle ear pressure. By using voluntary swallowing to mimic involuntary swallowing during sleeping, the actual pressure in the middle ear cavity after the opening of the eustachian tube was determined, and the effects of the opening/closing of the eustachian tube at the time of swallowing on middle ear pressure were further analyzed. In addition, middle ear pressure and acoustic stapedial reflex were examined in healthy volunteers and OSAHS patients while they were receiving CPAP treatment at different pressures to evaluate the effects of CPAP on the acoustic stapedial reflex.

Materials and Methods

General Data

This study was approval by the Institutional Review Board of the Navy General Hospital. Male patients who received a definite diagnosis of OSAHS via polysomnographic monitoring in our department between October 2014 and April 2015 underwent tympanometry. Patients with eustachian tube dysfunction, other ear diseases, and absence of acoustic stapedial reflex were excluded. Fifty OSAHS patients were assigned to the study group. In addition, healthy male adults were publicly recruited, and 50 volunteers without OSAHS who were selected in the same manner were assigned to the control group. All the subjects in control group had no history of snoring and a normal body mass index. Patients with hypertension, diabetes, and other diseases were excluded. OSAHS was diagnosed according to criteria of the Chinese Medical Association of Otorhinolaryngology: when the apnea hypopnea index in a patient with OSAHS is 5 to 15, it is considered mild; 15 to 30, moderate; and >30, severe. The index of the OSAHS patients ranged from 30.6 to 104.5, with an average of 58.22 ± 24.35. The clinical data of the 2 groups are listed in Table 1.

Methods

The subjects in both groups were kept in a tranquil and conscious state during the tympanometry test, which was performed with a middle ear analyzer (OTOflex 100; Otometrics, Taastrup, Denmark). First, the middle ear pressures on both sides were measured when the CPAP was set at zero; then, the pressures were measured after swallowing; last, the acoustic stapedial reflex of both ears was examined at 1 kHz. Subsequently, CPAP was applied via a face mask, and the tympanometry test was conducted with CPAPs at 5, 10, and 15 cm H2O. The middle ear pressures of both sides after and before swallowing were measured again. When the pressure was set at 15 cm H2O, the acoustic stapedial reflexes of both ears after swallowing were examined. While the subjects received 15 cm H2O, if the decibels required for triggering the acoustic stapedial reflex increased or if the acoustic stapedial reflex could not be triggered, CPAP was considered to exert a negative effect and reduce the sensitivity of the reflex. Finally, the total number of negative events in the 2 groups was recorded, and the incidence of negative events was further compared between the 2 groups. Measurements at an adjusted pressure were conducted 3 to 5 minutes after the previous measurement, which allows the middle ear pressure to return to the baseline.

Statistical Analysis

Data were analyzed with SPSS 21.0. The measurement results were presented as mean ± SD. The differences between the 2 groups were determined with a t test, and the count data were analyzed by a chi-square test. P < .05 was considered statistically significant.

Results

We obtained 1600 tympanometry charts. The mean middle ear pressure was 19.36 daPa when the subjects were in a tranquil state and the CPAP was set at 0 cm H2O before swallowing. Among the measured middle ear pressure values, the maximum and minimum values were 145 and −74 daPa, respectively. The changes in middle ear pressure in the study and control groups are shown in Table 2. The results showed that with the increase of the pressure in CPAP, the middle ear pressure of the subjects in both groups increased, with the increase being more significant after swallowing. Middle ear pressure positively correlated with the pressure of CPAP, with a Pearson correlation coefficient of 0.812. At CPAPs of 5, 10, and 15 cm H2O, the middle ear pressures in both groups after swallowing were

### Table 1. Comparison of Clinical Data between the 2 Groups.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control Group</th>
<th>Study Group</th>
<th>t</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>24.4 ± 2.5</td>
<td>45.4 ± 6.4</td>
<td>3.24</td>
<td>.002</td>
</tr>
<tr>
<td>Height, cm</td>
<td>169.2 ± 3.6</td>
<td>168.7 ± 4.2</td>
<td>0.67</td>
<td>.505</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>69.3 ± 6.3</td>
<td>85.2 ± 4.5</td>
<td>4.92</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Body mass index</td>
<td>24.7 ± 1.3</td>
<td>29.5 ± 2.4</td>
<td>3.81</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Neck circumference, cm</td>
<td>35.8 ± 3.2</td>
<td>41.6 ± 4.1</td>
<td>3.24</td>
<td>.002</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>69.5 ± 8.4</td>
<td>70.1 ± 9.5</td>
<td>0.71</td>
<td>.481</td>
</tr>
</tbody>
</table>

The index of the OSAHS patients ranged from 30.6 to 104.5, with an average of 58.22 ± 24.35. The clinical data of the 2 groups are listed in Table 1.
obviously higher than those before swallowing. The difference between them was statistically significant ($P < .05$).

At the same pressure of the CPAP, the middle ear pressure in the study group was always greater than that in the control group regardless of swallowing, with a statistically significant difference ($P < .05$; see Table 2). The negative events of acoustic stapedial reflex between the study and control groups at a frequency of 1 kHz and at a CPAP of 15 cm H$_2$O were also compared. After short-term CPAP therapy, the incidence rates of reduction in the sensitivity of the acoustic stapedial reflex were 3% and 5% in the OSAHS and healthy volunteer groups, respectively. The differences between them were not statistically significant ($\chi^2 = 0.521$, $P = .470$).

### Discussion

With the improvement of people’s standard of living, the incidence of OSAHS has tended to increase in recent years. As the first choice of conservative therapy for OSAHS, CPAP is widely accepted by an increasing number of physicians and patients. The working mechanism of CPAP is to provide a continuous physiologic pressure to keep the upper airway open during sleep. The key to CPAP treatment is the pressure adjustment.\textsuperscript{11} The ideal pressure level is the minimum pressure required for preventing apnea at different sleep phases and postures. The ideal pressure can not only eliminate snoring but also maintain blood oxygen saturation at a normal level (>90%) during sleep. In clinical practice, the final pressure used for treatment is usually much higher than the normal range of middle ear pressure.\textsuperscript{11} Long-term CPAP therapy administered via a face mask during sleep may lead to the pressure transmission to the middle ear through the opening of the eustachian tube, thus affecting the pressure in the middle ear.

As an important protective mechanism for the human body, swallowing facilitates the removal of saliva and fluid secreted by salivary glands that are retained in the pharynx, and it protects the lung and airway.\textsuperscript{12,13} However, swallowing does not only occur in a conscious state. Regular swallowing action also occurs during sleeping, especially during deep sleep.\textsuperscript{14,15} Studies in the literature have reported that OSAHS patients swallow less frequently during sleep than healthy people do. However, some studies also showed that swallowing often occurs after apnea or hypopnea in OSAHS patients. In 2011, Sato et al\textsuperscript{14} proved that when OSAHS patients were receiving CPAP treatment, the frequency of their swallowing during sleep did not significantly differ from that in healthy people. Therefore, we speculate that in OSAHS patients who are receiving CPAP treatment, normal swallowing occurs during sleep, which is accompanied by opening of the eustachian tube, through which the pressure of the CPAP can be continuously transmitted to the middle ear cavity.

In this study, the middle ear pressures of the OSAHS patients and healthy volunteers were measured at different pressures of the CPAP before and after swallowing. The results showed that for both the OSAHS patients and the healthy subjects, middle ear pressure increased with the increase pressure of the CPAP. In particular, the middle ear pressure after swallowing almost linearly correlated with the pressure of the CPAP, with a Pearson correlation coefficient of 0.812. The differences of the middle ear pressure before and after swallowing at CPAPs of 5, 10, and 15 cm H$_2$O were statistically significant ($P < .05$). At the same pressure of the CPAP, regardless of swallowing, the middle ear pressure in the study group was always slightly higher than that in the control group, with a statistically significant difference ($P < .05$). Therefore, we propose that the key influencing factors of middle ear pressure are CPAP and the swallowing action during CPAP treatment. CPAP is the fundamental factor that affects middle ear pressure. At the time of swallowing, the transmission of CPAP to the middle ear cavity via the eustachian tube is the determining factor of whether the middle ear pressure increases proportionally. Other influencing factors include the time and degree of the opening of the eustachian tube during swallowing and the contraction or relaxation of surrounding structures after the closing of the eustachian tube. At the same pressure of the CPAP, the middle ear pressure in the OSAHS group was slightly higher than that in the healthy group, regardless of the swallowing action. Given that most OSAHS patients are overweight, local fat accumulation and extrusion of soft tissues may cause a further increase in middle ear pressure. At a CPAP of 15 cm H$_2$O, the 2 groups had no obvious

### Table 2. Comparison of Middle Ear Pressure between the OSAHS and Healthy Volunteer Groups before and after Swallowing.$^a$

<table>
<thead>
<tr>
<th>CPAP, cmH$_2$O</th>
<th>Before Swallowing</th>
<th>After Swallowing</th>
<th>t$_1$</th>
<th>P$_1$</th>
<th>Before Swallowing</th>
<th>After Swallowing</th>
<th>t$_2$</th>
<th>P$_2$</th>
<th>t$_3$</th>
<th>P$_3$</th>
<th>t$_4$</th>
<th>P$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>21.2 ± 6.1</td>
<td>21.6 ± 7.2</td>
<td>0.238</td>
<td>.812</td>
<td>17.6 ± 7.2</td>
<td>17.7 ± 6.7</td>
<td>0.334</td>
<td>.739</td>
<td>2.364</td>
<td>.020</td>
<td>2.357</td>
<td>.020</td>
</tr>
<tr>
<td>5</td>
<td>22.6 ± 7.2</td>
<td>42.6 ± 8.1</td>
<td>3.624</td>
<td>.004</td>
<td>18.7 ± 7.6</td>
<td>44.2 ± 8.2</td>
<td>3.718</td>
<td>.003</td>
<td>2.276</td>
<td>.024</td>
<td>2.319</td>
<td>.022</td>
</tr>
<tr>
<td>10</td>
<td>22.7 ± 7.3</td>
<td>81.4 ± 11.7</td>
<td>5.334</td>
<td>&lt;.001</td>
<td>19.5 ± 7.2</td>
<td>85.6 ± 15.4</td>
<td>6.512</td>
<td>&lt;.001</td>
<td>2.204</td>
<td>.029</td>
<td>2.506</td>
<td>.014</td>
</tr>
<tr>
<td>15</td>
<td>23.4 ± 7.4</td>
<td>118.6 ± 15.2</td>
<td>9.154</td>
<td>&lt;.001</td>
<td>20.8 ± 8.4</td>
<td>120.5 ± 16.2</td>
<td>9.425</td>
<td>&lt;.001</td>
<td>2.251</td>
<td>.026</td>
<td>2.314</td>
<td>.227</td>
</tr>
</tbody>
</table>

Abbreviations: CPAP, continuous positive airway pressure; OSAHS, obstructive sleep apnea-hypopnea syndrome.

$^a$P$_1$, comparison before and after swallowing in the study group; P$_2$, comparison before and after swallowing in the control group; P$_3$, comparison between study and control groups before swallowing; P$_4$, comparison between study and control groups after swallowing.
difference in acoustic stapedial reflex. The incidence rates of the reduction in the sensitivity of the acoustic stapedial reflex in the 2 groups were only 3% (OSAHS) and 5% (healthy), indicating that short-term CPAP does not exert negative effects on the stapedius muscle or that the negative effects caused by the short-term pressure change are not sufficient to affect the sensitivity of the acoustic stapedial reflex.

Normally, middle ear pressure can rarely reach 40 daPa, whereas during this experiment, the mean middle ear pressure reached 40 daPa at a CPAP of 5 cm H2O. When OSAHS patients receive CPAP treatment, their middle ears are also subjected to long-term pressure that exceeds the physiologic level. Long-term positive pressure may exert negative effects on the neural reflex and muscular functions in the middle ear and eventually affect the hearing of OSAHS patients. Before prescribing long-term CPAP treatment for OSAHS patients, physicians should be vigilant of potential auditory problems—especially for OSAHS patients with hearing impairment or other ear diseases—and deliberately consider the possible long-term effects of CPAP treatment for OSAHS patients who need to receive ear surgery (eg, tympanoplasty, ossiculoplasty, or stapedectomy). Whether CPAP treatment should be administered immediately after surgery or when to receive the CPAP treatment needs to be further studied.

In addition, all the subjects in this study were tested in a conscious state, but in clinical practice, most OSAHS patients receive CPAP treatment during sleep. Certain errors may exist between the measured and actual values. However, in this study, the subjects were instructed to swallow voluntarily to mimic involuntary swallowing during sleep. Therefore, the changes in middle ear pressure should be similar to the actual values. Moreover, as all subjects received short-term CPAP therapy, the possible reduction in the sensitivity of the acoustic stapedial reflex caused by long-term CPAP treatment cannot be excluded. Owing to the limited number of cases in this study, errors might exist between the final statistical results and the actual values.

Conclusions
CPAP affected the middle ear pressures of both the OSAHS patients and the healthy subjects and positively correlated with middle ear pressure after swallowing. In addition, short-term CPAP treatment did not affect the acoustic stapedial reflex of the OSAHS patients and healthy subjects, but the possible effect of long-term CPAP treatment in reducing the sensitivity of the acoustic stapedial reflex cannot be excluded.

Author Contributions
Jinrang Li, design the study, revised the article, final approval, accountability for all aspects of the work; Keliang Li, collected data, analyzed the data, drafting the paper.

Disclosures
Competing interests: None.
