Relative Occurrence of Flow Limitation and Snoring During Continuous Positive Airway Pressure Titration*

Indu Ayappa, PhD; Robert G. Norman, MS; Jean-Jacques Hosselet, MD; Roger A. Gruenke, PhD; Joyce A. Walsleben, PhD; and David M. Rapoport, MD, FCCP

**Objectives:** To examine the relative temporal appearance of flow limitation and snoring during continuous positive airway pressure (CPAP) titration, compare their sensitivity as indicators of airway obstruction, and assess their relative utility as feedback variables for automatic titration of CPAP.

**Design:** Retrospective review of data.

**Setting:** University teaching hospital.

**Patients:** Fifty-three patients diagnosed as having obstructive sleep apnea or upper airway resistance syndrome undergoing CPAP titration.

**Measures and results:** We used a prototype automatic CPAP device that adjusts pressure in response to apnea, snoring, and/or flow limitation. The present study takes advantage of the frequent automatic decreases in pressure from a therapeutic level, as well as any technician-initiated decreases in pressure. We tabulated, for each pressure decrease of >0.4 cm H2O, the occurrences of snoring alone, flow limitation alone, or simultaneous appearance of both. Of 2,177 automatic pressure decreases, 64% resulted in flow limitation alone, 8% in snoring alone, and 22% in the simultaneous occurrence of both. Overall, 86% of decreases resulted in flow limitation alone or were simultaneous with snoring, whereas 30% of decreases resulted in snoring alone or were simultaneous with flow limitation. In 10 of 35 patients, snoring alone occurred in >10% of the pressure decreases. In all but 5 of 133 manual pressure decreases, flow limitation developed at or above the pressure at which snoring developed.

**Conclusions:** While detection of snoring occasionally provided additional information, overall flow limitation was the earliest indicator of obstruction during decreases in CPAP.

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**Key words:** auto-CPAP; CPAP; flow limitation; obstructive sleep apnea; snoring; UARS; upper airway

**Abbreviations:** AHI=apnea/hypopnea index; CPAP=continuous positive airway pressure; OSAS=obstructive sleep apnea syndrome; UARS=upper airway resistance syndrome

In recent years, there has been increasing recognition that abnormal respiratory events other than apnea can occur during sleep. These include hypopnea, snoring, elevated upper airway resistance events, and flow limitation. This expansion of what is considered “abnormal” has implications for the therapeutic titration of continuous positive airway pressure (CPAP). While all CPAP treatment protocols are directed to the elimination of apnea and hypopnea, there is less agreement on the goals of therapy when applied to more subtle indicators of upper airway dysfunction. Many clinical protocols quote the need to eliminate snoring, and this has also been used as a feedback signal to control some “auto-CPAP” devices. We have established that the presence of an abnormal contour on the inspiratory airflow waveform is indicative of flow limitation and noninvasively identifies increased upper airway resistance.

Both flow limitation and snoring identify behavior...
of the airway thought to be related to collapsibility, and thus share several characteristics. Both have been proposed to identify elevated upper airway resistance events missed by standard monitoring.3,4,10 Both are often seen in the same patients who elsewhere have apnea/hypopnea and both tend to precede these frank reductions in airflow. Furthermore, arousals can occur after either snoring11 or flow limitation,12 even without the occurrence of frank apnea or hypopnea. During CPAP titration, both flow limitation and snoring persist at pressures that have obliterated apnea and hypopnea, and both may appear and disappear with small changes in CPAP.

Previous investigations of the relationship between snoring and flow limitation in the same subject have resulted in contradictory results. Liistro and coworkers13 concluded that “flow limitation appears to be a sine qua non for snoring during sleep,” but in a later study that evaluated simulated snoring,14 they found that snoring was not necessarily accompanied by flow limitation. Our clinical experience suggests that some patients exhibit both flow limitation and snoring simultaneously, while others exhibit only one or the other with similar consequences.

In the present study, we report on data collected during titration of CPAP, examining the relative temporal appearance of flow limitation and snoring, and compare their sensitivity as indicators of airway obstruction.

**Materials and Methods**

Full-night polysomnography records from 53 patients (41 male, 12 female) with the obstructive sleep apnea syndrome (OSAS) or upper airway resistance syndrome (UARS) undergoing initial CPAP titration were reviewed. For some of the analyses, the subjects were arbitrarily grouped by their apnea/hypopnea index (AHI) into “moderate/severe OSAS” (AHI ≥30) and “UARS/mild apnea” (AHI <30), as is the clinical practice in our laboratory. CPAP was adjusted using a prototype of an automatically adjusting CPAP device that increased pressure in response to upper airway obstruction and decreased it when normal breathing was detected (see below). In addition, on several occasions during each recording, the technician systematically lowered CPAP from a therapeutic level to determine if excessive pressure was present (see below for details). Recordings included EEG (C3/A2, O1/A2), electro-oculography, submental electromyography, ECG, anterior tibialis electromyography, and respiratory effort (thoracic and abdominal movement). Airflow and respiratory pressure were measured via the CPAP generator from an internal pneumotachograph and pressure transducer.

Inspiratory and expiratory snoring were measured with a contact microphone (EFM Systems; Midlothian, VA), placed on the anterior part of the neck (over the trachea) and also with an acoustic vibration detection circuit (Nellcor Puritan Bennett France Development, Nancy, France). This circuit detected 30- to 280-Hz vibration in the air column of the CPAP circuit. A preliminary validation of the sensitivity of the acoustic vibration circuit relative to the surface microphone was carried out in 1,000 breaths in two patients. Each breath was scored separately for snoring from both the cervical microphone and the output of the snoring detection circuitry. Scoring of each signal was performed while blinded to the other. We then tabulated the number of breaths detected by only the cervical microphone, by only the acoustic vibration sensor, or by both simultaneously. Of the 1,000 breaths analyzed, 202 had “snoring” detected by at least one sensor; 147 of 202 “snores” (73%) were detected simultaneously by both sensors, 191 of 202 (95%) were detected by the acoustic vibration sensor, and 158 of 202 (78%) were detected by the cervical microphone. Only 11 acoustic events were detected by the microphone alone, whereas 44 acoustic events were detected by the acoustic vibration sensor alone. We thus concluded that the acoustic vibration board was the more sensitive indicator of “snoring” and used this signal in the present study.

Flow limitation was identified by the appearance of a characteristic plateau in the inspiratory flow/time contour,16 measured directly from the internal pneumotachograph within the CPAP generator. CPAP was titrated with a prototype computer-controlled device that used an algorithm responding to changes in the inspiratory flow/time contour and/or to the occurrence of snoring. The control algorithm increased CPAP in response to flow limitation and/or snoring and decreased pressure in response to their absence. The breath-by-breath basis of the control algorithm resulted in oscillation of CPAP around a critical therapeutic pressure that eliminated all apnea, hypopnea, snoring, and flow limitation, and provided frequent decreases in pressure. Only the downward pressure changes were analyzed in this study.

In 35 of the patients, all decreases in pressure of at least 0.4 cm H2O were identified. The breaths during and following each of these were examined for the appearance of flow limitation and snoring. We tabulated the pressure decreases as to whether they resulted in flow limitation alone, snoring alone, both snoring and flow limitation within two breaths of each other, or apnea/arousal.

We also analyzed all manual (nonautomatic) pressure decreases initiated by the technician in order to titrate CPAP. In the 53 patients, these manual CPAP titrations were performed one to four times per night in rapid eye movement and non-rapid eye movement sleep: starting from a therapeutic level, the pressure was decreased by 1 cm H2O each minute until apnea or arousal occurred. The pressure at which flow limitation first developed and the pressure at which snoring first developed were recorded and the difference between these pressures was calculated.

The protocol was approved by the New York University Institutional Board of Research Associates and all patients gave informed consent.

**Results**

Clinical data on the subjects are shown in Table 1. The variables reported cover the range of age, height, weight, gender, and severity of AHI seen in the sleep laboratory.

**Table 1—Clinical Data**

<table>
<thead>
<tr>
<th></th>
<th>OSAS (n=35)</th>
<th>Mild OSAS and UARS (n=18) (AHI &lt;30%)</th>
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</thead>
<tbody>
<tr>
<td>Age, y/</td>
<td>11-52</td>
<td>6-70</td>
</tr>
<tr>
<td>Sex, F/M</td>
<td>8/27</td>
<td>4/14</td>
</tr>
<tr>
<td>Height, cm</td>
<td>152.5-180</td>
<td>115-186.25</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>57.15-211.95</td>
<td>19.35-180</td>
</tr>
<tr>
<td>AHI/h</td>
<td>38.1-167.5</td>
<td>3.3-26</td>
</tr>
<tr>
<td>Prescribed CPAP, cm H2O</td>
<td>4-14</td>
<td>6-15</td>
</tr>
</tbody>
</table>
During CPAP titration, there were a total of 2,177 automatic pressure decreases in 35 subjects and 133 manual pressure decreases in 53 subjects. Oscillations in pressure during automatic CPAP ranged from 0.5 to 3 cm H₂O and during manual pressure adjustments, the pressure decreases were between 2 and 15 cm H₂O. Figure 1 shows examples of automatic pressure decreases resulting in flow limitation alone (top), snoring alone (center), and the simultaneous occurrence of both flow limitation and snoring (bottom). These examples all occurred in the same patient at different times during the night.

Figure 2 shows, for each subject, the proportion of pressure decreases resulting in flow limitation alone, snoring alone, or their simultaneous occurrence. In most patients, flow limitation was the most frequent result of pressure decrease. This was variably associated with snoring. However, snoring alone occurred in at least 10% of the pressure decreases in 10 of 35 patients. We could detect no statistically significant difference (unpaired t test, p>0.5) in the age, height, weight, AHI, or prescribed CPAP between these subjects and those in whom flow limitation predominated (snoring alone <10%). In particular, the proportion of subjects who showed snoring first >10% of the time was similar in those with UARS/mild apnea (3/11) and those with moderate/severe OSAS (7/24).

Table 2 shows summary data for all subjects. Flow limitation occurred significantly more often than snoring (86% vs 30%, p<0.001). Additionally, flow limitation alone occurred more frequently than snoring alone (64% vs 8%, p<0.001). Simultaneous occurrence of flow limitation and snoring was observed in 21% of decreases in CPAP. However, it should be noted that once one event occurred, the nature of our automatic CPAP titration algorithm caused pressure to be increased and this tended to preclude the subsequent appearance of the other (snoring or flow limitation).

Table 3 tabulates the effect of pressure decreases on the occurrence of flow limitation and snoring separately for subjects with an AHI of <30/h (UARS/mild OSAS) and those with ≥30/h (severe OSAS). There was no significant difference in the frequency of occurrence of flow limitation and snoring (χ²=0.6, p=not significant) as these occurred during CPAP titration.

Figure 3 shows the difference, for all manual pressure decreases (n=133), between the pressure at which flow limitation developed and the pressure at which snoring developed when CPAP was continuously decreased to the point of apnea or arousal. During these manual pressure decreases, flow limitation generally developed at or above the pressure at which snoring developed, but the difference in pressure was quite variable (ranging from 0 to 15 cm H₂O). In 33 of 133 decreases, snoring did not occur at any pressure prior to the termination of the CPAP decrease (due to appearance of apnea or arousal). However, in 3 of 133 instances, snoring developed at a pressure 1 cm H₂O higher than flow limitation, and in two instances, flow limitation never occurred during the change in CPAP.

There was no relationship between the level of
CPAP at which a pressure decrease was initiated and the relative frequency with which flow limitation and snoring occurred.

**DISCUSSION**

The present study demonstrates that flow limitation occurred more often than snoring during small decreases in CPAP from the therapeutic pressure that abolished all respiratory events. Furthermore, flow limitation generally either preceded snoring or occurred simultaneously with snoring. This was true for both the grouped data and for individual patients. When CPAP was lowered sufficiently for both flow limitation and snoring to occur (during 98 of 133 manual downward titrations), the difference in pressure at which they appeared was >5 cm H₂O in 11 of 98 titrations. Thus, overall, flow limitation was the more sensitive indicator of upper airway obstruction during downwards titrations of CPAP. Despite this, in 10 of 35 patients, snoring contributed to the early detection of upper airway obstruction in at least 10% of that patient’s decreases in CPAP.

The results we obtained are necessarily dependent on the chosen method of detecting flow limitation and snoring. Flow limitation was identified with custom software that analyzed the contour of the inspiratory flow signal. The flattened contour identified by this technique has been shown to correlate with directly measured elevated upper airway resistance. Clearly the automated detection of this shape will vary with the algorithm used, but our algorithm generally correlates with the visual detection of

![Figure 2](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21828/)

**Table 2—Relative Occurrence of Flow Limitation and Snoring During Decreases in CPAP**

<table>
<thead>
<tr>
<th>Pressure Decreases Resulting in</th>
<th>Automatic Decreases (n=2,177)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow limitation without/snoring</td>
<td>55.5%</td>
</tr>
<tr>
<td>Snoring without/flow limitation</td>
<td>29.5%</td>
</tr>
<tr>
<td>Flow limitation alone</td>
<td>64.5%</td>
</tr>
<tr>
<td>Snoring alone</td>
<td>8.5%</td>
</tr>
<tr>
<td>Flow limitation and snoring</td>
<td>21.0%</td>
</tr>
<tr>
<td>No flow limitation or snoring</td>
<td>6.0%</td>
</tr>
</tbody>
</table>

**Table 3—Occurrence of Flow Limitation and Snoring During Decreases in CPAP by Severity of Disease**

<table>
<thead>
<tr>
<th>Pressure Decreases Resulting in</th>
<th>AHI &gt;30 (n=24 Subjects)</th>
<th>AHI &lt;30 (n=11 Subjects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow limitation with/snoring</td>
<td>85%</td>
<td>87%</td>
</tr>
<tr>
<td>Snoring with/flow limitation</td>
<td>30%</td>
<td>28%</td>
</tr>
<tr>
<td>Flow limitation only</td>
<td>63%</td>
<td>67%</td>
</tr>
<tr>
<td>Snoring only</td>
<td>9%</td>
<td>8%</td>
</tr>
<tr>
<td>Flow limitation and snoring</td>
<td>21%</td>
<td>20%</td>
</tr>
<tr>
<td>No flow limitation or snoring</td>
<td>7%</td>
<td>5%</td>
</tr>
</tbody>
</table>
altered inspiratory contours (unpublished data). Snoring in the present study was identified from vibrations detected in the nasal CPAP air column by a proprietary analog circuit (Nellcor Puritan Bennett France Development). As shown by our preliminary testing (see “Materials and Methods” section), this circuit was more sensitive than a contact microphone placed on the trachea. Although the vibrations detected are not exactly what is heard audibly as “snoring,” they were always detected when the technician reported snoring. Thus, our data should maximize the occurrence of snoring and therefore tend to understate the difference between the sensitivity of flow limitation and snoring detection.

The method in which we controlled the CPAP was also a constraint on our data collection. In the automatic CPAP titration runs, as soon as either flow limitation or snoring (or both) were detected, the pressure was automatically increased. Thus, the appearance of flow limitation or snoring precluded the appearance of the other signal a few seconds later on a subsequent breath at the same or at a lower pressure. During the manual downward CPAP titrations, we did not face this limitation. From these data (Fig 3), we can confirm the generally greater sensitivity of flow limitation, as well as observe that not infrequently there were large differences in the CPAP at which flow limitation and snoring appeared.

The present study shows that, although flow limitation and snoring often coexist, neither is an absolutely necessary condition for the other to be present. Our data do not address the mechanisms by which these markers of elevated upper airway resistance or airway collapse occur, but do suggest that these may be slightly divergent. Despite this, the relative distributions of flow limitation and snoring were similar in patients with mild and severe disease (Table 3). Furthermore, our data show that across the entire spectrum of severity (UARS to OSAS), the airway shows similar collapsible behavior when titrated to a pressure just below therapeutic CPAP. We interpret this to suggest that there is similarity in the pathophysiologic state of these disorders.

The upper airway is known to show hysteresis in the appearance of its collapsible behavior. We have shown that the pressure at which flow limitation disappeared during CPAP increases was higher than that at which it recurred during CPAP decreases.9 The existence of a similar hysteresis in the behavior of snoring has never been investigated, and it is not...
addressed by our data. It is unclear what effect hysteresis might have on the relationship between the appearance of snoring and that of flow limitation during changes in CPAP. This may have implications for the issue of CPAP titration protocols.

There has been little standardization of the methods used in CPAP titration in clinical practice. The present data set has implications for the development of protocols used to titrate CPAP, whether by manual or automatic control. The sensitivity of the various indexes of subtle abnormalities of the upper airway will determine the pressure that is chosen as a therapeutic end point. The therapeutic pressure chosen would tend to be lowest if only apnea and hypopnea are examined. Other commonly used end points, the elimination of O₂ desaturations and arousal, tend to result in higher therapeutic pressures. Our data suggest that between flow limitation and snoring, the former will tend to be more sensitive in many situations and thus result in higher therapeutic recommendations. Montserrat et al. have come to the conclusion that “the contour of inspiratory flow (flow limitation) appears as the simplest variable that best correlates with the lowest esophageal pressure during CPAP titration.” Our data suggest that the elimination of both flow limitation and snoring may provide a more appropriate (and thus perhaps “best”) end point for therapy. However, the choice of any technique for choosing a single therapeutic pressure would need to be justified by a long-term study that addresses a clinically relevant outcome measure.

In automatic closed loop CPAP titration, commonly called “auto-CPAP,” the choice of the feedback variable is a critical determinant of the performance of the algorithm, because such algorithms are most stable when based on a sensitive indicator of the controlled process. This tends to minimize “overshoot,” which causes large oscillations. Both flow limitation and snoring were present long after all apneas and hypopneas had been obliterated, but our data show that flow limitation appears to be more sensitive overall than snoring. Thus, flow limitation may be the best single feedback variable on which to perform a therapeutic titration, while snoring may play a complementary role if multiple signals are used.

**References**

5. Rapoport DM. Methods to stabilize the upper airway using positive pressure. Sleep 1996; 19(9 suppl):S125-S130