Gender Differences in Sleep Apnea*

The Role of Neck Circumference

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Study objectives: To determine whether differences in sleep apnea severity between men and women referred to a sleep clinic are related to the differences in neck circumference (NC).

Study Design: Case series.

Setting: University hospital sleep disorders clinic.

Participants: A total of 3,942 patients (2,753 men and 1,189 women) referred to the sleep clinic.

Measurements and results: All patients underwent nocturnal polysomnography. NC was used as a surrogate measure of upper airway obesity. We found that sleep apnea, defined as the apnea/hypopnea index (AHI) > 10/h, was significantly more frequent (60% vs 32%, \(\chi^2 < 0.0001\)) and severe (mean ± SE, 25 ± 6/h vs 12 ± 19/h, \(p < 0.0001\)) in men than in women. Men had significantly larger NC than women, but the difference became much less pronounced when we normalized NC to body height (0.24 ± 0.02 vs 0.23 ± 0.03, \(p < 0.0001\)). Men had significantly higher AHI than women even after controlling for age, body mass index (BMI), and neck/height ratio (NHR); analysis of covariance showed that mean AHI was 24.4 ± 0.4 in men vs 14.8 ± 0.7 in women (\(p < 0.0001\)). This difference persisted even when we matched men and women for NHR and BMI. Finally, multiple regression analysis revealed the following: (1) NHR was the most significant predictor of AHI, accounting for 19% of the variability; and (2) the slope of AHI vs NHR was significantly higher in men than in women.

Conclusions: We conclude the following: (1) the frequency and severity of sleep apnea in the sleep clinic population is greater in men than women, and (2) factors other than NC, age, and BMI must contribute to these gender differences.

Key words: gender; neck circumference; sleep apnea

Abbreviations: AHI = apnea/hypopnea index; BMI = body mass index; NC = neck circumference; NHR = neck/height ratio; OSA = obstructive sleep apnea; \(O_2\)sat = oxygen saturation

More than 20 years ago, before obstructive sleep apnea (OSA) syndrome became well recognized as a distinct disease, Block et al.\(^1\) pointed out that respiratory pauses during sleep (apneas and hypopneas) and episodes of oxygen desaturation are more common among men than women, suggesting that hormonal factors may be one of the reasons accounting for these differences in sleep-disordered breathing. Gender differences in the abnormalities of nocturnal respiration were subsequently reported by other investigators, some of whom studied healthy community dwellers,\(^2–4\) while others studied patients referred to sleep clinics specifically for evaluation of possible sleep apnea.\(^5\) In the widely quoted Wisconsin Sleep Cohort Study\(^2\) the prevalence of sleep-disordered breathing in men (24%) was almost three times higher than in women (9%).

Not only is sleep-disordered breathing more common in men than women, but its severity is also gender dependent. Men have more severe sleep apnea than women, although this difference becomes less significant for postmenopausal women.\(^6,7\) The reasons for the gender differences in the prevalence and severity of sleep apnea are multifactorial, some of the most important factors being differences in body fat distribution,\(^8,9\) abnormalities in upper airway mechanics,\(^10,11\) control of breathing,\(^12,13\) and structural differences in upper airway dimensions.\(^12–15\)
This study focuses on the role of obesity in explaining some of the gender-related differences in sleep apnea. Several previous investigators have already emphasized its importance; both generalized obesity as reflected by weight or body mass index (BMI), as well as regional obesity as reflected by parapharyngeal fat deposits or neck circumference (NC). A short and fat neck in patients with sleep apnea, both men and women, is a very characteristic sign of this disease. Measurement of NC has become a standard part of physical examination of patients suspected of having sleep apnea. We know that regional distribution of body fat is different in men and women. The differences in lower-body obesity (waist and hips) are well described. Men tend to gain weight around the waist, whereas women tend to gain it around the hips.

Differences in upper-body obesity (NC) between genders are less well studied. It is therefore possible that gender differences in sleep apnea are at least partially related to gender differences in upper-body obesity. Consequently, in this study we undertook a systematic examination of the relationship between upper airway obesity and sleep apnea in a large cohort of men and women referred to a sleep disorder center.

**Materials and Methods**

**Patient Population**

Our total population consisted of 3,942 patients, 2,753 men and 1,189 women. They constituted a very heterogeneous group in terms of presenting complaint. Many were referred because of snoring; others because of bedpartner’s observation of episodes of cessation of breathing, thus raising a concern about sleep apnea. Others were referred because of daytime symptoms (eg, sleepiness, tiredness, or fatigue), and the remainder because of insomnia, suspected parasomnia, headaches, or other symptoms. All underwent full diagnostic polysomnography carried out in our in-hospital sleep laboratory.

**Overnight Polysomnography**

Surface electrodes were used to record two-channel EEG (C3A2, C4A1), electrooculography (F7A1, F8A2), and submental electromyography. Oronasal temperature monitored using thermistors served as a surrogate measure of airflow. Respiratory effort was recorded by respiratory plethysmography, with transducers placed around the chest and abdomen (Respirtrac; Ambulatory Monitoring; Ardsley, NY). Arterial oxygen saturation (O2sat) was monitored using a pulse oximeter (Biox 3700 or 3740; Ohmeda; Boulder, CO) set at its fastest response. All variables were recorded either on a polygraph recorder at a paper speed of 10 mm/s or using a computerized acquisition system. All polysomnograms were scored manually. Sleep stage and arousals were determined according to established criteria. An obstructive apnea was defined as a cessation of airflow for > 10 s despite persistent respiratory effort. An hypopnea was defined as a reduction in the amplitude of respiratory effort by at least 50% of the baseline sleeping level, for > 10 s and accompanied by oxygen desaturation of ≥ 4%. The apnea/hypopnea index (AHI) was defined as the number of apneas and hypopneas per hour of sleep.

**Anthropomorphic and Demographic Measurements**

The data collected included age, gender, height, weight, and NC. Since taller people are expected to have larger necks, we normalized NC for body height by calculating the neck/height ratio (NHR). Not unexpectedly, the effect of this normalization was to minimize the differences between men and women, as may be seen in Figure 1; we note that the distributions of NHR for men and women are closer together than the distributions of NC. Measurements of height, weight, and NC were performed by qualified sleep laboratory technicians on the evening of the sleep study. BMI was calculated as weight (in kilograms) divided by the square of the height (in meters).

**Statistical Analysis**

The data were analyzed in order to answer the main question posed in our study: can the difference in AHI between men and women be explained by the differences in NC (or NHR)? We
used two main techniques to answer this question: (1) t tests comparing groups of men and women matched for BMI and NHR, and (2) multiple regression analysis.

**Comparison of Matched Samples**

It is important to understand the rationale for this analysis. We hypothesized that if the only determinants of AHI are NC and BMI, then when we compare a group of men and women matched for NHR and BMI, they should have similar AHI. If we find differences in AHI, it implies that factors other than NC and BMI are responsible for the gender-related differences in apnea severity. Consequently, we classified all patients (men and women) into quartiles of NHR, and took each quartile and matched men and women within it one-for-one for BMI. This procedure resulted in four groups of patients—four quartiles of NHR—with men and women within each quartile having identical BMI. We used t tests to compare AHI between men and women within each group. This analysis of matched samples was preceded by a more general analysis of covariance comparing AHI between men and women after matching for age, BMI, and NHR.

**Multiple Regression Analysis**

This analysis was used to study the relationship between AHI and NC. Separate analysis was carried out for men and women, according to the model $AHI = \text{age}, \text{BMI}, \text{NHR}$. The slopes of the relationship between AHI and NHR were compared between men and women using analysis of covariance. All statistical analyses were carried out using SAS Statistical Software (Version 8; SAS Institute; Cary, NC).

**RESULTS**

Table 1 shows the summary of our patient population; it gives the results for the entire group of 3,942 patients, and also for men and women separately. Interestingly enough, men and women had similar age and BMI, but the NC was significantly larger in men. Although this difference persisted after normalizing for height, the effect of this normalization was to bring the distributions of NHR for men and women closer together (Fig 1).

Similar to what is invariably seen in clinic populations, we also found that sleep apnea was more common in men than in women. This result was independent of the definition of apnea, i.e., whether we use 5/h, 10/h, or 15/h as the AHI cutoff (Table 2); in fact, the more restrictive is the definition, the higher is the ratio of men to women with sleep apnea.

Analysis of covariance, carried out comparing AHI in men and women controlling for age, BMI, and NHR, revealed that men had significantly higher AHI than women (mean ± SE: 24.4 ± 0.4/h for men vs 14.8 ± 0.7/h for women, p < 0.0001). Quartile and matching analysis (Fig 2) shows the values of AHI for men and women within each neck quartile defined in Table 3. We note that within each quartile, AHI is significantly higher in men than in women, despite similar NHR and BMI.

Multiple regression analysis shows qualitatively similar results for men and women. NHR was the most significant predictor of AHI for both genders, accounting for 19% of variability (of a total of 22% for the entire model) in men, and for 22% variability (of total of 23% for the entire model) in women. Analysis of covariance demonstrated that the slope of the AHI vs NHR relationship was significantly higher in men than in women (Fig 3).

**DISCUSSION**

The main finding of our study is that in a sleep clinic population, the differences in apnea severity between men and women are only partially explained by the differences in NC; most (almost 80%) of the variability in AHI is due to other factors.

Since NC is a surrogate measure of upper airway fat, and fat deposition may affect both the anatomy and the function of the pharynx, let us briefly review the evidence linking pharyngeal properties, gender, and sleep apnea. Examination of pharyngeal resistance in men and women reveals conflicting results. Early investigations found that in awake normal men, pharyngeal resistance is double that in normal women; however, this difference was not reproduced in a younger group of men and women studied using different techniques. In a more recent study,

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**Table 1—Sleep and Anthropomorphic Data**

<table>
<thead>
<tr>
<th>Variables</th>
<th>All Patients (n = 3,942)</th>
<th>Men (n = 2,753)</th>
<th>Women (n = 1,189)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>48 ± 13</td>
<td>48 ± 13</td>
<td>48 ± 14</td>
</tr>
<tr>
<td>BMI</td>
<td>30.7 ± 7.2</td>
<td>30.6 ± 6.8</td>
<td>31.0 ± 8.9</td>
</tr>
<tr>
<td>NC, cm</td>
<td>40.3 ± 4.7</td>
<td>41.0 ± 5.6</td>
<td>36.5 ± 4.2</td>
</tr>
<tr>
<td>NHR</td>
<td>0.24 ± 0.03</td>
<td>0.24 ± 0.02</td>
<td>0.23 ± 0.03</td>
</tr>
<tr>
<td>AHI, No/h</td>
<td>21.5 ± 25.3</td>
<td>25.5 ± 26.6</td>
<td>12.4 ± 19.3</td>
</tr>
<tr>
<td>Mean $O_2$ sat, %</td>
<td>92.3 ± 3.7</td>
<td>92.2 ± 3.7</td>
<td>93.4 ± 3.5</td>
</tr>
<tr>
<td>Lowest $O_2$ sat, %</td>
<td>79.4 ± 15.6</td>
<td>77.9 ± 16.2</td>
<td>82.8 ± 13.3</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD.

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**Table 2—Frequency of Sleep Apnea in Men and Women According to Different Definitions of Apnea**

<table>
<thead>
<tr>
<th>Definition of OSA</th>
<th>Men With OSA, No. (%)</th>
<th>Women With OSA, No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHI &gt; 5/h</td>
<td>2,149 (78)</td>
<td>604 (51)*</td>
</tr>
<tr>
<td>AHI &gt; 10/h</td>
<td>1,657 (60)</td>
<td>386 (32)*</td>
</tr>
<tr>
<td>AHI &gt; 15/h</td>
<td>1,378 (50)</td>
<td>272 (23)*</td>
</tr>
</tbody>
</table>

*p < 0.0001 compared to men.
Trinder et al\textsuperscript{11} found similar pharyngeal resistance during sleep in healthy men and women, but men exhibited greater increments in upper airway resistance than women during established slow-wave sleep. Other investigators\textsuperscript{27,28} failed to find consistent differences in pharyngeal structure and/or function during sleep. For example, Rowley et al\textsuperscript{28} measured upper airway resistance and critical closing pressure in normal men and women during sleep and found no gender-related differences.

Similar uncertainties are found in studies of ventilatory responses in men and women. Early investigations during wakefulness\textsuperscript{29} revealed that obese men have depressed responses to hypoxia and hypocapnea, which may predispose them to disordered breathing during sleep. Later studies,\textsuperscript{12} performed during sleep, also indicated that men are less able to preserve ventilatory motor output during hypocapnia than women, thus predisposing them toward development of sleep-disordered breathing. The complexity of the problem is illustrated by recent work of Pillar et al,\textsuperscript{10} who showed that despite having similar central drive and ventilatory response to resistive loading, men had increased susceptibility to upper airway collapse during loaded breathing; the authors concluded that perhaps anatomic factors or intrinsic tissue properties are responsible for the observed gender differences in sleep apnea.

Based on the available data, it is still too premature to conclude that women have higher upper airway dilator muscle activity than men, thus accounting for reduced severity and lower prevalence of sleep apnea as compared to men. Differences in the upper airway anatomy between men and women are also a subject of some disagreement, although only a very few studies specifically addressed this issue. The major reason for the divergent findings is probably

| Table 3—Distribution of Sleep and Anthropomorphic Data According to NHR Quartiles$^*$ |
|-----------------|--------|--------|
| Quartile 1, NHR < 0.220 | Men    | Women  |
| Age             | 44 ± 14 | 44 ± 14 |
| BMI             | 24.2 ± 3.1 | 24.2 ± 3.1 |
| AHI             | 12.6 ± 15.4 | 5.5 ± 8.4 |
| Mean $O_2$ sat | 93.8 ± 1.9 | 94.6 ± 1.9 |
| Lowest $O_2$ sat | 85.5 ± 8.1 | 88.1 ± 6.5 |
| Quartile 2, 0.220 ≤ NHR < 0.235 | | |
| Age             | 47 ± 13 | 51 ± 13 |
| BMI             | 29.2 ± 3.9 | 29.2 ± 3.9 |
| AHI             | 17.1 ± 17.6 | 10.5 ± 14.6 |
| Mean $O_2$ sat | 92.7 ± 2.3 | 93.9 ± 2.4 |
| Lowest $O_2$ sat | 81.5 ± 10.7 | 84.5 ± 9.3 |
| Quartile 3, 0.235 ≤ NHR < 0.253 | | |
| Age             | 49 ± 13 | 52 ± 14 |
| BMI             | 33.9 ± 5.2 | 33.9 ± 5.2 |
| AHI             | 29.9 ± 26.9 | 16.1 ± 19.6 |
| Mean $O_2$ sat | 91.6 ± 2.8 | 92.9 ± 2.6 |
| Lowest $O_2$ sat | 76.9 ± 15.3 | 80.0 ± 14.0 |
| Quartile 4, NHR ≥ 0.253 | | |
| Age             | 50 ± 13 | 51 ± 13 |
| BMI             | 41.3 ± 7.2 | 41.3 ± 7.2 |
| AHI             | 47.2 ± 31.9 | 27.8 ± 30.3 |
| Mean $O_2$ sat | 88.5 ± 5.9 | 90.7 ± 5.2 |
| Lowest $O_2$ sat | 64.8 ± 20.7 | 72.3 ± 19.1 |

$^*$Data are presented as mean ± SD.
the fact that most measurements were carried out during wakefulness; additional reasons include differences in techniques, sample size, type of population studied, and lack of polysomnography in some studies. For example, some acoustic reflection measurements of pharyngeal area (all performed during wakefulness) found that normal women have smaller pharynx than men,\textsuperscript{30,31} while others did not.\textsuperscript{32,33} Mohsenin\textsuperscript{31} did find that men with sleep apnea had larger pharyngeal cross-sectional area than women, but the correlation between pharyngeal area and apnea severity was inconsistent, present in men but not in women. Cephalometric measurements do not demonstrate consistent differences in pharyngeal area between men and women, although some investigators do find relatively minor changes in certain ethnic groups of men vs women.\textsuperscript{14,34,35} CT and MRI studies noted more fat deposited along lateral pharyngeal walls in patients with sleep apnea than in control subjects\textsuperscript{17,15,36,37}; however, Whittle et al\textsuperscript{38} found similar total parapharyngeal fat volume in normal men and women, but greater total neck soft-tissue volume in men compared to women. Schwab\textsuperscript{39} pointed out current uncertainties regarding differences in upper airway structure and function between men and women, and concluded that there must be other important factors, in addition to gender, that affect upper airway calibre and increase the risk for sleep apnea. Kapsimalis and Kryger\textsuperscript{40,41} recently reviewed the entire subject of gender and sleep apnea, and concluded that several other factors in addition to obesity and upper airway fat must contribute to increased risk of sleep apnea observed in men.

Although there are still some uncertainties regarding gender-related differences in upper airway structure and function, there are by now no uncertainties regarding differences in pharyngeal properties between apneics and nonapneics, whether men or women. While early studies of sleep apnea emphasized the importance of obesity as a significant determinant of sleep-disordered breathing, subsequent investigations pointed out the importance of regional, rather than generalized obesity. Davies and Stradling,\textsuperscript{19} drawing on the results of Horner et al\textsuperscript{17} and Koenig and Thach,\textsuperscript{42} were first to note that NC was a better correlate of apnea severity than BMI or other indexes of obesity. This observation was confirmed by other investigators.\textsuperscript{20,43} Currently, neck size is considered to be one of the most important physical characteristic of patients with sleep apnea.

Our findings linking NC and sleep apnea in men

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Relationship between AHI and NHR for men and women obtained from multiple regression analysis, plotted for mean age of 48 years and mean BMI of 31.0 (mean ± SE).}
\end{figure}
and women indicate that regional distribution of body fat is a more significant determinant of AHI than generalized obesity. This interpretation is consistent with other investigations, cited above, showing that patients with sleep apnea have higher parapharyngeal tissue volume (either due to fatty deposits or tissue swelling) than nonapneic control subjects.

However, the difference in apnea severity between men and women is not related to neck size alone, because men had more severe sleep apnea than women despite having a similar NHR. The pattern of fat deposition is different in apneic men and women. As women become obese, more fat is preferentially deposited over the lower body as compared to the neck, so that by the time an apneic woman achieves the same AHI and NHR as a man, her BMI is higher than that of man. Predominance of lower distribution of body fat in women may protect them from OSA until sufficient fat is deposited around the upper airway (ie, the neck). However, this lower-body predominance of fat deposition is a normal pattern in women even in the absence of sleep apnea. Consequently, development of sleep apnea in women is not simply a consequence of increased neck fat, but must occur in conjunction with additional abnormality of pharyngeal structure and/or function. Parapharyngeal fat can affect pharyngeal cross-sectional area by direct loading of the pharynx with adipose tissue, and its collapsibility by infiltration of pharyngeal muscle tissue with fatty deposits.

Finally, we should emphasize again that our results apply to a sleep clinic, rather than a community population. There are no large-scale community studies comparing the relationship between NC and sleep-disordered breathing in men and women; however, a recent study of 15 men and 15 women from the general population found that NC was the key variable in determining the gender-related differences in the compliance of the upper airway. We speculate that this finding is probably true in sleep clinic patients as well, but there are additional factors, unrelated to NC, that account for the gender differences in the severity of sleep apnea.

In summary, we found that differences in NC between men and women explain about 20% of gender-related variability in apnea severity in patients referred to a sleep disorders clinic. Even after controlling for NC, BMI, and age, we found that women still had less severe sleep apnea than men. Consequently, functional differences in upper airway properties other than those directly related to “neck obesity” must contribute to gender differences in sleep apnea.

References
21 Davies RJ, At NJ, Stradling JR. Neck circumference and
31 Mohsenin V. Gender differences in the expression of sleep-disordered breathing: role of upper airway dimensions. Chest 2001; 120:1442–1447