S
leep-disordered breathing (SDB) may be considered a disease continuum. At one end lies primary snoring (PS), in which neither respiration nor sleep are significantly affected. Obstructive sleep apnea/hypopnea syndrome (OSA), at the opposite extreme, involves sleep-related upper airway obstruction that may result in repetitive sleep disruption, impaired oxygenation, excessive daytime sleepiness (EDS), and adverse hemodynamic consequences. The upper airway resistance syndrome (UARS) involves a milder degree of upper airway obstruction than OSA, and there is an absence of frank apnea or oxygen desaturation. However, arousals from sleep occur because of increased respiratory effort, and UARS may be associated with hypersomnolence and increased risk of cardiovascular sequelae, similar to OSA.

Both PS and OSA are readily identified during standard nocturnal polysomnography (NPSG) using a thermistor or thermocouple (TH). However, TH is unable to detect the subtle airflow abnormalities that characterize UARS. Conventional identification of UARS requires measurement of inspiratory effort, which correlates with upper airway resistance. Inspiratory effort is determined by estimating pleural pressure by monitoring esophageal pressure (Pes), which is invasive and uncomfortable, and may adversely affect sleep, and is thus not routinely used by most sleep centers. A simple and less invasive alternative to Pes monitoring to detect UARS is clearly needed.

Several recent studies have found that analysis of the inspiratory airflow vs time signal, measured using a nasal cannula/pressure transducer (NC), is comparable to the invasive determination of inspiratory pressure in assessing changes in upper airway resistance. This
analysis is based on the presence of a nonlinear airflow-pressure relationship, i.e., flow limitation, which develops when inspiratory resistance increases because of the inherent collapsibility of the upper airway. Preliminary investigations have found that NC is superior to TH in detecting flow-limited respiration in OSA as well as in UARS. However, these studies involved relatively small numbers of selected patients with known SDB. We sought to determine the diagnostic utility of NC, in comparison to TH, during routine, clinical NPSG in consecutive, nonselected patients with suspected SDB.

**Materials and Methods**

All patients underwent NPSG at the Roger Williams Sleep Disorders Center in Providence, RI, between March and September 1998. Patients were referred for suspected SDB, and none had been previously tested for, or diagnosed with, a sleep disorder. Patients were evaluated by history, physical examination, and the Epworth Sleepiness Scale (ESS) questionnaire. The study was approved by the institutional review board for human studies at Roger Williams Medical Center.

Because the sleep lab has two beds but only one NC, one bed was monitored using both TH and NC, while the second bed used only TH. Patients' bed assignments were randomized at the time of scheduling. Only those patients monitored with both NC and TH were included in the study.

Sleep monitoring was performed using surface-electrode recordings of central and occipital EEG (C3/A2, C4/A1, O2/A1, O1/A2 of the international 10–20 electrode placement system), electrocardiogram, and submental electromyogram. Sleep scoring was performed using criteria of Rechtschaffen and Kales. Leg movement was monitored using an anterior tibialis electromyogram. Cardiac monitoring was performed with ECG (modified lead V2). Blood oxygen saturation was determined with continuous pulse oximetry using a nasal cannula, and in two patients, the signal from the NC was unsatisfactory because of nearly complete nasal obstruction. An oronasal TH was used to measure airflow at the nose and mouth. An NC, which consisted of a ± 2 cm H2O pressure transducer (DP45; Validyne Engineering Corporation; Northridge, CA) connected to a nasal oxygen cannula, and in two patients, the signal from the NC was unsatisfactory because of nearly complete nasal obstruction and consequent mouth-breathing.

Respiratory arousal index (RAI) was defined as the number of apneas and/or hypopneas associated with an arousal per hour of sleep, as detected by TH (RAI-TH) or NC (RAI-NC). Apneas by TH or NC were defined as complete cessation of airflow for at least 10 s. Hypopneas by TH included any visually appreciable reduction in signal amplitude for two or more consecutive breaths followed by an arousal, regardless of oxygen desaturation. Hypopneas by NC included abnormality in the contour of the flow vs time signal for two or more consecutive breaths followed by an arousal, regardless of oxygen desaturation. Specifically, any flattening or plateau of this signal, which is normally rounded, or sinusoidal, was deemed to indicate flow limitation. Signal analysis for TH and NC and calculation of RAI were performed manually. Each signal was reviewed independently, without knowledge of the other signal (TH or NC) or any other patient information.

**Results**

Between March and September 1998, 182 overnight sleep studies were performed. Sixty-nine of these were studies to titrate continuous positive airway pressure (CPAP). Of the 113 diagnostic studies, 63 were performed with TH alone and 50 were performed with simultaneous recording of NC and TH. Five patients who had been assigned to combined NC and TH monitoring were studied using only TH; one patient refused to wear NC, two patients were unable to wear NC because they were oxygen dependent and already wore an oxygen cannula, and in two patients, the signal from the NC was unsatisfactory because of nearly complete nasal obstruction and consequent mouth-breathing.

Patient demographic and polysomnographic characteristics are shown in Table 1. There were 20 patients with OSA, 25 with UARS, and 5 with PS. Those with PS were younger than those with OSA and UARS. Patients with UARS and PS had a lower body mass index and less male predominance than those with OSA.

---

**Table 1—Patient Demographic and Polysomnographic Information**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>OSA (n = 20)</th>
<th>UARS (n = 25)</th>
<th>PS (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (range)</td>
<td>48 (28–66)</td>
<td>47.6 (28–81)</td>
<td>42.4 (35–55)</td>
</tr>
<tr>
<td>Male/female</td>
<td>15/5</td>
<td>14/11</td>
<td>3/2</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>35.9 (25–58)</td>
<td>31.9 (22–55)</td>
<td>29.4 (22–34)</td>
</tr>
<tr>
<td>ESS, mean (range)</td>
<td>13.5 (2–23)</td>
<td>10.8 (2–21)</td>
<td>7.2 (5–10)</td>
</tr>
<tr>
<td>TST, min</td>
<td>337.8 (252–414)</td>
<td>323 (180–408)</td>
<td>354 (342–360)</td>
</tr>
<tr>
<td>% SWS, mean (range)</td>
<td>6.3 (0–18)</td>
<td>5.7 (0–16)</td>
<td>9.3 (1–17)</td>
</tr>
<tr>
<td>RAI-TH, mean (range)</td>
<td>47.2 (16–100)*</td>
<td>8.4 (2–15)*</td>
<td>1.8 (0.2–3)*</td>
</tr>
<tr>
<td>RAI-NC, mean (range)</td>
<td>58.9 (24–116)*</td>
<td>25.2 (14–40)*</td>
<td>9 (6–13)*</td>
</tr>
</tbody>
</table>

*For each diagnostic category (OSA, UARS, and PS), mean RAI-TH and RAI-NC are significantly different, p < 0.001.

BMI = body mass index; TST = total sleep time; SWS = slow wave sleep.
mined by ESS, was highest in OSA and lowest in PS. All patients with OSA and UARS complained of EDS, despite some patients having a low score by the ESS. Total sleep time and slow wave sleep were reduced in OSA and UARS. Mean RAI-NC was greater than mean RAI-TH by 25% in OSA, 302% in UARS, and 500% in PS. The one-sided paired $t$ test\textsuperscript{18} on the means of RAI-NC and RAI-TH for OSA, UARS, and PS gave $t$ values of 5.74, 14.74, and 7.36, respectively, each with an associated $p < 0.001$. Hence, the mean values for RAI-NC were significantly larger than those for RAI-TH for each diagnostic category. The coefficients of variation of RAI-NC and RAI-TH measurements were 26% and 60%, respectively, for UARS, indicating that the RAI-NC measurements were relatively more consistent than those of RAI-TH.\textsuperscript{19}

A direct comparison of RAI-TH and RAI-NC for all 50 patients is shown in Figure 1. The RAI-NC was always greater than RAI-TH for each patient. The increased sensitivity of NC varied inversely with the RAI-TH.\textsuperscript{19}

A comparison of OSA, UARS, and PS as measured by RAI-NC and RAI-TH (Fig 2) was made using analysis of variance procedure. Analysis of variance gave an $F$ value of 27.66 for RAI-NC and 31.02 for RAI-TH, indicating that the values for each diagnostic category, determined by either RAI-NC or RAI-TH, were significantly different. The Newman-Keuls multiple comparison procedure\textsuperscript{20} showed that for RAI-NC, UARS was different from PS at a significance level of 0.10 and OSA was different from PS and UARS at a significance level of < 0.05. However, for RAI-TH, UARS and PS were not significantly different at a level of 0.10, but both groups were significantly different from OSA ($< 0.05$). Thus, RAI-NC was able to better differentiate UARS from PS.

**DISCUSSION**

The standard means to identify UARS is by monitoring Pes, which detects increased inspiratory effort in response to elevations in upper airway resistance. Pes monitoring is not used by most sleep centers, however, because of its invasive nature. Thus, most patients with UARS remain undiagnosed, and the prevalence of this form of SDB is unknown.\textsuperscript{2} A variety of noninvasive methods have been proposed to detect UARS, including analysis of systolic BP profile, thoracic and abdominal effort phase angles, pulse transit time, upper airway impedance using forced oscillatory flow, respiratory impedance plethysmography, and inspiratory flow contour.\textsuperscript{7,10} Of these methods, inspiratory flow contour analysis has been shown to accurately identify changes in upper airway resistance.\textsuperscript{10,11,21} The shape of a normal inspiratory flow vs time signal is rounded or sinusoidal. A flattening or plateau of this morphology implies flow limitation, which is characterized by a nonlinear relationship between airflow and driving pressure secondary to increased airway resistance.
Breathing. However, in most instances, significant unsatisfactory, because of nearly complete mouth-breathing. In only two instances was the signal SDB. The use of NC was well-tolerated by nearly all patients, and in only two instances was the signal unsatisfactory, because of nearly complete mouth-breathing. In most instances, significant mouth-breathing should not be a major impediment to the use of NC.12 Our results confirm previous findings that NC detects the majority of apneas and hypopneas seen with TH, whereas TH detects far fewer events seen by NC in milder degrees of SDB.12 The greater sensitivity of NC was most apparent in those with low numbers of TH-detected events (Fig 1). Moreover, NC was able to better differentiate UARS from PS, whereas there was overlap in the number of TH-detected events in UARS and PS (Fig 2). Although there was also overlap in RAI-NC between OSA and UARS (Fig 2), the importance of differentiating these two entities may be trivial, given the similar underlying pathophysiology, symptomatology, and potential clinical consequences.

We incorporated an RAI in our analysis for several reasons. First, frequent respiratory-related arousals have been shown to cause daytime somnolence,22 and their inclusion provides an additional physiologic correlate of EDS.23,24 Second, patients with UARS and PS do not have a significant number of apneas or hypopneas detected by TH, whereas the former group does have an increased arousal index. Finally, arousals represent a direct consequence of the preceding respiratory event, whereas the significance of respiratory events that do not cause discernible arousals is not known. Because of the greater sensitivity of NC, specificity was maximized by including only those respiratory events leading to an arousal. We found an unequivocal association between arousals and respiratory events in patients with UARS using NC, whereas with TH, this association was rarely detectable.

CPAP treatment may be beneficial for patients with mild SDB, including UARS, although compliance is generally poor.3,25,26 Of the 25 patients with UARS reported here, 9 were successfully treated with CPAP and 1 improved with weight loss. Eight patients refused CPAP treatment, and we were unable to obtain follow-up for the remaining 7 patients.

It was surprising to find UARS in 50% of the 50 patients reported herein. Because all patients were either self- or physician-referred for suspected SDB, we cannot extrapolate the prevalence of UARS in the general population from this study. However, our findings do suggest that UARS may have a high prevalence among individuals suspected of SDB.

There is a growing appreciation for the need to identify patients at the milder end of the spectrum of SDB.26 Our study confirms previous reports that NC is superior to TH in detecting mild, but clinically significant, sleep-related respiratory events. By maximizing diagnostic sensitivity (by detecting flow-limited respiratory events with NC) and specificity (by linking these respiratory events to an arousal), we have found a simple, objective means to identify UARS among patients with a range of SDB. NC may represent a novel and simple alternative to Pes monitoring to detect UARS during NPSG.

**REFERENCES**

1. Lugaresi E, Plazzi G. Heavy snorer disease: from snoring to the sleep apnea syndrome—an overview. Respiration 1997; 64(suppl 1):11–14
5. Silverberg DS, Oksenberg A. Essential hypertension and abnormal upper airway resistance during sleep. Sleep 1997; 20:794–806
7. Ruhle KH, Schlenker E, Randeraath W. Upper airway resistance syndrome. Respiration 1997; 64(suppl 1):29–34
15. Sleep Disorders Atlas Task Force of the ASDA. EEG arous-