Effect of negative expiratory pressure on respiratory system flow resistance in awake snorers and nonsnorers

CLAUDIO TANTUCCI, ALEXANDRE DUGUET, ANNA FERRERI, SELMA MEHRI, ISABELLE ARNULF, MARC ZELTER, THOMAS SIMILOWSKI, JEAN-PHILIPPE DERENNE, and JOSEPH MILIC-EMILI

Clinica di Semeiotica Medica, University of Ancona, 60020 Ancona, Italy; Laboratoire de Physio-Pathologie Respiratoire et Service de Explorations Fonctionnelles, Groupe Hospitalier Pitie-Salpetriere, University of Paris VI, Paris, Cedex 13, France; Divisione di Pneumologia, Ospedale Sant’Orsola-Malpighi, 40100 Bologna, Italy; and Meakins-Christie Laboratories, McGill University, Montreal, Quebec, Canada H2Z 2P2

Tantucci, Claudio, Alexandre Duguet, Anna Ferretti, Selma Mehri, Isabelle Arnulf, Marc Zelter, Thomas Similowski, Jean-Philippe Derenne, and Joseph Milic-Emili. Effect of negative expiratory pressure on respiratory system flow resistance in awake snorers and nonsnorers. J. Appl. Physiol. 87(3): 969–976, 1999.—In spontaneously breathing subjects, intrathoracic expiratory flow limitation can be detected by applying a negative expiratory pressure (NEP) at the mouth during tidal expiration. To assess whether NEP might increase upper airway resistance per se, the interrupter resistance of the respiratory system (Rint,rs) was computed with and without NEP by using the flow interruption technique in 12 awake healthy subjects, 6 nonsnorers (NS), and 6 nonapneic nonsnorers (S). Expiratory flow (V) and Rint,rs were measured under control conditions with V0.2-s NEP pulses from 1 to 7 cmH2O, in both the seated and supine position. In NS, Rint,rs with spontaneous increase in V and with NEP was similar (3.10 ± 0.19 and 3.30 ± 0.18 cmH2O·l·s at spontaneous V of 1.0 ± 0.01 l/s and at V of 1.1 ± 0.07 l/s with NEP (5 cmH2O), respectively). In S, a marked increase in Rint,rs was found at all levels of NEP (P < 0.05). Rint,rs was 3.5 ± 0.44 and 8.97 ± 3.16 cmH2O·l·s at spontaneous V of 0.81 ± 0.02 l/s and at V of 0.80 ± 0.17 l/s with NEP (5 cmH2O), respectively (P < 0.05). Although NEP increased Rint,rs markedly higher in S than in NS both seated (F = 8.77; P < 0.01) and supine (F = 9.43; P < 0.01). In S, V increased much less with NEP than in NS and was sometimes lower than without NEP, especially in the supine position. This study indicates that during wakefulness nonapneic S have more collapsible upper airways than do NS, as reflected by the marked increase in Rint,rs with NEP. The latter leads occasionally to an actual decrease in V such as to invalidate the NEP method for detection of intrathoracic expiratory flow limitation.

upper airway collapsibility; body position; resting breathing; snoring

RECENTLY, THE NEGATIVE expiratory pressure (NEP) method has been used to detect intrathoracic expiratory flow limitation in patients with chronic obstructive pulmonary disease (25). It consists of applying negative pressure at the mouth during a tidal expiration and comparing the ensuing flow-volume (V-V) curve with that of the previous control expiration. If NEP elicits increased V over the entire control tidal volume, the subject is not flow limited. In contrast, if with NEP the subject exhales partly or entirely along the control V-V curve, intrathoracic flow limitation is present. Although in normal subjects and chronic obstructive pulmonary disease patients the expiratory flow with NEP was previously reported as either increased or unchanged relative to control (15, 25), in subsequent experiments we have observed that in some instances NEP resulted in a drop in expiratory flow below control. Such a phenomenon was probably due to a marked increase in upper airway resistance. Indeed, because of their collapsibility, which is necessary to ensure swallowing and phonation, the upper airways, namely the oro- and hypopharynx, may represent a site susceptible to narrowing and closure in the face of administration of NEP (16).

The purpose of the present study was to assess whether NEP might increase upper airway resistance to such an extent as to mask any clue of intrathoracic flow limitation during the NEP test. Therefore, we determined in awake healthy subjects, both nonsnorers and snorers, the effects of different levels of NEP on expiratory flow resistance. Because the NEP method can be applied in any body position, we also investigated whether the gravitational instability associated with the assumption of the supine position could enhance the upper airway narrowing differentially and thus increase expiratory flow resistance during the NEP application in these two groups of subjects.

METHODS

Subjects. Twelve healthy men with no historical evidence of sleep disturbance, nocturnal apnea, hypersomnolence, or upper airway abnormality were studied. By interviewing their bedpartners, who completed a questionnaire assessing any history of snoring, nocturnal awakening, and excessive daytime sleepiness, six nonsnorers (subjects who occasionally snore) and six habitual snorers (subjects who snore almost nightly) were identified. Two nonsnorers were mild smokers (4 and 6 pack-yr, respectively). Informed consent was obtained from each individual.

Measurements. Lung volumes, maximal V-V curves, and airway resistance (Raw) were measured by using a constant-volume body plethysmograph (Autobox 2800; Sensor Medics, Yorba Linda, CA). Mouth flow was measured through a
hot-wire pneumotachograph linear up to 14 l/s (Sensor Medics). Volume was obtained by integrating the V̇ signal.

As soon as the subjects reached quiet, regular tidal breathing, the thoracic gas volume at end-tidal expiration (functional residual capacity [FRC]) was determined in duplicate by asking them to support their cheeks and pant at a frequency of <1 Hz against a closed shutter (13). Immediately after the opening of the shutter, the subjects inspired slowly until maximum to obtain the inspiratory capacity (IC) and compute the total lung capacity (TLC = FRC + IC), and then expired slowly and completely for measurement of vital capacity (VC) and computation of residual volume (RV = TLC – VC).

Subsequently, Raw was calculated by measuring at FRC, during gentle panting, inspiratory and expiratory changes in V and mouth pressure (Pm) after airway occlusion relative to changes (Δ) in pressure inside the box (Pbox). Raw was computed according to the equation Δpm/ΔPbox × ΔPbox/ΔV. The frequency response of the system was accurate up to 12 Hz.

Afterward, maximal V̇-V curves were determined by simultaneously plotting ΔV at the mouth against the expired volume obtained by time integration of V. In all instances the subjects inspired normally until TLC and then expired forcefully without an end-inspiratory pause to obtain the forced vital capacity (FVC). For analysis, the highest forced expiratory volume in s (FEV1) and the forced expiratory maneuver with the largest sum of FEV1 + FVC were selected from two acceptable expiratory maneuvers.

During the NEP test, V was measured with a Hans Rudolph pneumotachograph with a ±2.6 l/s linearity range (model 4700A; Hans Rudolph, Kansas City, MO) connected to the mouthpiece and a differential pressure transducer (MP45, ±2 cmH2O; Validyne, Northridge, CA), and pressure was measured at the airway opening (Pao) via a rigid polyethylene tube (ID = 1.7 mm) connected to a differential pressure transducer (DP15, ±150 cmH2O; Validyne). A solenoid valve (model RV-003, S/N 1003; Aeromech Devices, Almonte, PQ) was attached to the pneumotachograph to perform rapid airway occlusions. The solenoid valve, which could be activated either automatically or manually by a remote system, had a closure time of 12 ms, which was independent of V̇. The opening valve was activated when the expiratory flow reached a threshold level of 20 ml/s, with an optional delay that was empirically predetermined for each subject to apply NEP after ~50% of the control tidal volume had been exhaled. The NEP duration was 200 ms in all instances to avoid confounding behavioral responses that may be elicited by NEP (12).

The V and Pao signals were amplified (AC Bridge Amplifier-ABC module; Raytech Instruments), low-pass filtered at 50 Hz, sent to a 16-bit analog-to-digital converter (Direc Physiologic Recording System; Raytech Instruments) connected to an IBM-compatible computer (486DX, 66 MHz), and sampled at 200 Hz. Both digitized signals were displayed in real time on the computer screen together with the V signal obtained by numerical integration of the V signal. The tracings were continuously monitored both with respect to time and as V̇-V curves. The recordings were stored on the computer hard disk in Direc format and used for subsequent analysis. Data analysis was performed by using either the Direc (version 3.1; Direc NEP software, Raytech Instruments) or the Anadat (version 5.2; RHT-InfoDat, Montreal, PQ) data-analysis software.

In snorers, overnight sleep studies were performed to confirm the absence of obstructive sleep apnea-hypopnea syndrome and consisted of full polysomnography, including a measurement of airflow with thermocouples, detection of respiratory effort by inductive plethysmography, microphone recording of respiratory sounds, and monitoring of arterial oxygen saturation via a finger probe (Night Owl, Rocket Polygraph; Respironics, Murraysville, PA). Obstructive apnea was defined as the absence of airflow for >10 s with paradoxical thoracoabdominal respiratory movements, whereas hypopnea meant a >50% reduction in airflow amplitude with a decrease in oxygen saturation of at least 4%.

Experimental protocol. During the study, the subjects, wearing a noseclip and breathing through a rigid mouthpiece, were placed in a comfortable dentist’s chair with the neck fixed in a neutral position. Initially, they were studied sitting upright and, next, by rotating the chair, in a supine position without any change in the experimental setup. They were asked to firmly support their cheeks to minimize the artifacts in P and V due to the compliance of the upper airways.

The interrupter resistance of the respiratory system (Rint,rs) was measured during expiration in both positions according to the standard flow interruption technique as previously described in detail (2, 3). Briefly, when the expiratory flow is suddenly interrupted at the mouth, Pao immediately rises to P1, reflecting the resistive pressure drop across the respiratory system. Because of the inertial oscillations of P associated with the rapid closure of the valve, P1 is obtained by back extrapolation of the Pao signal after these oscillations to the time corresponding to zero flow (2). Division of this pressure change (Pao – P1) by the expiratory flow immediately preceding the interruption gives expiratory Rint,rs (2,
Anthropometric and functional characteristics of subjects

Table 1. Anthropometric and functional characteristics of subjects

<table>
<thead>
<tr>
<th>No.</th>
<th>Subject</th>
<th>Snoring Condition</th>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>BMI, kg/m²</th>
<th>FVC, %pred</th>
<th>FEV₁, %pred</th>
<th>TLC, %pred</th>
<th>VC, %pred</th>
<th>FRC, %pred</th>
<th>Raw, cmH₂O·l⁻¹·s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NS</td>
<td>35</td>
<td>187</td>
<td>85</td>
<td>24.3</td>
<td>104</td>
<td>124</td>
<td>110</td>
<td>115</td>
<td>100</td>
<td>1.68</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>NS</td>
<td>23</td>
<td>185</td>
<td>84</td>
<td>24.5</td>
<td>106</td>
<td>100</td>
<td>103</td>
<td>97</td>
<td>1.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>NS</td>
<td>28</td>
<td>175</td>
<td>72</td>
<td>23.5</td>
<td>111</td>
<td>95</td>
<td>96</td>
<td>106</td>
<td>87</td>
<td>1.92</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>NS</td>
<td>25</td>
<td>172</td>
<td>65</td>
<td>22.0</td>
<td>112</td>
<td>100</td>
<td>110</td>
<td>107</td>
<td>125</td>
<td>1.54</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>NS</td>
<td>24</td>
<td>185</td>
<td>66</td>
<td>19.3</td>
<td>99</td>
<td>105</td>
<td>96</td>
<td>94</td>
<td>129</td>
<td>1.27</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>NS</td>
<td>21</td>
<td>187</td>
<td>82</td>
<td>23.4</td>
<td>108</td>
<td>99</td>
<td>97</td>
<td>103</td>
<td>101</td>
<td>1.53</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>26</td>
<td>182</td>
<td>76</td>
<td>22.8</td>
<td>107</td>
<td>104</td>
<td>102</td>
<td>106</td>
<td>107</td>
<td>1.63</td>
</tr>
<tr>
<td>±SD</td>
<td></td>
<td></td>
<td>±5</td>
<td>±7</td>
<td>±9</td>
<td>±2.0</td>
<td>±5</td>
<td>±10</td>
<td>±7</td>
<td>±17</td>
<td>±0.24</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>S</td>
<td>51</td>
<td>173</td>
<td>86</td>
<td>28.7</td>
<td>112</td>
<td>94</td>
<td>98</td>
<td>107</td>
<td>110</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>S</td>
<td>42</td>
<td>177</td>
<td>63</td>
<td>26.5</td>
<td>104</td>
<td>87</td>
<td>93</td>
<td>99</td>
<td>108</td>
<td>1.95</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>S</td>
<td>44</td>
<td>173</td>
<td>73</td>
<td>24.4</td>
<td>115</td>
<td>96</td>
<td>97</td>
<td>110</td>
<td>104</td>
<td>1.36</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>S</td>
<td>28</td>
<td>191</td>
<td>102</td>
<td>27.9</td>
<td>93</td>
<td>103</td>
<td>100</td>
<td>94</td>
<td>101</td>
<td>1.34</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>S</td>
<td>29</td>
<td>161</td>
<td>65</td>
<td>25.1</td>
<td>81</td>
<td>89</td>
<td>92</td>
<td>88</td>
<td>100</td>
<td>2.37</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>S</td>
<td>37</td>
<td>178</td>
<td>82</td>
<td>26.0</td>
<td>81</td>
<td>87</td>
<td>89</td>
<td>81</td>
<td>81</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>38</td>
<td>176</td>
<td>82</td>
<td>26.4</td>
<td>98</td>
<td>93</td>
<td>95</td>
<td>97</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td>±SD</td>
<td></td>
<td></td>
<td>±9</td>
<td>±10</td>
<td>±13</td>
<td>±1.6</td>
<td>±15</td>
<td>±7</td>
<td>±4</td>
<td>±11</td>
<td>±0.40</td>
<td></td>
</tr>
</tbody>
</table>

BMI, body mass index; FVC, forced vital capacity; FEV₁, forced expiratory volume in 1 s; TLC, total lung capacity; VC, vital capacity; FRC, functional residual capacity; Raw, airway resistance; pred, predicted. NS, nonsnorers; S, snorers. *P < 0.01.

3). In normal subjects Rint,rs represents mostly airway flow resistance (i.e., Raw), although it also includes a small component due to the chest wall (Rint,w) (7, 17).

The Rint,rs first was measured during expiration without NEP while the subjects were exhaling voluntarily at different flow rates when sitting (Fig. 2A). Subsequently, NEP of −1, −3, −5, and −7 cmH₂O was randomly applied both in the seated and supine position, obtaining a wide range of flow rates. In all instances Rint,rs was measured by always interrupting V 120–180 ms after the onset of NEP application (Fig. 2, B and C).

The interruptions of expiratory flow were performed either in the absence of the NEP or during NEP after −50% of the control tidal volume had been exhaled.

Both in nonsnorers and snorers the values of interrupter resistance that were obtained at similar flow rates occurring immediately before the flow interruption were used to compare Rint,rs in the absence and presence of the NEP in the seated position and between the snorers and nonsnorers during the NEP application in either position.

Statistical analysis. Student's t-test was used to compare anthropometric and functional characteristics of the two groups. Two-way ANOVA was used to make a statistical comparison for Rint,rs in each group with V and NEP as within-position factors. Because no assumption about the scatter of the data could be made, a Mann-Whitney test was performed to make orthogonal comparison when allowed. P values < 0.05 were considered as significant.

Data are expressed as means ± SE unless otherwise specified.

RESULTS

All six subjects who were referred to as snorers were actually true nonapneic snorers, as objectively confirmed by visual scoring of microphone recording of the respiratory sounds in full-disclosure mode and by an hypopnea-apnea index (<5 episodes/h of sleep without overnight oxygen desaturation >4%).
The anthropometric and functional characteristics of the subjects are given in Table 1. Anthropometric features of snorers were similar to those of nonsnorers, except for age and the body mass index (BMI) (Table 1).

Pulmonary function tests were normal in all subjects without differences between snorers and nonsnorers. Raw was 1.63 ± 0.10 cmH2O·l−1·s in the nonsnorers and 1.79 ± 0.16 cmH2O·l−1·s in the snorers (Table 1).

Under control conditions, at resting expiratory flow rates, Rint,rs did not differ significantly between nonsnorers and snorers when sitting (2.33 ± 0.11 vs. 2.34 ± 0.27 cmH2O·l−1·s). With spontaneously increasing expiratory flows, Rint,rs increased more in snorers than in nonsnorers (Fig. 3, A and B). This was because the slope K2 of the classic Rørher’s equation (Rint,rs = K1 + K2V) was slightly greater in snorers than in nonsnorers (Table 2). In nonsnorers Rint,rs was measured at a lung volume (ΔV) 0.27 ± 0.04 liter above FRC, whereas in snorers the corresponding value was 0.36 ± 0.03 liter.

During application of NEP, the relationship of Rint,rs to V in nonsnorers did not change with respect to the values obtained by spontaneously increased flows (F = 0.07; not significant) (Fig. 3A). In contrast, in snorers Rint,rs exhibited a marked increase with NEP compared with the values measured under control conditions at similar flow rates (F = 8.46, P < 0.05) (Fig. 3B).

Baseline Rint,rs (NEP = 0 cmH2O) increased from the seated to supine position, in both nonsnorers (from 2.30 ± 0.10 to 2.89 ± 0.22 cmH2O·l−1·s; not significant) and snorers (from 2.80 ± 0.23 to 4.18 ± 0.66 cmH2O·l−1·s; P < 0.05). In the supine position, baseline Rint,rs was higher, although not significantly, in snorers (4.18 ± 0.66 cmH2O·l−1·s) than in nonsnorers (2.89 ± 0.22 cmH2O·l−1·s) at a comparable flow rate (0.45 ± 0.07 vs. 0.43 ± 0.04 l/s).

With NEP, Rint,rs was markedly higher in snorers than in nonsnorers, both seated (F = 8.77; P < 0.01) and supine (F = 9.43; P < 0.01) (Fig. 4, A and B). This difference increased with increasing level of NEP and was more pronounced in the supine position (Fig. 4B). In nonsnorers Rint,rs with NEP was measured at ΔV of 0.29 ± 0.03 liter in the seated position and 0.30 ± 0.02 liter in the supine position. In snorers the corresponding values of ΔV were 0.36 ± 0.01 liter and 0.42 ± 0.01 liter.

In all nonsnorers (subjects 1–6) during the application of NEP, V was consistently higher than before NEP, both seated and supine (Fig. 5). In contrast, the snorers (subjects 7–12) exhibited a smaller increase in expiratory flow with NEP that was independent of the level of NEP applied. In most of these subjects the expiratory flow with NEP was sometimes lower that before NEP, especially in the supine position (Fig. 5).

**DISCUSSION**

The main findings of this study are that, in healthy awake nonsnorers, NEP levels between −3 and −5...
cmH₂O, which are commonly used to detect intrathoracic expiratory flow limitation, did not increase expiratory flow resistance relative to that obtained without NEP at corresponding flow rates. In contrast, in healthy awake nonapneic snorers such levels of NEP were associated with a marked increase in interrupter expiratory resistance, which was more pronounced in the supine position. It follows that the NEP test may at times not be useful in assessing intrathoracic expiratory flow limitation in snorers, particularly when they are in the supine position.

Before a discussion of the results of the present study, some general considerations regarding the resistance measurement are required. In normal individuals Rint,rs represents Raw plus a small but definite component of newtonian Rint,w, which in supine, anesthetized-paralyzed normal subjects amounts to 0.4 ± 0.1 cmH₂O·l⁻¹·s⁻¹. Because Rint,w is independent of V and hence it affects only K₁ (see Table 2), by subtracting the average value of Rint,w (0.4 cmH₂O·l⁻¹·s⁻¹) from the individual values of Rint,rs measured during normal breathing at rest, Raw should be obtained. Thus for all subjects Raw should amount to 1.93 ± 0.14 cmH₂O·l⁻¹·s⁻¹. In the same subjects Raw measured directly with the body plethysmograph (Table 1) amounted to 1.71 ± 0.09 cmH₂O·l⁻¹·s⁻¹ and was lower, although not significantly, than the estimated value of Raw described above. This small discrepancy may be explained by the fact that Rint,rs was measured during expiration, whereas Raw obtained with the plethysmograph reflected both inspiration and expiration. In fact, Raw tends to be higher during expiration than inspiration because of greater laryngeal resistance (20). Furthermore, during panting laryngeal resistance tends to decrease.

Rint,rs with spontaneously increasing V. In both nonsnorers and snorers, Rint,rs increased with spontaneously increasing V according to Rorher’s equation (Fig. 3, A and B). The value of the coefficient K₂ (1.24 ± 0.18 cmH₂O·l⁻²·s⁻²) in the seated nonsnorers was higher than that previously ascribed to normal awake seated subjects (~0.3 cmH₂O·l⁻²·s⁻²) (8, 19). This probably reflects the fact that the latter measurements were obtained by using the esophageal balloon method and hence included viscoelastic pressure dissipations, the magnitude of which decreased with increasing V (19) and, as a result, K₂ was underestimated. Because, in humans, the upper airways contribute substantially to K₂ (6), the higher value of K₂ exhibited by our nonsnorers may also be due, in part, to greater flow turbulence in the upper airways during expiration. The even greater value of K₂ found in our six snorers could reflect structural or functional abnormalities in their upper airways.

The increase in baseline Rint,rs, which we observed in both nonsnorers and snorers in the supine position, is consistent with previous results in both normal subjects (9, 14) and nonapneic snorers (5, 18). In our nonapneic snorers, the increase in Rint,rs when there was a shift from the seated to the supine position was more marked than in our nonsnorers, suggesting a significantly greater reduction of upper airway dimensions.

Effect of NEP on Rint,rs. Although in the nonsnorers the relationship between Rint,rs and V was similar with V increased spontaneously and with NEP (Fig. 3A), in the snorers there was a marked increase in Rint,rs with NEP (Fig. 3B). Because in normal subjects Rint,w over the experimental V range (up to 1.2 l/s) is essentially independent of V (7), the marked increase in Rint,rs with NEP in the snorers (Figs. 2 and 3) must reflect a substantial increase in Raw, likely due to a reduction in caliber of the upper airways.

The fact that NEP increased Rint,rs only in snorers suggests that in nonsnorers there is a higher upper airway elastance and/or enough tone in the upper airway muscles to sustain NEP at least up to –7 cmH₂O.

When negative pressure pulses are applied at the mouth in normal awake subjects who relax the upper airway muscles, they are more prone to exhibit upper airway narrowing or even closure when V is present than under static conditions (0 flow) (26). This phenom-
non, which is present during both inspiration and expiration (21, 27), indicates that, under dynamic conditions, the relaxed upper airways are intrinsically unstable and relatively small intraluminal negative pressures can narrow or collapse them, unless there is activation of their dilating muscles. Our results show that, unlike in nonsnorers, in awake nonapneic snorers narrowing of upper airways can occur at relatively low values of NEP, suggesting that the upper airways of nonapneic snorers are much more collapsible than those of nonsnorers during wakefulness.

The decrease in tonic activity of upper airway muscles induced by sleep should enhance this abnormality. Indeed, during sleep a greater upper airway collapsibility in nonapneic snorers than in nonsnorers has been found in several previous studies (10, 13, 22). Abnormal tissue properties, abnormal linkage between dilator muscles and pharyngeal tissue caused by fatty infiltration of the lateral pharyngeal walls, or pharyngeal muscle hypotonia are factors that may contribute to increased collapsibility of the upper airways in the snorers (11). Because in the present study this functional characteristic was also demonstrated during wakefulness, snoring appears to be a problem inherent in highly compliant upper airways, although a facilitating role due to anatomic abnormalities of the upper airway at different sites (1, 4, 23) cannot be excluded. In addition, with the assumption of the supine position, Raw tends to increase more markedly in snorers. As a consequence, during sleep an upper airway instability, with repetitive oscillations of the walls, can occur once an appropriate relationship among V˙, airway compliance, and airway dimensions is attained in these subjects.

The results in Fig. 5 suggest that in snorers the NEP test may at times not be valid in detecting intrathoracic limitation of the lateral pharyngeal walls, or pharyngeal muscle hypotonia are factors that may contribute to increased collapsibility of the upper airways in the snorers (11). Because in the present study this functional characteristic was also demonstrated during wakefulness, snoring appears to be a problem inherent in highly compliant upper airways, although a facilitating role due to anatomic abnormalities of the upper airway at different sites (1, 4, 23) cannot be excluded. In addition, with the assumption of the supine position, Raw tends to increase more markedly in snorers. As a consequence, during sleep an upper airway instability, with repetitive oscillations of the walls, can occur once an appropriate relationship among V˙, airway compliance, and airway dimensions is attained in these subjects.

The results in Fig. 5 suggest that in snorers the NEP test may at times not be valid in detecting intrathoracic limitation of the lateral pharyngeal walls, or pharyngeal muscle hypotonia are factors that may contribute to increased collapsibility of the upper airways in the snorers (11). Because in the present study this functional characteristic was also demonstrated during wakefulness, snoring appears to be a problem inherent in highly compliant upper airways, although a facilitating role due to anatomic abnormalities of the upper airway at different sites (1, 4, 23) cannot be excluded. In addition, with the assumption of the supine position, Raw tends to increase more markedly in snorers. As a consequence, during sleep an upper airway instability, with repetitive oscillations of the walls, can occur once an appropriate relationship among V˙, airway compliance, and airway dimensions is attained in these subjects.

The results in Fig. 5 suggest that in snorers the NEP test may at times not be valid in detecting intrathoracic

Fig. 6. A: V˙-V loops obtained with NEP and preceding control tidal breath in a sitting snorer (subject 8) at rest. Arrows indicate onset and end of NEP application (−5 cmH₂O). With NEP expiratory flow shows transient drop below control flow, reflecting temporary increase in upper airway resistance. After this transient decrease in V˙, expiratory flow with NEP exceeded control flow, showing there was no intrathoracic flow limitation. FRC, functional residual capacity. B: same as in A, but flow with NEP remained below control flow throughout expiration, reflecting prolonged increase in upper airway resistance. In this case, NEP test is not valid for assessing intrathoracic flow limitation.
expiration, if the reduction in $V^\prime$ is transient, as shown in Fig. 6. As a rule, when intrathoracic flow limitation is present, the flow during NEP is partly or entirely superimposed on expiratory flow of the preceding control V-V curve. Conversely, in the presence of a marked increase in upper airway resistance as a result of NEP, as in snorers, flow with NEP sometimes drops below control. Subsequently, the relationship between flow with NEP and control flow in the expiratory V-V curve may change unpredictably, reflecting the changes in upper airway resistance in the face of prolonged application of NEP. In fact, the NEP test may still be valid for assessment of intrathoracic expiratory flow limitation, if the reduction in $V^\prime$ is transient, as shown in Fig. 6A. By contrast, if NEP elicits a sustained marked increase in upper airway resistance, such that the flow with NEP remains smaller than control flow until the end of expiration (Fig. 6B), the NEP test is no longer valid for assessment of intrathoracic expiratory flow limitation (25). However, this is usually uncommon even in snorers. Furthermore, valid measurements may be obtained with repeated NEP tests using low levels of NEP (e.g., $-3\text{ cmH}_2\text{O}$).

Age and BMI were higher in snorers. Age is considered a risk factor for snoring, along with others such as sex, obesity, smoking, nasal obstruction, and familial predisposition, because snoring prevalence increases by $-40$ yr of age (11); in the present study the snorers were older than the nonsnorers. Thus we cannot exclude that age rather than snoring was responsible for the increase in $R_{\text{int,rs}}$ with NEP in our snorers. However, this is unlikely for two reasons. First, definitely our snorers were not elderly ($38.4 \pm 3.7$ yr), and second, by dropping the youngest nonsnorer (subject 6) and the oldest snorer (subject 7), so that the age difference became nonsignificant, the effect of NEP on $R_{\text{int,rs}}$ remained identical in the snorers and nonsnorers and the mean values of $R_{\text{int,rs}}$ at different levels of NEP were superimposable in either the seated or supine position in both groups.

Despite a greater average BMI compared with that of the nonsnorers, all snorers had a BMI value in the normal range for men ($>29 \text{ kg/m}^2$), and no one could be categorized as an obese subject; hence, obesity may be reasonably ruled out as a confounding factor for $R_{\text{int,rs}}$ data in our snorers.

Although further studies are required to see whether the increase in Raw in the face of NEP occurs in all snorers but not in all nonsnorers, the results of this study suggest a potential role for the NEP technique to be applied in the assessment of upper airway function in subjects with proven obstructive sleep apnea/hypopnea syndrome, in view of its ability to differentiate among different categories of snorers while they are awake.

In conclusion, NEP, as used to detect intrathoracic expiratory flow limitation, does not increase airway expiratory flow resistance per se in awake healthy nonsnorers. In contrast, a marked increase in Raw, which likely reflects upper airways narrowing, can be induced by NEP in awake healthy snorers, sometimes promoting a paradoxical decrease in expiratory flow, especially in the supine position. This finding strongly indicates that the upper airway is more collapsible in nonapneic snorers than in nonsnorers even during wakefulness. A corollary is that in snorers the interpretation of the effect of NEP on the tidal expiratory flow can be complicated at times by a partial or total collapse of the upper airways.

We thank Patrice Vallée for invaluable technical assistance.

Address for reprint requests and other correspondence: C. Tantucci, Clinica di Semeiotica e Metodologia Medica, Ospedale Regionale Torrette, 60020 Ancona, Italy.

Received 2 November 1998; accepted in final form 5 May 1999.

REFERENCES


