Hemodynamic Effects of Nasal CPAP Examined by Doppler Echocardiography*

Judith A. Leech, M.D., F.C.C.P.; and Kathryn J. Ascah, M.D.

The effects of incremental application of nasal continuous positive airway pressure (0 to 15 cm H2O) on heart rate, pulmonary artery pressure, and cardiac index were studied noninvasively by Doppler echocardiography. By two-way analysis of variance within two groups (10 normal volunteers and six sleep apnea patients), no significant effects on heart rate, pulmonary artery pressure, ventricular size, or cardiac index could be found with increasing positive intrathoracic pressures and consequent lung hyperinflation. In subjects with normal cardiac function, nasal CPAP is safe from a hemodynamic viewpoint. This simple, repeatable and noninvasive technique may be used to assess the clinical safety and efficacy of prescribed nasal CPAP on cardiac hemodynamics in individual patients.

(Chest 1991; 99:323-26)

OSA = occlusive sleep apnea syndrome; AHI = apnea-hypopnea index; SI = shape index

Nocturnal nasal continuous positive airway pressure has become the first line therapy in occlusive sleep apnea syndrome.1 More recently, nasal CPAP has been recommended in central sleep apnea2 and in selected patients with combined Cheyne-Stokes respiration and congestive heart failure.3 While few side effects, apart from facial pressure and local irritative eye and nose effects, have been described, potential cardiac effects of the application of this form of positive intrathoracic pressure have not been well studied.

A potential fall in cardiac output similar to that seen with PEEP4,5 and variously explained by decreased venous return or impaired left ventricular function may occur.6,7 On the other hand, Takasaki et al8 have suggested that, at least in patients with CHF, there may be an actual improvement in left ventricular function, possibly through a fall in left ventricular afterload due to the generation of positive intrathoracic pressure.

The purpose of the present study was to examine the hemodynamics of nasal CPAP application noninvasively using Doppler echocardiography.

METHODS

Two groups were studied using echocardiographic techniques to

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Nasal CPAP (cm H2O)} & 0 & 5 & 10 & 15 & 20 \\
\hline
\text{Cardiac Index (L/min/kgm}^2\text{)} & 2.2 & 2.2 & 2.2 & 2.2 & 2.2 \\
\hline
\end{array}
\]

Figure 1. Cardiac index with incremental nasal CPAP (mean ± SEM); group 1 subjects.
Table 1—Left Ventricular Measurements in Diastole*

<table>
<thead>
<tr>
<th>Nasal CPAP, cm H2O</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, cm²</td>
<td>12.3</td>
<td>13.4</td>
<td>12.9</td>
<td>12.2</td>
</tr>
<tr>
<td>(± .9)</td>
<td>± .7</td>
<td>± .9</td>
<td>± .5</td>
<td>± .5</td>
</tr>
<tr>
<td>Circumference, cm</td>
<td>13.3</td>
<td>13.1</td>
<td>13.3</td>
<td>13.3</td>
</tr>
<tr>
<td>(± .4)</td>
<td>± .3</td>
<td>± .3</td>
<td>± .5</td>
<td>± .3</td>
</tr>
<tr>
<td>Shape index</td>
<td>.88</td>
<td>1.0</td>
<td>.9</td>
<td>.87</td>
</tr>
<tr>
<td>(± 0.3)</td>
<td>± .05</td>
<td>± .04</td>
<td>± .06</td>
<td></td>
</tr>
</tbody>
</table>

*Six group 1 subjects, mean ± 1 SEM.

...examine the effects of increasing levels of nasal CPAP. Group 1 consisted of normal volunteers recruited by advertisement. Present smokers, habitual snorers, or individuals with known cardiorespiratory disease were excluded. Group 2 consisted of patients with OSA, some of whom had known cardiac disease. Age, size, pulmonary function, arterial blood gases, apnea-hypopnea index (AHI), and nocturnal desaturation from nocturnal polysomnography were recorded in group 2 subjects. The nocturnal desaturation recorded was the average value of the nadir of desaturations following sleep-disordered breathing events.

Continuous positive airway pressure delivered by a tight-fitting nasal mask was applied for a minimum of 10 min at each of four sequential pressure settings (0, 5, 10, and 15 cm H2O). Sequential levels rather than random pressures were applied because of the known hysteresis effect with applications of PEEP. Patients were instructed to keep the mouth closed and glottis open throughout the examination. The pressure being delivered was continuously monitored at the nasal mask port and adjusted throughout the echocardiographic studies to within 2 cm H2O of the target setting at end expiration. With an open airway, the pressure within the nasal mask equals the intrathoracic pressure.

Doppler echocardiographic studies were conducted with the subjects in the left lateral or supine position using phased array or mechanical ultrasound instruments equipped with 2.5 or 3.5 mHz transducers. Standard two-dimensional echocardiographic views of the left and right ventricles were recorded from the parasternal and apical windows. Pulmonary blood flow was recorded with pulsed Doppler from a high parasternal short axis, with the sample volume placed just distal to the pulmonary leaflets. Aortic flow was recorded in a similar fashion from the cardiac apex. In all cases, an attempt to obtain the tricuspid regurgitant jet by chest wall Doppler was made. However, in three fourths of the subjects, no tricuspid regurgitant flow was detectable or the signal was suboptimal for quantitation. This prevalence of tricuspid regurgitation is similar to that reported in normal subjects. Imaging was carried out at baseline and during the three stages of CPAP and recorded on one-half inch VHS video tape for subsequent analysis.

Analysis of two-dimensional images and Doppler signals was carried out using an off-line echocardiographic analysis system calibrated for each instrument using a phantom. Cardiac output was calculated as the product of the cross sectional area of the aorta, aortic flow velocity integral and heart rate. Cardiac index was derived by dividing cardiac output by body surface area. Intraobserver and interobserver variability for calculating cardiac output in this manner is 1.6 and 2.9 percent, respectively. Since data were insufficient from peak tricuspid jet velocity to calculate pulmonary artery pressure, pulmonary artery pressure was estimated from the pulmonary flow signal using the equation of Babestani et al.* mean pulmonary artery pressure = $73.42 \times$ acceleration time.

In a subgroup of six group 1 patients, the effects of CPAP on ventricular size and configuration were also analyzed. The area and circumference of the left ventricular short axis cavity were measured and used to calculate the shape index (shape index [SI] = 4(area/circumference). The SI is an estimation of the roundness of the left ventricular cavity. When the ventricle is round, as in the normal situation, the index approaches one. Flattening of the interventricular septum, which occurs as right-sided pressures increase, depresses the shape index. Seven measures of the right ventricular diastolic cavity as described by Foale et al.* were also made at each level of nasal CPAP.

Two-way analysis of variance examining the intersubject and interpressure variability was used to compare each cardiac variable. The subjects were not obese with an average body mass index of 24.6 kg/m² (SEM = .66 kg/m²).

**Results**

**Group 1**

Nineteen normal volunteers were studied, of whom six were women. The average age was 38 years (SEM = 2.6 years) with a range of 23 to 76 years. Subjects were not obese with an average body mass index of 24.6 kg/m² (SEM = .66 kg/m²).

The effect of nasal CPAP level was not significant for heart rate ($p = 0.50$), mean pulmonary artery pressure ($p = 0.69$), nor cardiac index ($p = 0.93$) in the normal subjects, although the intersubject variability for each was significant. Figure 1 demonstrates mean...
results of cardiac index in these subjects at the applied levels of nasal CPAP. Results show no effect of applied positive pressure and may be lower on the average than would be seen using catheter techniques because of the noninvasive nature of the examination.

In the subset of six patients in whom left ventricular diastolic measurements were made (Table 1), increasing positive intrathoracic pressures did not affect left ventricular area, circumference, or shape. Similarly, multiple measurements of the right ventricular cavity failed to show any change with increasing levels of nasal CPAP (Table 2). Values for both ventricular sizes fell within normal limits regardless of applied positive pressures.

**Group 2**

There were six male patients in the OSA group. The average age was 45 years (range 23 to 64 years). Subjects were very obese with the exception of patient 3 who had pronounced micrognathia. All subjects had a severe degree of OSA as measured by an AHI of greater than 40 events per hour with relatively normal daytime arterial blood gas levels. Patient characteristics are described in Table 3.

Three patients had known cardiac disease. Patient 4 had electrocardiographic evidence of a previous anterior wall myocardial infarction. Patient 5 had a history of angina and documented significant three-vessel disease with normal left ventricular function. He was studied in a stable state immediately before aortocoronary bypass. Patient 6 presented in congestive heart failure with electrocardiographic evidence of a previous inferior wall myocardial infarction. At the time of this study, he had an ejection fraction of 35 percent.

Two way analysis of variance revealed the expected significant interindividual differences in cardiac output (F = 9.21, p < 0.0005) but no differences in cardiac index due to increasing levels of applied nasal CPAP (F = 1.08, p = 0.39). As Figure 2 shows, the three OSA subjects with known cardiac disease did not have greater falls in cardiac index than those without cardiac disease.

Lung hyperinflation did occur as a result of the increasing positive pressure delivered to the thorax. The effect of the hyperinflation was to make echocardiographic images more difficult to obtain in much the same way as emphysema affects the quality of echocardiographic images. The degree of difficulty of measurement of the right ventricular cavity was scored by two experienced observers and is shown in Table 4. Using this simple scoring system, it was clearly progressively more difficult to obtain a crisp echocardiographic signal at each increasing pressure level. While only three readings were of unsatisfactory quality (two of CPAP of 10 cm H$_2$O, one at CPAP of 15 cm H$_2$O), progressively greater time and effort were needed to obtain readable data at higher pressure settings.

**Table 4—Perceived Quality of Echocardiographic Signal in Group 1 Subjects**

<table>
<thead>
<tr>
<th>CPAP Level, cm H$_2$O</th>
<th>Observer 1</th>
<th>Observer 2</th>
<th>SEM (Pooled)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.8</td>
<td>1.7</td>
<td>0.15</td>
<td>(1-3)</td>
</tr>
<tr>
<td>5</td>
<td>2.2</td>
<td>2.1</td>
<td>0.16</td>
<td>(1-3)</td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
<td>2.6</td>
<td>0.19</td>
<td>(1-4)</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>2.9</td>
<td>0.13</td>
<td>(2-4)</td>
</tr>
</tbody>
</table>

*Scoring System: 1, easy; 2, slightly difficult; 3, very difficult; and 4, not possible.
DISCUSSION

In 19 normal subjects and six patients with OSA, we were unable to demonstrate a consistent fall, or rise, in cardiac output due to the incremental application of nasal CPAP. Similarly, heart rate, pulmonary artery pressure and ventricular size and shape were unaffected even as the lungs became hyperinflated from increasingly positive intrathoracic pressures.

Since the number of study subjects is small and the variance relatively large, the possibility of missing a statistically significant difference between pressure readings is relatively high, calculated to be about 70 percent. However, if one asks the probability of missing a clinically important difference, the β error for a change in cardiac output of, for example, 1 or 2 L/min would be 43 percent or 18 percent, respectively.6,14 We are, therefore, much less likely to be missing a change in cardiac output of the order to cause an important physiologic effect in normal subjects even though the sample size is small.

Positive pressure can be applied to the chest in a variety of ways including PEEP, CPAP, and nasal CPAP, as it is used in the treatment of obstructive sleep apnea syndrome. When the cardiac and hemodynamic effects of PEEP have been studied in animals or in humans with ARDS, several potential pathophysiological mechanisms of impairment of cardiac output have been implicated.6 Decreased systemic venous return due to increased intrathoracic pressure has been thought to be the main mechanism for the decrease in cardiac output.15 However, increased pulmonary vascular resistance16 and decreased left ventricular volume (due to an interventricular septal shift),17 contractility, or compliance18 have also been described in differing study conditions. The maintenance of a normal cardiac output in our study subjects was not due to an increase in heart rate as this also remained stable.

Left ventricular volume and shape remained normal, and the estimated pulmonary artery pressure and right ventricular size and volume data were similarly unaffected by these levels of positive intrathoracic pressure. This is indirect evidence that both afterload and preload were unaffected by this level of positive pressure. However, all our subjects were euvolemic with relatively normal cardiac function. The OSA patient in cor pulmonale or biventricular failure, with hypovolemia or profound hypoxemia during sleep may not be able to maintain cardiac output at similar pressure levels.

Only occasionally did the lung hyperinflation generated by 10 and 15 cm H2O of nasal CPAP interfere technically with the attainment of acceptable echocardiographic images. Massive obesity, as frequently found in OSA, may also interfere with the quality of the echocardiographic signal. This was not the case in our six patients, although several men weighed well over 136 kg (300) pounds.

We therefore suggest that this noninvasive technique can be used to assess changes in cardiac output in the OSA patient with more worrisome cardiac disease before the prescription of nocturnal home nasal CPAP on an indefinite basis.

ACKNOWLEDGMENTS: The authors wish to thank Bonny Chapman and Carla Alkerton for technical assistance and Debra Swihart for secretarial assistance. We would also wish to thank Medigs Eastern Ontario Ltd for supplying the CPAP system.

REFERENCES
2 Issa FG, Sullivan CE. Reversal of central sleep apnea using nasal CPAP. Chest 1986; 90:165-71
12 Asahak KJ, King ME, Gillam LD, Weyman AE. The effects of right ventricular hemodynamics on left ventricular configuration. Can J Cardiol 6; 99:1990
13 Fleiss JL. Design and analysis of experiments. Chichester: John Wiley and Sons, 1966
14 Day SJ, Graham DF. Sample size and power for comparing two or more treatment groups in clinical trials. Br Med J 1986; 286:663-65
18 Prewitt RM, Wood LDH. Effect of positive end-expiratory pressure on ventricular function in dogs. Am J Physiol 1979; 236:4534-44

Hemodynamic Effects of Nasal CPAP (Leech, Asahak)