Background and study objectives: Noninvasive positive airway pressure may play a significant role in treating patients with congestive heart failure (CHF). We tested our hypothesis that noninvasive bilevel positive airway pressure improves left ventricular performance in patients with chronic CHF secondary to severe systolic dysfunction.

Objectives: To determine the cardiac performance of patients using bilevel positive airway pressure, and to describe the hemodynamic effects of bilevel positive airway pressure and its use as a therapeutic adjunct in these patients.

Design: Prospective, cohort, nonrandomized study.

Setting: Outpatient medicine clinic.

Patients: Fourteen patients (9 men and 5 women) with stable chronic CHF with left ventricular ejection fraction < 35%; mean age was 60.6 years (range, 43 to 87 years).

Interventions: Bilevel positive airway pressure via nasal mask at an inspiratory pressure of 5 cm H2O and an expiratory pressure of 3 cm H2O on spontaneous mode at room air for 1 h.

Measurements and results: Myocardial performance and changes were measured using clinical and echocardiographic parameters. Baseline clinical and echocardiographic parameters were compared with the same parameters after 1 h of bilevel positive airway pressure. Statistically significant (p < 0.05, Wilcoxon matched pair signed-rank test) decreases were noted in these mean values: systolic BP from 136.21 to 124.14 mm Hg (p = 0.008), heart rate from 85.07 to 74.71 beats/min (p = 0.002), respiratory rate from 23.07 to 15.43 breaths/min (p = 0.001), and systemic vascular resistance from 1671.46 to 1236.27 dyne · s · cm-5 (p = 0.001). Statistically significant increases were noted in these mean values: cardiac output from 5.09 to 6.37 L/min (p = 0.004), ejection fraction from 28.71% to 34.36% (p = 0.001), and end-diastolic volume from 224.36 to 246.21 mL (p = 0.045).

Conclusion: Bilevel positive airway pressure has excellent potential for improving left ventricular performance of patients with chronic CHF secondary to severe systolic dysfunction.

Key words: bilevel positive airway pressure; congestive heart failure; echocardiography; systolic dysfunction

Abbreviations: CHF = congestive heart failure; CO = cardiac output; CPAP = continuous positive airway pressure; EDV = end-diastolic volume; EF = ejection fraction; ESV = end-systolic volume; HR = heart rate; LV = left ventricular; MAP = mean arterial pressure; NYHA = New York Heart Association; RR = respiratory rate; SBP = systolic BP; SV = stroke volume; SVR = systemic vascular resistance; WS = wall stress

Noninvasive positive airway pressure may play an important role in the treatment of patients with poorly compensated congestive heart failure (CHF).

More than 60 years ago, Poulton and Oxon described the use of continuous positive airway pressure (CPAP) delivered by the "pulmonary plus pressure machine" through a face mask to patients with "cardiac asthma." During the 1960s, attention turned toward using mechanical ventilation through the endotracheal tube, an invasive form of ventilatory support. The 1950s brought a renewed interest in noninvasive ventilation, with reported improvements among patients with chronic hypoventilation and COPD.
Ventilatory support in CHF has three goals: to improve oxygenation, to reduce respiratory work, and to improve left ventricular (LV) function. Three studies have shown that CPAP administered through a nasal mask can help augment cardiac function in patients with CHF. Patients with poorly compensated heart failure who received CPAP showed improved cardiac output (CO). Lenique et al reported a modest improvement in cardiac function with the use of CPAP, as evidenced by a significant decrease in mean transmural left and right filling pressures. Grace and Greenbaum demonstrated an improvement in CO among patients who received positive end-expiratory pressure and whose pulmonary arterial wedge pressure was >18 mm Hg. Finsky et al used high-frequency jet ventilation intermittent positive pressure breathing synchronized with cardiac systole and intermittent positive breathing to produce a beneficial effect on CO by reducing LV afterload. A previous study at this institution demonstrated that the severity of LV systolic dysfunction was the primary determinant of the degree of improvement in LV performance during the application of bilevel positive airway pressure. Comparing bilevel positive airway pressure with CPAP, Mehta et al found that bilevel positive airway pressure enhances gas exchange, has a rapid onset of effect, augments tidal volume, and may be more comfortable for patients than CPAP.

We proposed that noninvasive bilevel positive airway pressure might be an effective adjunct to pharmacologic therapy in patients who have CHF with systolic dysfunction. To our knowledge, no previous study has used echocardiography to fully examine the changes in cardiac performance of patients who have stable, chronic CHF with systolic dysfunction, and who receive bilevel positive airway pressure.

The data from this study are archived in the Research Department of Memorial Health University Medical Center in Savannah, GA.

**Inclusion and Exclusion Criteria**

Patients were eligible for the study if they met the following inclusion criteria: age ≥18 years, diagnosis of chronic CHF with more than one episode documented, LV systolic dysfunction with EF ≤35% as measured by echocardiography, stable cardiac and hemodynamic status categorized as NYHA class II or less, intact upper airway, sinus cardiac rhythm, in stable condition as an outpatient receiving optimal CHF medication for at least 1 month, and able to cooperate and to give informed consent.

Exclusion criteria consisted of unstable cardiac rhythm or hemodynamic instability, chest pain or unstable angina, myocardial infarction within the last 6 months, obstructive lung or other significant pulmonary disease, obstructive sleep apnea, agitated state, inability to cooperate, acute exacerbation of CHF, febrile, displaying signs of infection, or altered mental status.

To ensure the consistency of the echocardiographic measurements and to avoid variances among operators, the same echocardiographic technician followed the same protocol and performed the procedure on all patients. All echocardiographic values and calculations were generated by the computer system of the echocardiograph machine.

**Bilevel Positive Airway Pressure**

Noninvasive positive airway pressure was provided by BiPAP machines (Quantum pressure support ventilation, model 7700; Respironics; Marietta, GA). All patients received the same bilevel positive airway pressure setting administered through a tight-fitting silicone nasal mask secured to the patient by head straps for 1 h (inspiratory pressure, 5 cm H₂O; expiratory pressure, 3 cm H₂O; spontaneous mode on room air). The BiPAP machine is a noninvasive instrument that uses a dynamic pressure system to provide greater pressures during inspiration and lesser pressures during expiration. A mechanism in the ventilator senses when the patient is inhaling or exhaling and changes the pressure setting accordingly.

**Echocardiography**

M-mode two-dimensional color-flow Doppler echocardiography was performed using a Sonos 1000 (Hewlett Packard; Andover, MA). Although invasive methods have established standards for measuring stroke volume (SV) and CO, measurements of cross-sectional and velocity time integrals obtained from Doppler echocardiography are consistent with the results of invasive methods. Changes in myocardial performance were measured three times: (1) at baseline, (2) after the patient had received bilevel positive airway pressure for 1 h, and (3) after bilevel positive airway pressure had been discontinued for 1 h. Primary outcome measures were preload, myocardial contractility, and afterload. The following clinical parameters were measured: systolic BP (SBP), diastolic BP, heart rate (HR), respiratory rate (RR), and oxygen saturation. Systemic vascular resistance (SVR), double product, and triple product were calculated. Measured echocardiographic parameters included the following: EF, CO, end-diastolic volume (EDV), end-systolic...
volume (ESV), and wall stress (WS). The formulas for calculating SVR, mean arterial pressure (MAP), double product, and triple product are provided in Table 1.

Protocol

Patients were instructed to forego all medications during the 5 h prior to the study. The study began by placing the patient supine and elevating the head of the bed according to the patient’s comfort. After the patient had rested for 15 min, we obtained baseline measurements for vital signs and oxygen saturation using an automatic sphygmomanometer, an ECG precordial leads monitor, and a pulse oximeter. These measurements were repeated approximately every 30 min throughout the study period. The baseline echocardiogram was taken, then the patient was attached to the BiPAP machine for 1 h. Bilevel positive airway pressure was administered through a tight-fitting nasal mask at an inspiratory pressure of 5 cm H2O and an expiratory pressure of 3 cm H2O on spontaneous mode on room air for 1 h, and then a second echocardiogram was taken. The patient rested for another hour without bilevel positive airway pressure, and then the third echocardiogram was taken.

Statistical Analysis

Results are given as means ± SD. Clinical and echocardiographic parameters at baseline, after 1 h of receiving bilevel positive airway pressure, and 1 h after bilevel positive airway pressure was discontinued were compared by using the Wilcoxon matched pair signed-rank test. Values of p < 0.05 were accepted as statistically significant.

RESULTS

A computer search identified > 500 patients who had undergone echocardiography during the previous 6 months in the internal medicine and cardiology service. Further computer screening identified 250 patients who met some aspects of the inclusion criteria. Investigators screened the records of these patients for inclusion and exclusion criteria, and found 60 patients who met the study criteria. All of these patients were invited to participate, but many declined because they lacked transportation or were suspicious of clinical trials. Twenty patients agreed to participate; 18 patients kept their appointments and participated in the study. Three patients were excluded because their baseline EFs were > 35% on the day of the study. One patient who could not tolerate the nasal mask withdrew from the study. Fourteen patients (9 men and 5 women; mean age, 60.6 years; range, 43 to 87 years) completed the study.

Data for this study were collected from December 1998 through April 1999. Of the 14 patients who completed the study, CHF was attributed to ischemic heart disease in 9 patients, to idiopathic dilated cardiomyopathy in 3 patients, to hypertensive cardiovascular disease in 1 patient, and to alcoholic dilated cardiomyopathy in 1 patient. Two of the patients had diabetes mellitus type II, one had mild Alzheimer’s disease, and one had controlled hypothyroidism. Ten of the 14 patients were in NYHA class I, and 4 patients were in NYHA class II. With regard to medications, all 14 patients were receiving angiotensin-converting enzyme inhibitors and diuretics, 8 patients were receiving vasodilators, 10 patients were receiving digoxin, and 1 patient was receiving antiarrhythmics.

Study Outcomes

There were no deviations from the protocol, and there were no complications or side effects to the treatment with bilevel positive airway pressure. During the study period, none of the study participants complained of any chest pain or respiratory discomfort.

Many of the patients in the study remarked that they “felt better” after their sessions on the BiPAP machine, but we had no method for quantifying these subjective reports of improvement. One patient, who felt claustrophobic, withdrew from the study because he could not tolerate the nasal mask. Several minutes after bilevel positive airway pressure was initiated, the cardiac monitor of the patient who was receiving antiarrhythmics showed a series of nonsustained premature ventricular complexes of < 30-s duration that resolved spontaneously. The patient did not complain of chest pain. The remainder of the session was uneventful.

Table 1 compares mean clinical and echocardiographic measurements between baseline and after 1 h of bilevel positive airway pressure, between measurements after 1 h of bilevel positive airway pressure and after 1 h of rest after bilevel positive airway pressure, and between baseline and after 1 h of rest after bilevel positive airway pressure. Of particular note were the changes in echocardiographic measurements with EF, CO, and EDV, which showed statistically significant increases and were consequently reflected in statistically significant decreases in clinical measurements of SVR, double product, SBP, pulse, and RR.

DISCUSSION

CHF is the inadequacy of the heart for supplying the perfusion and oxygenation requirements of the tissues. Systolic and diastolic dysfunction are the two major mechanisms of CHF. Systolic dysfunction involves impaired cardiac contractility. The four factors that determine myocardial shortening are preload, afterload, contractility, and HR/rhythm. In this study, we considered SVR to be a reflection of the afterload, EF to be an indirect measure of myocardial contractility, and LV EDV to be an
Table 1—Comparison of Clinical and Echocardiographic Measurements

<table>
<thead>
<tr>
<th>Measure</th>
<th>Baseline</th>
<th>1 h Receiving Bilevel Positive Airway Pressure</th>
<th>1 h After Bilevel Positive Airway Pressure</th>
<th>Wilcoxon Signed-Rank Test Results (Two-Tailed Probabilities)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 h Receiving Bilevel Positive Airway Pressure</td>
<td>1 h After Bilevel Positive Airway Pressure</td>
<td>Baseline Compared</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 h Receiving Bilevel Positive Airway Pressure</td>
<td>1 h After Bilevel Positive Airway Pressure</td>
<td>Positive Airway Pressure Compared With 1 h After Bilevel Positive Airway Pressure</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>136.21 (19.19)</td>
<td>124.14 (16.49)</td>
<td>135.38 (18.08)</td>
<td>0.008†</td>
</tr>
<tr>
<td>Diastolic BP, mm Hg</td>
<td>83.36 (19.10)</td>
<td>77.43 (12.85)</td>
<td>81.00 (17.13)</td>
<td>0.093</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>85.07 (18.66)</td>
<td>74.71 (20.56)</td>
<td>80.50 (18.29)</td>
<td>0.002†</td>
</tr>
<tr>
<td>RR, breaths/min</td>
<td>23.07 (5.41)</td>
<td>15.43 (5.40)</td>
<td>19.00 (4.25)</td>
<td>0.001†</td>
</tr>
<tr>
<td>O₂ saturation, %</td>
<td>96.07 (2.23)</td>
<td>96.46 (2.34)</td>
<td>95.86 (2.66)</td>
<td>0.227</td>
</tr>
<tr>
<td>SVR†</td>
<td>1.67 (440.37)</td>
<td>1.23 (282.38)</td>
<td>1.50 (383.70)</td>
<td>0.001†</td>
</tr>
<tr>
<td>Double product‡</td>
<td>11.53 (264.92)</td>
<td>9.34 (353.12)</td>
<td>10.90 (284.57)</td>
<td>0.001†</td>
</tr>
<tr>
<td>Triple product¶</td>
<td>1.655 (591.90)</td>
<td>1.459 (704.683)</td>
<td>1.582 (594.896)</td>
<td>0.156</td>
</tr>
<tr>
<td>EF, %</td>
<td>28.71 (5.04)</td>
<td>34.36 (4.52)</td>
<td>31.57 (4.57)</td>
<td>0.001†</td>
</tr>
<tr>
<td>CO, L/min</td>
<td>5.09 (1.42)</td>
<td>6.37 (1.93)</td>
<td>5.54 (1.43)</td>
<td>0.004†</td>
</tr>
<tr>
<td>EDV</td>
<td>224.36 (44.40)</td>
<td>246.21 (48.47)</td>
<td>225.79 (51.94)</td>
<td>0.045†</td>
</tr>
<tr>
<td>ESV</td>
<td>159.93 (37.49)</td>
<td>167.45 (39.26)</td>
<td>159.65 (42.91)</td>
<td>0.451</td>
</tr>
<tr>
<td>WS</td>
<td>141.71 (30.69)</td>
<td>132.59 (40.98)</td>
<td>143.86 (34.33)</td>
<td>0.432</td>
</tr>
</tbody>
</table>

*Data are presented as mean (SD) unless otherwise indicated.
†Statistically significant (p < 0.05) comparisons.
‡SVR was calculated using the following formula: SVR = 80 \times \text{MAP}/\text{CO} (L/min). MAP = \text{SBP} + (\text{diastolic BP} \times 2)/3.
§Double product = \text{SBP} \times \text{HR}.
¶Triple product = \text{SBP} \times \text{HR} \times \text{WS}.
indirect measure of preload. Because EF represents functional emptying of the LV, it is useful in quantifying systolic dysfunction. Little and Braunwald\textsuperscript{13} defined systolic dysfunction as EF < 50%.

One hour of bilevel positive airway pressure produced a statistically significant decrease in SVR among the patients in the study. The proposed mechanism for this decrease in afterload is that positive airway pressure reduces the transmural pressure of the LV.\textsuperscript{15} Because both inspiratory pressure and expiratory pressure decrease transmural pressure and help alleviate CHF, both components are necessary. This decrease in SVR may have helped to effect the statistically significant improvement in the EF and may have caused the statistically significant increase in CO. Because decreases in LV afterload or SVR are the only pharmacologically induced changes that have been shown to reduce mortality in CHF,\textsuperscript{16,17} this mechanically induced change, attributed to bilevel positive airway pressure, could have notable clinical implications. Although both CO and EF decreased slightly at 1 h after bilevel positive airway pressure had been stopped, they nevertheless remained statistically significantly greater than the baseline values. Likewise, SVR was statistically significantly decreased from baseline measurements at 1 h after bilevel positive airway pressure had been stopped, and appeared to lead to increased CO, improved hemodynamics, and to return flow as reflected by the statistically significant increase in EDV. We believe that this increase further augmented myocardial contractility through the Frank-Starlings Law.\textsuperscript{18} The statistically significant increase in EDV was not accompanied by a statistically significant increase in ESV. This may imply an increase in SV, again due to the Frank-Starlings Law. Patients with systolic dysfunction require a larger EDV to produce adequate SV and CO.

In our study of patients with chronic CHF and severe systolic dysfunction, bilevel positive airway pressure enhanced LV performance by decreasing the afterload, augmenting contractility, and improving the preload. Furthermore, the low-pressure setting of the BiPAP machine improved the cardiac performance of patients who were receiving optimal pharmacologic therapy for CHF. The decrease in HR can be attributed to a compensatory response to the improvement in myocardial function. The decrease in RR can be explained by the reduced work required to breathe.\textsuperscript{11}

We selected bilevel positive airway pressure settings of 5 cm H\textsubscript{2}O for inspiratory pressure and 3 cm H\textsubscript{2}O for end-expiratory pressure. We selected these settings for several reasons. A previous study\textsuperscript{10} conducted at this institution had shown that these low settings were effective in improving CO and decreasing systemic resistance. Although higher settings could possibly increase CO further, settings of 5 cm H\textsubscript{2}O for inspiratory pressure and 3 cm H\textsubscript{2}O for end-expiratory pressure are more comfortable for the patients. Higher levels of pressure require a higher flow that is frequently uncomfortable for patients. The patients in our study had severe systolic dysfunction, and we chose these settings to avoid jeopardizing their conditions.

In a study comparing bilevel positive airway pressure with CPAP, Mehta et al\textsuperscript{11} noted an increased number of myocardial infarctions among patients receiving bilevel positive airway pressure at an inspiratory positive airway pressure of 15 cm H\textsubscript{2}O and an expiratory positive airway pressure of 5 cm H\textsubscript{2}O. In their summary statement, the authors suggested further trials using lower settings.

As best as we can determine, our study was the first to use echocardiography to monitor myocardial changes during the administration of bilevel positive airway pressure. Whereas earlier investigators have shown that CPAP can improve CO due to decreased preload,\textsuperscript{4–6} our findings focus a new emphasis on the ability of bilevel positive airway pressure to decrease SVR. This is analogous to a previous study by Buda et al,\textsuperscript{15} who showed that positive intrathoracic pressure caused a decrease in LV transmural pressure, thereby resulting in decreased LV afterload. The action of bilevel positive airway pressure closely resembles the natural physiologic state (breathing) and is more comfortable for the patients than CPAP.\textsuperscript{11} The patients received bilevel positive airway pressure through a nasal mask that allowed them to speak and drink. During the test, a number of patients voiced their preference for the nasal mask rather than the facemask, which they may have encountered during previous hospitalizations. One patient developed transient nonsustained premature contractions that were clinically insignificant.

No one knows the maximum benefits that can be attained by using bilevel positive airway pressure. The ultimate question is whether treatment with bilevel positive airway pressure can prolong life by decreasing the mortality due to CHF. Future studies should focus on measuring the duration of the positive effects of treatment with bilevel positive airway pressure. Additional studies should investigate the lowest EF value that will respond to treatment with bilevel positive airway pressure. In an earlier study\textsuperscript{10} from this institution, one patient with a very low EF of 9% demonstrated only a minor increase in EF with bilevel positive airway pressure. Drawing on patient data from the early 1980s, Rodeheffer et al\textsuperscript{19} found the age-adjusted, annual incidence of CHF to be 110/100,000, increasing to almost 3% at the age of 74 years. They concluded
that in light of the aging population, the incidence of CHF might prove a greater burden to society than has been anticipated. This possibility should motivate the medical community to explore fully the effects of bilevel positive airway pressure on CHF.

Our study had several limitations. Patients served as their own control subjects, thereby eliminating any randomization. In addition, the outpatient aspect of the study required that patients arrange for transportation to and from the hospital, a difficulty that sometimes precluded participation in the study. Furthermore, only 14 patients completed the study, rendering a small sample size. Despite these limitations, the positive effects seen after just 1 h of treatment with bilevel positive airway pressure warrant further investigation of the potential of this modality.

After receiving bilevel positive airway pressure for 1 h, patients with chronic CHF secondary to systemic dysfunction showed reductions in HR, RR, SBP, double product, triple product, and SVR. Concomitantly, EF and CO were increased. We believe that bilevel positive airway pressure has excellent potential for improving the LV performance of patients with chronic CHF secondary to severe systolic dysfunction.

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