Breathing Pattern Abnormalities and Arterial Oxygen Desaturation during Sleep in the Congestive Heart Failure Syndrome*

Improvement following Medical Therapy

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We observed breathing pattern abnormalities and arterial oxygen desaturation in patients with stable congestive heart failure during overnight polysomnography. To determine whether congestive heart failure was the reason for these abnormalities, we then studied six additional patients before and after treatment of heart failure. Breathing was more abnormal (153 ± 87 episodes/night) during decompensation of heart failure and improved with medical therapy (72 ± 100 episodes/night) (p<0.05). Abnormal breathing patterns resolved in three patients, improved in two, and were unchanged in one patient after therapy. Allographic cardiac transplantation in one patient whose sleep study remained unchanged after medical therapy was associated with resolution of breathing pattern abnormalities and severe desaturation during sleep. Therapy-related improvement in nocturnal respiratory events suggests congestive heart failure is a contributing factor for breathing abnormalities and arterial oxygen desaturation during sleep.

Breathing disturbances during sleep are now well-recognized and occur in many diseases.1,4 Heart disease is not generally considered a risk factor for breathing abnormalities during sleep, although recent data suggest that breathing pattern abnormalities and arterial oxygen desaturation are common in patients with coronary artery disease.5

In congestive heart failure, breathing abnormalities of breathing, such as Cheyne-Stokes breathing, have been classically described and are well documented.4,4 Little data exist, however, since the advent of sophisticated polysomnography, to characterize breathing pattern abnormalities in these patients, and to define physiologic sequelae such as hypoxemia and arrhythmias. The night breath study in a group of 11 patients with stable congestive heart failure syndrome. Polysomnographic recording showed abnormal breathing patterns, predominantly central apneas, in seven patients (64 percent) and arterial oxygen desaturation (>4 percent decrease in arterial oxygen saturation from baseline) in all 11 patients. Severe desaturation (>15 minutes SaO2 <85 percent) occurred in five patients (46 percent). These initial data did not determine whether these breathing pattern abnormalities were specifically related to the patients studied, to nocturnal sleep or to the congestive heart failure. To evaluate the contribution of congestive heart failure, we studied patients admitted for decompensated congestive heart failure before and after therapy for their heart failure.

Material and Methods

Patient Population

Seven hospitalized patients admitted for treatment of decompensated left ventricular heart failure were studied. All underwent an overnight sleep study both on hospital admission and following medical therapy for decompensated congestive heart failure syndrome (CHFS). The syndrome was defined when classic history, physical and roentgenographic findings of left ventricular congestive heart failure were present. Selection criteria for inclusion were primary left ventricular failure in the absence of known causes of right heart failure, absence of primary lung disease, absence of daytime hypoxemia and admission weight <125 percent of predicted ideal body weight. Left ventricular ejection fraction was determined by technetium-99m radionuclide scan or M-mode echocardiogram initially within 48 hours of hospital admission. Left ventricular ejection fraction was repeated the morning after the second sleep study. Significant primary obstructive lung disease was excluded by clinical findings and spirometric tests of lung function immediately prior to sleep study. Absence of hypoxemia was documented by arterial blood gas analysis and/or SaO2 >90 percent just prior to sleep study. All patients were receiving medications for heart failure including diuretics, vasodilators, antihypertensives, antiarrhythmics, and positive inotropic agents. Initial sleep studies were performed the first or second night after hospital admission. All patients were hemodynamically stable. Follow-up study after standard medical therapy was performed when symptoms, exercise tolerance, physical examination, and chest roentgenograms were improved as judged by the attending physician and the patient was...
Table 1—Patient Data

<table>
<thead>
<tr>
<th>Pt No.</th>
<th>Age</th>
<th>Sex</th>
<th>FEV₁ (%)</th>
<th>FVC (%)</th>
<th>FEV₁/FVC (%)</th>
<th>RA</th>
<th>ABG</th>
<th>Prior Awake</th>
<th>EF(%)</th>
<th>Total Sleep Time</th>
<th>Central Apneas</th>
<th>Hypopneas</th>
<th>Obstructive Apneas</th>
<th>Total BPA/hr</th>
<th>Initial %</th>
<th>Lowest %</th>
<th>Mins &lt;85%</th>
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<td>4.37</td>
<td>0.59</td>
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<td></td>
<td>2.66 ± 0.58</td>
<td>93</td>
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<td>72 ± 1</td>
<td>139</td>
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<td>2</td>
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<td></td>
<td></td>
<td></td>
<td>2.84 ± 0.58</td>
<td>99</td>
<td>0</td>
<td>2.9 ± 0.5</td>
<td>99 ± 0</td>
<td>1 ± 0</td>
<td>1 ± 0</td>
<td></td>
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<tr>
<td>3</td>
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<td></td>
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<td>3.88 ± 0.58</td>
<td>93</td>
<td>0</td>
<td>3.1 ± 0.5</td>
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<td>94 ± 1</td>
<td>1 ± 0</td>
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<td>4.1 ± 0.5</td>
<td>99 ± 0</td>
<td>93 ± 0</td>
<td>93 ± 0</td>
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<tr>
<td>5</td>
<td>76</td>
<td>M</td>
<td>1.39</td>
<td>2.00</td>
<td>0.74</td>
<td></td>
<td></td>
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<td></td>
<td>3.63 ± 0.58</td>
<td>93</td>
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<td>93 ± 0</td>
<td>94 ± 1</td>
<td>1 ± 0</td>
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<td>6</td>
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<td>3.73</td>
<td>0.96</td>
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<td>4.58 ± 0.58</td>
<td>93</td>
<td>0</td>
<td>4.8 ± 0.5</td>
<td>93 ± 0</td>
<td>94 ± 1</td>
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</tbody>
</table>

*Not available just prior to sleep study.

Sleep Study

The sleep study was performed in the pulmonary function sleep laboratory. The patient slept without supplemental oxygen. The following parameters were monitored: (1) arterial oxygen saturation continuously measured by ear oximeter; (2) oral and nasal airflow by a pressure mask as described by Milsap and using a Validyne carrier demodulator CDR; (3) chest and abdominal wall movements using impedance plethysmography (Respitrace); (4) cardiac rhythm by electrocardiogram (MCL-1); and (5) stage of sleep by continuous monitoring of electroencephalogram, electro-oculogram, and chin surface electromyogram. All parameters were recorded continuously on a 16-channel polygraph. The analog output from the ear oximeter was sampled each second, digitized, and processed by a minicomputer to obtain a cumulative frequency distribution of arterial oxygen saturation.

Definitions

Breathing pattern abnormalities during sleep were compiled and categorized as apnea or hypopnea according to standard definition. Cheyne-Stokes breathing pattern was defined as periodic waxing and waning of the depth of respiration on the polysomnographic recording with regularly recurring periods of apnea. The breathing patterns were considered abnormal if >30 episodes of apnea or hypopnea were recorded during the overnight sleep study, or if more than five episodes occurred per hour of sleep. Arterial oxygen desaturation was defined as >4 percent drop in saturation from the baseline awake value. Severe and prolonged desaturation was arbitrarily defined as ≥15 minutes per night total sleep time spent with an arterial oxygen saturation <85 percent and included nonapneic desaturations. Informed consent was obtained from all patients. The study was approved by the Human Subjects Committee of the University of Kansas Medical Center. Statistical analysis was performed by least square error linear regression, paired Student's t-test or Chi square. Observed differences were considered statistically significant when a p value of <0.05 was obtained.

RESULTS

Six patients were studied in a decompensated state, then restudied after vigorous medical therapy for their CHFS. Five men and one woman with decompensated CHFS underwent overnight sleep study within 48 hours of hospital admission (Table 1). All patients' conditions were diagnosed as ischemic, hypertensive, or idiopathic cardiomyopathic heart disease. The mean age was 60 ± 13 years. The mean male weight was 76 ± 16 kg, the female weighed 65 kg. Mean left ventricular ejection fraction was 28 ± 11 percent.

Results of overnight polysomnography are shown in Table 2. When decompensated, all patients had breathing pattern abnormalities. The number of abnormal patterns was high (135 ± 87 episodes/night SD, 34 ± 11 episodes per hour SD). Central apnea was the

Table 2—Types of Breathing Pattern Abnormalities (BPA) Before and After Medical Therapy of CHFS

<table>
<thead>
<tr>
<th>Pt No.</th>
<th>Age</th>
<th>Total Sleep Time</th>
<th>Central Apneas</th>
<th>Hypopneas</th>
<th>Obstructive Apneas</th>
<th>Total BPA/hr</th>
<th>Oxygen Saturation</th>
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<td>93 ± 0</td>
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<tr>
<td>4</td>
<td>59</td>
<td>4.00 ± 0.58</td>
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<td>4.1 ± 0.5</td>
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</table>

Mean ± SD

*Cheyne-Stokes breathing pattern.
†Data not available.
predominant event in four patients while hypopnea was predominant in two patients. Obstructive and mixed apneas were infrequently recorded. Arterial oxygen desaturation occurred in all patients. Initial arterial oxygen saturation was 95 ± 3 percent. Patients desaturated a mean of 21 ± 7 percent to a nadir of 75 ± 9 percent. Severe and prolonged desaturation was recorded in three patients; these three patients averaged nearly 80 minutes per night with an SaO₂ <85 percent. Five patients exhibited Cheyne-Stokes breathing pattern; the majority of central apneas in these patients occurred during Cheyne-Stokes breathing. Three of these patients had severe and prolonged arterial oxygen desaturation.

Following therapy (including ionotropic agents, diuretics and oxygen) for CHFS when judged clinically compensated, all patients underwent repeat polysomnography without supplemental oxygen (Table 2), an average of 42 ± 29 days later. There was no difference in total sleep time (4.5 ± 1.9 hours to 4.1 ± 2.0 hours SD) and no significant change in left ventricular ejection fraction (28 ± 11 percent to 28 ± 8 percent SD). Breathing pattern abnormalities resolved in three patients and improved in two. No change in breathing pattern abnormalities was found in the one patient whose severe and prolonged desaturation persisted after treatment of the CHFS. After therapy, the predominant breathing pattern abnormalities were again central apneas; there was not a significant change in the number of central apneas. The number of breathing pattern abnormalities improved significantly after decompensated heart failure was treated (153 ± 87 episodes per night to 72 ± 100 episodes per night SD, p = 0.03). There were fewer hypopneas (48 ± 40/night to 10 ± 13/night SD, p = 0.04). There was a trend for less prolonged severe desaturation after therapy. The severe desaturation recorded in three patients prior to therapy markedly improved in two patients but was unchanged in the third.

No correlation existed between age and the number of breathing pattern abnormalities with either decompensated CHFS (r = 0.43, p = 0.30) or compensated CHFS (r = 0.40, p = 0.30), or between age and the number of minutes SaO₂ <85 percent while either decompensated (r = 0.18, p = 0.40) or compensated (r = 0.60, p = 0.15). There was an inverse relationship between left ventricular ejection fraction and the number of breathing pattern abnormalities in both decompensated CHFS (r = 0.79, p = 0.03) and compensated CHFS (r = 0.91, p = 0.006).

Patient 6, the only patient without improvement in breathing pattern abnormalities or severe desaturation after vigorous medical therapy, later underwent allograftic cardiac transplantation. One month after transplant, following an uncomplicated postoperative course, he underwent repeat polysomnography as an outpatient (Table 3). No significant breathing pattern abnormalities were found; severe desaturation was eliminated.

**Discussion**

Clinicians have long recognized that breathing during sleep can be abnormal in congestive heart failure. Although recent studies have documented breathing pattern abnormalities during sleep in patients with congestive heart failure, our data are the first to document improvement in breathing pattern abnormalities following therapy for heart failure.

Our data support the concept that the sleep abnormalities found in our stable compensated patients are related to their heart failure. First, patients with known risk factors for sleep disordered breathing were screened from participation in the study. Secondly, polysomnographic findings were more abnormal at a time of clinical decompensation. Breathing pattern abnormalities, most notably hypopneas, improved significantly with medical therapy. Since the definition of hypopneas is dependent, in part, on a decrease in arterial oxygen saturation, improvement in saturation following therapy could affect the number of hypopneas detected. However, there was no significant difference in the initial arterial oxygen saturation when comparing the decompensated state (95.3 ± 3.3 percent) to the compensated state (96.5 ± 1.2 percent) (p = 0.25). Lastly, severe desaturation was eliminated and breathing pattern abnormalities improved in one patient following allograftic cardiac transplantation. Major mechanisms contributing to periodic breathing include increased controller gain, underdamping of responses and a delayed circulation time. Heart failure would certainly contribute to the latter. Delineation of the role of other possible mechanisms in this patient population including possible medication effect or change in central nervous system acid-base balance.

**Table 3—Polysomnography Results Before and After Heart Transplantation**

<table>
<thead>
<tr>
<th></th>
<th>LVEF(%)</th>
<th>Total BPA*</th>
<th>BPA per hr</th>
<th>Central Apneas</th>
<th>Hypopneas</th>
<th>Oxygen Saturation</th>
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<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
</tr>
<tr>
<td>Decompensated heart failure</td>
<td>50</td>
<td>267</td>
<td>50</td>
<td>241</td>
<td>26</td>
<td>96</td>
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<tr>
<td>Compensated heart failure</td>
<td>41</td>
<td>262</td>
<td>51</td>
<td>229</td>
<td>33</td>
<td>95</td>
</tr>
<tr>
<td>After heart transplant</td>
<td>83</td>
<td>25</td>
<td>4</td>
<td>0</td>
<td>23</td>
<td>96</td>
</tr>
</tbody>
</table>

*BPA, breathing pattern abnormalities.*
balance, requires further study.

Prediction of sleep abnormalities in this patient population is difficult. Although expected, no correlation existed between age and either the number of breathing pattern abnormalities or severe desaturation. Correlation did exist between the severity of left ventricular dysfunction as defined by left ventricular ejection fraction and breathing pattern abnormalities. Other parameters of heart function such as cardiac output or pulmonary capillary wedge pressure may also be predictive of sleep abnormalities, but were not evaluated. Cheyne-Stokes breathing pattern was not always a reliable predictor of severe prolonged desaturation. Of five patients with Cheyne-Stokes breathing, two did not have associated nocturnal desaturation.

None of our patients had significant chronic obstructive lung disease or obesity, both of which are associated with an increased incidence of breathing pattern abnormalities. It is likely that these disease states may compound breathing pattern abnormalities and arterial oxygen desaturation in compensated and decompensated congestive heart failure and place such patients at even greater risk for hypoxemia.

The magnitude and clinical significance of nocturnal desaturation and breathing pattern abnormalities during sleep in large numbers of stable congestive heart failure patients is unknown. Exact incidence data await further large studies. The clinical significance of our data also remains to be more clearly defined. No immediate adverse effects of desaturation or breathing abnormalities were noted. The possible sequelae of severe prolonged desaturation would appear to be of more significance than breathing pattern abnormalities. Severe and prolonged desaturation would not intrinsically appear to be benign, particularly in a patient population of already depressed myocardial function since myocardial efficiency decreases and oxygen consumption increases with arterial hypoxemia.

Treatment of breathing abnormalities during sleep in patients with compensated congestive heart failure is yet to be defined. Breathing pattern abnormalities and desaturation improved in most patients with standard medical therapy. Sleep disordered breathing and nocturnal hypoxemia are important factors in the pathogenesis of pulmonary heart disease (cor pulmonale) secondary to chronic obstructive lung disease and may contribute to progression of, or exacerbations of left ventricular failure. Correction of nocturnal hypoxemia with oxygen therapy improves cardiopulmonary hemodynamics. Long-term oxygen therapy improves survival in patients with cor pulmonale complicating chronic bronchitis and emphysema. Supplemental oxygen would appear to be a logical therapeutic modality in those patients with demonstrable severe and prolonged desaturation still present after medical therapy for congestive heart failure. Since awake arterial oxygen saturation is normal, the need for nocturnal oxygen therapy in this patient population may go unrecognized. Studies of larger numbers of patients are needed to evaluate the effects of long-term oxygen therapy in this patient population.

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