Efficacy and Compliance With Noninvasive Positive Pressure Ventilation in Patients With Chronic Respiratory Failure*

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Study objectives: Previous studies have shown the acute effects of noninvasive positive pressure ventilation (NPPV) in chronic respiratory failure; however, information on the chronic effects of NPPV is limited. We examined the acute and chronic effects of NPPV on gas exchange, functional status, and respiratory mechanics in patients with chronic respiratory failure related to restrictive ventilatory disorders or COPD.

Design: Descriptive analysis of prospectively collected clinical data.

Setting: Inpatient noninvasive respiratory care unit and outpatient clinic of university hospital.

Patients: Forty patients with chronic respiratory failure (20 with severe COPD and 20 with restrictive ventilatory disorders).

Interventions and measurements: All patients were admitted to a noninvasive respiratory care unit for 20 ± 3 days for inpatient evaluation consisting of medical treatment, rehabilitation, and NPPV evaluation and instruction. NPPV was titrated via a ventilatory support system (BiPAP; Respironics Inc; Monroeville, PA) or a portable volume ventilator (PLV 102; Lifecare, Inc; Boulder, CO) to achieve a ≥ 20% increase in baseline minute ventilation while monitoring gas exchange, expired volume, and clinical evidence of a decrease in the patient’s work of breathing.

Results: The patients’ mean age (± SD) was 65 ± 9.7 years, and there was a 3:1 female: male predominance. In the noninvasive respiratory care unit, 36 patients used NPPV for 7.31 ± 0.26 h/night. Four patients (three with COPD, one with restrictive disorder) withdrew from the study during the 3-week inpatient stay because they could not tolerate NPPV. Six patients (5 with COPD, 1 with restrictive disorder) used a portable volume ventilator and 34 patients used BiPAP (15 with COPD, 19 with restrictive disorders). At discharge, compared with admission, daytime Pao2/fraction of inspired oxygen (FiO2) increased (327 ± 10 vs 283 ± 13 mm Hg; p = 0.01), Paco2 was reduced (52 ± 2 vs 67 ± 3 mm Hg; p = 0.0001), and functional score increased (4.76 ± 1.16 vs 2.7 ± 1.64 arbitrary units (AUs); p < 0.01). Six months after discharge, improvements in Pao2/FiO2 (317 ± 10 vs 283 ± 13; p = 0.05), Paco2 (52 ± 2 vs 67 ± 3 mm Hg; p = 0.0001), and functional score (5.66 ± 0.41 vs 2.7 ± 0.3 AUs; p < 0.001) were maintained compared with admission values. FVC, FEV1, and maximum inspired and expired mouth pressures were unchanged before and after long-term NPPV. Ten patients (7 with COPD, 3 with restrictive disorders) discontinued NPPV at 6 months, and 3 progressed to tracheostomy. The remaining 26 patients continued to use NPPV at the 6-month follow-up. They claimed to use NPPV for 7.23 ± 0.24 h/night, but logged metered use was 4.5 ± 0.58 h/night. Problems that required adjustment in either the mask (36%) or ventilator source (36%) included mask leaks (43%), skin irritation (22%), rhinitis (13%), aerophagia (13%), and discomfort from mask headgear (7%).

Conclusion: NPPV acutely and chronically improves gas exchange and functional status in patients with chronic respiratory failure, but a significant number of patients do not tolerate NPPV on a chronic basis. Comprehensive follow-up is required to correct problems with NPPV and ensure optimal patient compliance.

Key words: COPD; hypoventilation; mechanical ventilation; noninvasive positive pressure ventilation; respiratory failure

Abbreviations: AU = arbitrary unit; FiO2 = fraction of inspired oxygen; NPPV = noninvasive positive pressure ventilation; Pmax = maximal expiratory mouth pressure; Pmax = maximal inspiratory mouth pressure; VRU = Ventilator Rehabilitation Unit; VT = tidal volume
Several studies have shown that noninvasive positive pressure ventilation (NPPV) can acutely improve gas exchange and sleep quality. However, reports describing the chronic effects of NPPV on gas exchange, respiratory mechanics, and functional status are limited and contradictory. This is even more problematic in patients with chronic respiratory failure related to COPD, in whom conflicting results regarding the beneficial effects of long-term NPPV application have been described. Moreover, few data exist describing long-term compliance with NPPV and the needs for adjustment of chronic outpatient NPPV care (i.e., changes in face mask or ventilator settings) to ensure patient compliance with chronic NPPV therapy.

In this study we evaluated the acute and chronic effects of NPPV on gas exchange, functional status, and respiratory mechanics in patients with chronic respiratory failure related to COPD or restrictive ventilatory disorders. We also sought to determine the incidence and type of problems that arise with long-term outpatient NPPV therapy so that these problems could be ameliorated in the future to improve long-term compliance. We initiated NPPV in a noninvasive respiratory care unit geared toward the evaluation and treatment of NPPV and followed patients after discharge in a comprehensive outpatient program in order to maximize compliance with chronic NPPV therapy.

**Materials and Methods**

**Patient Selection**

Forty consecutive patients were admitted to the Ventilator Rehabilitation Unit (VRU) at Temple University Hospital for evaluation and treatment of chronic respiratory failure. Prior to VRU admission and enrollment into the study, all patients were treated at least 48 h with maximally effective doses of inhaled bronchodilators (e.g., β-agonist and anticholinergic agents), systemic and/or inhaled corticosteroids, supplemental oxygen and, on occasion, theophylline. Following maximization of medical therapy, patients enrolled into the study fulfilled at least two of the clinical and two of the physiologic criteria listed in Table 1 before implementation of noninvasive ventilation.

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**Measurement of Spirometry, Respiratory Muscle Strength, and Arterial Blood Gases**

Characterization of the patients’ physiologic status was conducted by measuring spirometry, respiratory muscle strength, and gas exchange. FVC and FEV1 were measured using a spirometer (Gould 2400 Spirometer; Gould Inc; Dayton, OH) according to American Thoracic Society guidelines. Respiratory muscle strength was evaluated by measuring maximal inspiratory mouth pressure (Pimax) and maximal expiratory mouth pressure (Pemax), as previously described. Arterial blood gas analysis was performed using a gas analyzer (model BG3; Instrumentation Laboratory, Inc; Lexington, MA).

**Assessment of Functional Status**

Functional status of all patients was measured using a 7-point functional scale, where 1 = impaired cognition; 2 = awake, alert, oriented; 3 = chairbound; 4 = independent in activities of daily living; 5 = ambulatory, but homebound; 6 = performs all self-care activities at home (housework, cooking, etc.); and 7 = performs activities outside the house. Functional scores are recorded in arbitrary units (AUs).

**NPPV Technique**

All patients were evaluated for NPPV via a bilevel positive pressure ventilatory support device (BiPAP; Respironics, Inc; Monroeville, PA) or a portable volume ventilator (PLV-102 Volume Ventilator, Lifecare Inc; Boulder, CO). A description of the BiPAP ventilatory support device has been previously described. Appropriate settings of inspiratory and expiratory pressures, volumes, and ventilatory modes (i.e., BiPAP vs portable volume ventilator) were chosen while monitoring airway pressure, inspiratory and expiratory airflow and changes in tidal volume (VT). Airway pressures were measured at the mask pressure port by an in-line pressure transducer (range, ± 100 cm H2O; Validyne; Northridge, CA). Changes in airflow were measured by an in-line pneumotachograph (Hans Rudolph Inc; Kansas City, MO), which was placed between the mask and the exhalation valve. Inspiratory and expiratory volumes were recorded by integration of the airflow signal and recorded on a multichannel strip chart recorder (model ES 1000; Gould Inc). Inspiratory and expiratory pressures, and ventilator-delivered VT for patients using BiPAP or volume ventilator, respectively, were titrated until expired minute ventilation increased ≥ 20% above baseline values while simultaneously improving gas exchange (i.e., increased PaO2/FIO2 and lower PaCO2) and ensuring patient-ventilator synchrony. The choice of ventilator (i.e., BiPAP or portable volume ventilator) was determined by each patient’s degree of comfort with each source of ventilation, coupled with the ability to increase minute ventilation, improve gas exchange, and diminish the patient’s work of breathing. After initial evaluation, 34 patients received NPPV via BiPAP and 6 patients required NPPV via the portable volume ventilator.

**Choice of Mask for NPPV**

NPPV was applied in patients via nasal continuous positive airway pressure masks (Respironics, Inc), an Adam’s Circuit nasal mask (Puritan Bennett; Carlsbad, CA), an oronasal mask (Respironics, Inc), and a prototypical total face mask (Respironics, Inc).

**Compliance with NPPV Therapy**

Compliance with NPPV therapy for inpatients and outpatients was recorded as hours per day of use. Patient compliance with
NPPV in the hospital was monitored via direct observation by a respiratory therapist and recorded in a daily log. After discharge, patient compliance with NPPV was evaluated both by patients’ verbal report and by review of logged hours of use recorded from the ventilator meter by the durable home equipment vendor.

**Ventilator Rehabilitation Unit**

All aspects of inpatient NPPV care were conducted within the confines of the VRU, a special noninvasive respiratory care unit geared toward maximizing patients’ compliance with noninvasive ventilation. The VRU is one of four US Health Care Financing Administration Chronic Ventilator Demonstration sites. This program consists of a multidisciplinary inpatient and outpatient ventilator-dependent rehabilitation program that includes pulmonologists, respiratory therapists, physical therapists, speech therapists, nutritionists, psychologists, and nursing staff trained in advanced respiratory treatment of patients with chronic respiratory failure. All patients had a multidisciplinary approach to their inpatient treatment and attended a weekly outpatient clinic after discharge. Team meetings were held each week to assess each patient’s progress and plan further care.

To be enrolled into this program, patients must have demonstrated a willingness to actively participate in self-care and have an interested support person. Approximately 65% of the patients referred for enrollment into the program came from within the primary practice of Temple Hospital, and 35% were referred from outside hospitals.

**Data Collection Protocol**

An algorithm of the data collection protocol is shown in Figure 1. Baseline measurements of arterial blood gas tensions, respiratory mechanics, and functional status were obtained in all patients at VRU entry. All patients then underwent titration of pressure (BiPAP) or volume (PLV-102 ventilator) ventilators to achieve ventilation goals as previously outlined. The duration of NPPV use per day was increased in progressive fashion until patients were able to tolerate at least 6 h of NPPV treatment per night. During the patients’ stay in the VRU, they were evaluated by all members of the multidisciplinary team. Prior to discharge, patients and their families underwent additional NPPV instruction. At the time of discharge, repeat measurements of arterial blood gas tensions, respiratory mechanics, and functional score were obtained.

Patients were seen at home by a durable home equipment vendor and by a visiting nurse, and periodic phone calls were made by the VRU coordinator to discuss patients’ status and care plans. Patients were reexamined approximately every 4 to 6 weeks in the weekly outpatient clinic.

Measurements of arterial blood gas tensions, respiratory mechanics, and functional status were then repeated approximately 6 months after discharge. During the follow-up period, patients underwent adjustments in NPPV masks or ventilator settings if needed in order to maintain patient-ventilator synchrony and optimize gas exchange and functional status.

**Statistical Analysis**

A one-way analysis of variance with repeated measures was used to compare ventilatory variables, and arterial blood gases on admission, at discharge, and during outpatient follow-up. Separate analyses were done between COPD and restrictive ventilator disorder subsets. The Student’s t test was used to determine whether a significant relationship existed between respiratory mechanics before and after the institution of NPPV therapy. Demographic data are shown as mean ± SD; other results are expressed as mean ± SEM. A probability value of 0.05 was considered statistically significant.

**RESULTS**

**Patient Characteristics**

Patient characteristics are shown in Table 2. An equal number of the 40 patients enrolled in the study had COPD or restrictive disorders as the primary process responsible for respiratory failure. Of the 20 patients with restrictive disorders, 5 had kyphoscoliosis, 6 had obesity hypoventilation syndrome, 6 had an underlying chronic neuromuscular disease, and 3 had fibrothorax. For the total group, the average age was 65 ± 9.7 years with a 3:1 female: male predominance. Sixteen of the 40 patients (40%) had evidence of cor pulmonale by echocardiography or clinical examination, and 13 of the 40 patients (33%) had required intubation and mechanical ventilation for respiratory failure in the preceding 6 months.

Table 3 shows baseline gas exchange, respiratory mechanics and functional status in both patient groups. At baseline, both the COPD and restrictive disorders patient subsets had severe derangement in lung mechanics (FVC, 1.82 ± 0.14 vs 1.17 ± 0.15 L, respectively; FEV1, 0.71 ± 0.1 vs 0.79 ± 0.1 L, respectively). Furthermore, Pmax (32 ± 4 vs 36 ± 4 cm H2O), PIFmax (50 ± 24 vs 50 ± 9 cm H2O), PaO2/Fio2 (255 ± 16 vs 287 ± 18), and functional scores (3.3 ± 0.4 vs 3.1 ± 0.4 AUs) were similarly abnormal in both COPD and restrictive patients, respectively. Both patient groups had evidence of hypercapnic respiratory failure (Paco2 70 ± 3 mm Hg in COPD patients vs 62 ± 3 mm Hg in those

### Table 1—Health Care Financing Administration Chronic Ventilator Demonstration Project Criteria for Noninvasive Ventilation*

<table>
<thead>
<tr>
<th>Clinical Criteria</th>
<th>Physiologic Criteria</th>
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</thead>
<tbody>
<tr>
<td>Severe, irreversible disease</td>
<td>Vital capacity &lt; 25% predicted</td>
</tr>
<tr>
<td>Symptoms of nocturnal hypoventilation</td>
<td>Pmax &gt; −50 cm H2O (COPD), or &gt; −25 cm H2O (restrictive disorder)</td>
</tr>
<tr>
<td>Dyspnea at rest or sleep</td>
<td>PacO2 &gt; 45 mm Hg</td>
</tr>
<tr>
<td>Refractory cor pulmonale</td>
<td>Nocturnal SaO2 &lt; 98% despite supplemental O2</td>
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*Patients must satisfy at least two clinical criteria and two physiologic criteria. Modified from Braun et al.20 SaO2 = arterial oxygen saturation.
with restrictive disorders; \( p = 0.07 \), but COPD patients were more hypercapnic and had significantly lower pH values \( (7.33 \pm 0.01 \text{ vs } 7.37 \pm 0.01; p = 0.02) \).

**Acute Effects of NPPV**

Of the 40 patients admitted into the study, 4 (1 with restrictive disorder, 3 with COPD) discontinued NPPV prior to hospital discharge; thus, 36 of 40 (90%) were discharged home while using nightly NPPV. During the next 23 ± 5 weeks, another 10 patients (3 with restrictive disorders, 7 with COPD) discontinued NPPV (Fig 1).

**Table 2—General Characteristics in All Patients \((n = 40)\)**

<table>
<thead>
<tr>
<th>Etiology of Respiratory Failure</th>
<th>Restrictive Disorders</th>
<th>COPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>65 ± 9.7</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Presence of cor pulmonale</td>
<td>16/40 (40%)</td>
<td></td>
</tr>
<tr>
<td>Intubation &lt; 6 mos prior to evaluation</td>
<td>13/40 (33%)</td>
<td></td>
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*Restrictive disorders group \((n = 20)\) includes patients with kyphoscoliosis \((n = 5)\), obesity hypoventilation syndrome \((n = 6)\), neuromuscular disease \((n = 6)\), and fibrothorax \((n = 3)\). The COPD group comprised 20 patients.

**Table 3—Baseline Gas Exchange, Respiratory Mechanics, and Functional Status**

<table>
<thead>
<tr>
<th></th>
<th>Restrictive Disorders</th>
<th>COPD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas exchange</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{Pao}_2/\text{FiO}_2 )</td>
<td>287 ± 18</td>
<td>255 ± 16</td>
</tr>
<tr>
<td>( \text{PaCO}_2 )</td>
<td>62 ± 3</td>
<td>70 ± 3*</td>
</tr>
<tr>
<td>( \text{pH} )</td>
<td>7.37 ± 0.01</td>
<td>7.33 ± 0.01*</td>
</tr>
<tr>
<td><strong>Respiratory mechanics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{FVC}, \text{L} )</td>
<td>1.17 ± 0.15</td>
<td>1.92 ± 0.14*</td>
</tr>
<tr>
<td>( \text{FEV}_1, \text{L} )</td>
<td>0.79 ± 0.1</td>
<td>0.71 ± 0.1</td>
</tr>
<tr>
<td>( \text{PImax, cm H}_2\text{O} )</td>
<td>36 ± 1</td>
<td>32 ± 4</td>
</tr>
<tr>
<td>( \text{PEmax, cm H}_2\text{O} )</td>
<td>50 ± 9</td>
<td>50 ± 4</td>
</tr>
<tr>
<td><strong>Functional status</strong></td>
<td>3.1 ± 0.4</td>
<td>3.3 ± 0.4</td>
</tr>
</tbody>
</table>

*p < 0.05, comparison between restrictive ventilatory disorder and COPD groups.
In all patients who started NPPV, 34 used BiPAP (15 with COPD, 19 with restrictive disorders) and 6 required a portable volume ventilator (5 with COPD, 1 with restrictive disorder) in order to achieve ventilation goals. The average level of inspiratory positive airway pressure was 17 ± 6 cm H2O, and expiratory positive airway pressure was 3 ± 2 cm H2O with a mean pressure boost of 14 ± 3 cm H2O. The average delivered expired VT was 725 ± 140 mL with a rate of 22 ± 4 breaths/min in patients receiving NPPV via the portable volume ventilator.

Arterial blood gas analysis in all compliant patients was obtained while the patients were breathing spontaneously at the time of admission, while using NPPV at the optimum settings, during spontaneous breathing at discharge, and while spontaneously breathing at a follow-up visit approximately 23 ± 5 weeks after discharge, as shown in Figure 2. Mean PaO2/FIO2 values while using NPPV were higher than admission values (329 ± 17 vs 283 ± 13; p = 0.015); mean PaCO2 was significantly lower during NPPV than at admission (51 ± 2 vs 67 ± 3 mm Hg; p = 0.0001); and pH was greater during NPPV than at admission (7.41 ± 0.01 vs 7.35 ± 0.01; p = 0.0001). In compliant patients, the improvements in gas exchange (327 ± 10 vs 283 ± 13; p = 0.01), PaCO2 (52 ± 2 vs 67 ± 3; p = 0.0001), and pH 7.38 ± 0.01 vs 7.35 ± 0.01; p = 0.007) were maintained during spontaneous breathing, both at discharge and at follow-up (Fig 2).

The functional scores in compliant patients were significantly improved at discharge compared with scores at admission (from 4.8 ± 0.2 to 2.7 ± 0.3 AUs; p < 0.001; Fig 3).

Long-term Effects of NPPV

Patients who remained compliant with NPPV were reexamined at follow-up visits at 23 ± 5 weeks to determine whether improvements in gas exchange were maintained. In comparison with values obtained during spontaneous breathing on admission, improvements in PaO2/FIO2 (283 ± 13 vs 317 ± 10; p = 0.05), PaCO2 (67 ± 3 vs 52 ± 2 mm Hg; p = 0.001), and pH (7.35 ± 0.01 vs 7.38 ± 0.01; p = 0.03) were maintained (Fig 2).

To determine whether NPPV had an independent effect on the improvement observed in gas exchange, arterial blood gas values at discharge and follow-up were compared in patients who complied with NPPV vs patients who were noncompliant with NPPV. As
shown in Figure 4, \( \text{PaO}_2/\text{FiO}_2 \) tended to decrease (294 ± 12 to 259 ± 16; \( p = 0.10 \)) and \( \text{PaCO}_2 \) tended to rise (54 ± 2 to 60 ± 4 mm Hg; \( p = 0.19 \)) in the noncompliant group, but remained stable in patients who complied with NPPV.

As shown in Figure 3, functional scores in patients who complied with chronic NPPV therapy showed a further increase in score at 3 months in comparison with the score at discharge (5.53 ± 0.3 vs 4.8 ± 0.2 AUs; \( p = 0.02 \)), with maintained improvements at the 6- and 12-month follow-ups.

In contrast to the improvements in gas exchange and functional status, spirometry (FEV\(_1\) and FVC) and respiratory muscle strength (P\(_{\text{Imax}}\) and P\(_{\text{Emax}}\)) before and after approximately 6 months of NPPV therapy were not significantly different in patients with COPD or restrictive disorders (Fig 5, 6).

**Side Effects of NPPV**

Six months after discharge, 26 of the original 40 patients (65%) continued to be compliant with NPPV. Of the 20 original patients who had COPD, 10 completed the study (50%), while 16 of the 20 original patients with restrictive disorders (80%) remained on NPPV (Fig 1). Overall, outpatient use as actually measured on the meter log was 45% less than patients’ stated use (4.5 ± 0.56 vs 7.23 ± 0.24 h/night). Complications experienced with NPPV included significant mouth or mask leaks in 43%, skin irritation at the patient face mask interface in 23%, rhinitis or aerophagia in 13%, and discomfort from the mask or head gear in 5%. Thirty-six percent of patients required face mask or ventilator setting adjustments to maintain optimization of their gas exchange and compliance with therapy.

**Discussion**

Our data show that in moderately ill patients with chronic respiratory failure, NPPV was associated with acute and chronic improvements in gas exchange and functional status. In contrast, chronic NPPV was not associated with an improvement in spirometry or respiratory muscle strength. Despite enrollment in a comprehensive program (with both inpatient and outpatient components), only 65% of patients continued to use NPPV on a chronic basis. Only half of the patients with severe COPD and hypercapnic respiratory failure continued to chronically use NPPV therapy, whereas 16 of 20 patients (80%) with restrictive disorders remained compliant with NPPV. Minor complications and changes in gas exchange necessitated frequent adjustments in face mask or ventilator settings to maintain effectiveness and compliance with outpatient therapy. Based on the data, we suggest that comprehensive follow-up is needed to correct equipment problems and maximize patient compliance with NPPV therapy.

Our observations that NPPV improves gas exchange and functional status in patients with restrictive ventilatory disorders corroborate the findings of others\(^{4,12,14,19-21}\). As a whole, when noninvasive ventilation is used in patients with restrictive ventilatory disorders, the data uniformly show an improvement in patient symptoms and gas exchange,\(^{4,19,20,28}\) and occasionally demonstrate an improvement in respiratory muscle function\(^{20,28}\) and spirometric values.\(^{20}\) Although NPPV improves gas exchange and symptoms in patients with restrictive ventilatory disorders, its effect on respiratory muscle strength and spirometry is variable.\(^{20,23,25,28}\) Our findings are in agreement with those of others\(^{23,25,28}\) that improvements in gas exchange and functional status need not be accompanied by any change in spirometry or respiratory muscle strength.

Results of noninvasive ventilation in COPD patients with chronic respiratory failure have been even more inconsistent. Strumpf et al\(^{15}\), and Gay et al\(^{13}\)
have shown that NPPV in patients with chronic, stable, moderately severe COPD has no significant effect on gas exchange, functional status, or the patients’ quality of life. In contrast, other investigators have demonstrated that NPPV used daily for 1 week to 3 months had significant beneficial effects on gas exchange, sleep quality, exercise tolerance, and quality of life.\textsuperscript{5,6,7,14,17}

Why different investigators have found varying results in using NPPV in COPD patients, in contrast to patients with restrictive disorders, is not known, but several theories exist. First, patients with restrictive ventilatory disorders and hypercapnia suffer primarily from hypoventilation resulting from either respiratory muscle weakness or chronic resetting of the CO\textsubscript{2} threshold. Application of noninvasive ven-

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**Figure 5.** FVC and FEV\textsubscript{1} in all compliant patients with COPD (open bars) and restrictive ventilatory disorders (crosshatched bars) before and 6 months after implementation of NPPV. NPPV had no effect on FVC or FEV\textsubscript{1} in either patient group.

**Figure 6.** P\text{max} (MIP) and P\text{emax} (MEP) before (PRE) and after (POST) NPPV in compliant patients with obstructive disease and restrictive ventilatory disorders (restrictive disease), before and 6 months after NPPV. NPPV had no effect on maximum respiratory muscle pressures.
tilation in this patient group improves nocturnal ventilation and acts to reset the CNS CO₂ threshold. Some have suggested that the use of noninvasive ventilation provides intermittent chronic respiratory muscle resting and/or improves lung and chest wall compliance, thereby resulting in an improvement in respiratory mechanics that improves respiratory function, gas exchange, and functional status. The latter mechanisms appear less tenable because the presence of respiratory muscle fatigue has never been shown to exist in a chronic state in any patient group; also, several studies have failed to document an improvement in spirometric values or respiratory muscle strength, suggesting that NPPV does not improve respiratory mechanics.

COPD patients develop hypercapnia by very different mechanisms than patients who become hypocapnic because of restrictive ventilatory disorders. Most commonly, hypercapnia exists in this patient group because of an increase in physiologic dead space secondary to a ventilation/perfusion imbalance induced by bronchospasm or by the effect of emphysema altering CO₂ elimination across a significantly reduced alveolar capillary bed. In COPD patients, therefore, hypercapnia does not always signify hypoventilation, but may signify high physiologic dead space as a result of either reactive airways disease or structural changes in the lung. The application of NPPV in this scenario would be much less likely to uniformly improve gas exchange or functional tolerance. Moreover, the application of NPPV in patients with COPD whose lungs are severely hyperinflated and obstructed may further worsen the development of hyperinflation, thereby contributing to poorer tolerance of NPPV in contrast to patients with restrictive ventilatory disorders.

Although the above reasons support the notion that COPD patients do not tolerate NPPV as well as patients with restrictive disorders, some COPD patients chronically use NPPV for long periods of time and appear to derive physiologic and functional benefit. What makes this patient group distinct from other patient groups with COPD is currently unknown, but several hypotheses could be put forth.

First, some COPD patients have been shown to have an overlapping syndrome (ie, combination of COPD and obstructive sleep apnea syndrome) that may benefit from the use of nocturnal ventilation. This patient group may, therefore, favorably influence the beneficial effects of NPPV in chronic respiratory failure and COPD. Most studies that tend to demonstrate an improvement in symptoms and gas exchange with NPPV in severe COPD have included patients with moderate to severe hypercapnia on implementation. Indeed, our patients had higher levels of PaCO₂ than did any other patients in whom NPPV has been applied on a chronic basis. Our results are similar to those of Meecham-Jones et al., who showed a benefit in 12 patients with severe COPD whose mean PaCO₂ was ≥ 55 mm Hg. In contrast, Strumpf et al. and Gay et al. failed to show any benefit with NPPV in COPD patients whose average PaCO₂ levels were ≤ 45 mm Hg. Perhaps COPD patients with severe hypercapnia represent a subgroup of patients in whom hypventilation is a component of their disease, and thus they benefit from chronic NPPV application.

Our data suffer from the standpoint that the study did not have an appropriate control arm of patients who only received long-term oxygen or low levels of continuous positive airway pressure. We believe that this would not have been appropriate for those patients with restrictive ventilatory disorders because many studies have now shown the beneficial effects of NPPV therapy in this patient group. Our COPD patient group, as a whole, was extremely ill (ie, COPD patients were acedemic, 40% had cor pulmonale, and one third had been intubated ≤ 6 months prior to study entry) and had already failed maximal standard therapy. Despite the absence of an adequate control group, however, the observation that patients who were noncompliant with NPPV tend to showed a worsening in gas exchange and functional status supports our notion that NPPV had a important therapeutic role in those who complied with therapy.

Our chronic NPPV therapy compliance rate of 65% occurred in a comprehensive outpatient program that was geared toward maximizing patient comfort and the efficacy of NPPV application with frequent face mask changes or ventilator settings to optimize patient comfort and gas exchange. In the patients who were compliant with NPPV, they underestimated their use of noninvasive ventilation at least 45% of the time as compared with objective meter logs. This highlights the problems of prior studies that have commented on the efficacy of NPPV. Some patients who were previously reported not to have benefited from NPPV may have failed not because of lack of clinical efficacy, but rather because of noncompliance with prescribed NPPV therapy. Future studies must address the issue of efficacy vs compliance and ensure that objective parameters of NPPV use are measured.

It should also be recognized that patients with COPD developed a set of complications when they used NPPV that differed from those developed by patients with restrictive ventilatory disorders. The development of tracheobronchitis, with an increase in airway secretions, dynamic development of worsened airways obstruction, and the need for additional medications such as bronchodilators, poses problems in the application of NPPV therapy to this group. Obviously, worsening secretions or bronchospasm affect gas exchange and require an alteration in the

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application of NPPV. Furthermore, the development of worsening hyperinflation or the need for concomitant use of other medications may negatively influence patient compliance with NPPV, such that only the most motivated patient who perceives benefit will continue with therapy.

Our data are strengthened by the fact that they were collected prospectively in a comprehensive inpatient and outpatient program that was optimized to provide maximal medical therapy (including pulmonary rehabilitation) and compliance with NPPV treatment (i.e., adjustments of face mask and ventilator settings to maximize ventilatory support). Nonetheless, even in such a comprehensive program, we found that only approximately 50% of our patients with COPD could tolerate NPPV, in contrast to 75% of patients with restrictive ventilatory disorders.

In summary, our data corroborate prior studies that show an important beneficial effect of NPPV on gas exchange and functional status in patients with chronic respiratory failure secondary to COPD or restrictive ventilatory disorders. However, in our study, only 75% of patients with restrictive ventilatory disorders and 50% of patients with COPD continued to use NPPV during prolonged follow-up of approximately 6 months, despite enrollment in a comprehensive inpatient and outpatient program. Future studies, preferably conducted in a prospective, randomized, and controlled fashion, are required to determine the subgroups of COPD patients who may best benefit from NPPV therapy.

REFERENCES