Patients with severe COPD may be in a state of ventilatory muscle (VM) fatigue. In these patients, rapid and shallow breathing has been hypothesized to be a compensatory mechanism that prevents more severe fatigue from taking place. To test these hypotheses, we studied the effects of VM resting in a group of patients with severe COPD. Eleven clinically stable patients with COPD and chronic hypercapnia were studied. Six of them (group A) had a seven-day period of negative pressure-assisted ventilation (NPV), and five (group B) with similar functional characteristics served as a control group. Compared with a normal age-matched control group, both A and B groups exhibited significantly lower tidal volume (Vt), inspiratory time (Ti), total time of the respiratory cycle (Ttot) and Ti/Ttot ratio, decrease in muscle strength, and greater electromyographic activity of diaphragm (EMGd) and parasternal muscles, but similar ventilation and Vt/Tt. After the study period, group A exhibited significant increase in Vt, Ti, and Ti/Ttot (p<0.05), and decrease in PaCO₂ (p<0.05), EMGd, and EMGint (p<0.05 for both), and a slight but significant increase in maximal inspiratory pressure (MIP) (p<0.05). These data suggest that NPV rests VM, increases their strength, and reduces hypercapnia in patients with severe COPD.

Chest 1990; 97:322-27

RF = respiratory frequency; NPV = negative pressure ventilation; MIP = maximal inspiratory pressure; MEF = maximal expiratory pressure; Vr = minute ventilation; Ti = inspiratory time; Ttot = total time of the respiratory cycle; Vr/Tt = mean inspiratory flow; Ti/Ttot = fraction of the total time of the respiratory cycle when inspiratory muscles contract; P0.1 = mouth occlusion pressure; EMGd = electromyographic activity of the diaphragm; EMGint = electromyographic activity of the intercostal muscles.

In the last years, several studies have been devoted to investigating the role of respiratory muscle function in the development of hypercapnia in patients with COPD. Some of these studies have reported that in acutely ill patients, diaphragmatic muscle fatigue is associated with increase in PaCO₂, decrease in maximal inspiratory pressure (MIP), and increase in respiratory frequency (RF) along with a decrease in tidal volume (Vt). Similar ventilatory response, observed in patients with stable COPD during loaded breathing, has been interpreted as probably due to poor inspiratory muscle function. In this connection, Roussos has recently hypothesized that in patients with COPD, the rapid and shallow breathing accompanying chronic hypercapnia may stem from afferents arising from overloaded or fatigued respiratory muscles.

A previous article of Rochester et al and more recent articles have shown that negative pressure ventilation (NPV) rests respiratory muscle activity in normal man, while in patients with COPD this may occur or it may not. In patients with chronically stable COPD, NPV also causes PaCO₂ to decrease and MIP to increase. However, until now no study has been designed to assess the following: (1) whether, and to what extent, rest of respiratory muscles may influence the rapid and shallow breathing that accompanies respiratory muscle fatigue in these patients and (2) the interrelations among breathing pattern, arterial blood gas values, respiratory muscle strength, and phasic suppression of ventilatory muscle activity. The present investigation was carried out to contribute in this field.

METHODS

Subjects

Eleven hospitalized patients, nine men and two women, were studied after the nature of the experimental technique and the purpose of the investigation had been fully explained to them. Patients were defined as suffering from COPD according to the American Thoracic Society (ATS) criteria. All patients were free of active cardiovascular disease. An age-matched group of six normal subjects (mean ± SD age, 62.0 ± 8.7 years) was also included as a control.

Functional Evaluation

Routine spirometry obtained with subjects in a seated position and arterial blood gas values were measured as previously described. The normal values for lung volumes are those proposed by European Community for Coal and Steel. Maximal static
inspiratory and expiratory pressures (MIP and MEP) at functional residual capacity (FRC) and total lung capacity (TLC), respectively, against an obstructed mouthpiece, with a small leak to minimize oral pressure artifacts, were measured using a differential pressure transducer (Statham SC 1001). Subjects performed maximal inspiratory and expiratory efforts and were instructed to maintain maximal pressures for at least 1 s. The mean of three reproducible and satisfactory measurements was calculated.

After baseline routine testing during room-air breathing, the ventilatory pattern, respiratory drive, and mouth occlusion pressure were evaluated with subjects put in a comfortable supine position. In the apparatus we used, the inspiratory line was separated from the expiratory one by a one-way valve (Hans-Rudolph) connected to a Fleisch type 3 pneumotachograph. The flow signal was integrated into the volume. From the spirogram we derived, breath by breath, time and volume components of the respiratory cycle: inspiratory time (Ti), expiratory time (Te), total time of the respiratory cycle (Ttot), and Vt. Mean inspiratory flow (Vt/Ti), duty cycle (Ti/Ttot), respiratory frequency (RF = 1/Ttot x 60), and instantaneous ventilation (Ve = Vt x RF) were also calculated. Mouth pressure during Vr maneuvers was measured using a pressure transducer (Statham P23ID). Mouth occlusion pressure 0.1 s after the beginning of inspiration (Pm.in) was recorded as previously described. Expected CO2 (Pm,CO2) was sampled continuously at the mouth by an infrared CO2 meter. The values for dead space and resistance of the system up to flow of 4 L were 178 ml and 0.92 cm H2O L-1 s-1, respectively.

The electromyographic (EMG) activity of the respiratory muscles was recorded as previously described. The EMG of the chest wall muscles was recorded from the second parasternal intercostal (EMGint) and diaphragm (EMGd) muscles via large surface electrodes. The EMGd was recorded from the lower anterolateral rib cage as described by Gross et al.

Muscle action potentials ("raw") were differentially amplified, filtered between 80 and 1,000 Hz, to remove as much ECG as possible, without significantly filtering EMG. The filtered EMG signal along with mouth pressure recording were displayed on a single-beam storage oscilloscope (Tektronix 515S). The EMG activity was full-wave rectified and integrated over time (time constant, 150 ms) using a third-order, low-pass filter to provide a measurement of change in average electrical activity as a function of time, referred to as "moving time average" (xP). This method of analysis allows the description of the time course of inspiratory muscle activity which shows a definable rate of increase, reaching a peak of amplitude and then rapidly decreasing. Inspiratory activity was quantified both as peak of activity and as rate of rise of activity (slope). The former was directly measured in arbitrary units (xP) and the latter was obtained by dividing xP by the inspiratory time (xP/Ti).

Owing to the variability of the impedance between diaphragm and electrodes, absolute values (mV) are not comparable among different subjects. To overcome this problem in our subjects we obtained a reference value, measuring the EMG activity (xP) with the subject in a supine position, at maximal inflation (TLC). This xP reference value was the average of at least three measurements. All successive xP measurements have been expressed as a percentage of this reference value obtained at TLC and then divided by the inspiratory time. As EMG activity of an inspiratory muscle may include cardiac muscle activity, we checked cardiac artifacts to manually gate ECG, when necessary.

The output of CO2 meter, the flow signal, the integrated flow signal, the mouth pressure, and the moving time average were recorded continuously on a multichannel chart recorder. After a ten-minute adaptation period, baseline evaluation began. Respiratory cycles, occlusions, and EMG were continuously recorded over a 30-minute time period and the cycles following occlusions were discarded. Average values for each subject are presented.

Protocol
After baseline function testing, patients were randomly assigned to either study group (A) (six patients) or control group (B) (five patients). Group A had negative pressure-assisted ventilation using a tank ventilator (Pneumoflue). Ventilator frequency and peak negative pressure were adjusted to approximate the patient's spontaneous breathing frequency and minute ventilation, as measured by a Wright spirometer. Adaptation to the ventilator was considered satisfactory when the patient felt comfortable and he/she maintained stable Ve and oxymeglobin saturation (SaO2) as measured with an ear oximeter (Oxi Radiometer Copenhagen). To achieve this, the ventilator was set to deliver negative pressure between −30 to −30 cm H2O at ventilatory rate of 18 to 24 cycles/min. Group A received NPV four hours daily for seven consecutive days; two patients were accustomed to the tank respirator, as they had been previously treated for acute respiratory failure. Group B patients received no intervention.

At the conclusion of the study period all patients had pulmonary function test repeated and in group A, this was done two hours after discontinuation of NPV. In two patients breathing pattern and EMG were also evaluated one day after discontinuation of NPV.

Results were compared by the Wilcoxon test for paired samples and the Mann-Whitney U test for unpaired samples and a p value <0.05 was considered to be significant.

Results
Functional data of the three groups were summarized in Table 1. As shown, the study group (A) and the control group (B) exhibited similar VC, FRC, FV1, and FV1/VC ratio, MIP and MEP, and PaO2, and PaCO2; these values being significantly different compared with the mean value of the normal control group (C group). Breathing characteristics (Table 2) were also similar in groups A and B but, compared with group C, both groups A and B exhibited a significantly lower Vt (p<0.01) and Ti (p<0.01) and a

| Table 1 — Baseline Functional Data of the Three Studied Groups* |
|-------------|------|------|------|------|------|------|
| Age, yr     | Vc   | Frc  | Fve, % | FEV1/VC, FeV1, PaO2, PaCO2, MIP, | MEP, |
| Group A     | 68.8 ± 4.5 | 59.6 ± 8.0 | 147.8 ± 11.7 | 29.8 ± 9.7 | 38.4 ± 12.0 | 58.2 ± 8.0 | 60.5 ± 3.4 | 40.5 ± 13.9 | 83.5 ± 26.6 |
| Group B     | 71.0 ± 6.9 | 52.4 ± 3.2 | 147.6 ± 28.0 | 26.8 ± 5.9 | 42.4 ± 10.7 | 57.2 ± 4.6 | 56.9 ± 9.8 | 44.0 ± 10.0 | 54.0 ± 16.0 |
| Group C     | 62.0 ± 8.7 | 110.7 ± 8.6 | 105.2 ± 7.4 | 106.7 ± 11.4 | 70.6 ± 3.4 | 70.6 ± 3.4 | 70.6 ± 3.4 | 70.6 ± 3.4 | 70.6 ± 3.4 |

*Values are means ± ISD. Group A: study group patients; Group B: control group patients; Group C: normal subjects. VC = vital capacity; FRC = functional residual capacity; FV1 = forced expiratory volume in 1 s; PaO2 = arterial oxygen tension; PaCO2 = arterial carbon dioxide tension; MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure.  
†Percent of the predicted value.
greater RF (p<0.01 and p<0.05, respectively) and lower Ttot (p<0.01 and p<0.05, respectively) and Ti/ Ttot (p<0.05 for both comparisons). The VT/Ti was slightly greater in patients, but this difference was not significant; similarly, VE did not significantly differ among the three groups. In addition, in groups A and B both EMGd (p<0.01) and EMGint (p<0.01) were significantly higher than in normal subjects.

After a seven-day study period (Table 3), group A did not exhibit significant changes in VC, FEV1, and FRC. The MIP and MEP measurements before and after completion of the study period are shown for group A patients in Table 3 and in Figure 1 (top). As shown in Figure 1, MIP rose in each patient; average MIP increased from 40.5 to 44.6 cm H2O (p<0.05); MEP rose in five of the six patients and average MEP increased from 83.5 to 100 cm H2O (p = NS). After completion of the study period, PaCO2 decreased in each group A patient; the mean PaCO2 decreased from 60.5 to 51.2 mm Hg (p<0.05) while PaO2 rose in five patients and decreased in one; the mean PaO2 increased from 58.2 to 63.75 mm Hg (p = NS). Mean and individual changes in arterial blood gas values are depicted in Table 3 and Figure 1 (bottom), respectively. The group mean effects of assisted ventilation on breathing pattern are schematized in Table 3. Both VT and Ti increased (from 0.5±0.1 L to 0.67±0.1 L, with p<0.05, and from 1.08±0.2 s to 1.33±0.25 s, with p<0.05 respectively), whereas RF significantly decreased (from 21.6±3.9 cycles/min to 19.25±3.3 cycles/min, with p<0.05). The Ti/Ttot significantly increased (from 0.37±0.02 to 0.42±0.04 with p<0.05). The VT/Ti was found to increase (from 0.47±0.06 Ls⁻¹ to 0.52±0.08 Ls⁻¹); for the group this change was not significant. Mouth occlusion pressure (Po1) did not exhibit any significant difference among the three groups (Table 2). With assisted ventilation, Po1 did not exhibit any significant change (from 2.8±1.0 cm H2O to 2.0±0.8 cm H2O).

The EMGd at VT was a greater fraction of the maximal EMGd activity recorded at TLC in group A and B patients (45.4±23.7 percent TLCs⁻¹) and 34.2±14.1 percent TLCs⁻¹, respectively) than in normal subjects (3.6±2.3 percent TLCs⁻¹), the differences between A and C and B and C groups being highly significant (p<0.01) (Table 2). As was the case of EMGd, the EMGint at VT was a larger fraction of the maximal activity recorded at TLC both in group A and B patients (31±15 percent TLCs⁻¹ and 30.3±10.6 percent TLCs⁻¹, respectively) than in the normal control group (0.9±0.2 percent TLCs⁻¹). The differences between A and C and B and C groups are highly significant (p<0.01). No significant difference, however, was observed either in EMGd or in EMGint between A and B groups. After cessation of the study period EMGd decreased in each group A patient (Fig 2); mean EMGd decreased from 45.4 percent TLCs⁻¹ to 31.6 percent TLCs⁻¹ with p<0.05 (Table 3). However, patients with greater EMGd prior assisted ventilation exhibited the largest EMGd decrease with mechanical treatment, whereas in those patients (1 and 3) in whom EMGd at VT was a smaller fraction of their maximal EMGd activity at TLC, assisted ventilation caused only minimal EMGd decrease.

### Table 2—Breathing Pattern, Po1, and EMG Activity in the Three Groups*

<table>
<thead>
<tr>
<th>Group</th>
<th>VE/L</th>
<th>RF, cycles⁻¹</th>
<th>VT/L</th>
<th>Ti, s</th>
<th>Ttot, s</th>
<th>VT/Ti, Ls⁻¹</th>
<th>Po1, cm H2O</th>
<th>EMGd, %TLCs⁻¹</th>
<th>EMGint, %TLCs⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11.2±1.6</td>
<td>21.65±3.9</td>
<td>0.57±0.09</td>
<td>1.08±0.20</td>
<td>2.84±0.49</td>
<td>0.47±0.06</td>
<td>0.37±0.02</td>
<td>2.8±1.00</td>
<td>45.4±23.7</td>
</tr>
<tr>
<td>B</td>
<td>10.3±3.6</td>
<td>19.6±5.0</td>
<td>0.49±0.19</td>
<td>1.09±0.37</td>
<td>3.20±0.90</td>
<td>0.47±0.21</td>
<td>0.35±0.05</td>
<td>2.54±0.90</td>
<td>34.2±14.1</td>
</tr>
<tr>
<td>C</td>
<td>10.9±1.8</td>
<td>12.7±1.3</td>
<td>0.78±0.08</td>
<td>2.13±0.32</td>
<td>4.82±0.54</td>
<td>0.41±0.08</td>
<td>0.45±0.02</td>
<td>1.90±0.54</td>
<td>3.6±2.3</td>
</tr>
</tbody>
</table>

*Values are means ± 1SD. VE = minute ventilation; RF = respiratory frequency; VT = tidal volume; T = inspiratory time; Ttot = total time of the respiratory cycle; VT/Ti = mean inspiratory flow; Ti/Ttot = fraction of the total time of the respiratory cycle when inspiratory muscles contract; Po1 = mouth occlusion pressure; EMGd = electromyographic activity (moving time average) of the diaphragm; EMGint = electromyographic activity of the intercostal muscles. EMG was quantified as slope, obtained by dividing peak of inspiratory activity (xP) by inspiratory time (Ti); xP is expressed at VT in percent of the activity recorded at TLC.

†p<0.01.
‡p<0.05.

### Table 3—Functional Data of the Study Group before and after Seven-Day Assisted Ventilation (AV) Period*

<table>
<thead>
<tr>
<th>Control</th>
<th>Post AV</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC, L</td>
<td>1.71±0.36</td>
<td>1.98±0.47</td>
</tr>
<tr>
<td>FRC, L</td>
<td>4.65±0.69</td>
<td>4.30±0.42</td>
</tr>
<tr>
<td>FEV1, L</td>
<td>0.73±0.26</td>
<td>0.86±0.36</td>
</tr>
<tr>
<td>PaO2, mm Hg</td>
<td>58.20±5.00</td>
<td>63.75±5.80</td>
</tr>
<tr>
<td>PaCO2, mm Hg</td>
<td>60.50±3.27</td>
<td>51.20±3.81</td>
</tr>
<tr>
<td>MEF, cm H2O</td>
<td>40.50±13.90</td>
<td>44.60±14.60</td>
</tr>
<tr>
<td>MEP, cm H2O</td>
<td>83.50±26.60</td>
<td>100.00±17.80</td>
</tr>
<tr>
<td>Po2, cm H2O</td>
<td>2.80±1.00</td>
<td>2.00±0.80</td>
</tr>
<tr>
<td>EMGd, %TLCs⁻¹</td>
<td>45.40±23.70</td>
<td>31.60±15.20</td>
</tr>
<tr>
<td>EMGint, %TLCs⁻¹</td>
<td>31.00±15.00</td>
<td>15.40±4.70</td>
</tr>
<tr>
<td>VE, L/min</td>
<td>10.77±1.83</td>
<td>12.88±2.30</td>
</tr>
<tr>
<td>RF, cycles⁻¹</td>
<td>21.65±3.90</td>
<td>19.25±3.30</td>
</tr>
<tr>
<td>VT/L</td>
<td>0.50±0.09</td>
<td>0.67±0.10</td>
</tr>
<tr>
<td>Ti, s</td>
<td>1.08±0.20</td>
<td>1.33±0.25</td>
</tr>
<tr>
<td>Ttot, s</td>
<td>2.84±0.49</td>
<td>3.19±0.52</td>
</tr>
<tr>
<td>VT/Ti, Ls⁻¹</td>
<td>0.47±0.06</td>
<td>0.52±0.08</td>
</tr>
<tr>
<td>VT/Ttot</td>
<td>0.37±0.02</td>
<td>0.42±0.04</td>
</tr>
</tbody>
</table>

*Values are means ± 1SD. Same abbreviations as in Tables 1 and 2.
EMGint also decreased in each group A patient after cessation of study period (Fig. 2); mean EMGint decreased from 31 percent TLC$^{-1}$ to 15.4 percent TLC$^{-1}$, with $p<0.05$ (Table 3). It is also worth noting that in the above-mentioned patients (1 and 3), assisted ventilation caused EMGint to decrease more than EMGd.

In group B patients, no relevant changes in pulmonary volume, muscle strength, EMG, arterial blood gas values, and breathing pattern were observed during the study period.

In the two patients (2 and 5) in whom EMG was also evaluated one day after cessation of NPV, both EMGd and EMGint did not exhibit substantial percentage changes compared with the end of the seven-day period of NPV: EMGd was 105 percent ± 5 percent and EMGint was 106 percent ± 6 percent. Accordingly, neither $V_t$ nor $T_i$ nor RF exhibited substantial percent changes.

At the end of the study period each group A patient experienced a decrease in sensation of breathlessness. No ventilator-related complications were observed in them.

**Discussion**

Our data show that in chronically stable hypercapnic patients with COPD, NPV reduces respiratory muscle activity (EMG), slightly increases muscle strength (MIP and MEP), and improves arterial blood gas values ($P_{aO_2}$ and $P_{aCO_2}$). These changes were coincident with significant increases in $T_i$, $V_t$, and $T_i/T_t$ and a decrease in RF.

In patients with COPD, increase in airway resistance and lung hyperinflation enhance the energy demand of the respiratory muscles$^{2,4}$; furthermore, the hypoxemia reduces the available energy supply$^{2,4}$ and it is known that if energy demands are greater than supplies, the muscle will eventually fatigue.$^{2,4}$

In this study, both study group (A) and control group (B) exhibited hyperinflation (FRC) and airway obstruction (FEV$_1$), a markedly low inspiratory (MIP) and expiratory (MEP) muscle force, and chronic hypercapnia and hypoxia; so, consistently with the accumulating evidence that respiratory muscle fatigue and development of hypercapnia are closely related,$^{2,4}$ we think that both groups A and B were in a situation of respiratory muscle fatigue. In this situation and particularly in hyperinflated patients with COPD, rapid
and shallow breathing has also been observed and it has been related to afferents arising from vagal pulmonary endings. More recently, a decrease in both Vr and Tt with constant Vr/Tt and increase in RF have been interpreted as a compensatory mechanism by which overloaded or fatigued respiratory muscles contract at optimal length without substantially changing their geometry. Such a mechanism theoretically postpones more severe fatigue, but the increase in PaCO₂ is an unescapable consequence.

Basically, the rapid and shallow breathing, the increased neural drive, the decrease in muscle strength, and the chronic hypercapnia appeared to be concomitant in group A and B patients, consistently with the hypothesis that afferents arising from overloaded or fatigued respiratory muscles are involved in the rapid and shallow breathing and CO₂ retention. Furthermore, our data showing an increase in EMG seem to be in contrast with the hypothesis that central inhibition plays a major role in CO₂ retention. Both chemical and mechanical afferents arising from lung and/or chest wall could be involved in the observed increase in neural inspiratory drive (EMG).

After a seven-day period of assisted ventilation, lung volumes and FEV₁ showed limited changes, while muscle strength significantly improved, a pattern also noticed by others reporting on mechanical ventilation. It should be noted that in our study, average increase in actual MIP value, significant though it was, was less than that of another study, where, however, the average pre-NPV MIP was greater than that of our study (patients had less hyperinflation), and its percentage increase was slightly greater than that of our study. In another long-term designed study, MIP markedly increased but this increase might at least in part be due to length-tension characteristics, as expected by the reported marked VC increase. Indeed, based on length-tension and geometrical characteristics, a decrease in lung volume increases the ability of the respiratory muscles to generate inspiratory pressure. Nevertheless, correction of mechanical disadvantage secondary to hyperinflation seems to be improbable in the present study since neither FRC nor FEV₁ changed with NPV.

In patients with COPD, NPV has been reported to acutely suppress phasic ventilatory activity of the respiratory muscles, an observation that others, have been unable to confirm. On the other hand Levy et al have more recently noticed that prolonged NPV treatment decreases EMG activity in these patients. In the present study, a seven-day period of NPV caused both EMGd and EMGint to significantly decrease, the remaining EMGint activity being significantly lower compared with that of group B (p<0.01). So, a seven-day period of NPV resulted in a partial suppression of respiratory muscle activity. In general, our data confirm the observation of Levy et al that a short period of NPV reduces phasic activity of ventilatory muscles and extends those data for example, in patient 1 with a lower pre-NPV EMGd and a greater pre-NPV EMGint, minimal EMGd and greater EMGint decreases were observed with NPV. Moreover, in patient 3 in whom both EMGd and EMGint were the lowest prior to the study, NPV caused the minimal phasic EMG suppression; the opposite occurred in patients 2 and 5, that is, those with the greater baseline EMGd and EMGint activities. These data seem to indicate that the amount of phasic EMG suppression might depend on the extent of pretreatment activity. It is also well known that the degree of suppression improves with familiarity with the technique, nevertheless, in our study, the two patients (1 and 4) previously accustomed to iron lung exhibited no major decrease in EMG activity.

To our knowledge, few data have been provided until now on breathing pattern characteristics before and after a NPV study period. The latter study showed a significant increase in Vt with no consistent changes in Tt, Ttot, and Tt/Ttot. In contrast, in our study NPV resulted in significant changes in both volume (Vr) and time (Tt, RF, and Tt/Ttot) components of the respiratory cycle. These changes along with EMG changes persisted one day after discontinuation of NPV, and this indicates not merely an acute effect of NPV. The observation that these changes paralleled the consistent decrease in PaCO₂ could account for the observation that the more rapid and shallow the breathing the greater the arterial CO₂ tension and vice versa.

The answer to the question whether vagal or nonvagal afferents or both are involved in the lower Tt, Vr, and Tt/Ttot observed in patients is certainly difficult. However, we consider that (1) patients had stable tracheobronchial disease which has been suspected of being involved in the increase of vagal ending firing, resulting in Vr and Tt reduction, and (2) NPV is expected to modify neither tracheobronchial disease nor, as a consequence, vagal afferents from bronchial tree, while modulation in the firing of afferents arising from respiratory muscles is not expected with respiratory muscles resting. So, we suspect that peripheral nonvagal afferents from respiratory muscles were at least partially involved in the observed responses.

We also found a relief of sensation of dyspnea in patients with NPV. This observation could be interpreted in the light of the recent knowledge concerning the relation between dyspnea and increased respiratory drive.

In conclusion, patients with COPD may be in a situation of respiratory muscle fatigue characterized by decrease in muscle strength, increase in respiratory...
drive, and decrease in both Ti and V̇; the resulting rapid shallow breathing leads to alveolar hypoventilation. Negative pressure-assisted ventilation seems to partially suppress phasic ventilatory muscle activity and cause arterial blood gas values and muscle strength to improve, along with decrease in respiratory sensation of dyspnea. Change in timing seems to be linked to both EMG suppression and PaCO₂ amelioration. However, the evidence that change in breathing pattern, suppression of EMG phasic activity, and blood gas value improvement are closely interrelated is far from being conclusively provided.

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