Prevention of Pulmonary Morbidity for Patients With Neuromuscular Disease*

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Study objective: To evaluate the effects of a respiratory muscle aid protocol on hospitalization rates for respiratory complications of neuromuscular disease.

Design: A retrospective cohort study.

Methods: A home protocol was developed in which oxyhemoglobin desaturation was prevented or reversed by the use of noninvasive intermittent positive-pressure ventilation and manually and mechanically assisted coughing as needed. The patients who had more than one episode of respiratory failure before having access to the protocol were considered to have had preprotocol periods (group 1). Other patients were given access to the protocol when their assisted peak cough flows decreased to < 270 L/min before any episodes of respiratory distress (group 2). The number of hospitalizations and days hospitalized were compared longitudinally for preprotocol and protocol access periods (group 1). In addition, avoided hospitalizations were identified as “episodes” of need for continuous ventilatory support and desaturations reversed by assisted coughing that were managed at home. Data were segregated by access to protocol and by extent of baseline ventilator use.

Results: Of the 47 group 1 patients with preprotocol periods who have subsequently had episodes, 10 had episodes before requiring ongoing ventilator use. They had 1.06 ± 0.84 preprotocol hospitalizations per year per patient and 20.76 ± 36.01 hospitalization days per year per patient over 3.42 ± 3.36 years per patient vs 0.03 ± 0.11 hospitalizations per year per patient and 0.06 ± 0.20 hospitalization days per year per patient with protocol use over 1.94 ± 0.74 years per patient. Of these 47 group 1 patients, 33 eventually required part-time ventilatory aid and, using the protocol as needed, had 0.08 ± 0.17 hospitalizations per year per patient and 1.43 ± 3.71 hospitalization days per year per patient over 3.91 ± 3.50 years per patient, as opposed to 1.40 ± 1.96 hospitalizations per year per patient and 20.14 ± 41.15 hospitalization days per year per patient preprotocol and preventilator use over 5.89 ± 6.89 years per patient. Twelve patients in group 1 eventually required continuous noninvasive ventilation and, using the protocol as needed, had 0.07 ± 0.14 hospitalizations per year per patient and 0.39 ± 0.73 hospitalization days per year per patient over 5.35 ± 5.10 years per patient by comparison with 0.97 ± 0.74 hospitalizations per year per patient and 10.39 ± 8.66 hospitalization days per year per patient over 2.18 ± 1.91 years per patient preprotocol and preventilator use. For the 94 patients overall when having access to the protocol, 1.02 ± 0.99 hospitalizations per year per patient were avoided by 14 patients before requiring ongoing ventilator use over 4.82 ± 1.61 years, 0.99 ± 1.12 hospitalizations per year per patient were avoided by 73 part-time ventilator users over 3.21 ± 3.15 years, and 0.50 ± 0.85 hospitalizations per year per patient were avoided by 31 full-time ventilator users over 4.78 ± 4.88 years. All preprotocol and protocol rate comparisons were statistically significant at p < 0.004.

Conclusion: Patients have significantly fewer hospitalizations per year and days per year when using the protocol as needed than without the protocol. The use of inspiratory and expiratory aids can significantly decrease hospitalization rates for respiratory complications of neuromuscular disease.

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Key words: exsufflation; mechanical ventilation; neuromuscular disease; respiratory therapy

Abbreviations: IPPV = intermittent positive-pressure ventilation; MIC = maximum insufflation capacity; MI-E = mechanical insufflation-exsufflation; PCF = peak cough flow; PETCO₂ = end-tidal carbon dioxide tension; SaO₂ = arterial oxygen saturation; VC = vital capacity

The great majority of neuromuscular disease morbidity and mortality is caused by respiratory muscle weakness.1 Approximately 90% of episodes of respiratory failure occur during otherwise benign upper respiratory tract infections (“chest infections”) rather than from insidiously progressive CO₂ narcosis or other respiratory abnormalities.2 During chest infections, already impaired pulmonary function is
further compromised by airway mucus accumulation, fatigue, and worsening dysfunction of already weak inspiratory and expiratory muscles. Thus, for conventionally managed patients, chest infections result in repeated pneumonias, hospitalizations, endotracheal intubations, and ultimately, in tracheostomy and death.

Up to 24-h use of noninvasive intermittent positive-pressure ventilation (IPPV) has prolonged the survival of > 700 patients with neuromuscular ventilatory failure. For noninvasive IPPV to do this, however, the ability to clear the airway of secretions is critical, especially during chest infections and after surgical anesthesia. Peak cough flows (PCFs) of ≥ 160 L/min are the minimum required in adults to clear airway debris without resorting to tracheal intubation (Fig 1). In our experience, assisted PCFs of > 160 L/min can be attained for the great majority of adult patients with neuromuscular disease, except for those with advanced bulbar amyotrophic lateral sclerosis. We have found that when routinely measured assisted PCFs are < 270 L/min, they are very likely to decrease to < 160 L/min during chest infections, and the likelihood of pneumonia and respiratory failure increases greatly. Considering the fact that both hypercapnia and airway mucus accumulation can cause oxyhemoglobin desaturations, we hypothesized that if we could identify patients at high risk of developing acute respiratory failure on the basis of low PCFs, and train and equip these patients to prevent a sustained decrease in arterial oxygen saturation (SaO2) to < 95%, pulmonary morbidity and mortality could be prevented.

**Materials and Methods**

All of the patients in this study were referred to our Jerry Lewis Muscular Dystrophy Association clinic from neurologists who made the primary diagnoses or referred themselves to us once learning about us from other patients. Their diagnoses, confirmed in our clinic by standard criteria, mean ages when first experiencing respiratory distress, and pulmonary function are listed in Table 1. All of the patients resided at home and had dedicated family members or personal-care attendants.

The patients were routinely evaluated for vital capacity (VC) and maximum insufflation capacity (MIC) by spirometry (Wright spirometer; Mark 14; Ferraris Development and Engineering Co, Ltd; London, UK), end-tidal CO2 tension (PETCO2; Microscan 5060 capnograph; Biochem International; Waukesha, WI), SaO2 (Ohmeda model 3760; Ohmeda; Louisville, CO), and assisted and assisted PCFs (Access peak flowmeter; HealthScan, Inc.; Cedar Grove, NJ). Once assisted PCFs were determined to be < 270 L/min, patients were trained in receiving deep volumes of air via nose or mouthpiece and in manually and mechanically assisted coughing, and they became candidates for this study. Of the patients so evaluated, 94 met the PCF criteria and had one or more episodes requiring ventilatory support. Although exclusion criteria for this study were substance abuse and chronic lung disease as defined by long-term radiographic abnormalities in conjunction with SaO2 chronically < 95% or ratio of FEV1 to FVC of 2 SDs less than normal, no patients were excluded on the basis of these criteria.

Once VCs were < 2,000 mL or approximately 50% of predicted normal, the patients were trained in “air stacking” consecutively delivered volumes of air delivered from a manual resuscitator or volume-cycled ventilator. The patients received the air volumes via simple mouthpieces, nasal interfaces, or, for those with weak lips and buccal muscles, via an oral-nasal interface or lip seal (Maillinkrodt, Pleasanton, CA; Fig 2). They stacked the consecutively delivered air volumes, holding them with a closed glottis, until the lungs and chest walls were as deeply insufflated as possible. The air-stacking capability or MIC was quantified spirometrically. Patients who could air stack in this manner could also use noninvasive IPPV, that is, receive IPPV via mouthpieces and nasal interfaces (inspiratory muscle aids) as ventilatory support, whereas those not capable of holding deeper volumes than their VCs (MIC = VC) have more difficulty using noninvasive ventilation because of air leakage.

Patients with symptoms suggesting hypventilation, elevated PETCO2, or periods of daytime SaO2 < 95% underwent nocturnal SaO2 monitoring. With symptoms or nocturnal SaO2 means < 95%, the patients had trials of nocturnal nasal IPPV using a portable volume ventilator (PLV-100; Respironics Inc.; Murrysville, PA). The patients continued to use nocturnal nasal IPPV when they felt less fatigue or had relief of other symptoms of chronic hypventilation and when nocturnal mean SaO2 was shown to increase. Assist-control mode at a rate of 12 breaths/min and delivered volumes of 800 to 1,500 mL were used for virtually all adolescent and adult patients. Rates were increased and volumes decreased for young children. With time, more than nocturnal use often became necessary. Nocturnal to 16 h/d was considered part-time, and > 16 h/d was considered full-time. Most patients used noninvasive IPPV for daytime (continuous) ventilatory support for the first time during chest infections and weaned from continuous assistance, except during chest infections, often for at least several years.

The patients were also trained in manually and mechanically assisted coughing. Because normal cough volumes are 2.30 ± 0.5 L and assisted cough flows have been reported to be significantly increased by air stacking once VCs have decreased to < 1.5 L, to maximize assisted cough flows, the patients were told to air stack to deep lung volumes once their VCs were < 1,500 mL. Thus, an assisted cough most often consisted of insufflating volumes via simple mouthpieces, nasal interfaces, or, for those with weak lips and buccal muscles, via an oral-nasal interface or lip seal (Maillinkrodt, Pleasanton, CA; Fig 2). They stacked the consecutively delivered air volumes, holding them with a closed glottis, until the lungs and chest walls were as deeply insufflated as possible. The air-stacking capability or MIC was quantified spirometrically. Patients who could air stack in this manner could also use noninvasive IPPV, that is, receive IPPV via mouthpieces and nasal interfaces (inspiratory muscle aids) as ventilatory support, whereas those not capable of holding deeper volumes than their VCs (MIC = VC) have more difficulty using noninvasive ventilation because of air leakage.
assisted PCFs, timed to glottic opening.12 The patients were told to practice this technique with care providers, and their success was monitored by routinely measuring assisted PCFs via a peak flowmeter.

Mechanical cough assistance was provided by mechanical insufflation-exsufflation (MI-E) with the use of an In-exsufflator (JH Emerson Company; Cambridge, MA).12,13 The In-exsufflator provides an independently adjusted deep insufflation via an anesthesia mask or a tube if the patient is intubated. The MI-E provides an independently adjusted deep insufflation via an insufflator.14 No treated patients were symptomatic for under- or overventilation. Colds often necessitated almost continuous caregiver attention. This was especially true during severe episodes during which patients often slept poorly and required manually and mechanically assisted coughing essentially around the clock. No patients who were regularly evaluated failed to be properly trained and equipped or refused the protocol.

Conventional management was defined as any ambulatory management not including continuous ventilator use and mechanically assisted coughing with oximetry feedback. Differences between conventional and protocol approaches are summarized in Table 2. Patients were considered in group 1 when, managed conventionally, they had one or more episodes of respiratory failure before introduction of the protocol. Those who had two or more episodes of respiratory failure had “preprotocol periods.”

Table 1—Patient Information*

<table>
<thead>
<tr>
<th>Diagnoses</th>
<th>n</th>
<th>Age 1, yr</th>
<th>Age 2, yr</th>
<th>VC1, mL</th>
<th>VC2, mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMD</td>
<td>21</td>
<td>18.90 ± 3.54</td>
<td>25.0 ± 3.41</td>
<td>600 ± 186</td>
<td>320 ± 121</td>
</tr>
<tr>
<td>SMA</td>
<td>16</td>
<td>5.58 ± 5.63</td>
<td>7.1 ± 5.72</td>
<td>470 ± 330</td>
<td>407 ± 355</td>
</tr>
<tr>
<td>Myopathy</td>
<td>12</td>
<td>30.10 ± 15.26</td>
<td>41.5 ± 13.82</td>
<td>859 ± 612</td>
<td>735 ± 644</td>
</tr>
<tr>
<td>Non-DMD</td>
<td>6</td>
<td>34.15 ± 11.82</td>
<td>35.4 ± 10.56</td>
<td>690 ± 587</td>
<td>517 ± 549</td>
</tr>
<tr>
<td>ALS</td>
<td>4</td>
<td>55.83 ± 14.60</td>
<td>57.7 ± 13.95</td>
<td>780 ± 810</td>
<td>242 ± 239</td>
</tr>
<tr>
<td>PPS</td>
<td>5</td>
<td>58.74 ± 3.94</td>
<td>60.5 ± 5.78</td>
<td>773 ± 451</td>
<td>844 ± 470</td>
</tr>
<tr>
<td>Misc</td>
<td>7</td>
<td>43.43 ± 12.52</td>
<td>47.7 ± 14.23</td>
<td>1,822 ± 985</td>
<td>1,197 ± 821</td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>23.85 ± 17.68</td>
<td>32.5 ± 16.68</td>
<td>772 ± 555</td>
<td>571 ± 490</td>
</tr>
</tbody>
</table>

*DMD = Duchenne muscular dystrophy; SMA = spinal muscular atrophy; Myopathy = myopathies other than muscular dystrophies; non-DMD = muscular dystrophies other than Duchenne; ALS = amyotrophic lateral sclerosis; PPS = postpolio myelitis syndrome; Misc (miscellaneous) = (group 1; n = 7) myasthenia gravis, 2; multiple sclerosis, 1; Duchenne muscular dystrophy carrier, 1; sarcoid neuropathy, 1; toxic neuropathy, 1; phrenic neuropathy, 1; (group 2; n = 1) spinal cord injury (C4). VC1 = VC at initiation of protocol; VC2 = VC at most recent measurement; Age 1 = age when patient first acutely required ventilatory support; Age 2 = age at current time.

†Group 1 patients had one or more episodes of respiratory failure before access to the protocol.

‡Group 2 patients were given access to the protocol when their assisted PCF decreased to <270 L/min before any episodes of respiratory distress.

SaO₂ < 95%, particularly during chest infections. They were told that the desaturations would be caused by some combination of hypercapnia and, most commonly, airway mucous accumulation and if these were not managed immediately, the desaturations would persist, and atelectasis and pneumonia would result. If not already using noninvasive IPPV or MI-E, they were provided with rapid access (<2 h) to a portable volume ventilator and an In-exsufflator.14 No treated patients were symptomatic for under- or overventilation. Colds often necessitated almost continuous caregiver attention. This was especially true during severe episodes during which patients often slept poorly and required manually and mechanically assisted coughing essentially around the clock. No patients who were regularly evaluated failed to be properly trained and equipped or refused the protocol.

Conventional management was defined as any ambulatory management not including continuous ventilator use and mechanically assisted coughing with oximetry feedback. Differences between conventional and protocol approaches are summarized in Table 2. Patients were considered in group 1 when, managed conventionally, they had one or more episodes of respiratory failure before introduction of the protocol. Those who had two or more episodes of respiratory failure had “preprotocol periods.”

![Figure 2. Air stacking via a lip seal.](image1.png)

![Figure 3. A tussive squeeze applied during the exsufflation phase of MI-E.](image2.png)
During chest infections
1. Once in respiratory distress, the patient is evaluated by physical examination, chest radiograph, and arterial blood gas sampling.
2. Oxygen administered arbitrarily, and SaO2 maintained well above 95% irrespective of extent of hypercapnia.
3. Chest percussion, postural drainage, and bronchodilators administered and deep airway suctioning used via the nose or mouth.
4. Supplemental oxygen increased when desaturations occur.
5. Once intubated, ventilator weaning attempted at the expense of hypercapnia, and if unable to wean, tracheostomy is performed.

Protocol
1. Regular monitoring of VC, MIC, SaO2, and PetCO2. Air stacking introduced once VC is <2 L. The assisted coughing-oximetry feedback protocol is introduced when PCF is <270 L/min.
2. When symptomatic for hypoventilation, nocturnal nasal ventilation is introduced using portable volume-cycled ventilators.

During chest infections
1. Patient screened for symptoms, fever, dehydation, and oxyhemoglobin desaturation. When baseline SaO2 decreases to <95%, dyspnea persists despite continuous ventilator use and aggressive assisted coughing, dehydration is suspected, high fevers persist, or lethargy occurs, the patient presents for evaluation for changes in VC, chest radiograph, oximetry, PetCO2, and possible hospitalization.
2. Supplemental oxygen is avoided unless the patient is intubated.
3. MI-E is used as needed (up to almost continuously) via an oral-nasal mask along with exsufflation-timed abdominal thrusts or tussive squeezes to reverse oxyhemoglobin desaturations <95%, as requested by the patient, or when there is acutalutory evidence of secretion accumulation. The mouth may be suctioned after assisted coughing. Chest percussion, postural drainage, and bronchodilators are not systematically used, and the latter were generally avoided for patients with severe cardiomyopathies. No deep airway suctioning is done via the nose or mouth.
4. Assisted coughing is used when desaturations occur.
5. If intubated, patients are extubated only when SaO2 is normal on room air, whether or not they can maintain autonomous alveolar ventilation. They receive continuous noninvasive ventilation as needed, and hypercapnia is avoided.

For these patients, the hospitalization rates and days, number of intubations, and days intubated were quantitated during the preprotocol period beginning with the first episode, and compared with those subsequently while having access to the protocol but free of ongoing ventilator use, and when requiring ongoing part-time and full-time ventilatory assistance (Table 3). The group 1 patients who had access to the protocol immediately after the first episode of respiratory failure had no "preprotocol period."

Group 2 patients were those who were placed on the protocol when their assisted PCFs decreased to < 270 L/min and eventually had hospitalizations or "avoided hospitalizations" for respiratory distress. Avoided hospitalizations were tabulated for all patients (Table 4). Avoided hospitalizations were defined as acute episodes of respiratory distress and loss of autonomous ability to breathe during chest infections relieved by continuous ventilator use along with the use of assisted coughing and MI-E to reverse desaturation-associated mucus accumulation. For patients already requiring continuous ventilator use, only the acute need for increased use of assisted coughing and MI-E to reverse desaturation-associated mucous accumulation during febrile upper respiratory tract infections was the criterion for avoided hospitalizations.

A paired t test was used to compare hospitalization rates and days, number of intubations, and intubated days for the preprotocol and protocol access periods. The Wilcoxon signed-rank test was used for nonparametric distributions. A p < 0.05 was considered to represent statistical significance.

Table 2—Protocol vs Conventional Management of Intercurrent Respiratory Tract Infections for Patients With Neuromuscular Respiratory Muscle Weakness

<table>
<thead>
<tr>
<th>Category</th>
<th>Preprotocol</th>
<th>Protocol</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intubations, No.</td>
<td>0.75</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Days intubated</td>
<td>9.21</td>
<td>4.25</td>
<td>0.08</td>
</tr>
<tr>
<td>Days intubated</td>
<td>5.89</td>
<td>3.95</td>
<td>0.50</td>
</tr>
<tr>
<td>Hospitalization d/yr/patient</td>
<td>1.48</td>
<td>0.45</td>
<td>0.07</td>
</tr>
<tr>
<td>Hospitalization d/yr/patient</td>
<td>20.14</td>
<td>17.06</td>
<td>0.003</td>
</tr>
<tr>
<td>Hospitalization d/yr/patient</td>
<td>20.76</td>
<td>19.85</td>
<td>0.003</td>
</tr>
</tbody>
</table>

*Data from the first episode of respiratory failure until having access to the protocol (preprotocol period) and subsequently using the protocol (protocol period) for patients not requiring ongoing ventilator use; two patients went on to require part-time ventilator use.
†Data from the first episode of respiratory failure until having access to the protocol (preprotocol period) and subsequently using the protocol (protocol period) and part-time ventilatory assistance; four patients went on to require full-time ventilatory aid.
‡Data from the first episode of respiratory failure until having access to the protocol (preprotocol period) and subsequently using the protocol (protocol period) and ongoing full-time ventilatory assistance.

Table 3—Hospitalization Rate Comparisons for 47 Group 1 Patients With Preprotocol Periods and Subsequent Episodes of Respiratory Distress

<table>
<thead>
<tr>
<th>Category</th>
<th>Preprotocol</th>
<th>Protocol</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitalization d/yr/patient</td>
<td>1.06</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>Hospitalization d/yr/patient</td>
<td>20.76</td>
<td>0.06</td>
<td>&lt; 0.001</td>
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<tr>
<td>Respiratory Distress</td>
<td>3.42</td>
<td>1.94</td>
<td>0.26</td>
</tr>
<tr>
<td>Intubations, No.</td>
<td>0.75</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Days intubated</td>
<td>9.21</td>
<td>4.25</td>
<td>0.08</td>
</tr>
<tr>
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<td>5.89</td>
<td>3.95</td>
<td>0.50</td>
</tr>
<tr>
<td>Hospitalization d/yr/patient</td>
<td>1.48</td>
<td>0.45</td>
<td>0.07</td>
</tr>
<tr>
<td>Hospitalization d/yr/patient</td>
<td>20.14</td>
<td>17.06</td>
<td>0.003</td>
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<tr>
<td>Hospitalization d/yr/patient</td>
<td>20.76</td>
<td>19.85</td>
<td>0.003</td>
</tr>
</tbody>
</table>

*Data from the first episode of respiratory failure until having access to the protocol (preprotocol period) and subsequently using the protocol (protocol period) for patients not requiring ongoing ventilator use; two patients went on to require part-time ventilator use.
†Data from the first episode of respiratory failure until having access to the protocol (preprotocol period) and subsequently using the protocol (protocol period) and part-time ventilatory assistance; four patients went on to require full-time ventilatory aid.
‡Data from the first episode of respiratory failure until having access to the protocol (preprotocol period) and subsequently using the protocol (protocol period) and ongoing full-time ventilatory assistance.
patients have not had any chest infections or episodes of respiratory distress since
beginning the protocol. Eighteen of the group 1 patients were put on the protocol at age 24.29 years. The 23 group 2 patients were put on the protocol at age 27.24 years before their first potential episode of respiratory failure at 23.85 years of age, 14.91. This was 1.59 \pm 1.13 years before their first potential episode of respiratory failure.

There were six patients in group 1 who were managed conventionally up to an initial hospitalization for respiratory failure and were then given access to the protocol. Their data are analyzed separately because they had no preprotocol period to compare with protocol periods. All six began the protocol along with nocturnal (part-time) ventilatory aid. Of the six, four avoided 0.95 \pm 0.84 hospitalizations per year over 4.05 \pm 3.27 years per patient (p = 0.11) and the other two have had no chest infections or episodes of respiratory distress since beginning the protocol. Eighteen of the group 1 patients have not had any chest infections or episodes of respiratory distress since learning the protocol.

The rates of hospitalizations, hospitalization days, number of intubations, and intubation days for the remaining 47 group 1 patients are noted in Table 3. Avoided hospitalizations of both groups combined are summarized in Table 4. The protocol was used by 11 group 1 patients for a mean of 0.98 \pm 1.57 years before requiring ongoing ventilatory assistance, 2.90 \pm 2.45 years for 51 group 1 patients while using ongoing part-time ventilatory assistance, and by 21 group 1 patients using ongoing full-time ventilatory assistance for 4.35 \pm 4.81 years. The protocol was used by 3 group 2 patients 1.43 \pm 2.37 years before requiring ongoing ventilatory assistance, 22 group 2 patients using part-time ventilatory assistance for 3.61 \pm 2.88 years, and 9 group 2 patients using full-time ventilatory support for 5.29 \pm 4.88 years. The p values as determined by t test compared the actual hospitalization rates with those that would have occurred with conventional management.

One 15-year-old patient with Duchenne muscular dystrophy, who had unassisted PCFs of 250 L/min and assisted PCFs of 300 L/min, did not meet the criteria for training and inclusion in this study. One month later, he experienced a chest infection, had pneumonia, and was hospitalized. The protocol was instituted. He did not require intubation and was discharged after a hospitalization of 8 days.

### Results

The 94 study patients included 68 men and 26 women, currently with the mean age of 31.09 \pm 18.91 years (range, 2.5 to 73.5 years). All had sufficient bulbar muscle function to permit speech and had assisted PCFs > 160 L/min. PÆCO2 levels were normal for all 24-h noninvasive ventilatory support users. No nonventilator users or part-time ventilator users had PÆCO2 levels > 50 mm Hg.

Seventy-one group 1 patients had initial episodes of respiratory failure at 23.85 \pm 17.68 years of age, 4.20 \pm 5.66 years before being referred to us and having access to the protocol at age 27.24 \pm 18.84 years. The 23 group 2 patients were put on the protocol at age 24.29 \pm 14.91. This was 1.59 \pm 1.13 years before their first potential episode of respiratory failure.

### Discussion

This study has no true control group. However, it would be unethical to compare the hospitalization rates of an untreated group with the hospitalizations avoided by treatment. Conventional management includes the hospitalization and invasive respiratory management of any patient requiring ventilatory support with no ventilator-free breathing ability, whereas for us, the need for continuous ventilator use was a key criterion for establishing an “avoided hospitalization.”

At least while they were free of chest infections, assisted PCFs of > 160 L/min were attainable for all the protocol-using patients throughout the study period. This was true despite the fact that 31 of these patients eventually went on to require full-time noninvasive ventilatory support and 1 patient had a VC < 100 mL. Thus, all of these patients were candidates for long-term management of ventilatory muscle failure without resort to tracheostomy.

The use of assisted PCF < 270 L/min as a threshold criterion for introduction of this protocol appears to be reasonable because we have only one patient who experienced pneumonia despite having assisted PCFs greater than this. Further, it was approximately 1.5 years from learning the protocol until needing to use it on the average. Earlier introduction

### Table 4—Hospitalizations Avoided per Patient per Year

<table>
<thead>
<tr>
<th>Variables</th>
<th>None</th>
<th>Part-time</th>
<th>Full-time</th>
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<tr>
<td>Patients, No.</td>
<td>14</td>
<td>73</td>
<td>31</td>
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<tr>
<td>Episodes/patient/yr†</td>
<td>1.06 ± 0.96</td>
<td>1.17 ± 1.12</td>
<td>0.85 ± 0.87</td>
</tr>
<tr>
<td>Hospitalizations/patient/yr</td>
<td>0.04 ± 0.10</td>
<td>0.17 ± 0.38</td>
<td>0.05 ± 0.12</td>
</tr>
<tr>
<td>Hospitalizations avoided/patient/yr</td>
<td>1.02 ± 0.99</td>
<td>0.99 ± 1.12</td>
<td>0.80 ± 0.86</td>
</tr>
<tr>
<td>Protocol access, yr/patient</td>
<td>4.82 ± 1.61</td>
<td>3.21 ± 3.15</td>
<td>4.78 ± 4.88</td>
</tr>
<tr>
<td>Maximum yr‡</td>
<td>31.5</td>
<td>13.8</td>
<td>16.8</td>
</tr>
<tr>
<td>p value*</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
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</tbody>
</table>

‡Maximum No. of years that hospitalizations were avoided.

†Episode is defined as an occurrence of respiratory distress during a chest infection that leads to either hospitalization (hospitalizations/patient) or the need for continuous ventilatory support with oxyhemoglobin desaturations reversed by assisted coughing managed at home (hospitalizations avoided/patient).

* p value compares the episode rate vs the hospitalization rate.
of the protocol would further increase up-front expenses. It is also possible that other patients with PCFs > 270 L/min developed respiratory failure and never returned to our clinic.

The fact that assisted PCFs can exceed 270 L/min when patients are well does not mean that they will exceed 160 L/min or be adequate to clear airway secretions during chest infections (thus the great utility of MI-E for many), nor is it a guarantee that the patients will have access to assisted coughing when and as often as they need it during infections. All of the patients in this study had very dedicated, capable, and willing care providers who assisted coughing during chest infections, at times every 5 to 10 min, essentially around the clock. Patients without dedicated and effective care providers would not succeed in avoiding conventional invasive management.

Before initiating this protocol, we informed patients to contact us at the first sign of a chest infection, and we would provide them with an oximeter and respiratory muscle aids to avert hospitalization. However, two consecutive patients presented to us only after they had already developed severe oxyhemoglobin desaturation and pneumonia, and they required hospitalization and were intubated. We therefore believe that an oximeter in the home is especially important for immediate feedback to the patient during chest infections. Pneumonia and need for intubation are very unlikely when the SaO2 baseline is maintained at > 94% without supplemental oxygen.

Although the delivered volumes we used may appear to be high, the efficacy of noninvasive ventilation depends on the alertness of the CNS during sleep to decrease insufflation leakage to avoid asphyxia and hypercapnia, and to obstruct the airway and increase leakage to decrease insufflation volumes to avoid hyperventilation. Although we monitored PETCO2 during sleep in the past, we no longer think that this is necessary. As noted in the “Results,” all treated patients were asymptomatic for under- or overventilation, and all maintained essentially normal PETCO2 levels. For patients using only nocturnal noninvasive IPPV, daytime hypercapnia was usually mild and well-tolerated when SaO2 remained within normal limits.

Most protocol patients first used noninvasive IPPV during chest infections and were weaned to ongoing nocturnal use of noninvasive IPPV after their first averted hospitalizations. Oximetry was useful in guiding the eventual ongoing daytime need and nocturnal use of noninvasive IPPV. Nonprotocol patients tended to have repeated episodes of respiratory failure until being introduced to the protocol or undergoing tracheostomy.

Although both tracheostomy and noninvasive respiratory aids can prolong life, tracheostomy is associated with numerous complications, an initial mean hospital stay of 72 days, and more hospitalization days subsequently than is noninvasive management. It might be that the significantly lower hospitalization rates of noninvasive vs tracheostomy mechanical ventilation users are related to reduced pulmonary inflammation, maintenance of physiologic airway defense mechanisms, and maintenance of pulmonary health long-term by avoiding invasive respiratory interventions. Further, patients almost invariably prefer noninvasive aids over tracheostomy for safety, convenience, appearance, comfort, facilitating effect on speech, sleep, and swallowing, and general acceptability. Noninvasive aids should also, therefore, be preferred by clinicians when effective.

Our patients were trained in the use of respiratory muscle aids, including volume-cycled ventilators, in the clinic and home settings. Unlike the pressure-cycled machines conventionally used for nocturnal nasal IPPV, the volume-cycled machines permitted the air stacking necessary to maximize cough flows. Fourteen noninvasive IPPV users went on to require definitive 24-h ventilatory support using volume-cycled ventilators without as yet ever being hospitalized. Thus, provided that proper attention is given to assisting cough, this study demonstrates that even long-term and full-time need for ventilatory support can be safely provided noninvasively.

References

9 Bach JR, Alba AS, Saporito LR. Intermittent positive pressure ventilation via the mouth as an alternative to tracheostomy for 257 ventilator users. Chest 1993; 103:174–182