Use of Inspiratory Strength Training to Wean Six Patients Who Were Ventilator-Dependent

Background and Purpose. Patients who are unable to wean from mechanical ventilation (MV) after resolution of critical illness or surgery risk increased morbidity and death and consume a disproportionate amount of intensive care unit resources. Decreased inspiratory muscle strength is often cited as a major factor contributing to prolonged MV. The purpose of this case report is to describe the rationale and application of inspiratory strength training (IST) as an adjunct to lengthen unassisted breathing trials and to ultimately wean patients with chronic mechanical ventilator dependency. Case Description. Six patients who had been ventilator-dependent for 18 to 221 days (mean of 72 days) after surgery and were diagnosed with “failure to wean” performed low-repetition, high-resistance breathing exercises that were coupled with increasing time off the ventilator. Outcomes. All 6 patients were weaned from the ventilator in 9 to 28 days (mean of 17 days). The patients’ training pressure increased from a mean of 9.3 cm H2O to 27.5 cm H2O, for an increase of 195%. The volitional maximum inspiratory pressure (MIP) increased from a mean of 22.5 cm H2O to 54 cm H2O, for a 140% gain in pressure. Discussion. Although it is not clear why the patients appeared to benefit from IST, possible explanations include: (1) addressing inspiratory muscle pump dysfunction, (2) standardization of breathing patterns, 3) routinization of the patients’ unassisted breathing trials, and (4) nonspecific training effects. Future research should address these possibilities when attempting to understand the effects of IST in the weaning of patients with chronic ventilator dependency. [Sprague SS, Hopkins PD. Use of inspiratory strength training to wean six patients who were ventilator-dependent. Phys Ther. 2002;82:171–181.]

Key Words: Dyspnea, Inspiratory muscle training, Inspiratory strength training, Pulmonary rehabilitation, Weaning from mechanical ventilation.

Samuel S Sprague, Phillip D Hopkins
Increased morbidity and mortality and high health care costs are some of the risks associated with ventilator dependence.

About 50% of patients in hospital critical care units depend on mechanical ventilation (MV) for a brief period following surgery or for severe medical problems. Once stabilized, they are usually taken off the ventilator within a few hours and are able to breathe with little effort. Some patients, however, have difficulty breathing and become dependent on the ventilator. Risks associated with ventilator dependence include increased morbidity and mortality and high health care costs. Although patients with chronic ventilator dependency (CVD) comprise only 5% to 10% of patients in intensive care units (ICUs), they may consume 50% of all ICU resources (staff time and equipment usage), and charges of over $3,000 a day are not uncommon. The annual national cost of patients on a ventilator for 2 to 3 weeks, excluding physician costs, has been estimated to be $1.3 to $1.5 billion. Acute care MV appears to be increasing at a rate of 50% per decade.

Although methods for weaning patients from MV vary from setting to setting, they generally consist of progressive decreases in the positive pressure used to inflate the lungs and changes in the frequency and volume of the breaths. These methods allow patients to assume a greater proportion of the work of breathing over time. Unassisted breathing trials (UBTs), defined as regular periods of breathing off the ventilator, are initiated and lengthened in duration until the patients are weaned from MV. Patients are considered weaned when they can breathe on their own for 48 hours and are not returned to MV. According to Manthous et al, success during weaning is measured by stability of heart rate, blood pressure, respiratory rate, and oxygen saturation; arterial blood gas values that do not demonstrate acute respiratory acidosis or hypoxemia; and the patients’ comfort in breathing (absence of dyspnea).

Tobin and Alex reviewed research literature and concluded that failure of the respiratory muscle pump, defined as the diaphragm and accessory muscles of inspiration (intercostal, scalene, and sternocleidomastoid muscles), is probably the most common cause of long-term dependence on MV. Respiratory muscle pump failure stems from 2 problems: increased load on the muscle pump and decreased neuromuscular capacity of the system. An increased muscle pump load can be caused by high carbon dioxide production, elevated work of breathing due to an increased airway resistance or a reduction in pulmonary compliance, large dead space ventilation (volume of air moved inside the bronchi and equipment tubing that does not contribute to gas exchange in the lungs), and an intensified respiratory drive caused by a variety of patient-specific factors, not always related to carbon dioxide retention or other gas saturation. Decreased neuromuscular capacity may be caused by phrenic nerve dysfunction, diagnosed or undiagnosed neuromuscular disorders due to MV dependence (the same factors that weaken the patient and cause MV dependence also degrade health and function of neuromuscular components of the respiratory system), and reduced endurance or respiratory muscle strength necessary to move gases in and out of the lungs.

Reduced strength can result from systemic problems such as malnutrition, renal failure, sepsis, a history of heavy corticosteroid use, mineral and electrolyte abnormalities, and neuromuscular blockers.

Physical changes of the muscle pump such as hyperinflation of the chest wall, which negatively affects the length-tension relationship of the diaphragm, also can impair the capacity of the muscle pump. Hyperinflation of the chest wall is a common symptom of chronic obstructive pulmonary disease (COPD) but also appears in patients who are aggressively ventilated with high positive pressure support while on MV. Either an increase in load or a decrease in capacity may leave patients unable to breathe on their own (Fig. 1).

When patients with CVD attempt to increase their time off the ventilator, dyspnea (defined as air hunger result-
ing in difficult or labored breathing\textsuperscript{13}) is often the limiting factor.\textsuperscript{10} Dyspnea has been found to be correlated with respiratory muscle weakness in studies of patients with various disorders.\textsuperscript{8,10,14,15} Researchers\textsuperscript{14,15} have shown that patients with COPD and patients with congestive heart failure can increase their maximum inspiratory pressure (MIP) and decrease their dyspnea via inspiratory muscle training (IMT), with the most rapid inspiratory strength gains in the first 2 weeks of training. The training described was regular, systematic application of resistance for brief periods to assess whether this intervention would address dyspnea in patients with COPD\textsuperscript{14} and in patients with congestive heart failure.\textsuperscript{15}

Although resistance training of the muscles of inspiration has not typically been incorporated in attempts to wean patients with CVD from the ventilator, it has been used with some success. Researchers have used inspiratory resistance training with resistance levels at least 50\% of MIP for continuous periods of 15 to 30 minutes, 1 to 3 times a day.\textsuperscript{16–18} The reports describe the use of devices with apertures of varying diameters to supply the resistance. The size of the aperture does not change during the exercise, but the rate of the air moving through it does change. Such devices allow varying resistance during each inspiration, depending on the breathing rate (flow rate of air). Resistance varies directly with flow rate due to friction; the higher the airflow rate, the higher the resistance. The varying resistance makes it difficult, if not impossible, to quantify and control the work performed by the patient during each breath because the airflow rate (ie, resistance or work) is not controlled.\textsuperscript{19} Quantification and control of work are important to accurately measure force production during exercise, to not overload the system during training, and to accurately progress the workload. Although the results of the investigations showed reduced morbidity for the patients studied and other researchers have found that inspiratory strength training (IST) is a possible benefit to this population of patients,\textsuperscript{5,8} little else has been published on use of strength training of the inspiratory muscles to wean patients with CVD from the ventilator.

Any IST protocol must be tailored to the unique nature of the respiratory muscle pump and the patients with CVD.\textsuperscript{8} Research has shown that strengthening a weak and fatigable diaphragm may increase its endurance capacity and that standard weaning techniques (ie, synchronized intermittent mandatory ventilation or pressure support coupled with UBTs) may not provide sufficiently intense muscular activity or sufficient rest to improve respiratory muscle endurance.\textsuperscript{8,16,20} The respiratory muscle pump is unable to tolerate prolonged submaximal loading (60\% of maximum transdiaphragmatic twitch pressure, or the pressure difference generated when magnetically stimulating the diaphragm via the phrenic nerve) without the probability of muscle pump failure or profound dyspnea.\textsuperscript{21} Some researchers\textsuperscript{22} concluded that, for subjects without respiratory problems, an inspiratory load of 60\% of transdiaphragmatic twitch pressure until task failure (inability to breathe independently without debilitating dyspnea that requires MV) requires more than 24 hours for muscle pump recovery to baseline function. Although inspiratory muscle pump failure must be avoided when training patients with CVD, the diaphragm is under some volitional control,\textsuperscript{23} and we believe that brief, intense strengthening exercises similar to those used to train limb muscles are a promising adjunct to regular weaning strategies of low-intensity endurance training via decreased ventilator support and progressively lengthening UBTs. The early strength gains in skeletal muscle that are observed suggest that brief and intense bouts of muscle contractions may stimulate more effective muscle performance via neural factors (more efficient activation of motor units [ie, neurons and muscle fibers] they control) before any muscle hypertrophy or fiber type changes can be

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**Figure 1.**

Reduced respiratory muscle capacity and increased load combine to produce severe dyspnea.
expected, as building “new” muscle requires 8 to 20 weeks of consistent overload.24,25

The need for intervention to address respiratory muscle weakness in the patients described in this case report was a concern because time on the ventilator has been correlated with an increase in morbidity and mortality and a decrease in successful weaning.3,5 Even people without known respiratory problems show rapid deterioration of respiratory muscle function in a short period of time when MV is initiated.26–28 Therefore, once patients diagnosed with “failure to wean” were medically stable and available for treatment, IST was begun in an attempt to assist in reversing the anticipated decline in muscle pump function.

We reasoned, based on established and accepted models for training skeletal muscle for strength while attempting to avoid muscle fatigue,29 that 4 sets of 6 to 8 repetitions at about 50% of volitional MIP, once a day, 6 to 7 days a week, would stimulate the neuromuscular component of the respiratory system without inducing muscle pump failure. Training to failure would be avoided by allowing the patients to have control over the set-by-set increase, or decrease, of resistance via a perceived exertion scale. Use of a perceived exertion scale provides feedback that allows the therapist to adjust resistance for each bout to approximate consistent perception of effort by the patient.30 Inspiratory muscle pump failure would also be avoided by allowing adequate rest between sets (with patient-driven resumption of training) and with adequate rest between daily training sessions, as determined by interviewing the patient and ICU staff. The protocol described in this case report differs from those used in previous attempts to wean patients with CVD from the ventilator in that we used a device (Threshold IMT*) that provides a specific, measurable resistance that is constant throughout each breath and is independent of flow rate,31,32 and the resistance was administered over a short period of time with a relatively high intensity. This case report describes how IST at about 50% of patients’ volitional MIP for short, intensive periods was used as an adjunct intervention to lengthen UBTs and attempt to wean 6 patients with CVD from the ventilator.

Case Description

Patients

Intensive care unit physicians had diagnosed “failure to wean” for the 6 patients following use of traditional ventilator weaning methods, but the patients were medically stable in the opinion of the referring physician and were able to follow simple instructions, as determined by appropriately answering questions via written responses and agreed-on signals, such as hand signals, nodding or shaking the head. Patients were treated if they demonstrated both the ability and willingness to participate in the training. This group represents the first patients for whom complete data sets were collected as this new treatment was being instituted at an acute care hospital. Twenty-nine other patients for whom incomplete data sets existed were treated with IST as described in this report. Those patients fell into 4 categories: (1) patients (n=17) who tolerated IST and who were weaned from the ventilator, but for whom incomplete data sets existed (eg, no final MIP measurement was taken until 72 hours or longer after the patient was off the ventilator; (2) patients (n=4) who tolerated IST and were progressing with IST and UBTs, but were unexpectedly transferred to stand-alone ventilator weaning facilities and did not return so we did not know their weaning status; (3) patients (n=6) who tolerated IST initially, but as their medical status declined, were discontinued from IST sessions and later died on the ventilator; and (4) patients (n=2) who tolerated IST initially, but as their medical status declined, were discontinued from IST sessions and were later weaned without IST intervention.

The 6 patients had been ventilator-dependent for 18 to 221 consecutive days (mean of 72 days). They had compromised nutritional status, as identified by their prealbumin levels. Patients 1, 2, and 6 had chronic renal failure, renal insufficiency, or both. All patients had methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant enterococci (VRE), or both, and half had sepsis. Prior to initiation of IST, these patients’ daily tolerance for unassisted breathing varied between 0 and 120 minutes (Table).

The 6 patients had been in the ICU in the supine position in bed, with occasional periods in a bedside chair. None had stood, and only 2 patients had participated in any formal strengthening or exercise program prior to the training described here. Patient 6 was treated with IST by the first author (SSS) prior to training. Although the patient made considerable gains in his UBTs at that time (he was off the ventilator 18 hours a day after 17 days of IST), he was transferred to a stand-alone ventilator weaning facility. He was readmitted to the acute care hospital after 50 days of failed weaning attempts at the stand-alone ventilator weaning facility. At readmission, the patient could not tolerate any time off the ventilator. Patient 1 also was treated with IST prior to training and prior to his transfer to a stand-alone ventilator weaning facility. His IST treatments at that time were discontinued after only 3 days because of hemodynamic instability.

* Respironics HealthScan Asthma & Allergy Products, 908 Pompton Ave, Cedar Grove, NJ 07009.
The use of a Passy-Muir device† to allow the patients to speak with a tracheostomy while off the ventilator was attempted when they were able to breath unassisted for 2 to 4 hours. Although patients may perceive this device as increasing the difficulty of breathing, it is generally not enough to exclude an attempt. All patients were connected to ICU monitoring devices that provided real-time measurements of heart rate, blood pressure, oxygen saturation, and respiratory rate.

**Examination**
After the first author received the referral to provide the IST, each patient’s medical stability was confirmed through chart review and inquiries with the ICU staff, followed by a brief assessment of the patient’s cognitive status. The patients indicated their willingness to participate in IST and demonstrated their ability to follow simple commands consistently (>75% of the time) by either nodding their head or with simple hand squeezes or gestures in response to simple yes/no questions.

**Measurement of MIP**
Patients’ tracheostomies and bronchi were suctioned if their secretions were overtly copious and if they so desired. The balloon cuff of the tracheostomy was then inflated between 8 and 10 cm/H₂O of pressure, and the inner cannula (a solid plastic tube inserted into the tracheostomy tube to allow the clearance of secretions) was removed if the tracheostomy tube was unfenestrated (without a hole to allow breathing through both the mouth and nose). If the tracheostomy tube was fenestrated (with a hole to allow breathing), an inner cannula was inserted. This was done to ensure that the patients would breathe only through the tracheostomy tube. The patients were positioned with the head of the bed elevated to 45 degrees or higher, depending on comfort, and were encouraged to breathe deeply and slowly. Once a deep and slow breathing pattern was demonstrated, the patients were encouraged to exhale maximally (to residual volume) and to inspire maximally while a manometer‡ was attached to the trachea tube. The hole in the extension tubing was occluded briefly while the patients inspired maximally for 1 to 3 seconds, and then the occlusion was opened to allow them to inhale. This was repeated 5 to 10 times, and the 3 highest repeatable values were averaged and recorded as the patients’ volitional MIP. This method has been shown to be accurate and reproducible in measuring a patient’s volitional MIP when tested by the same person (average coefficients of variation=10%–30%).33

**Intervention**
The device used was the Threshold IMT (Fig. 2), which features a one-way, spring-loaded valve that allows

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**Table.**
Patient Characteristics™

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (y)</th>
<th>Sex</th>
<th>Primary Diagnosis</th>
<th>Secondary Diagnosis</th>
<th>Daily Unassisted Breathing Trials (min) Prior to IST</th>
<th>Days on Ventilator Prior to IST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>76</td>
<td>M</td>
<td>Emergency hemicolecotomy with 2 Gore-Tex patchesb in abdomen</td>
<td>Chronic renal insufficiency, severely dilated trachea, MRSA/VRE sepsis</td>
<td>0</td>
<td>221</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>M</td>
<td>Emergency laparoscopic surgery to drain pancreatic acsites</td>
<td>Alcohol dependence, 25-year history of 3 pack/d cigarette habit, MRSA colonization</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>F</td>
<td>Emergency gastric bypass revision and spleenectomy</td>
<td>PTSD, dysthymia, hysterecomy, gastric outlet dilation, migraines, VRE/MRSA sepsis</td>
<td>90</td>
<td>51</td>
</tr>
<tr>
<td>4</td>
<td>78</td>
<td>M</td>
<td>Dissecting abdominal aortic aneurysm with surgical repair</td>
<td>Chronic renal insufficiency, hypertension, distant CVA, postoperative MI, Parkinson’s disease, VRE colonization</td>
<td>120</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>62</td>
<td>M</td>
<td>Cancer of the cervical spine with roentgenographic therapy and chemotherapy</td>
<td>MRSA colonization</td>
<td>90</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>72</td>
<td>M</td>
<td>CABG, hemicolecotomy-ileostrony, and spleenectomy</td>
<td>Renal failure, CAD, CHF, PE, depression, anxiety disorder, MRSA sepsis</td>
<td>0</td>
<td>92</td>
</tr>
</tbody>
</table>

a CHF=congestive heart failure, MRSA=meticillin-resistant Staphylococcus aureus, CABG=coronary artery bypass graft, VRE=vancomycin-resistant enterococci, PTSD=posttraumatic stress disorder, IST=inspiratory strength training, CAD=coronary artery disease, PE=pulmonary edema, CVA=cerebrovascular accident, MI=myocardial infarct, M=male, F=female.

patients to exhale with no resistance, but requires the patients to reach the preset load to inhale. Because all of the patients had tracheostomies and could breathe only through this aperture when the tracheostomy cuff was inflated, the mouthpiece provided with the training device was discarded. A series of fittings was constructed to allow the IMT device to seal with the tracheostomy tube and to allow a 1- to 3-L/min bleed of oxygen into the series. The series consisted of: (1) a tracheostomy elbow ventilator adaptor with a 15-mm inner-diameter base and a 22-mm outer-diameter arm, (2) a universal cuff adaptor with a 22-mm inner diameter, and (3) a pressure line adaptor with a 22-mm inner diameter and a 22-mm outer diameter. This series of fittings and the oxygen bleed were determined by the professional staff (attending physician, nursing staff, respiratory therapists) to be of such low volume that the dead space and change in interdevice pressure would be negligible.

The “threshold” nature of the IMT device, which allows a breath only when the set resistance is met, ensures that patients will train at a specific resistance. This encourages patients to breathe deeply and forcefully to open the valve and receive a breath sufficient for gas exchange. Although this is immediately evident to some patients who begin breathing forcefully and maximally from the start, others may not generate an adequate force for 5 to 15 seconds. Once the patient is able to produce adequate force to open the valve, the subsequent breaths are generally more forceful, and the patient typically can complete the set. The accuracy and reproducibility of resistance values obtained with the IMT device are described elsewhere.31,32

Patients were shown the IMT device, and the threshold effect was explained. To standardize the patients’ breathing pattern during each session, the first author observed each inspiratory effort with the device, coaching the patients to attain a distinct and recognizable breath against the resistance. Although the volume of these breaths was not recorded, the standard for a high-quality breath was for the patients to open the valve for 1 to 2 seconds, maintain a respiratory rate of <30 breaths per minute and an oxygen saturation level of >90% during all 6 to 8 breaths of the set. The therapist’s comments, along with the sound produced by the device when the valve opened, provided feedback to the patients regarding the quality of their inspiratory efforts. Attempts to inhale against the resistance that produced only instantaneous opening of the valve were not counted as a training breath, and the patients were encouraged to intensify their contraction to sustain a high-quality breath to keep the valve open for 1 to 2 seconds.

After the first IST session, the Category Ratio Scale (CR-10) of the Borg Rating of Perceived Exertion Scale was administered, with 0 representing no effort, 1 representing the least possible effort needed to complete the set, and 10 representing the greatest effort possible. This scale has been shown to be accurate in measuring exertion during resistance exercises in subjects who were not on ventilators.30 We did not assess the reliability of our CR-10 measurements. The patients indicated the level of perceived exertion by mouthing the number, circling it on a visual analog scale, writing it, or holding up their fingers. If the level of perceived exertion was rated from 1 to 5, a patient was progressed by 1 to 2 cm/H2O of resistance. The resistance was not changed if the level of perceived exertion was rated from 6 to 8, and the resistance was decreased by 1 to 2 cm/H2O if the level of perceived exertion was rated 9 or 10.

The IST was attempted once a day, 6 to 7 times a week. Four sets of 6 to 8 breaths were completed every training day, with a 5- to 10-minute rest between sets. When resting, patients were placed on the ventilator if they were not undergoing UBTs. If they were undergoing UBTs, they rested using a tracheostomy tent with humidified or nonhumidified oxygen. Some treatments had to be interrupted by the therapist when the patient could not maintain the resistance or generated insufficient force to open the valve. During these interruptions, the pressure was decreased, and the patient was encouraged to breathe in a pattern that resulted in a high-quality breath.
be deferred until the patient’s medical status stabilized. The MIP was measured once a week to establish that the resistance levels were about 50% of volitional MIP and to measure patients’ inspiratory muscle strengthening progress. The appropriateness of these training pressure levels was measured after every set by administration of the perceived exertion scale. Figure 3 shows training pressures over time.

Treatments lasted from 30 to 50 minutes (including rest between sets), depending on the patients’ ability to tolerate treatment that day and any complications (eg, unwillingness or inability [severe dyspnea] to perform back-to-back sets; increased heart rate, blood pressure, or respiratory rate; technical difficulties with the cuff; overmedication; nausea; vomiting). As with the MIP measurement, patients were treated with the head of the bed elevated to 45 degrees or more and were encouraged to breathe deeply and slowly. They had to demonstrate a respiratory rate of 30 breaths per minute or less and an oxygen saturation level of more than 90%. Each patient’s heart rate and blood pressure were kept within the norms specified by the physician. These norms varied from patient to patient, and no log of each specific norm was kept. Treatment was discontinued or delayed until values returned to acceptable levels, as determined by each patient’s physician.

To promote consistency of treatment and patient cooperation, the UBTs were usually initiated at the same time each day, typically in the morning, when the patients were likely to be most awake and alert. Because adequate sleep is essential for effective participation, ICU team members were encouraged to conduct tests and procedures during daytime hours. When IST was initiated, all patients began concurrent general rehabilitation including active and active-assisted range of motion exercises, low-level resistive limb exercises or passive range of motion exercises, and stretches to all extremities administered by the first author. Three of the 6 patients (patients 3, 4, and 5) tolerated transfer training, standing and sitting balance, and marching in place, which was done after the IST session.

For patients 1 and 6, who were not breathing on their own prior to IST, a 5- to 15-minute UBT was initiated after the first IST session. When they tolerated UBTs between 0.5 and 4 hours, trials were increased daily by 50% to 100% of the previous trials (eg, if a patient tolerated a 1-hour UBT on Monday, Tuesday’s UBT would be between 1.5 and 2 hours). After 4-hour UBTs were well tolerated, times were ideally increased by 25% to 50% of the prior trial. Once a patient had been off the ventilator for a 14-hour period, UBTs were ideally increased by 10% to 25% a day. These were targeted progressions, and not all trials could increase in this
The ICU team (physicians, nurses, respiratory therapists) evaluated each patient’s condition throughout all UBTs and interpreted the patient’s comfort level and vital signs, halting the UBTs if the patient’s vital signs were outside of the norms or the patient perceived inability or discomfort with continuation of the UBTs. The physicians decided when the patients would return to the ventilator.

The physicians also determined the specific ventilator settings, which generally consisted of decremental synchronized intermittent mandatory ventilation or pressure support. An explanation of the specific implementation and titration of the various ventilator settings used with these patients is beyond the scope of this report.

Because the diaphragm almost exclusively takes over the work of breathing during sleep, it is more susceptible to fatigue at that time, and increased ventilatory support is important. Before each IST session, the first author confirmed through the ICU team that the patients received sufficient rest since the last session. Many investigators have emphasized the need for adequate rest during attempts to wean from the ventilator. Generally, “adequate” rest is defined as the minimization of the work of breathing to enable the patient to comfortably rest or sleep and to allow recovery from fatigue. There is no formula for the ideal ratio of rest to work because every patient is different, but it is generally agreed that as long as patients report relative comfort and their vital signs and blood gases are within normal limits, UBTs can proceed.

Patients were considered weaned after they were off the ventilator for 48 hours. Treatment was discontinued after the patients had been transferred to the hospital’s general medicine ward, usually within 3 to 5 days after last being on the ventilator.

**Outcomes**

All patients were weaned from the ventilator in 9 to 28 days (mean of 17 days) after the initiation of IST, and none required additional MV once weaned except for patient 6, who died of renal failure 4 days after being returned to MV and after being off the ventilator for 21 days (Fig. 4). Mean training pressures increased from 9.3 cm/H2O to 27.5 cm/H2O, for a total increase of 195% (Fig. 5). The MIP increased from a mean of 22.5 cm/H2O to 54.0 cm/H2O, for a 140% gain in pressure (Fig. 6). All patients were discharged from the ICU to the general medical ward, where patient 1 died from a mucus plug occlusion while being repositioned 20 days after weaning from the ventilator. The remaining patients were then transferred to a rehabilitation unit and discharged to home or to a nursing home.

**Discussion**

The IST sessions may have assisted in weaning these patients from MV by several mechanisms. The first mechanism is reversal of disuse atrophy affecting the
muscles of respiration. Many commonly used settings of the ventilator appear to take over much of the work of breathing, and among the current literature there is a question as to the extent of disuse atrophy or the evidence of any significant disuse atrophy. In our patients and patients reported in previous research, the total time that the patients were on MV correlated with difficulty in weaning. Studies of rats and primates with phrenic nerve disruption on controlled MV have shown significant inspiratory muscle strength decrease and deterioration in the contractile properties of the diaphragmatic muscle tissue. However, have noted that with the type of MV support most patients receive, the diaphragm continues to contract even while patients are on the ventilator. Patient 1, for example, had a pretraining MIP of 40 cm/H₂O, which was higher than patient 5’s MIP at weaning, and he had been on the ventilator for 221 days, which was more than twice as long as the other patients. This finding suggests what the literature supports, that length of time on the ventilator is not directly correlated with respiratory muscle atrophy. The level of muscle atrophy, if any, cannot be accurately inferred in patients who are dependent on a ventilator, regardless of the length of time on MV. The rapid strength gains demonstrated by the patients in this report indicate a neural adaptation response to the training.

A second explanation for the possible contribution of IST in weaning these patients from MV is that the training altered neuromuscular dysfunction specific to inspiration. Spitzer et al studied 21 patients with CVD who were unable to wean from the ventilator and found that previously unsuspected or undiagnosed neuromuscular disease contributed to MV dependency in 86% of that sample. The authors of that report believed that these diseases were the most important factor related to prolonged ventilator dependency in all patients with CVD. They further concluded that the diseases probably resulted from the patients’ prolonged critical illness and subsequent or concurrent MV dependence. Other studies have also shown the prevalence of polyneuropathies among patients in ICUs that contribute to ventilator dependency, and some studies showed that MV inhibits normal functions of the central and peripheral neuromuscular components in the respiratory systems of people without known neuromuscular disease who were on MV for short periods. Milner-Brown and Miller demonstrated that patients with diverse neuromuscular diseases can increase their limb strength through a high-load, low-repetition strengthening program similar to the one used described in our report. The rapid strength gains demonstrated by the patients in our report indicate a neural adaptation response to the training.

A third possible explanation of these patients’ progress involves improvement in their breathing patterns (ie, slow, deep breathing versus rapid, shallow breathing) that may have resulted from IST. As Caruso et al observed, when patients breathe against a resistance that they cannot overcome, they increase their effort in an attempt to breathe to fulfill their physiological requirements. Because the resistance settings that we used were about 50% of volitional MIP, the patients were able to open the valve even though initially it may have appeared to be difficult for some. All patients were encouraged by the first author to sustain the required force production for the duration of their inspiration, which led to a standardized training breath. Caruso et al found that patients’ breathing patterns reveal an increase in both mean inspiratory force and duration of inspiration as they are weaned from MV. Future studies of IST in the weaning of patients with CVD should show whether the standardization of training breaths translates to deeper, slower, and more effective breathing during UBTs that promotes weaning.

Tobin and Alex noted that much variation exists in techniques for determining when a patient is ready for weaning and how progressive decreases in positive pressure and time off the ventilator are carried out. We believe that the attempted systematization of the UBT after IST was initiated in our 6 patients may have
accelerated weaning. Study of patients who are ventilator-dependent is needed to identify the point at which IST should begin relative to UBT as well as the frequency and duration by which UBTs are increased.

Effects related to interpersonal factors between the therapist and the patient and to participation in a general rehabilitation program cannot be ruled out because IST requires close, almost daily, interaction between the therapist and the patient. All but a few of the interventions described in this report were carried out by the first author, who also provided general rehabilitation for the 6 patients. Any attempt to further study the effectiveness of IST in the weaning of patients with CVD from the ventilator should take into account the possible effects of a general rehabilitation program and the psychosocial component of the patient-therapist relationship.

It is important to note that 2 patients who were weaned from MV subsequently died from other medical problems. Weaning from a ventilator allowed them to interact with their loved ones in the interim, and all of the patients stated that their quality of life increased after weaning. This suggests that even patients who are chronically or terminally ill might benefit from IST. Three of the patients (patients 1, 2, and 6) had been diagnosed with chronic renal insufficiency or renal failure and were undergoing hemodyalisis during IST. In one study, this population of patients was identified as having a lower rate of weaning (13% compared with 54% of a comparison group of patients without renal failure or chronic renal insufficiency and not on hemodialysis). Patients 1 and 6 had been discharged from the hospital to stand-alone ventilator weaning facilities for 142 and 30 days, respectively, prior to the IST trials, but they were unsuccessful in attempts at weaning at those hospitals. They were subsequently weaned after 28 days of IST. All the patients in this report had compromised nutritional status, and all were colonized or septic with virulent strains of microbes. Poor nutritional status, sepsis, renal failure, and long-term dependence on MV are often cited as major threats to weaning from MV.5,8,10

Initiating a program of IST intervention in any hospital may be difficult because the patients are often have complex medical problems and the intervention is new. The ICU team (physicians, nurses, respiratory therapists) need to coordinate their efforts to enable the regular, consistent, and progressive muscle training protocol. The discontinuation or tapering of corticosteroids, neurodepressants, and muscle relaxants, if possible, is important, because they can make weaning more difficult.8,10

Therapists who want to use IST for weaning patients from ventilators need to be prepared for difficulties. Patients with CVD are often critically ill and may be anxious and apprehensive about attempts to discontinue MV.40 The therapist must not only be able to establish rapport with the patients and gain their trust for what can be a frightening task, but also must continue to encourage them daily to increase resistance and UBTs. As noted in Liaw and colleagues’7,9 report of a study on resistive IMT in patients with acute, complete cervical spinal cord injury, only highly motivated patients are able to complete the treatments necessary to breathe off the ventilator for strength gains, and they must be closely supervised and constantly encouraged. Especially during the first few UBTs, therapist must be present to decrease patients’ anxiety and ensure their comfort.

In conclusion, this case report illustrates how the use of IST with patients who are ventilator-dependent may promote weaning, even in people who are terminally ill. Although our case report could not demonstrate a cause-and-effect relationship between IST and weaning, it did reveal questions for future research: (1) Did IST facilitate the weaning of these patients, and if so, how? (2) When should IST be initiated—before the patient is given the “failure to wean” diagnosis or before a tracheostomy or even before elective surgery in order to prevent the inability to wean from MV (ie, as preparation to maximize inspiratory strength before the patient’s body incurs MV dependence)? (3) What is the optimal progression of IST? (4) What other patient populations may benefit from this intervention (eg, patients with cervical spinal cord injury who are dependent on MV)? and (5) Would training the muscles of expiration benefit patients with CVD? Until these questions are answered by controlled studies, we believe that physical therapists can use IST in acute care and long-term ventilator rehabilitation hospitals if it is applied in a careful and team-oriented manner.

References


