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Use of Inspiratory Muscle Strength Training to Facilitate Ventilator Weaning*

A Series of 10 Consecutive Patients

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Background and purpose: **We instituted a low-repetition, high-intensity inspiratory muscle strength training (IMST) program and progressively longer spontaneous breathing periods (SBPs) in a group of medically complex patients who were dependent on mechanical ventilation (MV) and had failed to wean.**

Case descriptions: **IMST was provided to 10 consecutive patients (four men, six women; mean [± SD] age, 59 ± 15 years) who had failed to wean from MV by conventional methods for ≥ 7 days. Prior to initiating IMST, patients had received MV support for a mean of 34 ± 31 days. Daily IMST consisted of four sets of six breaths through a threshold inspiratory muscle trainer that had been set at an intensity to yield an exertion rating of 6 to 8 of a maximal value of 10. At the start of IMST, patients were tolerating 2.1 ± 3.4 consecutive hours of SBPs. The duration of the SBPs was increased daily, as tolerated. Patients were considered to have been weaned from MV when they were able to breathe without MV support for 24 consecutive hours.**

Outcomes: **After 44 ± 43 days of IMST, 9 of 10 patients were weaned from MV. The initial IMST pressure was 7 ± 3 cm H_2O, and it was increased to 18 ± 7 cm H_2O ($p < 0.05$).**

Discussion: **These results indicate that an IMST protocol that produces significant increases in threshold training pressure, in combination with progressive SBPs, aids in weaning patients from MV. Although promising, these preliminary observations must be tested in a controlled trial.**

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Key words: respiratory muscle training; ventilator dependence; ventilator weaning

Abbreviations: IMST = inspiratory muscle strength training; MV = mechanical ventilation; SBP = spontaneous breathing period

Dependence on long-term mechanical ventilation (MV) following the resolution of acute illnesses is a significant health-care problem.[1] Respiratory muscle weakness is often implicated as a contributor to weaning failure. However, there is little information available on the use of respiratory muscle training programs for patients who are difficult to wean from MV. Case studies have been published describing resistive endurance[2–4] or eucapnic hyperventilation[5] inspiratory muscle training programs to aid in the weaning of patients with long-term MV dependence. These endurance training methods resulted in modest increases in negative inspiratory force. Despite the generally promising results in these cases, inspiratory muscle training programs for ventilator-dependent patients are rare. Overall, there is little agreement on the best method to wean patients from dependence on MV.[6]

Inspiratory muscle strength training (IMST) has been shown to improve respiratory muscle strength and exercise performance in individuals with inspiratory muscle weakness and poor exercise tolerance.[7,8] IMST can be performed with resistance or pressure threshold devices. Resistance-training devices typically consist of breathing through a series of adjustable orifices providing flow-dependent resistances that decrease as airflow decreases. Pressure-threshold devices provide a constant, sustained pressure challenge throughout the entire inspiration that is independent of airflow.[9] When inspiring through a

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pressure-threshold device, the individual must generate a minimum inspiratory muscle force to overcome a threshold load by generating an inspiratory pressure sufficient to open the spring-loaded valve, and must sustain this pressure level throughout the inspiration (an isotonic load). The inspiratory pressure load provided by a pressure-threshold device does not modify airflow mechanics.[9] Therefore, pressure-threshold training provides a quantified pressure challenge to the inspiratory muscles that is independent of airflow. Pressure-threshold IMST has also been shown to reduce exertional dyspnea in patients with emphysema,[7] increased glottal airway resistance,[10] and cystic fibrosis.[11] We applied pressure-threshold IMST to a group of medically complex MV-dependent patients who had failed conventional weaning trials. We anticipated that pressure-threshold IMST would increase inspiratory muscle strength, similar to the effect in individuals who are not dependent on MV, and would facilitate weaning from MV.

Materials and Methods

Patient Descriptions

Patient characteristics, causes of respiratory failure, and weaning outcomes are found in Table 1. Five patients failed to wean following surgical procedures, and the remaining five patients received primary medical diagnoses. Six of 10 patients were transferred to our hospital from other hospitals.

IMST Protocol

IMST was initiated when the attending physicians determined that the patient was medically stable and had failed to wean with standard weaning techniques. All patients were receiving pressure-support MV with back-up rates of two to eight breaths, were alert and able to cooperate with training, and had failed to wean for ≥ 7 days prior to initiating IMST. Previous weaning strategies varied by attending physician and included decreasing pressure support and attempting to increase periods of spontaneous breathing periods (SBPs) without MV support. Evidence of the failure to wean was provided by the inability to tolerate or increase the duration of SBP based on blood gas derangements and/or signs of respiratory distress during SBP for 7 days.

A threshold device (PEP; HealthScan Products, Inc; Cedar Grove, NJ) was used for training over the range of 4 to 20 cm H_2O, and a threshold IMT device (HealthScan Products, Inc) was used when training pressure exceeded 20 cm H_2O. The PEP device is commercially marketed as a positive expiratory pressure device to enhance mucus clearance. It was used as an inspiratory training device by having patients inhale through the exhalation orifice. The threshold IMT is commercially marketed as an inspiratory muscle trainer. In both devices, the pressure-threshold setting is provided by an adjustable, spring-loaded, threshold poppet valve. To inhale with either device, the patient must generate an inspiratory pressure greater than the indicated threshold pressure setting to compress the spring and open the poppet valve, and the inspiratory pressure must be maintained above the threshold pressure to keep the poppet valve open. The patient exhales through the training device via a low-resistance, one-way, silicone rubber dia-

Table 1—*Patient Data**

Patient No. (Age, yr/Sex)	Cause of Respiratory Failure	Total MV, d	IMST Start Day	IMST, d	Start IMST Pressure, cm H_2O	Final IMST Pressure, cm H_2O	Begin SBP Time, h	Outcome
1 (58/F)	COPD, hip fracture and hip replacement	68	34	34	12	35	2	Weaned
2 (59/F)	Wegener granulomatosis	49	29	20	4	11	0	Weaned
3 (61/M)	Myocardial infarction, post-coronary artery bypass graft	63	53	10	8	16	11	Weaned
4 (52/M)	Myocardial infarction, post-coronary artery bypass graft	167	23	144	7	24	0.6	Weaned
5 (28/F)	Quadriparesis secondary to axonal degeneration	45	14	31	8	14	0	Weaned
6 (67/M)	Pneumonia, COPD	54	21	33	8	18	0	Weaned
7 (79/M)	Coronary artery disease, congestive heart failure, aortic valve replacement	56	27	29	10	13	1	Weaned
8 (68/F)	Necrotizing pancreatitis, debridement of pancreatic abscess	127	115	12	4	16	2	Weaned
9 (75/F)	Aspiration pneumonia	115	14	101	4	20	0	Not weaned
10 (44/F)	Axonal polyneuropathy	40	10	30	7	13	4	Weaned
Mean		78.4	34.0	44.4	7.6	18.0	2.1	
SD		42.8	31.0	43.2	2.7	7.1	3.4	

*Total MV = total no. of days patient received mechanical ventilation; IMST start day = No. of days patient received MV before starting IMST; IMST no. = No. of days patients received IMST; start IMST pressure = threshold pressure at the start of IMST; final IMST pressure = IMST training pressure at wean day or (for patient 9) transfer to ventilator-weaning hospital; begin SBP time = No. of consecutive hours of spontaneous breathing patients were tolerating on IMST start day; Outcome = patient disposition, weaned vs not weaned.

phragm. Training devices were connected to the tracheostomy tube with 15-mm and 22-mm adapters. Training bouts consisted of three to five sets of six repetitions breathing through the trainer. IMST sessions were usually conducted in the morning, 5 to 7 days per week. Supplemental oxygen was added as needed during IMST. Training was conducted with the patient in bed with an approximately 30° head-up tilt. Patients were instructed to maximally exhale before taking a breath and to try to maximally fill the lungs fully with each inspiration. This training breath was repeated six times in each training set. Patients were returned to MV for rest between training sets as needed. Three to five sets of six training breaths were completed for a total of 18 to 30 training breaths per day. Following each training set, the patient indicated a rating of perceived respiratory exertion on a linear scale of 0 to 10, with 0 representing no inspiratory effort and 10 equaling a maximal inspiratory effort. The training threshold pressure setting was adjusted to an exertion rating of 6 to 8. If an exertion rating fell below 6, the pressure was increased, and if the exertion rating exceeded 8, the pressure was reduced. Patients were observed during training for cardiac arrhythmias, for pulse oximetric saturation decreases of ≥ 5% from baseline, for significant changes in BP, and for subjective evidence of distress. A signal was used to indicate whether the patient wanted to stop training before competing six repetitions and return to MV. The complete IMST session took approximately 10 min per day.

Patients had gradually increasing SBPs as tolerated. SBPs were terminated when the patients exhibited signs of respiratory distress (*ie*, tachypnea, oxygen-hemoglobin saturation decreasing ≥ 5% from baseline, hypotension, tachycardia, or subjective signs of respiratory distress). Patients were considered to have been weaned from MV when they were able to breathe spontaneously for a consecutive 24-h period.

Statistical Analysis

Differences were compared with *t* tests, and data are shown as the mean ± SD. The use of the patients' medical charts to obtain data for this report was approved by the institutional review board.

Results

On the day that IMST began, patients had been MV-dependent for 34 ± 31 days and were tolerating 2.1 ± 3.4 consecutive hours of SBP. Four of the patients were not tolerating any spontaneous breathing at the start of IMST (Table 1). The six patients who were tolerating SBP when IMST began were completing an average of 3.4 ± 3.9 h. The initial IMST pressure was 7 ± 3 cm H_2O, and pressure was increased to 18 ± 7 by the day that weaning or transfer occurred ($p < 0.05$). After 44 ± 43 days of IMST, 9 of 10 patients had been weaned. None of the weaned patients required additional MV support before hospital discharge. The one patient who was not weaned was transferred to a facility specializing in ventilator weaning and died 8 days later. The patients received a mean of 78 ± 43 total days of MV in our facility. Excluding the one patient who required 144 days of IMST before weaning, the mean number of IMST days for the remaining nine patients decreases to 33 ± 27 days.

Discussion

Endurance respiratory muscle training programs have been used to aid weaning in ventilator-dependent patients.[2–5] Our training method differed from those of previous studies in two respects, as follows: (1) we used a pressure-threshold training device rather than a resistive flow device or eucapnic hypernea; and (2) we attempted to train the inspiratory muscles for increases in strength rather than endurance.

Pressure-threshold training was expected to be more effective than resistance training because the threshold device allows the training pressure to be set independently of inspiratory flow and breathing pattern compensation.[9] Flow-resistance training can be used to increase the strength of the respiratory muscles but requires the subjects to maintain high inspiratory flow rates for the full duration of inspiration. Subjects soon learn that if they change their breathing patterns and inhale at low flow rates, the inspiratory resistance, and hence the perception of inspiratory difficulty, decreases. Low inspiratory flow, while more comfortable for the patients, provides a decreased IMST stimulus.

We believed that a pressure-threshold IMST protocol that was similar in principle to strength-training programs for limb muscles was appropriate for MV-dependent patients for four reasons. First, like skeletal muscle, respiratory muscle weakens with disuse.[12,13] Second, traditional weaning methods, such as altering MV modes to provide respiratory muscle rest, decreasing pressure support, increasing trigger thresholds to initiate machine-supported breaths, and spontaneous breathing trials, were unlikely to provide a sufficient training stimulus to improve inspiratory muscle strength. Third, it has been our observation that some patients fail weaning trials based on their perception of the difficulty of maintaining spontaneous breathing effort, despite maintaining adequate minute ventilation and viable blood gas levels (*ie*, they were capable of maintaining a sufficient ventilatory response for short periods of time but the subjective effort of breathing was too difficult to be sustained for prolonged periods of time). Fourth, the perception of respiratory effort is inversely related to respiratory muscle strength. Partial curare-induced respiratory muscle weakness increases the perception of respiratory effort during a standard breathing task,[14] while inspiratory muscle strength training reduces the perception of respiratory effort when breathing during a standard task.[15,16]

Extrapolating from the effects of inactivity in limb muscles to those in respiratory muscles, one would predict that MV, with the accompanying decreased respiratory muscle activity, would lead to inspiratory muscle weakness. This is supported by Anzueto et al,[12] who found that 11 days of controlled MV and neuromuscular blockade resulted in a 45% decrease in phrenic nerve-stimulated transdiaphragmatic pressure in primates. Le Bourdelles et al[13] have shown that 48 h of controlled MV significantly reduced diaphragmatic strength measured *in vitro* in a rodent model. While these controlled MV protocols[12,13] are likely to have induced more respiratory muscle weakness than the pressure-support MV used in our patients, the low IMST pressures tolerated by the subjects on beginning training documents the weakened condition of their inspiratory muscles.

As greater IMST pressures were tolerated, the patients were able to sustain longer SBPs, but the small number of patients prevents a definitive analysis. Bellemare and Grassino[17] demonstrated an exponential relationship between the diaphragmatic tension-time index and how long loaded breathing could be tolerated. This suggests that inspiratory muscle strength is predictive of the ability to sustain spontaneous breathing when breathing requires a significant portion of the inspiratory muscles' pressure-generating capability. As an external inspiratory load or diaphragmatic tension-time index is decreased, or inspiratory pressure-generating capability is increased, the ability to sustain spontaneous breathing effort moves from a gradual increase to an abrupt increase and approaches infinity (*ie*, the MV weaning threshold).

Muscle strength gains are highly specific to the training mode, speed, and task.[18] The duration of training was probably insufficient to elicit significant muscular changes in fiber-type distribution or muscle fiber cross-sectional area in most of our subjects. As a result of strength training, changes in the motor program, in the excitability of the neuromuscular system, or both may have occurred. Neural adaptations that may have potentially occurred as a result of training include an improved ability to attain a maximal volitional contraction,[19] a decreased coactivation of antagonist muscle groups,[20] an enhanced synchrony of motor unit firing,[21] an increased reflex potentiation,[18] and more efficient motor programming.[22] In the future, such dependent measures should be included in order to describe these neuromuscular adaptations to pressure-threshold MST.

Given the effects of inactivity on neuromuscular function and the inverse relationship between respiratory muscle strength and the perception of breathing effort, we predicted that a high-intensity pressure-threshold IMST program coupled with progressively longer SBPs would increase inspiratory muscle strength and endurance, decrease the patients' perception of respiratory distress during spontaneous breathing, and facilitate weaning. The rapid increases observed in IMST pressures suggest neural adaptations, rather than muscle hypertrophy adaptations, to training. The exact mechanism of these adaptations remains unknown. Regardless of the mechanisms responsible for the increased IMST pressures, this method contributed to successfully weaning 9 of 10 of these medically complicated, MV-dependent patients. Controlled trials are needed to confirm the benefit of IMST for weaning long-term ventilator-dependent patients.

References

1 Wagner DP. Economics of prolonged mechanical ventilation. Am Rev Respir Dis 1989; 140:S14–S18

2 Abelson K, Brewer K. Inspiratory muscle training in the mechanically ventilated patients. Physiother Can 1987; 39:305–307

3 Aldrich TK, Karpel JP. Inspiratory muscle resistive training in respiratory failure. Am Rev Respir Dis 1985; 131:461–462

4 Aldrich TK, Karpel JP, Uhrlass RM, et al. Weaning from mechanical ventilation: adjunctive use of inspiratory muscle training. Crit Care Med 1989; 17:143–147

5 Belman MJ. Respiratory failure treated by ventilatory muscle training: a report of two cases. Eur J Respir Dis 1981; 62:391–395

6 Butler R, Keenan SP, Inman KJ, et al. Is there a preferred technique for weaning the difficult-to-wean patient? A systematic review of the literature. Crit Care Med 1999; 27:2331–2336

7 Larson JL, Kim MJ, Sharp JT, et al. Inspiratory muscle training with a pressure threshold breathing device in patients with chronic obstructive pulmonary disease. Am Rev Respir Dis 1988; 138:689–696

8 Lisboa C, Villafranca C, Leiva A, et al. Inspiratory muscle training in chronic airflow limitation: effect on exercise performance. Eur Respir J 1997; 10:537–542

9 Johnson PH, Cowley AJ, Kinnear WJ. Evaluation of the THRESHOLD trainer for inspiratory muscle endurance training: comparison with the weighted plunger method. Eur Respir J 1996; 9:2681–2684

10 Sapienza C, Brown J, Martin D, et al. Inspiratory pressure threshold training for glottal airway limitation in laryngeal papilloma. J Voice 1999; 13:382–388

11 Sawyer EH, Clanton TL. Improved pulmonary function and exercise tolerance with inspiratory muscle conditioning in children with cystic fibrosis. Chest 1993; 104:1490–1497

12 Anzueto A, Peters JI, Tobin MJ, et al. Effects of prolonged controlled mechanical ventilation on diaphragmatic function in healthy adult baboons. Crit Care Med 1997; 25:1187–1190

13 Le Bourdelles G, Viires N, Boczkowski J, et al. Effects of mechanical ventilation on diaphragmatic contractile properties in rats. Am J Respir Crit Care Med 1994; 149:1539–1544

14 Campbell EJ, Gandevia SC, Killian KJ, et al. Changes in the perception of inspiratory resistive loads during partial curarization. J Physiol (Lond) 1980; 309:93–100

15 Redline S, Gottfried SB, Altose MD. Effects of changes in inspiratory muscle strength on the sensation of respiratory force. J Appl Physiol 1991; 70:240–245
16 Kellerman B, Martin D, Davenport P. Inspiratory strengthening effect on resistive load detection and magnitude. Med Sci Sports Exerc 2000; 32:1859–1867
17 Bellemare F, Grassino A. Effect of pressure and timing of contraction on human diaphragm fatigue. J Appl Physiol 1984; 53:1190–1195
18 Sale DG. Neural adaptation to resistance training. Med Sci Sports Exerc 1988; 20:S135–S145
19 Leong B, Kamen G, Patten C, et al. Motor unit discharge rates in older weight lifters during maximal voluntary contractions [abstract]. Med Sci Sports Exerc 1995; 27:S6
20 Carolan B, Cafarelli E. Adaptations in coactivation after isometric resistance training. J Appl Physiol 1992; 73:911–917
21 Milner-Brown HS, Stein RB, Lee RG. Synchronization of human motor units: possible roles of exercise and supraspinal reflexes. Electroencephalogr Clin Neurophysiol 1975; 38: 245–254
22 Yue G, Cole K. Strength increases from the motor program: comparison of training with maximal voluntary and imagined muscle contractions. J Neurophysiol 1992; 67: 1114–1123

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