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ARTICLE

The Effectiveness of Inspiratory Muscle Training in Weaning Critically Ill Patients from Mechanical Ventilation

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ABSTRACT

BACKGROUND: Inspiratory muscle weakness is a consequence of mechanical ventilation that contributes to weaning failure in critical ill patients. Since 1980, case reports of inspiratory muscle training (IMT) in ventilated, difficult to be weaned patients have proposed that this training strategy is associated with successful weaning.

OBJECTIVE: We evaluated the efficacy of the inspiratory muscle training on the weaning process.

METHODS: We conducted a literature search in the following databases: PubMed, EMBASE, Scopus and Google scholar. Selected keywords included inspiratory/ respiratory muscle training, weaning/failure, mechanical ventilation, critically ill, threshold load, intubated/ tracheostomy.

RESULTS: In our analysis we included three randomized control trials involving 150 patients. The studies used different devices of training and training protocols. Inspiratory muscle training significantly increased inspiratory muscle strength in relation to sham or no training.

CONCLUSION: Although IMT leads to significant increase of respiratory muscle strength, it has not yet been clearly demonstrated that this also leads to successful weaning. Further larger randomized studies are needed to determine the beneficial effect of IMT in weaning patients from ventilatory support.

Abbreviations
ICU = intensive care unit
IMT = inspiratory muscle training
MV = mechanical ventilation
SBT = spontaneous breathing trial
MIP = maximal inspiratory pressure

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INTRODUCTION

Mechanical ventilation (MV) supports breathing in critically ill patients in the setting of intensive care unit (ICU).[1] Although indispensable, MV has been implicated in the dysfunction of the diaphragm and respiratory muscle weakness.[2,3] Weaning from mechanical ventilation can be defined as the process of gradually withdrawing ventilatory support and liberating the patient from the endotracheal tube.[4] The weaning process represents the 40–50% of the total duration of mechanical ventilation.[4] Furthermore, a 26–42% rate of weaning failure has been reported after a single spontaneous breathing trial (SBT).[4] It is well documented that weakness of the inspiratory muscles is a cause of weaning failure.[4,5] Prolonged MV promotes diaphragmatic weakness due to both atrophy and contractile dysfunction.[6,7] In addition, prolonged MV and weaning failure are indicators of poor prognosis.[8] Prolonged ventilation increases the risk of complications, such as infections and critical illness neuromuscular syndromes.[9]

Weaning failure has a significant financial impact on health economy as long-term ventilated patients are major resource users within Critical Care. A survey in North America has established that whilst only 6% of ICU admissions were ventilated for 7 or more days, they consumed 37% of resources during their stay.[10] Another survey from New York State in 1993 estimated, from diagnostic codes, that $650 million was spent on the care of long-term ventilated patients.[11]

Since 1980, case reports of inspiratory muscle training (IMT) programs in ventilator- dependent patients have suggested that IMT is associated with increased inspiratory muscle strength and successful weaning from mechanical ventilation (Table 1).[12-16]

INSPIRATORY MUSCLE TRAINING DEVICES

There are three different types of IMT devices that can be used: the resistive type, the pressure threshold and the isocapnia hyperpnea maneuver. The *resistive type* includes several orifices of different diameter in order to provide resistance to inspiration. Its main disadvantage is that the patient could alter the degree of difficulty despite the resistance that was set depending on his/her breathing flow rate. The *pressure threshold* device is the most frequently used. It is most reliable as the patient has to generate a required flow- independent

TABLE 1. Summary of Case Studies (n=5) of Inspiratory Muscle Training (IMT)

Study	Participants	Intervention	Outcome
Belman et al (1981)	Patients intubated due to acute respiratory failure, diagnosed with weaning failure (n=2)	Isocapnic hyperpnea via MV	Patients successfully weaned from MV
Aldrich et al (1989)	Patients with stable chronic respiratory failure who have failed repeated weaning attempts (n=27)	Pflex inspiratory muscle trainer or a combination with intermittent mandatory ventilation One session per day Starting from 5 to 10 min and progressed to 30 min Resistance level (R2) set at 8 cm H_2O/L.sec at 0.25 L/sec and progressed to (R3) 13 cm H_2O/L.sec at 0.25L/sec and finally to (R4) 28 cm H_2O/L.sec at 0.25L/sec	MIP (mean± SD) was improved from -37±15 to -46± 15cm H_2O ($p<0.001$) Vital Capacity (mean± SD) improved from 561±325 to 901±480 ml ($p<.001$) Weaning success, n=12
Martin et al (2002)	Intubated patients due to surgical and medical diagnoses (n=10)	Threshold PEP device or threshold IMT device Pressure was adjusted to exertion rate of 6-8 5-7 days per week 3-5 sets of 6 breaths	9 of 10 patients were weaned from MV Initial IMST pressure (mean± SD) was increased from 7± 3 to 18 ±7 cm H_2O ($p<0.005$)
Sprague et al (2003)	ICU patients ventilator-dependent after surgery, diagnosed with failure to wean (n=6)	Threshold device at 50% of MIP Once a day, four sets of 6-8 breaths and 5-10 min rest between sets	All patients were weaned from MV. MIP increased from -22.5 to -54 cm H_2O
Bissett et al (2007)	79 year old man after laparotomy (n=1)	Threshold device at 50% of MIP Once a day, 3 to 5 sets of 6 breaths	On day 27 was weaned from MV

ICU = Intensive Care Unit; IMST = inspiratory muscle strength training; MIP = maximal inspiratory pressure; MV = mechanical ventilation; PEP = positive expiratory pressure; SD = standard deviation inspiratory pressure in order to open a valve in the device and start the training process.[16] The *isocapnic hyperpnea* maneuver is performed while the patient maintains a specified level of ventilation in the form of volitional hyperpnea for 12 minutes and various amounts of carbon dioxide are added to the inspired air in order to maintain isocapnia in the arterial blood.[17] The mechanically ventilated patient could also undertake IMT by adjusting the ventilatory sensitivity settings in a way that the patient in order to initiate inspiratory flow will have to generate greater intrathoracic pressures.[12,18]

METHODS

We conducted a literature search in the following databases: PubMed, EMBASE, Scopus and Google scholar. The keywords used were the following: inspiratory/ respiratory muscle training, weaning/failure, mechanical ventilation, critically ill, threshold load, intubated/ tracheostomy. In the review we included only randomized control trials.[18-20]

RESULTS

From our search, three randomized controlled trials[18-20] on inspiratory muscle training in facilitating weaning from mechanical ventilation were identified (Table 2). We included only randomized trials in our review as these studies are rated higher in an evidence rating scale.[21]

Carouso et al[18] adjusted the pressure trigger sensitivity of the ventilator to 20% of the first recorded Maximal Inspiratory Pressure (MIP). First training sessions had a duration of 5 minutes, and every session was increased by 5 minutes until it reached 30 minutes. If the patient was able to withstand the 30 minute period, then there was an increase of 10% of the initial MIP. Training was performed twice a day, five days a week. The control group received no IMT. Twenty five patients completed the study, 12 were randomized to the intervention group. The IMT was well tolerated but failed to abbreviate weaning and decrease the reintubation rate (Table 2).

Cader et al[19] used pressure threshold device with the training starting once the patient was changed from controlled to spontaneous ventilation. The patient started with a load of 30% of his/her MIP and the load was daily increased by 10% depending on patients' tolerance. The training session was performed twice a day, seven days a week and had a duration of 5 minutes. The control group received no training of the respiratory muscles. Maximal inspiratory pressure increased significantly, more in the intervention group that the control (mean difference between groups 7.6 cm H_2O, 95% confidence intervals-CI 5.8 to 9.4). The effect of IMT on the weaning process was to reduce this period by 1.7 days (95% CI 0.4 to 3) (Table 2).

In the third study of Martin et al,[20] patients used a threshold device to perform four sets of 6 to 10 breaths per day, with two minutes of rest connected to ventilation between each set, for five days a week. The device was set to the highest pressure setting that the patient could open the valve during inspiration and the pressure was increased daily depending on patients' tolerance. In this study, the control group undertook a sham training of the inspiratory muscles by using a resistive device that needs minimum pressure to allow airflow. There were observed no adverse events during training treatments. Twenty five of 35 patients from the IMT group were weaned, and sixteen of 34 from the sham group ($p=0.039$). The sham group's MIP was not significant changed (-43.5 ± 17.8 to -45.1 ± 19.5 cm H_2O, $p=0.39$), while the IMT increased significantly (-43.5 ± 17.8 to -54.1 ± 17.8 cm H_2O, $p<.0001$) (Table2).

DISCUSSION

The effect of IMT on respiratory muscle strength is evident and in agreement with studies on different populations such as patients with chronic heart failure and chronic obstructive pulmonary disease.[22,23] All three studies that we reviewed used the same technique of measuring MIP, which is the most appropriate for ICU patients as less co-operation is required.[24,25] Important limitation in the studies of Caruso et al and Cader et al was the absence of a sham group. Familiarization of the IMT group with the technique of measurement through their training may have resulted in the improvement in MIP.

In an effort to facilitate weaning from mechanical ventilation, researchers examined the use of IMT during the weaning period as there were many case reports that demonstrated an increase in maximal inspiratory pressure (Table 1).[10-15] It is well documented that increased values of MIP are associated with weaning success.[26,27] The effect of IMT on weaning success was not significant in the three randomized trials. However, there are differences in the training protocols of the studies that may have contributed to this inconclusive result. The training protocols that were selected were not all of sufficient intensity or duration to provide a training effect. Cader et al used the ventilator as inspiratory muscle trainer by adjusting sensitivity. In this case we have resistance only in the beginning of the opening of the valve system, while, when using a threshold device, resistance is maintained for the whole period of inspiration. Additionally, in ICU patients, the level of maximal inspiratory pressure required to provide the appropriate training effect is unknown. The progression of duration and load also differed between the three studies. The training period ranged from 3 to 18 days, not sufficient to cause an increase in muscle fibers[24] and have an effect on weaning success. There is also significant difference in the days in mechanical ventilation that the patients commenced IMT, resulting in a population with various degrees of respiratory

TABLE 2. Summary of Reviewed Randomized Controlled Trials of Inspiratory Muscle Training

Study	Participants	Intervention	Outcome
Caruso et al (2005)	Patients intubated due to acute respiratory failure (n=40)	Intervention group (n=20): adjustment of ventilatory trigger sensitivity to 20% of MIP and increased by 10% to 40% Twice per day Increased by 5 min each session until 30 min Control group (n=20): no intervention	Weaning duration(mean± SD): 31±22h, control and 23±11 h, training group, p=0.24 Reintubation rate: 5 control and 3 training group, p=0.39 MIP in control group showed a modest increase while in training group a small decrease (p=0.34)
Cader et al (2010)	Patients intubated due to acute respiratory failure	Intervention group (n=21): Threshold device at 30% MIP Twice per day for 5 min MIP increased 10% per session to maximum 40% MIP Control group (n=20): no training	MIP in intervention group was increased from -15.1 to -25 cm H_2O and in control group from -15.3 to -17.6 cm H_2O, a significant increase in intervention group by 7 cm H_2O (p=0.001) Weaning period (mean ±SD) in trial group was 3.6±1.5 days while in control group 5.3±1.9 days (p=0.72)
Martin et al (2011)	Intubated due to medical and surgical diagnoses	Intervention group (n=35): Threshold device at highest pressure tolerated. 5 days per week. 4 sets of 6-10 breaths Control group (n=34): Sham intervention via a modified Pflex resistive device at low load	MIP (mean± SD) in intervention group was increased from -43.5±17.8 to -54.1 ±17.8 cm H_2O (p<0.0001) while in control group from -43.5±17.8 to -45.1±19.5 cm H_2O (p=0.39) 71% of patients in intervention group and 47% in control group were weaned from MV
Bissett et al (2012)	Patients were either ventilator dependent (>7 days) or had recently been weaned from MV (>7 days)	Intervention group: Threshold device, daily on weekdays. 5 sets of 6 breaths Control group: deep breathing exercises without resistance device	MIP QOL Functional status Rate of perceived exertion Post ICU length of stay Rate of reintubation Duration of ventilation No results have been published yet

h = hour(s); ICU = intensive care unit; MIP = maximal inspiratory pressure; MV = mechanical ventilation; QOL = quality of life; SD = Standard deviation.

muscle atrophy and training effect.

It should be pointed out that although MIP was increased, it remained below normative values.[20] We should also take into consideration that apart from inspiratory muscle strength there are other factors that may influence the success of a weaning procedure such as respiratory, cardiovascular, nutritional, psychological and neurological status.[16]

In an attempt to provide further data regarding IMT in ventilated patients, Bissett et al[22] designed a two center randomized controlled trial, to examine the effects of IMT on post- weaning outcomes. IMT will be performed using threshold muscle trainer and the training parameters are based on previous case studies.[10,14,15]

CONCLUSION

Inspiratory muscle training increases inspiratory muscle strength and improves respiratory funcion. IMT is a safe method to improve weaning outcome in ICU patients. Future research is needed in order to be able to determine the time that IMT will be initiated, the optimal load and its progression in order to have the desired training effect. Randomized controlled trials are needed to confirm the benefits of IMT on long-term ventilator-dependent patients.

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