Inspiratory muscle training increases inspiratory muscle strength in patients weaning from mechanical ventilation: a systematic review

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Question: Does inspiratory muscle training improve inspiratory muscle strength and endurance, facilitate weaning, improve survival, and reduce the rate of reintubation and tracheostomy in adults receiving mechanical ventilation? **Design**: Systematic review of randomised or quasi-randomised controlled trials. **Participants**: Adults over 16 years of age receiving mechanical ventilation. **Intervention**: Inspiratory muscle training versus sham or no inspiratory muscle training. **Outcome measures**: Data were extracted regarding inspiratory muscle strength and endurance, the duration of unassisted breathing periods, weaning success and duration, reintubation and tracheostomy, survival, adverse effects, and length of stay. **Results**: Three studies involving 150 participants were included in the review. The studies varied in time to commencement of the training, the device used, the training protocol, and the outcomes measured. Inspiratory muscle training significantly increased inspiratory muscle strength over sham or no training (weighted mean difference 8 cmH_2O, 95% CI 6 to 9). There were no statistically significant differences between the groups in weaning success or duration, survival, reintubation, or tracheostomy. **Conclusion**: Inspiratory muscle training was found to significantly increase inspiratory muscle strength in adults undergoing mechanical ventilation. Despite data from a substantial pooled cohort, it is not yet clear whether the increase in inspiratory muscle strength leads to a shorter duration of mechanical ventilation, improved weaning success, or improved survival. Further large randomised studies are required to clarify the impact of inspiratory muscle training on patients receiving mechanical ventilation. **Review registration**: PROSPERO CRD42011001132. **[Moodie L, Reeve J, Elkins M (2011) Inspiratory muscle training increases inspiratory muscle strength in patients weaning from mechanical ventilation: a systematic review. *Journal of Physiotherapy* 57: 213–221]**

Key words: Systematic review, Respiratory muscle training, Mechanical ventilators, Weaning, Intensive care, Physiotherapy

Introduction

Mechanical ventilation temporarily replaces or supports spontaneous breathing in critically ill patients in intensive care units. Weaning is the withdrawal of mechanical ventilation to re-establish spontaneous breathing. Patients are considered to have successfully weaned from ventilatory support when they can breathe on their own for at least 48 hours (Sprague and Hopkins 2003). Weaning typically comprises 40–50% of the total duration of mechanical ventilation, with almost 70% of patients in intensive care weaning without difficulty on the first attempt (Boles et al 2007). Other patients have a more difficult or prolonged period of weaning, which is associated with a poorer prognosis (Vallverdu et al 1998, Esteban et al 1999). Failure to wean results in prolonged ventilation with an increased risk of respiratory muscle weakness, critical illness weakness syndromes, nosocomial infection, and airway trauma (Boles et al 2007, Gosselink et al 2008). Despite representing only a small percentage of ICU patients, those who fail to wean from ventilation consume a disproportionate share of healthcare resources (Sprague and Hopkins 2003) with an increase in mortality, morbidity, and ICU length of stay (Choi et al 2008, Epstein 2009, Gosselink et al 2008).

Weakness or fatigue of the diaphragm and the accessory muscles of inspiration is widely recognised as a cause of failure to wean from mechanical ventilation (Choi et al 2008, Petrof et al 2010). There is also some evidence to suggest that mechanical ventilation may adversely affect diaphragmatic structure and function. These alterations, known as ventilator-induced diaphragmatic dysfunction, involve changes in myofibre length and rapid atrophy (Petrof et al 2010). Patients who undergo prolonged periods of ventilation also demonstrate decreases in respiratory muscle endurance (Chang et al 2005).

Inspiratory muscle training is a technique that loads the diaphragm and accessory inspiratory muscles with the aim of increasing their strength and endurance. Theoretically, mechanically ventilated patients could undertake inspiratory muscle training in several ways: isocapnic/normocapnic hyperpnoea training, the application of devices that impose resistive or threshold loads, or adjustment of the ventilator sensitivity settings, such that patients need to generate greater negative intrathoracic pressures to initiate inspiratory flow (Hill et al 2010, Caruso et al 2005, Bissett and Leditschke 2007). Inspiratory muscles respond to

What is already known on this topic: Inspiratory muscle weakness in critically ill patients appears to contribute to slow or unsuccessful weaning from mechanical ventilation. Several trials of inspiratory muscle training to facilitate weaning in intensive care have been performed, with inconsistent results.

What this review adds: Pooled data from randomised trials confirm that inspiratory muscle training increases inspiratory muscle strength, but it is not yet clear whether it shortens the mechanical ventilation period, improves weaning success, or improves survival.

training in the same way as other skeletal muscles in terms of the principles of overload, specificity, and reversibility (Romer and McConnell 2003, McConnell et al 2005). In healthy people and in people with chronic obstructive pulmonary disease, inspiratory muscle training has been shown to increase inspiratory muscle strength and endurance (McConnell and Romer 2004, Gosselink et al 2011, Geddes et al 2008). Sprague and Hopkins (2003) hypothesised that inspiratory muscle training may also increase inspiratory muscle strength and endurance in ventilated patients and thus potentially assist patients in weaning from ventilation. In addition, reducing ventilation time may help to reduce the incidence of ventilator-associated complications and may decrease length of stay in the intensive care unit and in hospital. In patients who have failed to wean from mechanical ventilation using conventional weaning techniques, several case reports have demonstrated increases in inspiratory muscle strength after inspiratory muscle training, followed by successful weaning (Abelson and Brewer 1987, Aldrich and Uhrlass 1987, Aldrich et al 1989, Sprague and Hopkins 2003, Martin et al 2002, Bissett and Leditschke 2007).

As no systematic appraisal of studies investigating the effect of inspiratory muscle training on weaning from mechanical ventilation has been indexed on the PEDro website or in PubMed, we undertook such a review, which aimed to answer the following specific research questions:

1. Does inspiratory muscle training improve inspiratory muscle strength and endurance in adults receiving mechanical ventilation?
2. Does it improve the success and reduce the duration of weaning?
3. Does it improve survival and reduce reintubation and tracheostomy?

Method

In addition to registration on PROSPERO, a more detailed protocol for conducting this review was submitted for peer review and publication (Moodie et al 2011) prior to commencing the review process.

Identification and selection of studies

Five electronic databases were searched (PEDro, PubMed, CENTRAL, EMBASE, and CINAHL) from the earliest available date until April 2011. Two authors (LM and JR) independently reviewed all the retrieved studies against the eligibility criteria (Box 1). Studies were not excluded on the basis of language or publication status. The title and abstract were examined and full text was obtained if there was ambiguity regarding eligibility. If the two authors could not reach agreement, a third author (ME) made the decision regarding eligibility. The reference lists of any eligible studies were screened to identify other relevant studies. We asked the authors of eligible studies and manufacturers of inspiratory muscle training devices if they were aware of any other eligible studies. The following keywords were included in our search: *randomised controlled trial*, *inspiratory/respiratory/ventilatory muscle training/ conditioning, pressure threshold load, incremental threshold load, isocapnic/normocapnic hyperpnoea, resistance load, mechanical ventilation, weaning, critically ill, intubated/ventilated/tracheostomy* (see Appendix 1 on the eAddenda for the full search strategy).

Box 1. Inclusion Criteria.

Design
- Randomised controlled trial and quasi-randomised controlled trials*

Participants
- Patients aged > 16 years who were intubated or tracheostomised receiving full or partial mechanical ventilation

Intervention
- Inspiratory muscle training via any of the following:
  - isocapnic/normocapnic hyperpnoea
  - inspiratory resistive training
  - threshold pressure training
  - adjustment of ventilator pressure trigger sensitivity

Outcome measures
- Inspiratory muscle strength
- Inspiratory muscle endurance
- Duration of unassisted breathing periods
- Weaning duration
- Weaning success
- Reintubation
- Tracheostomy
- Intensive care unit or hospital length of stay
- Mortality
- Adverse effects

Comparisons
- Inspiratory muscle training versus sham/no training

* Only the first arm of cross-over trials was included.

Assessment of characteristics of studies

Quality: The methodological quality of the studies was assessed using the PEDro scale (de Morton 2009). The PEDro scale scores the methodological quality of randomised controlled studies out of 10. The score for each included study was determined by a trained assessor (ME). Scores were based on all information available from both the published version and from communication with the authors. No study was excluded on the basis of poor quality.

Participants: Studies involving hospitalised patients over 16 years of age who were intubated or tracheostomised receiving full or partial mechanical ventilation, and for whom liberation from mechanical ventilation was a goal of clinical care, were included in the study. Where available, the age, gender, height, weight, cause of admission, and severity score of the participants at admission were recorded. Pre-intervention characteristics including severity score, ventilation status, ventilation period and endotracheal tube/ tracheostomy, inspiratory muscle strength and inspiratory muscle endurance were also recorded where available.

Intervention: The experimental intervention was inspiratory muscle training. The control intervention was sham or no inspiratory muscle training. The device used, the ventilation mode while training, training pressure, duration, frequency, and progression of training were recorded for the experimental group and for the control group if it received sham training. The method of inspiratory muscle training (isocapnic/normocapnic hyperpnoea, inspiratory

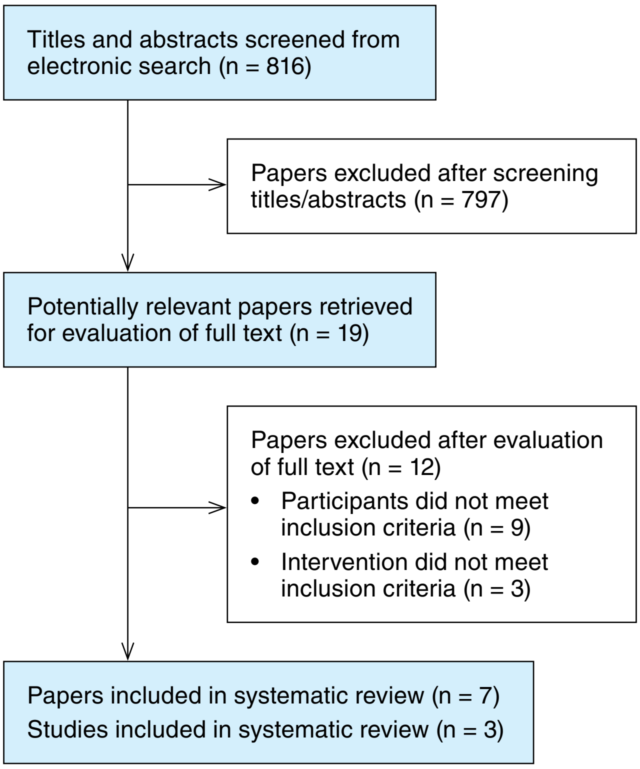

Figure 1. Flow of studies through the review.

resistive training, threshold pressure loading, or adjustment of ventilator pressure trigger sensitivity) was also recorded.

Outcome measures: Primary outcome measures were measures of inspiratory muscle strength at a controlled lung volume (eg, maximal inspiratory pressure at residual volume), inspiratory muscle endurance, the duration of unassisted breathing periods, weaning success (ie, proportion of patients successfully weaned, defined as spontaneous breathing without mechanical support for at least 48 hours), weaning duration (ie, from the identification of readiness to wean, as determined by the authors and/or commencement of inspiratory muscle training, to the discontinuation of mechanical ventilation) and reintubation (ie, proportion of extubated patients who were reintubated within the follow-up period of the study). Secondary outcomes were tracheostomy (ie, proportion of extubated patients tracheostomised after the commencement of training), survival, adverse effects, and length of stay in hospital or the intensive care unit.

Data analysis

The relevant data including study characteristics and outcome data were extracted from the eligible studies by two reviewers (LM and JR) using a standard form and the third author (ME) arbitrated in cases of disagreement. The reviewers extracted information about the method (design, participants, and intervention) and outcome data for the experimental and control groups. Authors were contacted where there was difficulty in interpreting or extracting data. The data analysis was performed using Revman 5.1 (Revman 2011). A fixed-effect model was used unless there was substantial heterogeneity ($I^2 > 50\%$), when a random-effects model was used. Continuous outcomes were reported as weighted mean differences with 95% CIs, while dichotomous outcomes were reported as risk ratios with 95% CIs.

Results

Flow of studies through the review

The search retrieved 816 studies. After screening titles and abstracts, 797 were excluded and 19 full text articles were identified. After evaluation of the full text, nine studies were excluded on the basis of participants not meeting the inclusion criteria. A further three were excluded on the basis of the intervention not meeting the inclusion criteria. Therefore seven papers (Cader et al 2010, Caruso et al 2005, Martin et al 2006a, Martin et al 2006b, Martin et al 2007, Martin et al 2009, Martin 2011) met the inclusion criteria for the review. One trial was reported across five publications (Martin et al 2006a, Martin et al 2006b, Martin et al 2007, Martin et al 2009, Martin et al 2011), so the seven included papers provided data on three trials. No additional studies were found by searching the reference lists of the included publications or by contacting manufacturers and authors. Figure 1 presents the flow of studies through the review. Authors of all the included studies were contacted to clarify interpretation and or extraction of data and all authors responded to the queries. There were no disagreements regarding eligibility or the extracted data, so arbitration by the third author was not required.

Description of studies

All of the studies (n = 3) reported the effects of inspiratory muscle training on inspiratory muscle strength as measured by maximal inspiratory pressure. Two studies reported data about weaning success (Cader et al 2010, Martin et al 2011), two studies reported data on weaning duration (Cader et al 2010, Caruso et al 2005), and three studies reported survival data (Cader et al 2010, Caruso et al 2005, Martin et al 2011). Therefore, the effect of inspiratory muscle training was examined using meta-analysis for four outcomes: inspiratory muscle strength, weaning success, weaning duration, and survival. Only one study reported data about reintubation (Caruso et al 2005) and tracheostomy (Cader et al 2010) and so these outcomes could not be meta-analysed. No studies reported inspiratory muscle endurance, the duration of unassisted breathing periods, and length of stay in the intensive care unit and hospital. The quality of the included studies is outlined in Table 1 and a summary of the studies is presented in Table 2.

Quality: The mean PEDro score of the included studies was 6. In all studies, randomisation was carried out correctly and group data and between-group comparisons were reported adequately. No study blinded participants or therapists, but one study (Martin et al 2011) blinded assessors.

Participants: There were 150 participants across the three studies. The mean age of participants across the three studies ranged from 65 to 83 years, and 50% were male. The reasons for mechanical ventilation included respiratory, surgical, cardiovascular, other medical, trauma, sepsis, and decreased level of consciousness. One study (Cader et al 2010) excluded patients who were tracheostomised, one study (Martin et al 2011) included only tracheostomised patients, and it is unknown whether participants in the other study were ventilated via tracheostomy or endotracheal tube.

Table 1. PEDro scores for included studies (n = 3)

Study	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	< 15% dropouts	Intention-to-treat analysis	Between-group difference reported	Point estimate and variability reported	Total (0 to 10)
Cader et al (2010)	Y	Y	Y	N	N	N	N	Y	Y	Y	6
Caruso et al (2005)	Y	N	Y	N	N	N	N	N	Y	Y	4
Martin et al (2011)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8

N = No, Y = Yes

APACHE II scores ranging from 20 to 24 were reported in two of the studies (Caruso et al 2005, Cader et al 2010) and SAPS II score was reported in one study (Martin et al 2011). In all three studies, the mean duration of ventilation before inspiratory muscle training commenced was reported and varied greatly between 1 (Caruso et al 2005) and 45 days (Martin et al 2011). Prior to initiation of training, the mean maximal inspiratory pressure of the participants, measured at residual volume, ranged from 15 to 51 cmH_2O among the included studies. No study reported the maximal inspiratory pressures as a percentage of the predicted values. However, because maximal inspiratory pressure in healthy individuals ranges from 104 to 129 cmH_2O for men and 70 to 98 cmH_2O for women (ATS/ERS 2002), the maximal inspiratory pressures of the participants can be considered extremely low.

Intervention: A threshold pressure device was used for inspiratory muscle training in two of the studies (Cader et al 2010, Martin et al 2011) and adjustment of the sensitivity of the pressure trigger on the ventilator was used in one study (Caruso et al 2005). Training protocols used starting pressures ranging from 20% of maximal inspiratory pressure to the highest pressure tolerated. The duration of the training sessions varied from 5 to 30 min and the frequency from 5 to 7 days a week. Two studies reported that physiotherapists or respiratory therapists supervised the training (Cader et al 2010, Caruso et al 2005). One study (Martin et al 2011) provided sham training to the control group with a modified Pflex device, while the other studies provided usual care only to the control group.

Outcome measures: In all three studies, inspiratory muscle strength was measured by maximal inspiratory pressure in cmH_2O. This was measured after the application of a unidirectional valve for 20 to 25 seconds, which is intended to ensure the measurement is taken from residual volume. Two studies recorded the number of patients successfully weaned as a percentage of the total number of participants, defined as spontaneous breathing without ventilator support for 48 hours (Cader et al 2010) or 72 hours (Martin et al 2011). In two studies weaning duration was recorded in hours (Caruso et al 2005) or days (Cader et al 2010) and results were converted to hours.

Effect of intervention

Inspiratory muscle strength: Three studies (Cader et al 2010, Caruso et al 2005, Martin et al 2011) with 122 participants provided post-intervention data for pooling with a fixed-effect model to show the effect of inspiratory muscle training on increasing inspiratory muscle strength when compared to control (Figure 2, see also Figure 3 on the eAddenda for a detailed forest plot). Results showed a significant improvement in maximal inspiratory pressure favouring inspiratory muscle training over no or sham training (MD = 8 cmH_2O, 95% CI 6 to 9).

Weaning success: Two studies (Cader et al 2010, Martin et al 2011) with 110 participants provided post-intervention data about the effect of inspiratory muscle training on the proportion of patients successfully weaned from mechanical ventilation. A random-effects model was used as there was significant heterogeneity ($I^2 = 60\%$). The overall effect was not significant but favoured the experimental group (RR = 1.20, 95% CI 0.76 to 1.91) (Figure 4, see also Figure 5 on the eAddenda for a detailed forest plot).

Table 2. Summary of included studies (n = 3).

Study	Design	Participants	Intervention	Outcome measures
Cader et al (2010)	RCT	Intubated via endotracheal tube due to acute respiratory failure Starting PS after a period of controlled ventilation Exp: n = 21 (9 male) Age (yr) = 83 (SD 3) APACHE II = 20 Con: n = 20 (10 male) Age (yr) = 82 (SD 7) APACHE II = 20	Exp: Threshold device at 30% MIP in supine 45 degrees up 5 min Twice daily MIP increased 10% of initial MIP daily, as tolerated Stopped if adverse signs Con: No training	MIP Weaning duration Mortality Tracheostomy Weaning success
Caruso et al (2005)	RCT	Intubated due to acute respiratory failure or decreased consciousness Receiving controlled ventilation or PS Exp: n = 20 Completed n = 12 (8 male) Age (yr) = 67 (SD 10) APACHE II = 23 Con: n = 20 Completed n = 13 (9 male) Age (yr) = 66 (SD 17) APACHE II = 24	Exp: Adjustment of ventilator trigger sensitivity to 20% of initial MIP 5 min Twice daily Increased by 5 minutes each session to 30 minutes Increased by 10% of initial MIP to maximum 40% MIP Con: No training	MIP Weaning duration Mortality Reintubation Adverse effects Ventilation duration
Martin et al (2011)	RCT	Intubated and ventilated due to medical and surgical diagnoses Exp: n = 35 (16 male) Age (yr) = 66 (SD12) SAPS II = 33.5 Con: n = 34 (15 male) Age (yr) = 65 (SD 11) SAPS II = 33	Exp: Threshold inspiratory device set at highest pressure tolerated Start pressure 7.2 to 12.3 cmH20 6 to 10 breaths x 4 sets x 5 days/week Until weaned or 28 days Con: Sham: modified Pflex inspiratory resistive device at low load	MIP Weaning success Mortality

APACHE II = Acute physiology and chronic health evaluation II score, MIP = maximal inspiratory pressure, PS = pressure support, RCT = randomised controlled trial, SAPS II = Simplified Acute Physiology Score

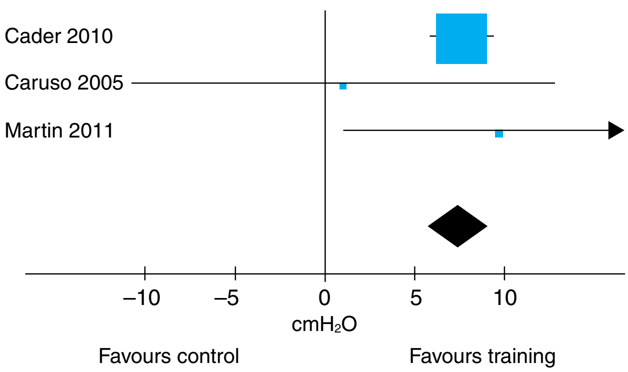

Figure 2. Mean difference (95% CI) of the effect of inspiratory muscle training on inspiratory muscle strength as measured by maximal inspiratory pressure (in cmH_2O) by pooling data from three studies (n = 122).

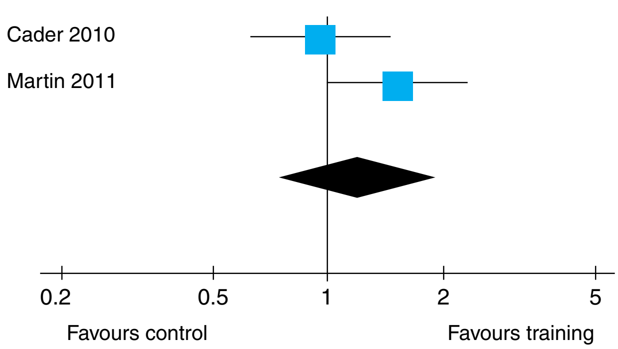

Figure 4. Risk ratio (95% CI) of the effect of inspiratory muscle training on weaning success (% of patients successfully weaned) by pooling data from two studies (n = 110).

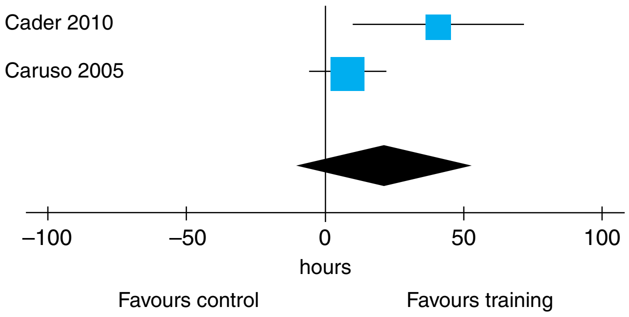

Figure 6. Mean difference (95% CI) of the effect of inspiratory muscle training on weaning duration (in hours) by pooling data from two studies (n = 53).

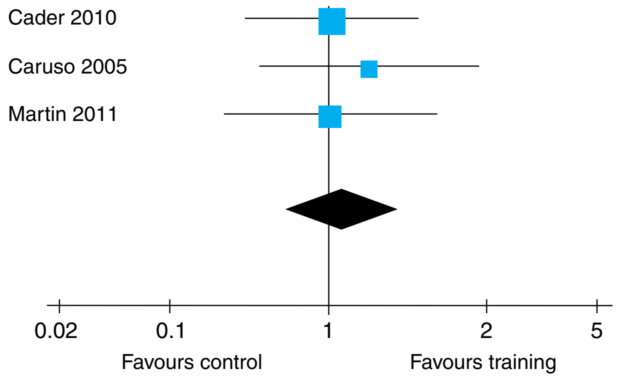

Figure 8. Risk ratio (95% CI) of the effect of inspiratory muscle training on survival by pooling data from three studies (n = 150).

Weaning duration: Two studies (Cader et al 2010, Caruso et al 2005) with 53 participants provided post-intervention data for pooling to examine the effect of inspiratory muscle training on the duration of weaning from mechanical ventilation. A random-effects model was used as there was significant heterogeneity (I^2 = 73%). The overall effect was not significant (MD = 21 hours, 95% CI –10 to 53) but favoured the experimental group (Figure 6, see also Figure 7 on eAddenda for detailed forest plot).

Survival: Three studies (Cader et al 2010, Caruso et al 2005, Martin et al 2011) with 150 participants provided data on the effects of inspiratory muscle training on survival (RR = 1.22, 95% CI 0.54 to 2.77). The overall effect was not significant but favoured inspiratory muscle training (Figure 8, see also Figure 9 on eAddenda for detailed forest plot).

Reintubation: Only one study (Caruso et al 2005) reported the effect of inspiratory muscle training on reintubation, providing data on 34 participants. Three of 17 (18%) of the experimental group and five of 17 (29%) of the control group were reintubated. This difference between groups was not statistically significant (RR = 0.60, 95% CI 0.17 to 2.12).

Tracheostomy: One study (Cader et al 2010) reported the effect of inspiratory muscle training on tracheostomy, providing data on 33 participants. Three of 17 (18%) of the experimental group and 2 of 16 (13%) of the control group received a tracheostomy, which was not a statistically significant difference (RR = 1.41, 95% CI 0.27 to 7.38).

Adverse events: One study (Martin et al 2011) reported no adverse effects during either the training or the sham training. One study (Cader et al 2010) did not document occurrence of adverse events. One study (Caruso et al 2005) reported adverse effects in the experimental group including paradoxical breathing, tachypnea, desaturation, haemodynamic instability, and supraventricular tachycardia. However, it is not clear whether the control group underwent an equivalent period of observation for adverse events.

Discussion

Numerous case reports and case series have described the use of inspiratory muscle training in mechanically ventilated patients (Martin et al 2002, Bissett and Leditschke 2007, Sprague and Hopkins 2003, Aldrich et al 1989, Aldrich and Uhrlass 1987, Abelson and Brewer 1987). All of these studies observed an increase in maximal inspiratory pressure or training pressure and suggested that this may have aided weaning from mechanical ventilation. While the data analysed in this review confirm that inspiratory muscle training improves maximal inspiratory pressure significantly, it remains unclear whether these benefits translate to weaning success and a shorter duration of mechanical ventilation. Although only three randomised trials were identified by this review, the total number of patients who contributed data was substantial (n = 150). The average rating of the quality of the three studies in this review (ie, 6 on the 10-point PEDro scale) is greater than the average score for trials in physiotherapy (Maher et al 2008). Therefore this review provides strong evidence that inspiratory muscle training significantly increases inspiratory muscle strength in mechanically ventilated patients. The non-significant trends on the remaining outcomes favour inspiratory muscle training over control and the 95% CIs contain clinically worthwhile benefits, strongly suggesting that further research is required. However, it is not possible to provide a recommendation to implement the training to facilitate weaning from mechanical ventilation based on the current evidence.

Although individual studies varied in their conclusions about the effect of inspiratory muscle training on maximal inspiratory pressure, the pooled data show that the training significantly increases inspiratory muscle strength. At present there is no established minimum clinically important difference in maximal inspiratory pressure in this patient group. The mean pressures recorded at baseline in the three included studies ranged from 15 to 51 cmH_2O, which is below the predicted normal for healthy individuals (ATS/ERS 2002). Even after training in the experimental group, the mean maximal inspiratory pressures in all studies ranged from 25 to 56 cmH_2O, which remain substantially lower than normal values. Sahn and Lakshminaryan (1973) suggested that a low maximal inspiratory pressure was an important predictor of weaning failure, although this finding has not been reproduced consistently in the literature (Bruton et al 2002).

These results must be interpreted in the context of the reliability of inspiratory muscle strength measures in ventilated patients. It has been highlighted that maximal inspiratory pressure is difficult to measure reliably in intubated patients (Bruton et al 2002). This has been overcome by the use of a unidirectional valve, which allows maximal inspiratory pressure to be performed easily even in unco-operative patients (Caruso et al 1999, Eskandar and Apostolakos 2007). Using a unidirectional valve requires a physiological response demanding less patient co-operation, and is more accurate than other methods of measuring maximal inspiratory pressure (Caruso et al 1999). This technique was used by the authors in all three studies. Authors have suggested using the maximal value of three manoeuvres to minimise variability (Caruso et al 2008, Marini et al 1986) however only one included study (Martin et al 2011) reported undertaking such repetitions. Although a unidirectional valve was used, measurement variability could occur due to the effects of controlled ventilation, varying levels of consciousness and sedation. However, this technique currently represents the best method for estimating inspiratory muscle strength in mechanically ventilated patients (Caruso et al 1999, Caruso et al 2008). Due to the design of the studies, the experimental group had greater opportunity to practise the maximal inspiratory pressure measurement procedure, eg, during titration of the training load, and to accommodate to the feeling of loaded breathing during training. It is therefore possible that some or all of the improvement in maximal inspiratory pressure in the experimental group could be attributed to familiarisation with the technique.

This review showed that the overall effect of inspiratory muscle training on weaning success was not significant, although the best estimate was that it probably increases the likelihood of weaning success by about 20%. Although this did not reach statistical significance, the 95% CI includes some possible clinically worthwhile effects so further research is warranted. Although maximal inspiratory pressure increased, it remained below normative values in all three studies and did not translate into statistically significant weaning success in the available data. Apart from its association with inspiratory muscle strength, weaning success has also been shown to be dependent on cardiovascular stability, sepsis, and nutritional, psychological and neurological status (Sprague and Hopkins 2003). It is possible that these factors may have influenced results.

The overall effect of inspiratory muscle training on weaning duration was not statistically significant, although the best estimate was that the average effect might be to reduce weaning time by 21 hours. In our opinion, this would be clinically worthwhile because successful withdrawal of mechanical ventilation at any stage is associated with a higher survival rate (Eskandar and Apostolakos 2007). The 95% CI suggests that the average effect of inspiratory muscle training could, at best, reduce weaning time by more than two days which has implications in reducing the risk of ventilator acquired complications and the associated health care costs. However, it is equally possible that the improvement in inspiratory muscle strength with training is inadequate to improve weaning duration, because the 95% CI does not exclude neutral and mildly negative effects.

The overall effect of inspiratory muscle training on mortality was not statistically significant but favoured the training group. By strengthening the inspiratory muscles, the training may decrease the duration of ventilation and associated complications, potentially contributing to a reduction in mortality. The outcomes of reintubation (Caruso et al 2005) and tracheostomy (Cader et al 2010) were each measured by one study and neither identified a statistically significant or clinically worthwhile effect.

Because the confidence intervals around the estimates of the effect of inspiratory muscle training on weaning success and weaning duration include values that we consider to be clinically worthwhile, we recommend further research to refine these estimates. However, using the existing data in this review, we calculate that data from 400 patients would be needed to identify a statistically significant effect on weaning success. Similarly, 118 patients would be needed to identify an effect on weaning duration. Data from additional patients would be needed to determine whether such effects are clinically worthwhile. Data from cohorts as large as this could be accumulated over time through future meta-analyses. However, intensive care management is constantly changing, eg, the implementation of sedation breaks into usual care (Kress et al 2000, Schweickert et al 2004). Such advances in usual care may alter the efficacy of inspiratory muscle training and this may limit the extent to which it is appropriate to meta-analyse existing and future trials of inspiratory muscle training in intensive care.

If further research is to be conducted to determine the effects of inspiratory muscle training on clinical outcomes, the training regimen and the outcomes should be chosen carefully. The training protocols in the three studies in this review differed and it is possible that not all were of sufficient intensity or duration to provide a training effect. The training period of participants in our studies ranged from 3 to 18 days yet other studies, albeit in different populations, trained people with chronic obstructive pulmonary disease and found significant increases in the proportion of type I and size of type II muscle fibres after five weeks of training (Ramirez-Sarmiento et al 2002). As the training duration in the studies we reviewed was short by comparison it is possible the changes seen in increased inspiratory muscle strength may have been due to the adaptation of neural pathways to improve motor unit recruitment and breathing pattern rather than a change in muscle hypertrophy or fibre type.

One study included in this review investigated the effect of inspiratory muscle training on breathing pattern as measured by the Index of Tobin, which is the ratio of respiratory frequency (in breaths per min) to tidal volume (in litres) (Yang and Tobin 1991). This index is a predictor of weaning (Yang and Tobin 1991). Although the Index of Tobin was not one of the outcomes we included in our review, one study (Cader et al 2010) found a significant reduction (ie, improvement) in the Index of Tobin (MD = 8, 95% CI 3 to 14) in the participants who underwent inspiratory muscle training. The authors suggested this indicated a more relaxed breathing pattern, which may be more compatible with weaning success as hypothesised by Sprague and Hopkins (2003).

Other differences in the training protocols may have contributed to the difference in effects seen in the included studies. The studies report a wide variation in the point of care at which training commenced. Caruso et al (2005) commenced training after 24 hr of ventilation, whereas Martin et al (2011) commenced after a mean of 45 days. The background mode of ventilation that the participants were receiving also differed between the studies. In the study by Cader et al (2010) it was pressure support, in the study by Caruso et al (2005) it was pressure- or volume-controlled ventilation, and in the study by Martin et al (2011) it was assist-control or synchronised intermittent mandatory ventilation or pressure support. Additionally participants in the study by Caruso et al (2005) remained sedated and had only a small increase in maximal inspiratory pressure, from 51 to 56 cmH_2O. Thus it is possible that sedation and mode of ventilation limited training efficacy. In a later study, deeper levels of sedation were associated with a decrease in maximal inspiratory pressure during mechanical ventilation (Caruso et al 2008).

The mode of inspiratory muscle training also differed between studies and included threshold pressure training and adjustment of ventilator trigger sensitivity. It has been suggested that with adjustment of the ventilator trigger sensitivity, maximal inspiratory pressure may not be maintained as resistance is only offered initially when the valve opens (Cader et al 2010). These authors suggest that threshold pressure training instead provides resistance for a longer duration and thus may be more effective for inspiratory muscle training. Studies in our review also used differing training regimes with the starting pressures and loads ranging from 20% of maximal inspiratory pressure (Caruso et al 2005) to the highest pressure tolerated (Martin et al 2011). Differences in the progression of duration and load were also seen throughout the three studies in this review. In recent systematic reviews of inspiratory muscle training in chronic obstructive pulmonary disease (Gosselink et al 2011, Geddes et al 2008), 30% of maximal inspiratory pressure is recommended as the minimal initial training pressure required to increase inspiratory muscle strength. In intensive care patients, the level of maximal inspiratory pressure required to provide an adequate training stimulus is currently unknown.

Physiotherapists, with their knowledge of exercise prescription in the intensive care environment, are ideally placed to pursue further research in this area and – should inspiratory muscle training be shown to be effective – to prescribe and supervise inspiratory muscle training in selected patients who are receiving mechanical ventilation. Inspiratory muscle training in the form of threshold pressure training is low cost, easy for patients to use, and requires little staff training. The training protocols used in the three studies in this review are of relatively short duration, which makes the training a realistic and feasible treatment within the overall rehabilitation of patients in the intensive care unit.

In summary, this systematic review has found that inspiratory muscle training (in the form of threshold pressure training and ventilator sensitivity adjustment) significantly increases inspiratory muscle strength with minimal reported adverse effects when used for the purpose of weaning from mechanical ventilation. Although the mean estimates of the effects of the training on mortality and on the success and duration of weaning favour inspiratory muscle training, they remained statistically non-significant, so further research is required to determine whether they should be used in clinical practice. ■

eAddenda: Figures 3, 5, 7, 9 and Appendix 1 available at jop.physiotherapy.asn.au

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