INVITED REVIEW

Effects of Exercise Training and Inspiratory Muscle Training in Spinal Cord Injury: A Systematic Review

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Abstract

Objective: To provide a systematic review of the studies assessing exercise training and inspiratory muscle training (IMT) in individuals for the improved respiratory function of patients with spinal cord injury (SCI).

Methods: Thirteen studies (5 exercise training, 8 IMT) were identified. Articles were scored for their methodological quality using the Physiotherapy Evidence Database scores and Downs and Black tools for randomized and nonrandomized studies, respectively. Conclusions were based on the most rigorously executed studies using Sackett's levels of evidence.

Results: Study comparison was compromised by diverse research designs; small sample sizes; and heterogeneity of studied populations, protocols, and outcome measures. Based on current literature, there is level 2 evidence supporting exercise training as an intervention to improve respiratory strength and endurance and level 4 evidence to support exercise training as an intervention that might improve resting and exercising respiratory function in people with SCI. There is level 4 evidence to support IMT as an intervention that might decrease dyspnea and improve respiratory function in people with SCI.

Conclusions: There are insufficient data to strongly support the use of exercise training or IMT for improved respiratory function in people with SCI. There is some evidence of efficacy of both regimens; however, the evidence is not of the best possible quality.

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Key Words: Spinal cord injuries; Exercise training; Inspiratory muscle training, Rehabilitation; Respiratory dysfunction; Systematic review

INTRODUCTION

The respiratory system, composed of the lungs, respiratory muscles, and associated neuronal controls, is a complex physiological unit that must operate in a cyclical and highly coordinated fashion 24 hours a day in order to sustain life. Spinal cord injury (SCI) impairs neuronal control of respiratory muscles and in turn respiratory function. Despite advances in patient care resulting in significant improvements in acute and long-term survival rates, individuals with SCI continue to have a mortality rate 47% higher than able-bodied people (1). Respiratory complications remain one of the leading causes of morbidity and mortality among individuals with SCI (2,3).

Numerous protocols of respiratory training have been employed as a means of improving respiratory function in individuals with SCI. Two specific training modalities that have been clinically evaluated are exercise training and inspiratory muscle training (IMT). This review systematically assessed the efficacy of exercise training and IMT for the improved respiratory function of patients with SCI to facilitate the identification of optimal clinical care for clinicians who treat patients with SCI. This article is organized into 2 sections: the first section reviews the current understanding of SCI-related respiratory impairment and the mechanisms by which exercise training and IMT are believed to mitigate these impairments; the second section reports the search strategy employed in this review and the results and analyses of studies that have assessed exercise training and IMT.

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RESPIRATORY DYSFUNCTION IN SCI

SCI-related respiratory dysfunction is largely dependent on the level of injury, completeness of injury, and time since injury (1,4,5). Higher lesions result in greater denervation of the expiratory and inspiratory muscles, and, thus, injuries to the cervical and upper thoracic regions of the spinal cord result in greater reductions in inspiratory and expiratory function. Complete paralysis of all muscles involved with respiration occurs when the lesion is above C3; this type of injury requires immediate and ongoing ventilatory support in order to sustain life. When the injury is between C3 and C5 (innervation of the diaphragm), respiratory insufficiency occurs via respiratory muscle dysfunction. Although primary and some accessory muscles of inspiration are fully innervated with injuries below cervical lesions, the ability to ventilate at higher levels is still compromised because the intercostals and other chest wall muscles do not provide the integrated expansion of the upper chest wall as the diaphragm descends during inspiration. There is some evidence that the chest wall is pulled in during diaphragm excursion, which could further limit inspiratory capacity. Furthermore, ventilation during exercise can be greatly compromised; the expiratory muscles actively contract in healthy people, whereas in SCI, partial or fully denervated expiratory muscles have impaired contractile activity and thus exhibit diminished exercise ventilation and ventilatory reserve.

Lung volumes, such as inspiratory capacity and expiratory reserve volume, reflect these diminished capacities for full inspiration and forced expiration in people with SCI. Both inspiratory capacity and expiratory reserve volume are progressively smaller in higher cervical lesions vs lower thoracic and lumbar lesions (4). The forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) are usually measured in apparently healthy people to detect airways obstruction and restrictive lung disease. Due to reduced inspiratory muscle force, these measures are diminished in people after SCI with higher lesions and especially in people with tetraplegia (4,5) and demonstrate moderate correlation with injury level (4). Whereas incomplete lesions appear to mitigate FEV_1 and FVC losses, smoking and longer duration of injury are associated with greater reductions in FEVs (5).

Although cough is an important defense mechanism against respiratory tract infections and atelectasis, the capacity to generate cough and clear respiratory secretions is severely compromised in most individuals with SCI due to the impaired innervation of the abdominal muscles at most SCI levels. The respiratory system has other important roles, such as speaking and posture-related activities (eg, trunk stability), which can also be negatively affected by the SCI, especially with higher lesions. Respiratory system complications can be exacerbated by preexisting medical conditions, history of smoking, advanced age, and therapeutic measures to manage the resuscitation phase of the injured patient (6–8).

Exercise Training

As with able-bodied individuals, there is strong evidence supporting the use of exercise training for improved cardiovascular health among people with SCI (9). This is important because there is a high incidence of physical inactivity in individuals with SCI and they are at increased risk of secondary conditions, such as cardiovascular disease, diabetes, osteoporosis, and obesity (9).

With respect to respiratory function, exercise training in patients with SCI improves both the control of breathing (eg, minute ventilation [$\dot{V}_E$] and tidal volume [V_t]) and respiratory sensations (eg, dyspnea). Specifically, exercise training results in a lowered $\dot{V}_E$ at any given absolute oxygen consumption or power output and is associated with decreased feelings of breathlessness. Although the former reduces the work of breathing during exercise, the latter prevents its early termination. These training effects are likely due to a reduction in one or more of the mechanisms (neural and/or humoral) purported to cause the hyperpnea of exercise.

Recent evidence suggests that improvements in respiratory function associated with exercise training may be partly explained by the adaptive response of the respiratory system itself (10–12). Structural adaptations may be muted to a greater extent among individuals with SCI, considering the small amount of muscle mass used in wheelchair propulsion or arm-cranking exercise. In contrast, respiratory muscles have been shown to be both metabolically and structurally plastic. As such, it is possible that the positive effects of exercise training in SCI may reside in an increase in respiratory muscle strength and endurance in addition to adjacent effects of reduced ventilatory demand during exercise via peripheral adaptations. A training response of the respiratory muscles has been demonstrated directly in animal models (10) and indirectly in able-bodied humans (11,12).

Inspiratory Muscle Training

Approximately two thirds of the prevalence of dyspnea in patients with SCI is attributed to inspiratory muscle paralysis (13), with greater severity associated with higher levels of injury. Improved inspiratory muscle strength and endurance could potentially improve cough and maximal exercise ventilation in addition to decreasing dyspnea.

Inspiratory muscles can be trained similarly to the limb muscles with inexpensive devices that increase the resistive or threshold inspiratory load on the inspiratory muscles (14). The 2 main types of devices used to improve the strength and endurance of inspiratory muscles are resistive and threshold trainers. Both of these devices have a 1-way valve that closes during inspiration so that the subject must breathe through a small-diameter hole for the resistive trainer or against a

Table 1. Measures of Respiratory Muscle Strength and Endurance

Term	Abbreviation	Definition
Maximal inspiratory pressure	MIP or PI_{max}	Estimate of inspiratory muscle force as reflected by the maximal pressure exerted by the inspiratory muscles measured at the mouth.
Maximal expiratory pressure	MEP or PE_{max}	Estimate of expiratory muscle force as reflected by the maximal pressure exerted by the expiratory muscles measured at the mouth.
Maximal voluntary ventilation	MVV	Maximal ventilation in 15 s, which reflects the "sprint" capacity of the respiratory muscles. Maximal ventilation can be measured over several min (between 4 and 15), which is more reflective of the endurance of the respiratory muscles.
Maximal sustainable mouth pressure	SIP	Maximal mouth pressure sustained during a 10-min period of threshold loading, which is usually lower than the MIP. This is an estimate of the endurance of the inspiratory muscles.
Endurance time sustained on training load	T_{lim}	Endurance time while breathing on a resistive or threshold trainer at a defined level of the MIP.
Maximal incremental threshold load	TL_{max}	Maximal load (usually defined as an inspiratory mouth pressure) attained on an incremental threshold loading test, whereby the load is progressively increased every 2 to 3 min.

spring-loaded valve for the threshold trainer. The 1-way valve opens during expiration such that no load is imposed during the expiratory phase of respiration.

Evidence showing decreased dyspnea and improved strength and endurance after IMT is well documented in people with other health conditions, such as chronic obstructive pulmonary disease (COPD) (14). Table 1 outlines common measures that are indicative of respiratory muscle strength and endurance. In neuromuscular disorders such as SCI, maximal lung volumes that measure inspiratory capacity also can reflect increased inspiratory muscle strength.

STUDY DESIGN

A systematic search of multiple databases (MEDLINE/PubMed, CINAHL, EMBASE, PsycINFO) was executed to identify all relevant literature published from 1980 through 2006. Databases were searched for spinal cord injury, tetraplegia, quadriplegia, or paraplegia paired with the following key words: exercise, ventilation, respiratory muscle, respiratory muscle strength, maximal inspiratory pressure, maximum voluntary ventilation, and pulmonary function. Articles were included if they were published in English and involved human subjects and a specific intervention. To ensure the ability to generalize to a SCI population, we excluded studies in which less than half of the reported sample had SCI. Studies describing the acute responses to exercise in people with SCI were not included nor were studies concerned with competitive athletes. Studies with no measurable outcome associated with the intervention were also not included. References of all identified articles were

Table 2. Five Levels of Evidence

Level	Research Design	Description
1	Randomized controlled trial (RCT)	RCT, PEDro score ≥6. Includes within subjects comparison with randomized conditions and cross-over designs.
2	RCT	RCT, PEDro score <6.
	Prospective controlled trial	Prospective controlled trial (not randomized).
	Cohort	Prospective longitudinal study using at least 2 similar groups with 1 exposed to a particular condition.
3	Case control	A retrospective study comparing conditions, including historical controls.
4	Pre-post	A prospective trial with a baseline measure, intervention, and a post-test using a single group of subjects.
	Post-test	A prospective post-test with 2 or more groups; intervention, then post-test (no pretest or baseline measurement) using a single group of subjects.
	Case series	A retrospective study usually collecting variables from a chart review.
5	Observational	Study using cross-sectional analysis to interpret relations.
	Clinical consensus	Expert opinion without explicit critical appraisal, or based on physiology, biomechanics, or "first principles."
	Case report	Pre-post or case series involving 1 subject.

PEDro, Physiotherapy Evidence Database.

Table 3. Exercise Training

Reference	Methodological Quality Score and Study Type	Population Characteristics	Treatment	Results
Silva et al[19]	D&B = 16; level 2 cohort, non-RCT	24 subjects (12 with paraplegia, 12 able-bodied individuals); median age SCI: 31 y (range 22–54 y); control: 30 y (range 22–52 y); LOI T1-T12, all ASIA A; time since injury >3 y	Arm-cranking aerobic training: 30 min, 3 x/wk x 6 wk	Subjects with SCI showed significant increases in FVC ($P < 0.05$) and ventilatory muscle endurance ($P < 0.001$), so that maximum voluntary ventilation at 70% time values after training was not different from the initial values of able-bodied individuals.
Bougenot et al[20]	D&B = 16; level 4 case series	7 subjects (all men); mean age 35 ± 13 y; LOI T6-L5, all ASIA A; time since injury >1 y	Wheelchair ergometry aerobic training: 45 min, 3 x/wk x 6 wk	(a) While peak $\dot{V}_E$ remained unchanged after the training, resting $\dot{V}_E$ significantly lowered after training at the same work rate. (b) Exercise training showed improvements in maximal tolerated power.
Sutbeyaz et al [21]	D&B = 15; level 4 case series	20 subjects (12 men, 8 women); mean age 31 ± 8.17 y; LOI T6-T12, 14 complete, 6 incomplete; time since injury 3.8 ± 5.8 y	Ventilatory and upper extremity muscle exercise: 60 min (session total), 3 x/wk x 6 wk; diaphragmatic, pursed-lip breathing for 15 min; air shifting for 5 min; voluntary isocapnic hypernea for 10 min; arm-crank exercise for 30 min	(a) After training, FVC, FEV_1, and VC were significantly higher than the baseline values. (b) Exercise testing showed increased peak $\dot{V}_E$ and peak workload and a reduction in the ratio of physiological dead space to tidal volume compared with baseline values.
Le Foll-de-Moro et al[22]	D&B = 14; level 4 case series	6 subjects (5 men, 1 woman); mean age 29 ± 14 y; T6-T11/12; mean time since injury 94 d (range = 73–137 d)	Wheelchair ergometry interval-aerobic training: 30 min (6 × 5-min bouts: 4 min moderate intensity, 1 min high intensity), 3 x/wk for 6 wk; progressed throughout training program to achieve 50% and 80% of heart rate	(a) While peak $\dot{V}_E$, breathing frequency, $\dot{V}_t$, and ventilatory reserve improved, it was not statistically significant. (b) The oxygen cost of $\dot{V}_E$ decreased significantly (−20%) after training. (c) For the wheelchair test at the same workload after training, $\dot{V}_E$ and breathing frequency decreased and Vt increased (consistent with improved ventilatory efficiency and greater reliance on aerobic capacity after training). (d) Spirometric values and lung volumes showed small trend towards improvement after training.
Hooker and Wells[23]	D&B = 12; level 4 case series	8 subjects (4 men, 4 women); low-intensity group: LOI C5-T7 (age range 26–36 y); moderate intensity group: C5-T9 (age range 23–36 y)	Wheelchair ergometry aerobic training: 20 min, 3 x/wk for 8 wk; low intensity exercised at a power output = 50%–60% of maximal heart rate; moderate intensity exercised at a power output = 70%–80% maximal heart rate	(a) No change to Vo_{2max} or peak power after training. (b) No detectable changes during submaximal or maximal exercise were detected. (c) Training intensity was insufficient, subjects did not comply with the program, or study was underpowered due to small sample size and heterogeneity of subject responses.

D&B, Downs and Black; RCT, randomized controlled trial; SCI, spinal cord injury; LOI, level of injury; FVC, forced vital capacity; V_E, minimal ventilation; FEV_1, forced expiratory volume in 1 second; V_t, tidal volume; and Vo_{2max}, maximum oxygen consumption.

Table 4. Inspiratory Muscle Training

Reference	Methodological Quality Score and Study Type	Population Characteristics
Liaw et al[24]	D&B = 19; level 2 cohort, RCT	20 subjects; IMT (N = 10) vs control (N = 10); 8 men, 2 women in each group; mean age IMT 30.9 ± 11.6 y, control 36.5 ± 11.5 y; LOI C4-C7; time since injury 30–134 d
Derrickson et al[25]	PEDro = 6; level 1, RCT	11 subjects; IMT (N = 6) vs breathing (N = 5), 9 men, 2 women; mean age 28.5 ± 5.6 y; LOI C4-C7 (neurologically complete); time since injury 2–74 d; studied at >24 h after spontaneous breathing
Loveridge et al[26]	PEDro = 4; level 1, RCT	12 subjects; IMT (N = 6) vs control (N = 6); mean age IMT 31 ± 4.1 y, control 35 ± 12 y; LOI C6-C7; time since injury >1 y
Uijl et al[27]	D&B = 14; level 2 cohort experimental crossover design with sham phase followed by IMT phase, non-RCT	9 subjects (8 men, 1 woman); mean age 34.4 y (range 20–49 y); LOI C3-C7, ASIA A (n = 3), B (n = 3), and C and D (n = 3); time since injury: 2–27 y
Gross et al[28]	D&B = 12; level 4 case series, non-RCT	6 subjects (4 men, 2 women); age range 18–41 y; time since injury >1 y
Hornstein and Ledsome[29]	D&B = 11; level 4 case report, non-RCT	10 subjects; time since injury acute post-traumatic phase. No additional population characteristics.
Rutchik et al[30]	D&B = 10; level 4 pre-post test design, non-RCT	9 subjects; mean age 36 y (range 24–65 y); time since injury >1 y
Ehrlich et al[31]	D&B = 7; level 4 case report, non-RCT	26-y-old man; C3-C4

D&B, Downs and Black; RCT, randomized controlled trial; IMT, inspiratory muscle training; VC, vital capacity; MIP, maximal inspiratory pressure; SCI, spinal cord injury; PEDro, Physiotherapy Evidence Database; FVC, forced vital capacity; SIP, maximal sustainable mouth pressure; V_t, tidal volume; IVC, inspiratory vital capacity; FEV_1, forced expiratory volume in 1 second; EMG, electromyography; and MEP, maximal expiratory pressure.

searched, and relevant articles were retrieved. Articles were scored for their methodological quality using either the Physiotherapy Evidence Database (PEDro) score (15) for randomized controlled trials (RCTs) or the Downs and Black tool (16) for nonrandomized studies. A thorough report of these tools and their psychometric properties is reported elsewhere (17). In brief, PEDro scores range from 0 to 10 and Downs and Black scores range from 0 to 28; higher scores for each tool indicate higher methodological quality. Scoring was executed by 2 independent reviewers, and discrepancies were resolved through discussion or a third independent reviewer. Tables were generated from the extracted data that included sample subject characteristics, nature of the intervention, outcome measures, and key results. Subsequent to individual study assessment, conclusions were drawn about the accumulated studies based on a modified version of Sackett's levels of evidence (Table 2) (18). RCTs received priority when formulating conclusions. If studies addressing the same treatment differed in quality, more weighting was applied to the studies with higher quality scores when deriving the final conclusions.

RESULTS

Exercise Training

Those studies concerned with exercise training principally included subjects with paraplegia. Five studies assessing the respiratory effects of exercise training in individuals with SCI were identified for review (N = 65) (19–23). Study characteristics and results are listed in Table 3. All studies employed a case series design with the exception of 1 cohort trial (19). As a group, these studies were

Table 4. Extended.

Treatment	Results
Target resistive IMT 15–20 min 2 x/d x 6 wk; other rehab activities continued	(a) Pre-post % change of VC and total lung capacity (L and % predicted) in IMT group was greater compared with change in control values. (b) MIP improved in both groups, which might be due to natural progression of improvement from SCI, learning to do the maneuver, and/or insufficient length of training.
Resistive IMT without target (N = 6) and breathing (N = 5) with abdominal weights; 5 x/wk x 7 wk	(a) Significant improvements in both groups in FVC, maximal voluntary ventilation, peak expiratory flow rate, and MIP ($P < 0.001$–0.05) after 7 wk of treatment. (b) No significant differences between treatment groups for any of the improvements in pulmonary variables; however, mean changes between wk 1 and 7 tended to be larger for the IMT group.
Resistive IMT without target (85% SIP), 15 min 2 x/d, 5 x/wk x 8 wk	(a) Increased MIP and SIP in both the control group (30% ± 19% and 31% ± 18%, respectively) and the IMT group (42% ± 24% and 78% ± 49%, respectively) but no difference in post-training improvements between groups. (b) The increased MIP and SIP resulted in a slower and deeper breathing pattern and a significantly shorter inspiratory time:total time of respiratory cycle in both trainers and control subjects.
"Sham" training followed by target flow IMT. Both protocols employed same training time of 15 min 2 x/d x 6 wk	(a) Significant increase in peak power, V_t, and oxygen consumption during maximal exercise test at 6–12 wk of IMT ($P < 0.05$). (b) TL_{max}, a measure of inspiratory muscle endurance, increased after both sham training and IMT ($P < 0.05$ and $P = 0.01$, respectively). (c) No significant improvement in MIP, IVC, or FEV_1 for either group or differences in post-training change between groups.
Resistive IMT without target 30 min/d x 6 x/wk x 16 wk	During training, progressive and significant increases in MIP and the critical mouth pressure resulted in EMG signs of diaphragm fatigue.
Resistive IMT without target 15 min 2 x/d x 6 wk	(a) Four mo after IMT began, MIP improved from 45 ± 4.1 mmHg to 59 ± 6.8 mmHg, but no statistical tests were performed on the data. (b) Two case reports showed improvement in MIP and decreased dyspnea.
Resistive IMT without target 15 min 2 x/d x 8 wk	(a) Significant increase in MIP, MEP, and lung volumes after IMT. (b) At 6 mo (4 mo after training stopped), trends towards baseline and repeat measures in 7 of 8 subjects showed no difference between baseline and 6-mo outcomes. (c) Compliance ranged from 48% to 100% of IMT sessions.
Threshold IMT and positive expiratory pressure value (Peripep) for 1 y	(a) Number of respiratory infections decreased from 3 to 2. (b) Number of respiratory infections requiring acute care hospitalization decreased from 2 to 0. (c) MIP increased from 10 to 42 cmH_2O. (d) Daily suctioning 10 x/d decreased to intermittent suctioning not required daily.

difficult to interpret because of relatively small sample sizes; differences in the type of exercise modality evaluated (wheelchair vs arm-crank exercise); and inconsistencies in the frequency, intensity, and duration of exercise training used. Despite these limitations, evidence from 2 studies supported the efficacy of exercise training for improved respiratory function (13,19), and trends for its therapeutic potential were suggested by another 2 studies (20,22). Only 1 study failed to demonstrate an effect after exercise training; this study, however, was ranked last according to its Downs and Black methodological score (23). Based on these findings, there is level 2 evidence to support that exercise training improves expiratory capacity and ventilatory muscle endurance (19) and level 4 evidence to support that exercise training is associated with improved lung volumes and FEVs (13). There is some evidence from level 4 studies that V_E (20,22), as well as V_t and ventilatory reserve, may be improved after exercise training (22). There were no reports of negative consequences of exercise training.

Inspiratory Muscle Training

Our search captured 8 studies assessing the respiratory effects of IMT in individuals with SCI (N = 78) (24–31). As with studies assessing exercise training, most studies were not comparable on account of diverse research designs, heterogeneity of subject characteristics, or differences in training techniques (Table 4). Those studies concerned with inspiratory muscle included subjects with both paraplegia and tetraplegia.

Only 3 studies utilized an RCT design (24–26), 2 of which showed improved measures of inspiratory muscle and lung function in both control (or sham) and training groups (25,26). In contrast, Liaw et al (24) showed significant improvement in total lung capacity. Of the nonrandomized studies, 1 cohort study showed improvements in endurance measures with no change in lung volumes or measures of respiratory capacity (27). One case series (28) and 1 pre-post study (30) demonstrated significant improvements in respiratory muscle strength, findings that were consistent with the positive, nonsignificant trends of 2 other studies (29,31). Of note, follow-up data from Rutchik et al (30) showed respiratory benefits to be lost after the cessation of IMT. Based on these findings, there is only level 4 evidence to support IMT as a means to improve inspiratory muscle function and decrease dyspnea in individuals with SCI.

DISCUSSION

Based on the current literature, there is insufficient evidence to strongly support either exercise training or IMT as a means to improve pulmonary function or ventilatory responses in individuals with SCI. There is some evidence for efficacy of both regimens; however, the evidence is not of the best possible quality.

Exercise training has been evaluated in a limited number of studies that assessed various training protocols. Although the data from these studies suggest the potential of exercise training to improve exercise ventilation and ventilatory efficiency, well-designed RCTs are needed to determine the true impact of exercise training on pulmonary function. Combined with the well-known able-bodied response to upper-limb training, exercise training may offer a strong clinical tool for the management of people with SCI and at least should be encouraged for the maintenance of general cardiorespiratory health in this population.

In contrast to exercise training, IMT has been evaluated by 3 randomized studies. Although the results of these studies failed to support the efficacy of IMT, poor study design may have impeded the demonstration of the true therapeutic potential of IMT. For example, comparable improvements of respiratory function in control and treatment groups may reflect learning of testing maneuvers, benefit from other rehabilitation or lifestyle activities, and/or natural progression of improvement after SCI. All randomized studies used an inspiratory resistive device with no target to control for decreasing resistance with slower flows. As such, the training methods may have induced an alteration in breathing pattern towards slower inspiratory flows rather than a training response against higher inspiratory pressures.

Our assessment of RCTs of IMT confirms the findings of 2 previous systematic reviews of RCTs assessing the efficacy of IMT (32) and respiratory muscle training (33) for individuals with SCI. Although RCTs are the “gold standard” for assessing treatment efficacy, we believe more comprehensive data can be gleaned from the systematic assessment of both randomized and nonrandomized studies. Thus, the strength of our review is the inclusion and assessment of nonrandomized studies of IMT and exclusion of confounding respiratory interventions (eg, expiratory muscle training, pectoralis muscle training) (33).

Nonrandomized studies evaluating IMT demonstrated significant positive findings associated with its utilization in persons with SCI. Although the methodological design of these studies suggests caution when interpreting their results, their positive findings, coupled with the demonstrated efficacy threshold IMT has shown for improving inspiratory muscle strength and endurance in people with COPD, clearly demonstrate the need for a larger and more robust RCT in a SCI population. In addition to random allocation to either a control or a treatment group, such a study should also employ (a) a research design that controls for the influence of learning or recovery from SCI on IMT outcome measures of inspiratory muscle strength and endurance and dyspnea; (b) optimal training techniques of threshold loading, targeted resistive devices, or isocapnic hyperpnea; (c) outcomes of inspiratory muscle strength and endurance, dyspnea, quality of life, and daily function; and (d) a comparison of the relative effectiveness of IMT relative to or as an adjunct to other rehabilitation interventions.

Ideal training regimes for both exercise training and IMT have not been identified. Based on the protocols employed by Silva et al (19) and Sutbeyaz et al (21), improved respiratory function requires a high training intensity performed for 30 minutes 3 times per week for 6 weeks. Parameters to optimize IMT are only available for people with other respiratory conditions, namely COPD. For this population, the optimal IMT protocol should utilize threshold or targeted resistive trainers at an intensity of 30% to 70% of maximal inspiratory pressure, for a duration up to 30 minutes per session, performed continuously or in intervals, 4 to 6 days/week and be continued indefinitely (34). Progression of intensity (maximal inspiratory pressure) should not exceed 5% per week. Until more rigorous research is performed to further delineate the most effective exercise training and IMT protocols, prescription of these training modalities should be approached cautiously. Of equal importance, overly aggressive prescription of IMT has the potential to fatigue and injure the inspiratory muscles, which can increase the person’s predisposition to respiratory compromise. Parameters to monitor during IMT in order to avoid untoward responses, such as muscle fatigue and hypercapnia, have been described elsewhere (35).

Finally, additional large-scale, cross-sectional and longitudinal studies are required to fully characterize pulmonary function in SCI. Secondary respiratory complications related to other respiratory pathologies (eg, COPD, asthma) are not well described. In particular, the consequences of aging on pulmonary function are not well defined in SCI. With healthy aging, there is a decline in lung function, primarily because of a loss of elastic recoil. Moreover, additional age-related changes that are known to negatively affect gas exchange are decreased surface area of the lung, decreased pulmonary capillary blood volume, increased dead space ventilation, and decreased distensibility of the pulmonary arterial vasculature. A greater understanding of the interactions among SCI, aging, and the respiratory system is necessary for comprehensive patient management.

It is important to note that most exercise studies included only individuals with paraplegia who have lower-level lesions and minimal deficits in pulmonary function, whereas the respiratory muscle training studies enrolled only persons with cervical injury (Tables 3 and 4). This is an essential consideration from the theoretical and practical viewpoints because cervical injuries cause profound reductions in inspiratory muscle function and are associated with the greatest prevalence of breathlessness and highest risk of death due to respiratory complications. It is in this group that improvements in pulmonary function may have the greatest clinical benefit. Conversely, those with lower-level paraplegia typically have FEVs that are within the "normal" range such that improvements may be (a) difficult to achieve and (b) of limited clinical significance.

CONCLUSIONS

Consistent improvement in respiratory function after respiratory muscle training has not been demonstrated in people with SCI. There is level 2 evidence supporting exercise training as an intervention to improve respiratory strength and endurance and level 4 evidence to support exercise training as an intervention that might improve resting and exercising respiratory function in people with SCI. There is level 4 evidence to support IMT as an intervention that might decrease dyspnea and improve respiratory function in some people with SCI. We conclude that there are insufficient data to strongly support the use of exercise training or IMT for improved respiratory function in people with SCI. There is some evidence of efficacy of both regimens; however, the evidence is not of the best possible quality.

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