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REVIEW ARTICLE

# Physiotherapy Secretion Removal Techniques in People With Spinal Cord Injury: A Systematic Review

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**Abstract**

**Objective:** To address whether secretion removal techniques increase airway clearance in people with chronic spinal cord injury (SCI).

**Data Sources and Study Selection:** MEDLINE/PubMed, CINAHL, EMBASE, and PsycINFO were searched from inception to May 2009 for population keywords (spinal cord injury, paraplegia, tetraplegia, quadriplegia) paired with secretion removal–related interventions and outcomes. Inclusion criteria for articles were a research study, irrespective of design, that examined secretion removal in people with chronic SCI published in English.

**Review Methods:** Two reviewers determined whether articles met the inclusion criteria, abstracted information, and performed a quality assessment using PEDro or Downs and Black criteria. Studies were then given a level of evidence based on a modified Sackett scale.

**Results:** Of 2,416 abstracts and titles retrieved, 24 met the inclusion criteria. Subjects were young (mean, 31 years) and 84% were male. Most evidence was level 4 or 5 and only 2 studies were randomized controlled trials. Three reports described outcomes for secretion removal techniques in addition to cough, whereas most articles examined the immediate effects of various components of cough. Studies examining insufflation combined with manual assisted cough provided the most consistent, high-level evidence. Compelling recent evidence supports the use of respiratory muscle training or electrical stimulation of the expiratory muscles to facilitate airway clearance in people with SCI.

**Conclusion:** Evidence supporting the use of secretion removal techniques in SCI, while positive, is limited and mostly of low level. Treatments that increase respiratory muscle force show promise as effective airway clearance techniques.

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**Key Words:** Spinal cord injuries; Paraplegia; Tetraplegia; Respiratory complications; Ventilation; Physiotherapy; Airway clearance; Assisted breathing devices; Paripep; Flutter; Threshold

## INTRODUCTION

Respiratory complications are a leading cause of morbidity and mortality in people with spinal cord injury (SCI) and are more pronounced in individuals with higher level and complete injuries (1–5). A major contributor to respiratory illness in individuals with SCI is secretion retention, particularly among individuals with cervical lesions (1–5). Higher levels of SCI result in greater denervation of the ventilatory muscles thereby decreasing both inspiratory capacity and expiratory muscle force and resulting in an impaired cough (5). Figure 1 shows the innervation of the respiratory muscles (2). Cervical SCI also denervates sympathetic pathways leading to a state of parasympathetic dominance that may increase mucus production (6) and contribute to airway hyperresponsiveness (7). A diminishing cough combined with mucus hypersecretion can overwhelm mucociliary clearance in people with SCI.

The impact of SCI on normal airway clearance can be exemplified by examining the sequence of a cough. After

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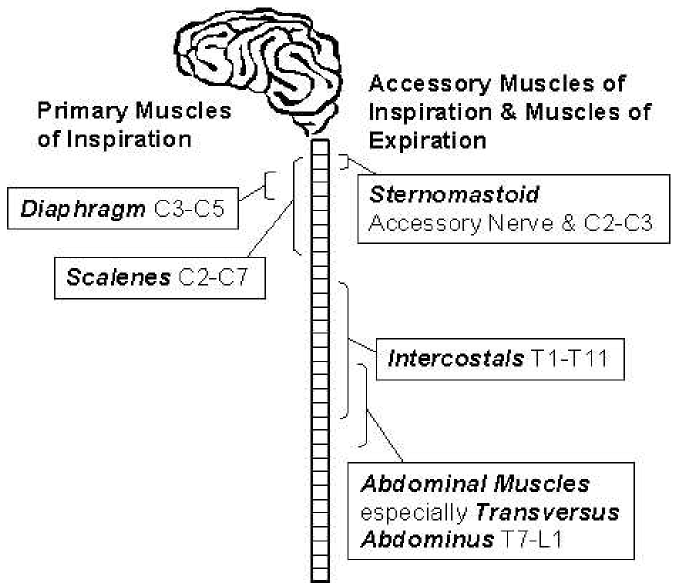


**Figure 1.** *Innervation of respiratory muscles. Reprinted with permission from ICORD Press (2).*

full inspiration to total lung capacity, the glottis is closed followed by an increasing intrathoracic pressure. Opening of the glottis is followed by a forced, high-velocity expiratory flow, which facilitates propagation of sputum towards the upper airway to expectorate or swallow. The ability to inspire to a normal vital capacity (VC) is progressively hindered with higher levels of SCI due to a greater denervation of inspiratory muscles. Inspiring to a lower VC therefore decreases the inward recoil of the chest wall and lungs that contributes to maximal expiratory flow. Forced expiratory flow is further impaired in people with SCI when the injury affects the abdominals (T7-L1) and other expiratory muscles, such as intercostals (thoracic roots), pectoralis (C5-T1), or latissimus dorsi (C6-C8). With high thoracic SCI (T2-T4) the VC might only be 30% to 50% of normal, and the cough might be weak and possibly ineffective (8). Spirometric measures, such as forced vital capacity (FVC), forced expiratory volume in 1 second, and VC, are therefore often valuable predictors of cough strength (9,10).

Non-SCI factors such as smoking, chronic obstructive pulmonary disease, asthma, and aging exacerbate increased mucus secretions resulting from cervical SCI (2,11). Increasing mucus production combined with a diminishing cough and breathing at a lower lung volume, contributes to microatelectasis and potential trapping of retained secretions (12). Ultimately, an ineffective cough, microatelectasis, and retained secretions increase the risk for both pneumonia and mucus plugs, which may lead to potential lung collapse and consolidation (12).

Physiotherapy treatment to facilitate airway clearance (5,13) in people with SCI has included traditional chest physiotherapy techniques of manual percussions and vibrations as well as postural drainage (5). In addition, techniques to enhance forced expiration, including cough, have been used, such as those that improve inspiratory capacity and strength or increase expiratory flow and strength (1,9,12,14–23). Despite these physiotherapy techniques being commonly used there is a scarcity of published evidence to support their effectiveness in SCI. This systematic review was done to answer the question, "Do secretion removal techniques increase airway clearance in people with chronic SCI?" We focused on interventional and survey studies within the scope of physiotherapy practice, therefore excluding pharmaceutical interventions. With the exception of case series or case reports, no studies using a more rigorous design, such as ones that examined percussions, postural drainage, or positive expiratory pressure valves (eg, Flutter) (24), were retrieved from our systematic review. Thus, we extended our search to include studies that examined various outcomes that would contribute to an effective cough as outlined in Table 1. We also limited our systematic review to the chronic phase of SCI among adults with tetraplegia or high paraplegia recognizing that respiratory complications associated with the acute phase of SCI are often managed using more invasive interventions in an acute care hospital setting (25–27). In addition, sequelae associated with this acute phase, such as neurogenic pulmonary edema, unstable fractures, or aspiration pneumonia (25–27), would complicate the interpretation of outcomes as the result of airway clearance interventions such as percussion or assisted cough.

## METHODS

### Search Strategy

The databases MEDLINE/PubMed, CINAHL, EMBASE, and PsycINFO were searched for relevant literature from the databases' inceptions through to May 2009. The grey literature was also searched using Google Scholar. Population keywords (spinal cord injury, paraplegia, tetraplegia, quadriplegia) were paired with known terms related to secretion removal interventions and outcomes (see Table 1 for details). References of pertinent articles were also searched and relevant studies were retrieved.

### Study Criteria

Studies needed to meet several inclusion criteria, including (a) assessing a physical therapy secretion removal technique as a means of increasing airway clearance; (b) comprising a predominately (≥50%) SCI sample; and (c) examining techniques among individuals with chronic tetraplegia or high paraplegia, which was defined as individuals who were extubated or on chronic modes of mechanical ventilation. Studies not reporting respiratory outcomes related to secretion removal (see Table 1 for search terms related to outcomes) were excluded, as were articles with a sole focus on pharma-

**Table 1.** Search Terms Used to Identify Articles About Physiotherapy Interventions and Secretion Removal Outcomes

| Intervention | Search Terms |
|---|---|
| Secretion removal techniques | Active cycle breathing, autogenic drainage, cough, forced expiratory technique, huff, percussion, postural drainage, suctioning, vibration |
| Positive expiratory pressure devices used for secretion removal | Acapello, Flutter, Therapep |
| Other | Exercise training |
| Breathing exercises to increase inspiratory muscle force or inspiratory capacity | Breath stacking, frog breathing, glossopharyngeal breathing, inspiratory muscle training, insufflation, lung volume recruitment, manual inspiration, manual ventilation, maximal breath, neck breathing, positioning, resisted breathing program |
| Assisted breathing devices to increase inspiratory capacity | AmbuBag, assisted ventilation, binders, BiPap, Bird, diaphragmatic pacing, functional electrical stimulation, intermittent positive pressure ventilation, phrenic nerve pacing |
| Assisted coughing | Assisted cough, cough assist machine, exsufflation |
| Search Terms Related to Outcomes | |
| Airway clearance, chest x-ray, auscultation, cough, incidence of hospitalizations, independent breathing time, inspiratory capacity, inspiratory flow, lung volume, maximal expiratory pressure, maximal inspiratory pressure, mucociliary clearance, oxygen saturation, peak expiratory flow, pneumonia, pulmonary function, respiratory distress, respiratory function, respiratory infections, respiratory rate, secretion removal, shortness of breath, sputum, sputum redistribution, tidal volume, ventilation, vital capacity, work of breathing | |

ceutical interventions. Only studies published in English were reviewed. See Appendix 1 for excluded articles. Titles and abstracts were scanned independently by 2 reviewers (D.R. and J.B.) to identify intervention and survey studies for possible inclusion in the review. Discordant selections were settled by consensus between the 2 reviewers in the presence of a third reviewer (K.K.) who offered an opinion when consensus could not be reached.

## Evaluation of Methodologic Quality

The methodologic quality of articles was assessed using either the PEDro scale (28,29) for randomized controlled trials or the Downs and Black tool for all other study designs (30,31). PEDro scores range from 0 to 10 and Downs and Black scores range from 0 to 27. Higher scores on both scales indicate greater methodologic quality. Scoring was executed by 3 independent reviewers (K.K., J.R., B.S.) and discrepancies were resolved through discussion or a fourth independent reviewer. Studies were also assigned levels of evidence as per a modified Sackett scale (Table 2) (32).

## Data Abstraction

Data were abstracted from selected articles by 4 reviewers (J.B., D.R., J.R., and B.S.). Tables were generated from the extracted data and included subject characteristics, nature of the intervention, outcome

**Table 2.** Five Levels of Evidence[a]

| Level | Research Design Description |
|---|---|
| 1 | Well-performed randomized controlled trial (RCT): includes within-subjects comparison with randomized conditions and crossover designs |
| 2 | Prospective controlled trial: (not randomized) or cohort using at least 2 similar groups with one 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 posttest using a single group of subjects<br>Post-test: a prospective posttest with two or more groups—intervention<br>Case series: a retrospective study usually collecting variables from a chart review |
| 5 | Observational: a study using cross-sectional analysis to interpret relations<br>Clinical consensus: an expert opinion without explicit critical appraisal or based on physiology, biomechanics, or "first principles"<br>Case report: a pre-post or case series involving 1 subject |

[a] Adapted from *Spinal Cord Injury Research Evidence* (31).

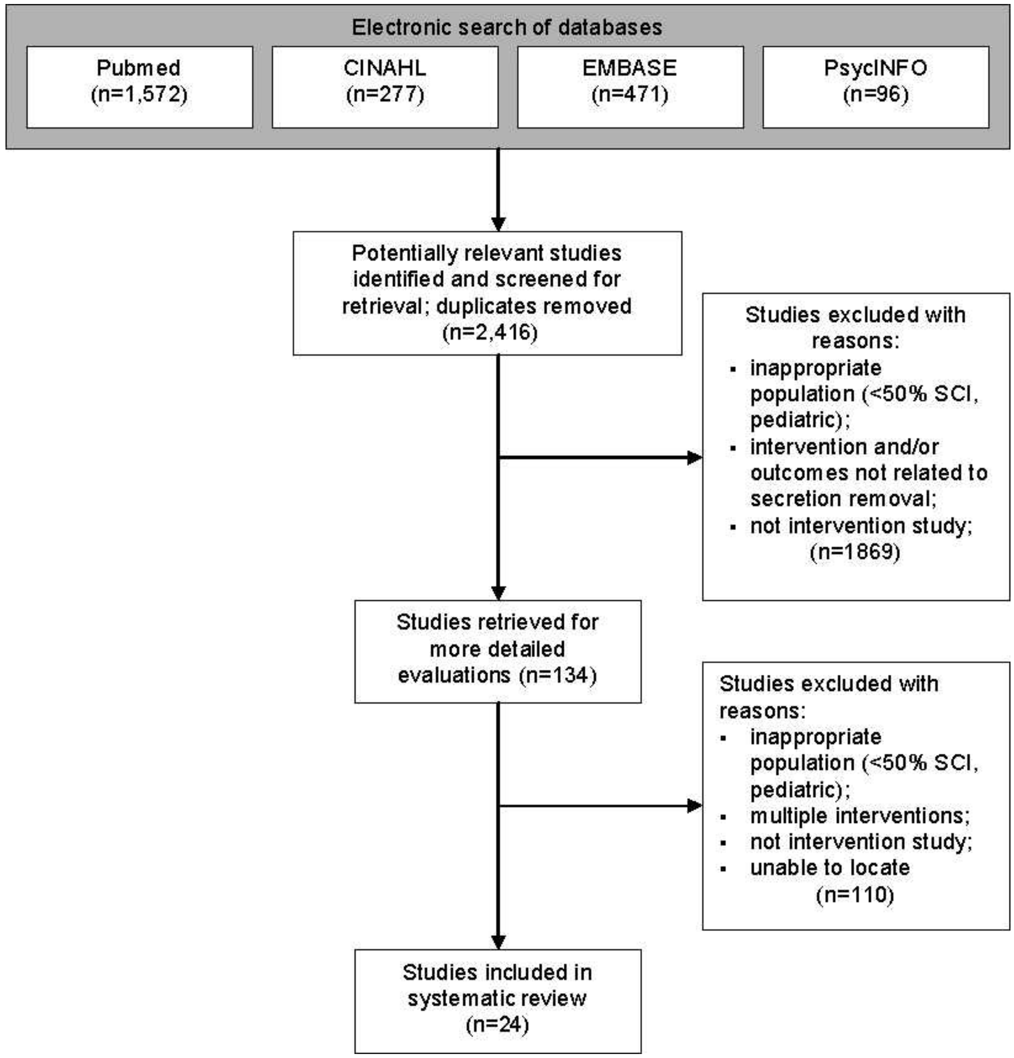


**Figure 2.** *Flowchart illustrating different phases of the search.*

measures, key results, and respective methodologic scores.

### Data Synthesis

Due to the diverse range of interventions captured and the myriad of outcomes with which they were assessed, a quantitative merging of the data was not feasible. Therefore, this review is limited to a systematic assessment of the captured studies' findings.

## RESULTS

The search strategy, as outlined in Table 1 and Figure 2, yielded 2,416 articles. After review of titles and abstracts, 133 were of potential interest. After review of the full-length articles, 24 were found to meet the inclusion criteria and 109 articles were excluded because no intervention was examined, the intervention was not focused toward secretion removal, the article was descriptive and did not utilize a clearly described research design, people with SCI were not included, and/or the person with SCI was in the acute rather than the chronic phase (see Appendix 1 for the list of excluded articles). Of the 24 studies, 2 were randomized controlled trials, 3 were prospective controlled design, 9 had pre-post designs, 3 were retrospective case series, and 7 were case reports.

The participants in each of the studies ranged in number from 1 to 40 and in age from 15 to 70 years, with a mean age of 30.9 years. Gender, as reported in 22 studies, was shown to be 84% male. Most studies reported on people who had sustained cervical level SCI, only 2 studies (12,23) described individuals with thoracic level SCI, and none included people with paraplegia. Most of the studies examined the immediate effect of the interventions; however, some of the reports described long-term outcomes and benefits.

### Secretion Removal Techniques

Our systematic search strategy did not reveal any experimental studies in people after SCI that examined facilitation of secretion removal by manual techniques including postural drainage, manual or mechanical

**Table 3.** Secretion Removal Techniques

| Author and Year | Country | Downs and Black Score | Research Design | Total Sample Size | Methods: Population | Methods: Treatment | Methods: Outcome Measures | Outcome |
|---|---|---|---|---|---|---|---|---|
| Ehrlich et al, 1999[16] | Canada | 7 | Case report | N = 1, level 5 | Male, age 27 y with C3-C4 tetraplegia, 4 YPI | Threshold IMT and positive expiratory pressure valve (Paripep) for 1 year | Respiratory infections, hospitalizations, MIP, MEP, frequency of suctioning | 1 Number of respiratory infections decreased from 3 to 2. 2. Number of respiratory infections requiring acute care hospitalization decreased from 2 to 0. 3. MIP ↑ from −10 to −42 $cmH_2O$, MEP ↑ from 30 to greater than 60 $cmH_2O$. 4. Daily suctioning ↓ from 5 times daily to intermittent suctioning not required daily. |
| Dee & Suratt, 1964[1] | USA | 3 | Case series | N = 2, level 4 | 2 men, age 28 and 23 y, with C5 tetraplegia, 1 mo and 1 YPI | Tracheal suctioning, chest physiotherapy | Ventilation scintiscan | Patients experienced sudden loss of consciousness and hypoxemia. Ventilation scintiscans suggested mucus plugging as cause. Patient 1 relieved with tracheal suctioning and chest physiotherapy and patient 2 by bronchoscopic suctioning. |
| Slonimski & Aguilera, 2001[12] | USA | 4 | Case report | N = 1, level 5 | Male, age 60 y, with T7 ASIA A (see Table 2 for definition) SCI, 17 YPI | Chest physiotherapy, pharmacologic intervention | Chest x-rays, oxygen saturation | Severe atelectasis secondary to mucus plugging resolved with chest physiotherapy techniques (suctioning, assisted cough) and pharmacologic intervention (acetylcysteine, bronchodilators). |

IMT, inspiratory muscle training; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; SCI, spinal cord injury; and YPI, year post injury.

vibrations, or any that investigated the use of positive expiratory flow devices that increase airway clearance such as Flutter, Therapep, Acapello, or Paripep. Two case reports and 1 case series, however, described positive outcomes from "chest physiotherapy" (1,12) and an expiratory flow device (16) (Table 3). Two of the studies highlight the significance of how mucus plugging, a life-threatening consequence in people after cervical SCI, can be successfully managed with vigorous chest physiotherapy (1,12). In spite of these 2 reports, evidence of the positive benefit of this intervention is lacking due to (a) the limited number of subjects (only 1 or 2 persons in each report) and (b) a vague description of the chest physiotherapy techniques that were applied to each of these patients. Although 1

**Table 4.** Breathing Exercises

| Author and Year | Country | Downs and Black Score | Research Design | Total Sample Size | Methods | | | Outcome |
|---|---|---|---|---|---|---|---|---|
| | | | | | Population | Treatment | Outcome Measures | |
| Montero et al, 1967[14] | USA | 11 | Pre-post | N = 14, level 4 | 14 complete cervical cord transections between C5 and C7, ages 15–7 y, 6 mo to 3 YPI | GPB training 30–60 minutes 3 times a week for 1–6 weeks (until subject learned technique) | Pulmonary function tests, no statistical analysis | 1. With GPB, VC measured 95% of predicted normal, sufficient to allow for a productive cough, to clear throat and to raise voice.<br>2. After training, breath-holding time ↑ from 30% to 93% of predicted normal value, max breathing capacity ↑ from 33% to 49%, VC ↑ from 35% to 65%, and max $V_{exp}$ ↑ from 39% to 92%. |
| Warren, 2002[15] | USA | 8 | Case report | N = 1, level 5 | Male, age 19 y, with C2 complete tetraplegia | 5 weeks GPB and 4 weeks NAMB | Time off ventilator, VC with GPB | 1. After GPB training 3–4 times/week, patient achieved 30 minutes off ventilator with VC of 2,650 mL. Cough became weak functional from nonfunctional allowing him to clear throat and small amount of secretions.<br>2. After 4 weeks, patient discontinued NAMB due to frustration with lack of progress<br>3. Upon 4-year follow-up, patient using GPB 1 h/day for transfers, dressing, and bathing. |
| Clough, 1983[17] | USA | 8 | Case report | N = 1, level 5 | Male, age 16 y, with C5 complete tetraplegia, 5 YPI | GPB training program (14 half hour treatments over 6-week period) | FVC | 1. Subjective feeling of stretching sensation in chest wall with GPB.<br>2. Cough appeared to be deeper and stronger.<br>3. Increase in FVC of 1.6 L (70% improvement from baseline) with GPB. |
| Metcalf, 1966[18] | USA | 11 | Case series | N = 23, level 4 | 23 (17 males, 6 females) with complete tetraplegia between C4 and C7, mean age 26 y, range 14–49 | GPB | VC in supine position | 1. Mean GBP VC was 81% of the predicted normal VC.<br>2. Without GBP, mean VC for this group was 59% of normal. |

report described this type of treatment more fully at the end of the article, this is still insufficient evidence to adequately endorse the techniques.

The article by Ehrlich et al (16) reported that the use of Paripep and inspiratory muscle training for 1 year decreased respiratory infections, decreased hospitalizations due to infection, and decreased suctioning. Although inspiratory muscle force increased 4-fold from 10 to 42 $cmH_2O$, the 2 interventions were used in conjunction with one another for all but 3 weeks of the

**Table 4.** Continued

| Author and Year | Country | Downs and Black Score | Research Design | Total Sample Size | Methods: Population | Methods: Treatment | Methods: Outcome Measures | Outcome |
|---|---|---|---|---|---|---|---|---|
| Nygren-Bonnier et al, 2009[33] | Sweden | 14 | Pre-post | N = 25, level 4 | 25 (20 males, 5 females) with complete cervical cord transections between C4 and C8, mean age 47 y, range 21–70, at least 1 YPI | 10 cycles of GPB 4 times a week, for 8 weeks | VC, ERV, FRC, RV, TLC, MEP, MIP, chest expansion | 1. VC, ERV, FRC, RV, and TLC all increased significantly after the training period.<br>2. Increase in peak cough flow was dependent on the glossopharyngeal inspiratory volume.<br>3. Neither MIP nor MEP changed significantly.<br>4. Chest expansion increased significantly after training. |

ERV, expiratory reserve volume; FRC, functional residual capacity; FVC, forced vital capacity; GPB, glossopharyngeal breathing; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; NAMB, neck accessory muscle breathing; RV, residual volume; TLC, total lung capacity; $V_{exp}$, expiratory flow; VC, vital capacity; and YPI, years post injury.

1-year intervention; thus, it is difficult to separate any benefit derived from the use of Paripep from that derived from inspiratory muscle training.

In summary, level 4 and 5 evidence, based on 2 case reports (12,16) and 1 case series (1), supports the effectiveness of secretion removal techniques.

## Interventions Affecting Cough

The search strategy for our systematic review retrieved several studies that focused on components of cough. These were classified according to the sequential events that contribute to an effective cough including breathing exercises, assistive breathing, and respiratory muscle training (RMT) that improve the VC. The impact of electrical muscle stimulation on inspiratory and expiratory muscle force was examined, as was the effectiveness of assistive devices that facilitate inspiratory capacity, expiratory flow, or cough.

*Breathing Exercises*. See Table 4. Five articles reported the benefits of different types of breathing exercises such as glossopharyngeal breathing (GPB) or neck accessory muscle breathing in subjects with cervical injuries (level of C2 or higher) (14,15,17,18,33). Length of training ranged from 1 to 8 weeks. The 2 pre-post studies and 2 case reports showed improvements in VC of 7.5% (33), 86% (18), 70% (17), and 35-fold (15). This latter result came from a single case study in which the subject improved from an FVC of 75 to 2,650 mL over the course of 5 weeks of GPB training. Further, 2 of the studies stated that the mean GPB VC was 16% (18) and 28% (33) higher than the VC without GPB. Attributes of cough improved as reflected by an increased strength of cough (17), increased expiratory flow (14,33), and changes from a nonfunctional to a functional cough (15).

Thus, there is level 4 (based on 2 pre-post studies [14,33] and 1 case series [18]) and level 5 evidence (from 2 case reports [15,17]) supporting the effectiveness of GPB to improve cough, a secretion removal technique.

*Assisted Breathing by Use of Abdominal Binders or Strapping*. See Table 5. Three studies that used either a pre-post or prospective controlled design described the benefits of abdominal binders or strapping on VC or expiratory muscle force in people after cervical SCI (n ranged between 7 and 10) (19–21). In spite of different binder techniques, all studies reported improvements in inspiratory pressures (20,21), VC (20,21), maximal expiratory flow rate (21), or maximal expiratory pressures (19).

Two studies incorporated postural changes with and without binder use. In both, FVC was greater in the supine position than in sitting (19,20) and FVC (19,20) and maximal expiratory pressure (19) were greater in the seated position when the binder was used. The binders also increased VC and transdiaphragmatic pressure on maximal sniff in the 70-degree tilt position (20). Both studies conclude that binders assist breathing of individuals with tetraplegia when used in upright postures.

In the study by Estenne et al (21), abdominal strapping resulted in a significant increase in VC and decreases in both functional residual capacity and residual volume. Small, inconsistent increases in maximal esophageal pressure and expiratory flow rates were also observed, but the authors question whether these changes would translate to an improved cough.

Thus, there is level 2 evidence (from 1 prospective controlled trial [20]) and level 4 evidence (based on 2 pre-post studies [19,21]) supporting the effectiveness of abdominal binders for assisted breathing.

**Table 5.** Assisted Breathing—Abdominal Binders and Posture

| Author and Year | Country | Downs and Black Score | Research Design | Total Sample Size | Methods: Population | Methods: Treatment | Methods: Outcome Measures | Outcome |
|---|---|---|---|---|---|---|---|---|
| Boaventura et al, 2003[19] | Brazil | 10 | Pre-post | N = 10, level 4 | 10 (9 males and 1 female) with complete cervical lesion between C4 and C7, ages 16–49 y, >1 YPI | Abdominal binder vs no binder used in seated vs supine postures | MIP, MEP, FVC | 1. FVC higher in supine vs sitting position with and without binder<br>2. No difference in MIP or MEP between supine and sitting position<br>3. No effect of binder on MIP, MEP, or FVC in supine position<br>4. MEP and FVC in the sitting position significantly higher ($P < 0.05$) with use of abdominal binder |
| Goldman et al, 1986[20] | UK | 9 | Prospective controlled trial | N = 7, level 2 | 7 men with complete tetraplegia between C5 and C7, mean age 33 y, range 24–44, >3 mo PI | Conventional elastic abdominal binder vs newly designed thermoplastic abdominal binder vs no binder, each used in positions: supine vs sitting vs 70-degree tilt on tilt table | Sniff $P_{di}$, $P_{Imax}$, VC | 1. Sniff $P_{di}$ and VC decreased in sitting and 70-degree tilt compared with supine position<br>2. Both binders improved VC in the seated position and at the 70-degree tilt, and sniff $P_{di}$ at 70- degree tilt. The thermoplastic binder was as effective but no better than the conventional binder<br>3. Abdominal binders assist breathing in tetraplegic patients in seated or raised to near vertical positions |
| Estenne et al, 1998[21] | USA | 10 | Pre-post | N = 8, level 4 | 8 men with SCI between C5 and C8, mean age 34 y, range 21–52, >0.5 YPI | Abdominal strapping | $P_{es}$, $V_{exp}$, VC, FRC, TLC, RV | Strapping the abdomen in SCI resulted in:<br>1. Significant ↑ in VC<br>2. Significant ↓ in FRC and RV Small, inconsistent ↑ in maximal $P_{es}$ and $V_{exp}$ unlikely to produce clinically relevant improvement in cough |

FRC, functional residual capacity; FVC, forced vital capacity; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; $P_{es}$, esophageal pressure; $P_{Imax}$, maximum static inspiratory mouth pressure; PI, post injury; RV, residual volume; SCI, spinal cord injury; sniff $P_{di}$, transdiaphragmatic pressure during maximal sniff; TLC, total lung capacity; $V_{exp}$, expiratory flow; VC, vital capacity; and YPI, years post injury.

*Respiratory Muscle Training.* The benefit of inspiratory muscle training (IMT) in this population has been recently summarized in 4 systematic reviews (2,11, 34,35), the most recent one published in September 2008. In brief, because of differing research designs, heterogeneity of subjects, and differences in training protocols, none of the studies performed to date could be combined for a meta-analysis. Further, none of the studies performed thus far appear to apply an effective IMT protocol with the exception of the case study that used a threshold training device (16) and a randomized control trial (RCT) on 14 participants that used normocapnic hyperpnea training (36). Both of these reports provide evidence that respiratory infections occur less frequently and inspiratory muscle strength and endurance improve after IMT (16,36). This recent, high-quality RCT (PEDro = 8) provides level 1 evidence that RMT improves respiratory muscle strength and decreases the number of respiratory infections (36), both of which infer improved airway clearance. Specific measures of airway clearance, however, were not measured.

*Electrical Stimulation.* See Table 6. Two case reports and 2 pre-post test design studies described the effect of electrical stimulation of the lower thoracic-lumbar spinal cord (T9, T11, and L1) (37,38) and the abdominal wall muscles on expiratory pressures and peak expiratory flow rates (39,40). Stimulation of the lower thoracic-lumbar spinal cord was performed up to 60 times daily for 2 to 3 months (37,38), whereas stimulation of the abdominal muscle wall was performed over 3 sessions (39) or daily for 4 weeks (40). The intensity of the stimulation was increased to obtain maximal expiratory flow rates but was constrained to a level that did not induce spasticity or co-contraction of the adjacent musculature. All protocols increased peak flow rates and cough peak flows in all studies (37–40). During combined T9 + L1 stimulation, airway pressures and expiratory flow rates increased to at least 132 $cmH_2O$ and 7.4 L/s, respectively (37,38), which are consistent with values from a healthy person. The mean maximal pressure generation was lower (137 $cmH_2O$); however, several subjects achieved values in the normal range (37) (normal maximal expiratory pressure is approximately 200 $cmH_2O$ in men and approximately 150 $cmH_2O$ in women) (41).

Thus, there is level 4 evidence based on 2 pre-post trials and level 5 evidence from 2 case reports that supports the use of electrical stimulation of the lower thoracic-lumbar spinal cord (T9, T11, and L1) (37,38) and the abdominal wall muscles (39,40) to improve expiratory flow rates during cough.

*Assisted Coughing.* See Table 7. The systematic search retrieved 3 reports that described outcomes related to assisted cough techniques including 2 controlled trials (9,22) and 1 pre-post design (23). Most patients had cervical lesions with the exception of the report by Braun et al (23), which included 2 individuals with thoracic SCI. All 3 reports showed that manual abdominal compression applied by 1 (22) or 2 persons (9,22,23) resulted in improved cough expiratory flows. The 2 articles that examined the combination of 2 or more methods found that positive oral pressure insufflation combined with abdominal compression resulted in the highest cough expiratory flow rates (9,22).

Thus, there is level 2 (based on 2 prospective controlled trials [9,22]) and level 4 (based on 1 pre-post trial [23]) evidence supporting the effectiveness of abdominal assisted coughing.

*Intermittent Positive Pressure Breathing.* Intermittent positive pressure breathing (IPPB) has been reported to improve cough; however, our search strategy did not reveal any articles that evaluated the impact of this technique on any aspect of secretion removal including VC, expiratory flow rates, or cough. Three studies, however, described the impact of IPPB on lung mechanics and aspects of ventilation (42–44), but no increases in VC were reported that could be attributed solely to the IPPB intervention. Another RCT that examined mechanical insufflation-exsufflation as a clearance technique was excluded because it provided insufficient description of the subjects to determine time from injury (45).

## Adverse Effects

The systematic search strategy revealed only a couple of reports that described adverse effects of physical therapy techniques aimed toward secretion removal. Both of these articles described adverse events in response to assisted cough maneuvers. Greenfield filters that are inserted into the inferior vena cava can be displaced distally and be deformed by quad coughs (46). Further, a case report described a perforation of the small bowel after a quad cough maneuver that required surgical repair (47). Although an assisted cough was not definitively determined to be the underlying trauma that caused the bowel perforation, this case report highlights the importance of applying the appropriate force during this maneuver to people after SCI.

## DISCUSSION

We found only 3 articles that addressed secretion removal directly (1,12,16). This was surprising given that respiratory complications are the leading cause of morbidity and mortality in people with chronic SCI. Most articles examined related interventions that improve different components of cough, including those that increase VC, maximum respiratory pressures, or flow rates. Dramatic reductions of suctioning frequency (16) and changes in a ventilation scintiscan and chest radiograph (1,12) provide evidence that chest physiotherapy (1,12) or the use of the expiratory flow device Paripep (Table 3) (16), can be effective; however, a major limitation of these studies was that the specific chest physiotherapy techniques (postural drainage, manual or mechanical vibrations, etc) were not described (1,12).

**Table 6.** Functional Electrical Stimulation

| Author and Year | Country | Downs and Black Score | Research Design | Total Sample Size | Methods: Population | Methods: Treatment | Methods: Outcome Measures | Outcome |
|---|---|---|---|---|---|---|---|---|
| DiMarco et al, 2009[37] | USA | 12 | Pre-post | N = 9, level 4 | 9 (8 men, 1 woman), with cervical SCI between C3 and C6, mean age 41 y, range 23–52, >1 YPI | Lower thoracic spinal cord stimulation at T9, T11, and L1 | Peak airflow and $P_{air}$ | 1. High peak airflow rates and large airway pressure during stimulation at each electrode lead 2. Maximum airflow rates and airway pressure achieved with combined stimulation of any 2 leads 3. At total lung capacity, mean maximum peak airflow rates and airway pressure generation were 8.6 ± 1.8 L/s and 137 ± 30 cm$H_2O$, values characteristic of normal subjects |
| Gollee et al, 2008[39] | UK | 12 | Pre-post | N = 4, level 4 | 4 (3 males, 1 female) with tetraplegia between C4 and C6, mean age 37 y, range 16–49, >3 mo PI | Surface FES of abdominal wall muscles | $V_T$, CPF, RR, $V_{minute}$, Et$CO_2$ | 1. Significant ↑ in $V_T$ during quiet breathing (range, 0.05–0.23 L) 2. Significant ↑ in CPF (range, 0.04–0.47 L/s) 3. RR during quiet breathing ↓ in all subjects when stimulated 4. $V_{minute}$ ↑ by 1.05–2.07 L/min 5. No significant changes in Et$CO_2$ |
| Lee et al, 2008[40] | AUS | 10 | Case report | N = 1, level 5 | Male, age 65 y, with C4 ASIA C tetraplegia, 8 mo PI | SES of abdominal wall muscles, cough training daily for 4 weeks | PEFR, $FEV_1$, FVC, MECP, MEP, suctioning frequency | 1. At baseline, SES produced ↑ MEP (80%), MECP (67%), PEFR (11%), and small ↑ in FVC and $FEV_1$ 2. After 2 weeks of cough training, tracheal suctioning no longer needed to manage secretions 3. After 3 weeks training, tracheostomy removed 4. 1-year post discharge, SES with posterolaterally placed electrodes also enhanced voluntary cough attempts |
| DiMarco et al, 2006[38] | USA | 9 | Case report | N = 1, Level 5 | Male, age 52 y, with C5-C6 ASIA C, incomplete tetraplegia, 7 YPI | Lower thoracic spinal cord stimulation at T9, T11, and L1 | $P_{air}$, expired volume, $V_{exp}$ | 1. $P_{air}$ and $V_{exp}$ greater with T9 stimulation than L1 stimulation 2. With combined (T9 + L1) stimulation, $P_{air}$ and $V_{exp}$ values characteristic of normal subjects 3. No increase in pressure generation with addition of third lead |

AUS, Australia; CPF, cough peak flow; Et$CO_2$, end-tidal $CO_2$; FES, functional electrical stimulation; $FEV_1$, forced expiratory volume in 1 second; FVC, functional vital capacity; MECP, maximal expiratory cough pressure; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; $P_{air}$, airway pressure; PEFR, peak expiratory flow rate; PI, post injury; RR, respiratory rate; SCI, spinal cord injury; SES, surface electrical stimulation; $V_{exp}$ expiratory flow rate; $V_{minute}$, minute ventilation; $V_T$, tidal volume; and YPI, years post injury.

**Table 7.** Assisted Coughing—Manual Assistance, Insufflation-Exsufflation

| Author and Year | Country | Downs and Black Score | Research Design | Total Sample Size | Methods: Population | Methods: Treatment | Methods: Outcome Measures | Outcome |
|---|---|---|---|---|---|---|---|---|
| Kirby et al, 1966[22] | USA | 10 | Prospective controlled trial | N = 12, level 2 | 12 (9 males and 3 females) with SCI between C4 and C6, mean age 25 y, range 16–58 | (1) Insufflation by positive oral pressure, (2) compression of the trunk by thoracoabdominal corset, (3) manual compression of the abdomen and lower thorax by 2 people, (4) 1 + 2, (5) 1 + 3 | Maximum flow and cough volume | 1. Cough unaffected by use of corset<br>2. Manual compression and insufflation by positive pressure improves cough<br>3. Optimal cough resulted from combining positive pressure insufflation with manual compression |
| Kang et al, 2006[9] | Korea | 15 | Prospective controlled trial | N = 40, level 2 | 40 (34 men and 6 women) with cervical complete motor SCI between C3 and C8, mean age 35.1 ± 4.7 y, 6.1 ± 4.7 mo PI | (1) Insufflation by positive oral pressure, (2) abdominal compression, (3) 1 + 2 | VC, MIC, MIP, MEP, PCFR | 1. All 3 assisted-cough methods showed significantly ↑ PCFR than the unassisted method ($P < 0.001$)<br>2. Abdominal compression showed ↑ PCFR than insufflation assisted<br>3. Combined treatment showed ↑ PCFR than either technique applied in isolation<br>4. VC correlated with voluntary cough capacity<br>5. MIP showed higher correlation with voluntary or assisted cough capacity than MEP, so increased inspiratory muscle strength should be considered in pulmonary rehab |
| Braun et al, 1984[23] | USA | 9 | Pre-post | N = 13, level 4 | 13 (11 males and 2 females) with complete SCI between C4 and T6, mean age 30.9 ± 17.3 y, 11 cervical and 2 thoracic lesions | Abdominal compression | Peak expiratory flow rate during cough and forced vital capacity maneuver | 1. ↑ peak flow during cough with abdominal compression occurred in 12/13 subjects (0–57% improvement, mean ↑ 13.8% over the unassisted cough; $P < 0.01$)<br>2. Confirms that largest lung volume possible prior to cough initiation is required for maximally effective cough |

MEP, maximal expiratory pressure; MIC, maximum insufflation capacity; MIP, maximal inspiratory pressure; PCFR, peak cough flow rate; PI, post injury; SCI, spinal cord injury; and VC, vital capacity.

Enhancement of VC, an essential component of an effective cough, is improved by the use of abdominal binders or strapping (19–21), GPB (14,15,17,18,33), and RMT by normocapnic hyperpnea (36). Benefits from each of these strategies may be dependent on a variety of factors. For instance, abdominal binding is a passive approach but requires skill in its application and may be more effective in upright postures. From a clinical perspective, anatomy of the thorax and abdomen, in addition to patient compliance, may determine whether changes are sufficient to improve cough (21). GPB, the most widely studied of the 3 techniques, requires engagement and learning of the person with SCI but has the advantage of being a technique that can be performed independently. RMT likely shows the most untapped potential of the three. Although earlier systematic reviews (2,11,34,35) describe questionable benefit from RMT, a recent RCT provides strong evidence that this therapy enhances lung expansion and flow rates in patients with SCI and reduces respiratory infection frequency (36).

Respiratory muscle training has been used with variable success in other patient groups with neuromuscular conditions such as myasthenia gravis (48) and amyotrophic lateral sclerosis (ALS) (49) and in patients with chronic respiratory disease (50). Major considerations when determining potential benefit include an evaluation of the underlying adaptability of the respiratory muscles in addition to the choice of training technique. A finite potential for respiratory muscle adaptation might explain the equivocal benefit of RMT reported in ALS and Duchenne muscular dystrophy (49,51). This variable should be considered when evaluating RMT for those with high SCI; however, to date, the lack of improvements following RMT in many previous studies on this population have been attributed to ineffective training protocols and not to limited ability of the respiratory muscles to adapt (2,11,34,35). In contrast, the normocapnic hyperpnea training used in a recent RCT (36) consistently provided a training load via high flow ventilation that could be reasonably expected to recruit muscles at a higher velocity of contraction and a greater range of motion during inspiration and expiration. A more practical approach that may prove to be equally effective for people with SCI is the use of a Threshold device (HealthScan Products Inc, Cedar Grove, NJ); however, this method primarily stresses the inspiratory muscles only. Inspiratory muscle training using threshold or targeted techniques have demonstrated widespread benefits in people with chronic obstructive pulmonary disease (50).

Assisted cough techniques that include insufflation and manual compression (9,22,23) or electrical stimulation (37–40) are effective in improving cough and/or peak expiratory flow rates in people with SCI. Normocapnic hyperpnea training may result in comparable gains toward improving cough (36); however, the relative benefits of these approaches have not been compared. Assisted cough techniques require another person with the necessary skill, whereas electrical stimulation and the benefits derived from RMT can be used independently. The most obvious drawback of electrical stimulation is the surgical implantation of the electrodes (37,38) or maintenance of the surface application of electrodes (39,40). Preference for a given technique might not only depend on successful outcomes of airway clearance but also on the potential adverse events, as well as comfort and compliance of the person with SCI.

Worthy of note, none of the reports describing IPPB that met the inclusion criteria of this systematic review showed improvements in VC, flow rates, or cough (42–44). However, considering the potential benefit of IPPB on respiratory compliance and lung volumes, this intervention is worthy of further study. Another study (45) that used an RCT design showed improvements in forced expiratory volume in 1 second, FVC, and peak expiratory flow rate following mechanical insufflation-exsufflation (MIE); however, this study did not include a detailed description of the level of injury or the time since injury to allow for adequate comparison of the 2 groups. Other issues of concern were a lack of description of the random allocation method or subject number and characteristics in the control vs treatment group. Although this RCT implies a strong design, the poor comparability of subject groups and lack of information confound interpretation of the positive outcomes. Several reports describe the use of MIE to successfully facilitate airway clearance in mid and late stages of ALS (52–55); however, in spite of the similarities between late-stage ALS and high-level SCI, published reports on the efficacy of MIE in airway clearance for SCI remain lacking. Indeed, only 2 other reports on the use of MIE in SCI were retrieved from our search. One was a survey study investigating patient and care-provider perceptions of MIE for airway clearance in SCI (56). The other examined the use of MIE in 46 patients with various neuromuscular disorders including 9 with SCI (57). Although neither of these studies met the inclusion criteria of this systematic review, both report positive outcomes and perceptions of MIE use in SCI. In view of the sparse yet positive literature on this subject, further investigation into the use of MIE in SCI is warranted.

A systematic search of adverse effects resulting from secretion removal techniques only revealed 2 reports that described events purportedly due to manual assisted cough. In 9 individuals, Greenfield filters were displaced proximally (46) and in 1 individual, the small bowel was perforated and required surgical repair (47). The small number of reported adverse affects is consistent with the sparse literature investigating secretion removal in people with SCI. In other populations that experience respiratory complications, bronchial clearance by manual percussion and vibration techniques has been associated with such adverse events as oxygen desaturation, bronchospasm, fractured ribs, bruising, and patient intolerance (58). Although people with SCI may be at risk of experiencing similar adverse responses, these data are not available. Of clinical importance, individuals predisposed to such adverse events are more often critically ill patients or those with comorbid issues such as bronchial hyperresponsiveness, bone decalcification, or coagulopathy (58). In any event, the adverse events reported in response to the manual assisted cough technique in people with SCI provide ample indication that therapists should be prudent when applying this technique and should monitor the patient accordingly.

This systematic review is limited by the small number of studies that primarily consisted of weaker designs and small sample sizes. Most of the studies had 14 subjects or less and 50% were a pre-post design or case series, which only provide level 4 evidence. A second major limitation was that the studies asked various questions related to aspects of airway clearance; however, no two RCTs asked a similar question. Of those studies that showed improved pulmonary function related to airway clearance, more clinically relevant outcomes such as hospitalizations, respiratory infections, or impact on health-related quality of life were not often reported. Of course, publication bias of studies primarily reporting positive outcomes need to be considered while reviewing the evidence of this systematic review.

Perhaps the greatest void in the literature was a lack of reference to other secretion removal techniques that have proved to be effective in other patient populations (59–61). Techniques such as huffing, active cycle breathing techniques, autogenic drainage, and the use of positive expiratory pressure devices are well-described airway clearance therapies used in people with respiratory conditions that result in excessive mucus production (24). Only Ehrlich et al (16) described the use of a positive expiratory pressure valve even though similar devices have shown significant benefits in patients with chronic bronchitis (60), cystic fibrosis (61), and bronchiectasis (62). Similar to the technique used by Ehrlich et al (16), use of IMT may be a prerequisite to ensure adequate inspiratory volumes for the effective use of positive expiratory pressure devices. The successful application or limitations of other airway clearance techniques in people with SCI, in addition to those reported in this review, are worthy of exploration.

## CONCLUSION

In conclusion, level 4 evidence supports the use of secretion removal techniques in people with SCI and higher levels of evidence (levels 1, 2, and 4) are reflected by investigations that examined the various components of cough. The most promising are treatments that promote respiratory muscle force. A thorough scouring of the literature revealed a paucity of articles that used a large number of participants and only 2 randomized controlled trials were retrieved. The more common study designs of case reports and pre-post tests during the last decade reflects the difficulty of performing large-scale randomized trials in people with SCI and limits clinical recommendations supported by higher levels of evidence. In spite of this low level of evidence, clinical use of secretion removal techniques in individuals with chronic SCI are highly recommended given the high incidence of pulmonary complications. The merits of various airway clearance techniques are described elsewhere for other populations and should be carefully considered when selecting the best approach for those with chronic SCI (58).

This review yielded the following clinical messages:

(a) The evidence supporting use of secretion removal techniques in people with SCI, although positive, is limited and mostly low level.
(b) Insufflation combined with manual assisted cough provides the most consistent evidence.
(c) Treatments that increase respiratory muscle force show promise as effective airway clearance techniques.

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## APPENDIX 1 EXCLUDED ARTICLES (N = 109)

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