Mechanical Insufflation-Exsufflation Device Prescription for Outpatients With Tetraplegia

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Abstract

Background: Mechanical insufflation-exsufflation (MIE) is an option for secretion mobilization in outpatients with spinal cord injury (SCI) who lack an effective cough and are at high risk for developing pneumonia.

Objective: To describe characteristics of persons with SCI who received MIE devices for outpatient use and compare respiratory hospitalizations before and after MIE prescription.

Design: Retrospective cohort study of all persons who were prescribed MIE devices for outpatient use during 2000 to 2006 by a Veterans Affairs SCI service.

Results: We identified 40 patients with tetraplegia (4.5% of population followed by the SCI service) who were prescribed MIE devices. Of these, 30 (75%) had neurologic levels of C5 or rostral, and 33 (83%) had motor-complete injuries. For chronically injured patients who were prescribed MIE for home use, there was a nonsignificant reduction in respiratory hospitalization rates by 34% (0.314/y before MIE vs 0.208/y after MIE; $P = 0.21$). A posthoc subgroup analysis showed a significant decline in respiratory hospitalizations for patients with significant tobacco smoking histories.

Conclusions: Mechanical insufflation-exsufflation was typically prescribed for people with motor-complete tetraplegia. Outpatient MIE usage may reduce respiratory hospitalizations in smokers with SCI. Further research of this alternative, noninvasive method is warranted in the outpatient SCI population.

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Key Words: Spinal cord injuries; Tetraplegia; Pneumonia; Cough; Respiratory therapy

INTRODUCTION

Ineffective cough is a common consequence of spinal cord injury (SCI) because of paralysis of the thoracic-innervated primary expiratory muscles, as well as inspiratory muscle weakness. Peak cough flows of less than 2.67 L/s (160 L/min) are predictive of failed extubation or decannulation in patients with neuromus-

cular disorders (1) likely due to difficulty clearing bronchial secretions. This inability to cough forcefully and mobilize bronchial secretions or aspirated oropharyngeal material is likely a primary contributor to respiratory complications after SCI. Respiratory disorders account for 28% of deaths in the first year after injury and 22% of deaths in subsequent years (2). Pneumonia and influenza account for 16.5% of all deaths after SCI, in contrast to the general population, in whom they account for only 2.5% of deaths (3,4). The highest incidence rates of pneumonia are seen in persons with motor-complete tetraplegia, both during the acute period and chronically (2).

A number of invasive and noninvasive techniques are currently used to facilitate clearance of bronchial secretions, including tracheal suctioning, bronchoscopy, manually assisted cough ("quad cough") with or without air stacking, percussion, and postural drainage (5,6). Investigational techniques to activate paralyzed expiratory muscles include magnetic stimulation, surface electrical stimulation, and spinal cord stimulation with

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epidural electrodes (7–9). Mechanical insufflation-exsufflation (MIE) therapy is an additional noninvasive aid that augments inspiratory and expiratory flow to improve secretion mobilization. With typical MIE treatments, an insufflation pressure of +40 cmH₂O is delivered to the airways by the device, which then rapidly alternates to an exsufflation pressure of –40 cmH₂O, producing a flow rate in the airways that approximates a normal cough (10). It is possible that outpatient use of MIE, either prophylactically or in response to symptoms of respiratory tract infection, could reduce the frequency of severe respiratory complications, such as pneumonia, thereby reducing the rate of respiratory-related hospitalizations.

To date, there has been no description of clinical characteristics of the population of patients with SCI who are prescribed MIE devices for outpatient use. Preliminary results from a survey indicate that most SCI specialists had some inpatient experience with its use; however, only 28% had ever prescribed MIE for outpatient use (11). A more recent study indicated comparable inpatient usage experience (51%) and somewhat more prevalent (42%) experience using it with outpatients, although the low response rate in that survey (16%) may have biased those findings (12). Patients typically prefer MIE over suctioning (13), and in outpatient settings the treatments are most commonly administered by family members or other caregivers, not nurses (12). Medical complications associated with the use of MIE appear to be rare (14), although barotrauma is a potential concern in some patient populations given the positive pressure associated with the insufflation phase of MIE.

The primary purpose of this study was to characterize people with SCI followed by our service who have been prescribed MIE devices for use in outpatient settings. We also determined respiratory-related hospitalization rates among persons with tetraplegia both before and after MIE device prescription. We hypothesized that outpatient use of MIE could reduce the rate of respiratory hospitalizations.

METHODS

The study received approval from institutional review boards at the University of Washington and the Veterans Affairs Puget Sound Health Care System (VAPSHCS) in Seattle, Washington. We conducted a retrospective review of medical records for persons with spinal cord disorders who had been prescribed MIE devices for outpatient use. Since initiating the use of MIE as a standard treatment for inpatients, our SCI service began prescribing the devices to outpatients we consider to be at high risk for developing pneumonia. These patients generally have chronic copious secretion production, inadequate secretion mobilization using other noninvasive techniques, and high rates of respiratory hospitalization. Previously, such patients and their caregivers were taught manually assisted cough as a prophylactic outpatient measure to improve mobilization of respira-

tory secretions. The protocol on our inpatient SCI unit specifies the pressures listed in the introduction and employs an exsufflation-timed abdominal thrust to optimize flow. If our patients have cuffed tracheostomy tubes, the cuff is inflated before MIE use. In the setting of cuffless tracheostomy tubes, higher insufflation and exsufflation pressures might be needed to optimize efficacy. Further, our patients without tracheostomy tubes use either the oronasal mask or mouthpiece attachments for MIE, typically after testing each with respiratory therapists.

We first obtained a list of all persons with SCI who received care through the SCI Service at the VAPSHCS during calendar years 2000 to 2006. This patient list was generated from a locally maintained computerized registry (VA Spinal Cord Disorders Registry) of veterans with SCI or disorders of various traumatic and nontraumatic etiologies. We next obtained a list generated from a prosthetics department database that included all persons treated at VAPSHCS who had been prescribed MIE devices (CoughAssist, J. H. Emerson, Inc, Cambridge, MA) during the same period. We cross-referenced the 2 lists and excluded individuals with primary neurologic diagnoses other than SCI, such as amyotrophic lateral sclerosis. Of the 883 persons who received care through the SCI service during this period, 41 (4.6%) were identified as having been prescribed MIE devices. Because our identification method would potentially miss persons who had their MIE devices purchased for home use by non-VA funding sources or supplied by long-term care facilities where they reside, we also examined a locally maintained list of ventilator-dependent veterans currently served by VAPSHCS. All persons on this list who used MIE had them purchased by VA and were listed in the prosthetics database, with the exception of one individual whose MIE device was prescribed before 2000.

We next performed a review of all hospitalizations for these 41 persons at VAPSHCS from 1995 through 2006, excluding any hospitalizations that preceded the onset of SCI. We determined the neurologic classifications for injury level (single neurologic level definition) and ASIA Impairment Scale grade by reviewing electronic medical records from each person's most recent hospitalization (15). Of the 41 patients who were prescribed MIE devices, all except one had a neurologic impairment classification of tetraplegia. The one person with paraplegia had a T3 neurologic level, was prescribed MIE during a long hospitalization for pressure ulcer treatment, and died of complications unrelated to MIE 1 day after hospital discharge. This patient was excluded from the study analyses. The remaining 40 patients served as the study subjects and were further classified as "acute" or "chronic" based on when MIE prescription occurred. Prescription was considered to have occurred acutely if MIE had been prescribed during their initial rehabilitation after SCI (ie, before the first discharge to community

living or infrequently to permanent residence in an extended-care facility). All other patients were considered to have had chronic SCI at the time of prescription. Age and duration of injury were determined in reference to the time of chart review or time of death, not the time of MIE prescription. One investigator initially reviewed all charts and categorized hospitalizations dichotomously (respiratory or nonrespiratory related) based on review of the admitting diagnoses listed in hospital admission notes and discharge summaries. To verify the reliability of our hospitalization classification, a second investigator blindly rereviewed 10 respiratory and 10 nonrespiratory admissions that were randomly selected from all admissions. The second investigator's classification matched the first investigator's for all 20 of these admissions. Respiratory diagnoses at the time of admission were further classified as pneumonia, bronchitis, or other (eg, mucous plug, hypoxia, pleural effusion, pulmonary embolus). We also collected information on respiratory complications of nonrespiratory admissions through review of discharge summaries, chest imaging reports, and respiratory therapy notes. Respiratory complications that developed during nonrespiratory admissions included pneumonia, bronchitis, atelectasis, mucous plugging, and ventilatory failure. Many of the nonrespiratory admissions were performed for elective and nonurgent indications (eg, elective surgery, respite for caregivers, long travel times between home and the medical center).

Hospitalizations and complications were then categorized as either "pre-MIE" if they occurred before the date of MIE prescription or "post-MIE" if they occurred after. If MIE was prescribed during a hospital stay, that hospitalization was classified as pre-MIE. We also collected information on respiratory conditions, including smoking status, sleep-disordered breathing, and other respiratory comorbidities (eg, chronic obstructive pulmonary disease [COPD], lung cancer, asthma). Smoking status was determined from the social history taken at the time of admission for the most recent hospitalization. If the most recent hospitalization was the initial SCI rehabilitation, the smoking status before SCI was recorded. Patients were defined as smokers if they were currently smoking at the most recent hospitalization or if they had at least a 20 pack/y smoking history. Diagnoses of COPD, asthma, or sleep-disordered breathing were based on the diagnoses recorded by the treating physicians, not on the investigators' interpretation of any pulmonary function tests (PFT) or polysomnography results. For PFTs performed before 2001, the results were no longer available in the medical record but would have been available to the clinicians treating the patients during the pre-2001 hospitalizations. Ventilator status was defined as ventilator-free, part-time mechanical ventilation or full-time mechanical ventilation and was based on status at the most recent hospitalization.

Statistical analyses were performed using SPSS version 13.0 (SPSS Inc, Chicago, IL). Statistical signifi-

Table 1. Demographics of the Study Population

	Acute SCI		Chronic SCI	
	(n = 14)		(n = 26)	
	mean	SD	mean	SD
Age (y)	50.3	11.2	58.3	12.9
Duration of injury (y)	2.3	1.7	22.5	15.1
Duration of records before MIE (y)	–	–	6.8	3.7
Duration of records after MIE (y)	2.0	1.5	1.9	1.3

Acute SCI indicates that MIE was prescribed during the initial rehabilitation after SCI; chronic SCI indicates MIE was prescribed at a later time. Age and duration of injury are stated for the time the chart review was conducted or at the time of death, not the time of MIE prescription. Records before and after MIE indicate the years of medical records available for review.

SCI, spinal cord injury; MIE, mechanical insufflation-exsufflation.

cance was set at $P < 0.05$. Hospitalization rates for both pre- and post-MIE prescription were compared using the Wilcoxon signed-rank test. This was performed for patients with chronic SCI who had at least 1 year of hospitalization data from both pre- and post-MIE prescription. We also performed an analysis using all patients with chronic SCI with any duration of both pre- and post-MIE hospitalization data. Posthoc power analyses were conducted using GPOWER (16) to determine the sample size necessary for finding a 50% reduction in the respiratory-related hospitalization rate after MIE prescription at a power (1 beta) of 0.8, and the analysis was also performed using the achieved sample size to calculate the detectable reduction in respiratory hospitalization rate at a power of 0.8.

RESULTS

Characteristics of the study group are presented in Tables 1 through 3. Of the 40 patients who had been prescribed MIE devices for outpatient use, 14 had it prescribed during their initial rehabilitation after acute SCI, and 26 had chronic SCI at the time of prescription. Two of the acute patients (14%) and 6 of the chronic patients (23%) were deceased at the time of review. Pneumonia was the cause of death in 2 of the people with chronic injuries (Table 3). Mean age at time of chart review or time of death did not differ significantly between acute and chronic patients. The most common neurologic level of injury overall was C4 (28%), and 76% of patients had injury levels at C5 or rostral (Table 2). Motor-complete injuries (AISA or AISB) were present in 83% of patients. Neither neurologic level nor ASIA Impairment Scale grade differed significantly between acute and chronic groups. Motor vehicle collision was the most common etiology overall, although falls accounted

Table 2. Neurologic Classifications and Injury Mechanisms for the Study Population

	n	%
Neurologic level		
C2	8	20
C3	3	8
C4	11	28
C5	8	20
C6	8	20
C7	2	5
AIS		
A	22	55
B	11	28
C	6	15
D	1	3
Etiology		
MVC	14	35
Sports	10	25
Fall	9	22
Medical/surgical	3	8
Other	4	10

AIS, ASIA Impairment Scale grade; MVC, motor vehicle collision.

for a greater proportion of injuries in the acute group than in the chronic group (43% vs 12%; $P = 0.04$; Fisher exact test).

Respiratory conditions, ventilator status, and PFT results are summarized in Table 4. Half of all patients had at least one other respiratory comorbidity, such as COPD (20%). Nearly 58% of patients were current smokers ($n = 8$) or had significant smoking histories ($n = 15$) at the time of their most recent admission. Among all patients, 23% were on either part-time (nighttime only) or full-time mechanical ventilation via tracheostomy and volume-cycled ventilators. Overall, 53% of the patients had been diagnosed with sleep-disordered breathing. The prevalence of these respiratory conditions did not vary between acute and chronic groups, nor were there

Table 3. Causes of Death in the Study Population

	Acute SCI (n = 2)	Chronic SCI (n = 6)
Complications from pneumonia	0	2
Nonrespiratory infection	1	1
Nonrespiratory malignancy	0	1
Respiratory malignancy	0	1
Unknown	1	1

Both patients with unclear cause of death died at home, and all other deaths occurred during an admission.
SCI, spinal cord injury.

Table 4. Respiratory Conditions in the Study Population

	n	%
Ventilator status		
Full time	4	10
Nighttime only	5	13
Smoking history	23	58
Sleep-disordered breathing	21	53
Any other respiratory comorbidity	20	50
Chronic obstructive pulmonary disease	8	20
	Mean	SD
FVC	1.7	0.7
FEV ₁	1.5	0.6
FEV ₁ /FVC ratio	0.84	0.11

Spirometry data were available from 22 of 40 patients. Other respiratory comorbidities included chronic obstructive pulmonary disease, asthma, restrictive lung disease, and lung cancer. FVC, forced vital capacity; FEV₁, forced expiratory volume in 1 second.

significant differences in the PFT parameters between the 2 groups.

Table 1 shows the mean years of medical records that were available for review for patients with acute and chronic SCI. Of the 26 patients with chronic SCI, 2 had never been seen at the SCI center before the time of MIE prescription. Therefore, there were no data regarding hospitalizations on these 2 patients before MIE prescription. One person with chronic SCI had medical records before MIE prescription; however, he died shortly after the prescription was placed for MIE and before receiving the MIE device. Thus, 23 patients had both pre- and post-MIE data, and of these, 16 had at least 1 year of both pre- and post-MIE hospitalization records.

We compared respiratory hospitalization rates for those patients with at least 1 year of both pre- and post-MIE data. Among these 16 patients, mean respiratory hospitalization rates were 0.314 (SD 0.291; median 0.24, interquartile range 0.53) per year before MIE and 0.208 (SD 0.308; median 0, interquartile range 0.47) per year after MIE ($P = 0.21$). A posthoc power analysis indicated that detection of a 50% reduction in respiratory hospitalizations after MIE (0.314–0.157/y) at a power of 0.8 and alpha of 0.05 would have required a sample size of 31. With the achieved sample size of 16, there was 0.8 power to detect a true change in respiratory hospitalization rates from 0.314 to 0.089 per year (72% reduction).

For the 23 patients with any duration of hospitalization data from both before and after MIE, respiratory hospitalization rates were 0.310 (SD 0.323) per year before MIE and 0.319 (SD 0.846) after MIE ($P = 0.15$). For these same 23 people, pneumonia hospitalization rates were 0.230 (SD 0.310) per year before MIE and 0.282 (SD 0.846) after MIE ($P = 0.38$). The lone hospitalization for pulmonary embolus occurred in 1 of

these 23 patients, within the first year after SCI and after MIE prescription. Respiratory complications occurred during nonrespiratory admissions at similar rates both before and after MIE prescription (0.138 vs 0.135 hospitalizations/y; $P > 0.05$).

Respiratory hospitalizations occurred at a significantly greater rate during the pre-MIE period for the 15 smokers than for the 9 nonsmokers with pre-MIE hospitalization data. Nonsmokers averaged 0.14 (SD 0.16) respiratory hospitalizations per year, and smokers averaged 0.41 (SD 0.35) respiratory hospitalizations per year ($P = 0.04$; Mann-Whitney U test). For the 14 smokers with hospitalization data before and after MIE prescription, the rate of respiratory hospitalizations declined significantly after prescription of MIE, from 0.42 (SD 0.36) to 0.19 (SD 0.32) per year ($P = 0.03$; Wilcoxon signed-rank test). Rates of respiratory hospitalizations did not differ significantly among patients with vs without a diagnosis of sleep-disordered breathing. Further, patients with other respiratory comorbidities had a mean of 0.53 (SD 1.05) respiratory hospitalizations per year compared with 0.20 (SD 0.49) respiratory hospitalizations per year for patients with no additional respiratory comorbidities ($P =$ not significant). Respiratory hospitalization rates did not differ significantly for the 5 full-time or part-time ventilator users with pre- and post-MIE data.

DISCUSSION

Mechanical insufflation-exsufflation has been investigated in a number of patient populations for its ability to improve respiratory outcomes in persons with neuromuscular disorders. Miske et al (17) previously studied the implementation of MIE in a pediatric population with neuromuscular disease and found a decreased frequency of pneumonia in a small subset of patients. Vianello et al (18) found that invasive ventilatory support was less commonly needed in adults with neuromuscular disease and respiratory tract illnesses when MIE was used; low-magnitude pressures (mean +19 and -33 cmH₂O) in that study may be the reason bronchoscopic secretion removal was also required by many in the MIE group (18). This is the first study to describe a population of persons with SCI who received MIE devices for outpatient use and to analyze pre- and post-MIE respiratory hospitalizations.

Patients in this study had a high rate of respiratory hospitalizations, with approximately a 31% chance of being admitted for respiratory causes annually, and as anticipated, most of these hospitalizations were due to pneumonia. The pneumonia hospitalization rate is higher than that of the general population. In the US population, there are approximately 10 cases of pneumonia per 1,000 patients per year, and only 25% of these cases require hospitalization (19). Patients in this study had approximately a 23% chance of being hospitalized for pneumonia annually before MIE, a rate nearly 100 times

higher than that of the general population. Because of the retrospective study design and lack of documentation for routine care, we were unable to characterize the respiratory hospitalizations in greater detail; for example, not all records indicated the frequency of MIE use (or other secretion mobilization techniques) during the hospitalization.

Surprisingly, in this sample of individuals with impaired respiratory function, 20% were still smoking at the time of their most recent hospitalization. Smokers had a significantly higher rate of respiratory hospitalizations, with a nearly 3 times greater chance of being admitted for respiratory causes annually during the pre-MIE period. A posthoc subgroup analysis indicated that the rate of respiratory hospitalizations declined significantly in smokers after MIE prescription. Tobacco smoking is recognized as a cause of increased bronchial secretions because of stimulation of bronchial secretion by nicotine, as well as airway inflammation with chronic exposure to irritants in tobacco smoke (20,21). Although a relatively small percentage of patients had a diagnosis of COPD, PFTs are likely insensitive for detecting airflow obstruction in persons with tetraplegia, because they may be masked by neuromuscular dysfunction (22) and testing results were not available for all patients in this study.

Additionally, there is some evidence that persons with SCI who smoke may develop COPD at a more rapid rate than smokers without SCI (23). Therefore, initiating use of more effective secretion mobilization, such as MIE, could be most beneficial for smokers, particularly those with chronic bronchitis. Determining the smoking history from record review was problematic due to inconsistent recording of number of pack years, but current smoking status was documented more consistently. Nonetheless, our findings suggest that MIE should be considered in particular for individuals with tetraplegia and respiratory impairment who currently smoke or have a significant smoking history.

The failure of this study to reveal a significantly lower rate of respiratory hospitalizations in the overall study population after MIE prescription may be due to a variety of factors. First, the sample size was small, because not all patients had sufficient duration of both pre- and post-MIE data for inclusion in the analysis. Due to this small sample size, the study had low statistical power to detect a clinically significant reduction in respiratory hospitalizations. Nearly twice the sample size would be required to detect a 50% reduction in respiratory hospitalizations. We considered alternate statistical techniques employed for event history analyses, such as Poisson regression, but concluded that the one chosen was the most conservative.

Second, the device may have been prescribed to some patients who did not have severely impaired cough, which would reduce the ability to demonstrate efficacy in reducing respiratory complications. We

consider this to be unlikely for most of these patients, because peak cough flows are typically low for patients with these SCI neurologic impairment classifications (24) and also because the patients were experiencing a mean of more than 0.3 respiratory hospitalizations annually. However, patients did not undergo measurement of unassisted peak cough flow to confirm that their cough was inadequate before MIE prescription. In addition, some patients may have been able to achieve an adequate assisted cough using air stacking followed by abdominal thrust (24).

Next, patient compliance with MIE therapy at home was not addressed in this study. It is not clear how many patients who were prescribed MIE devices for outpatient use were actually using the device either for daily prophylactic secretion mobilization or in response to respiratory infections. The use of oximetry in patients with neuromuscular disease can help guide the need for MIE in expelling respiratory secretions when oxygen saturations drop below 95% (25). Prior criteria at our center restricted the prescription of oximeters for outpatient use by many patients who received MIE. Therefore, not all of the patients were using home oximetry to guide decisions regarding MIE usage. Yet this would clearly benefit patients with SCI and their caregivers in monitoring the need for and relative success of MIE treatments in the outpatient setting. We also do not know whether the recommended inspiratory and expiratory pressures (10) were utilized by patients and caregivers in the outpatient setting.

Additionally, our respiratory hospitalization rates likely underestimate the true rates, because they included only hospitalizations at our center and not other hospitals. However, most patients followed by our service lack comprehensive health insurance other than that provided by the Department of Veterans Affairs, and often they choose to travel longer distances to receive treatment of acute medical conditions in a tertiary care medical center with a specialized SCI unit.

It is possible that our clinical decision making and practice pattern regarding MIE prescription are not optimal. In general, the decision to prescribe MIE to recently injured individuals for outpatient use is based on whether they have required MIE for secretion mobilization or to prevent atelectasis when other techniques have proved insufficient during the initial hospitalization. For individuals with chronic injuries, the decision to prescribe MIE is often based on frequency of respiratory hospitalizations. The study findings thus represent the practice of one group of clinicians at a single center, which may or may not represent optimal MIE prescription practices.

Further, MIE might not prevent pneumonia from developing in persons with tetraplegia, even if it improves secretion mobilization or reduces the case fatality rate for respiratory infections. Finally, providers may choose to admit a person with tetraplegia who has respiratory symptoms and possible pneumonia, even if

secretion management at home using MIE might be sufficient. Algorithms for hospitalization decisions, such as the pneumonia severity index (Pneumonia PORT) (26), estimate mortality risk for the general population of outpatients presenting with pneumonia but have not been validated for individuals with SCI. Experienced SCI clinicians are aware of the potential for rapid deterioration and mortality and the need for optimization of secretion mobilization when individuals with tetraplegia develop pneumonia.

CONCLUSIONS

Outpatient use of MIE among persons with tetraplegia is one technique for managing respiratory secretions. It may decrease the rate of pneumonia and respiratory hospitalizations, particularly in those with a history of tobacco smoking who have greater ongoing needs for respiratory secretion clearance. The efficacy of MIE in reducing respiratory hospitalizations should be investigated in a future study with a larger sample size and a standardized assessment of hospitalization indications, standardized patient instructions, and monitoring of compliance with outpatient usage recommendations.

REFERENCES

1. Bach J, Saporito L. Criteria for extubation and tracheostomy tube removal for patients with ventilatory failure: a different approach to weaning. *Chest*. 1996;110(6):1566–1571.
2. DeVivo M, Krause J, Lammertse D. Recent trends in mortality and causes of death among persons with spinal cord injury. *Arch Phys Med Rehabil*. 1999;80(11):1411–1419.
3. DeVivo M, Black K, Stover S. Causes of death during the first 12 years after spinal cord injury. *Arch Phys Med Rehabil*. 1993;74(3):248–254.
4. Minino A, Heron M, Smith B. Deaths: preliminary data for 2004. *Natl Vital Stat Rep*. 2006;54(19):1–49.
5. Bach J. Update and perspective on noninvasive respiratory muscle aids. Part 2: the expiratory aids. *Chest*. 1994; 105(5):1538–1544.
6. Consortium for Spinal Cord Medicine. Respiratory management following spinal cord injury: a clinical practice guideline for health-care professionals. *J Spinal Cord Med*. 2005;28(3):259–293.
7. Lin V, Singh H, Chitkara R, Perkas I. Functional magnetic stimulation for restoring cough in patients with tetraplegia. *Arch Phys Med Rehabil*. 1998;79(5):517–522.
8. Spivak E, Keren O, Niv D, et al. Electromyographic signal-activated functional electrical stimulation of abdominal muscles: the effect on pulmonary function in patients with tetraplegia. *Spinal Cord*. 2007;45(7):491–495.
9. DiMarco A, Kowalski K, Geertman R, Hromyak D. Spinal cord stimulation: a new method to produce an effective cough in patients with spinal cord injury. *Am J Respir Crit Care Med*. 2006;173(12):1386–1389.
10. Bach J. Mechanical insufflation-exsufflation: comparison of peak expiratory flows with manually assisted and unassisted coughing techniques. *Chest*. 1993;104(5):1553–1562.

11. Burns SP, Ludwig MA, Guihan M, Kapur V. Respiratory management practices utilized by spinal cord injury specialists [abstract]. *J Spinal Cord Med*. 2004;27(2):190.
12. Schmitt JK, Stiens S, Trinchler R, et al. Survey of use of the insufflator-exsufflator in patients with spinal cord injury. *J Spinal Cord Med*. 2007;30(2):127–130.
13. Garstang S, Kirshblum S, Wood K. Patient preference for in-exsufflation for secretion management with spinal cord injury. *J Spinal Cord Med*. 2000;23(2):80–85.
14. Suri P, Burns SP, Bach JR. Pneumothorax associated with mechanical insufflation-exsufflation and related factors. *Am J Phys Med Rehabil*. 2008;87:951–955.
15. American Spinal Injury Association. Scoring, scaling, and classification. *Reference Manual for the International Standards for Neurological Classification of Spinal Cord Injury*. Chicago, IL: American Spinal Injury Association; 2003: 46–60.
16. Faul F, Erdfelder E, Lang A-G, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39:175–191.
17. Miske L, Hickey E, Kolb S, Weiner D, Panitch H. Use of the mechanical in-exsufflator in pediatric patients with neuromuscular disease and impaired cough. *Chest*. 2004;125(4): 1406–1412.
18. Vianello A, Corrado A, Arcaro G, et al. Mechanical insufflation-exsufflation improves outcomes for neuromuscular disease patients with respiratory tract infections. *Am J Phys Med Rehabil*. 2005;84(2):83–88; discussion 89–91.
19. Centers for Disease Control and Prevention. Premature deaths, monthly mortality, and monthly physician contacts: United States. *MMWR Morb Mortal Wkly Rep*. 1997; 46(24):556–561.
20. Stolz D, Anderson S, Gysin C, et al. Airway reactivity to inhaled mannitol in cigarette smokers: a longitudinal study. *Respir Med*. 2007;101(7):1470–1476.
21. Saetta M, Turato G, Facchini F, et al. Inflammatory cells in the bronchial glands of smokers with chronic bronchitis. *Am J Respir Crit Care Med*. 1997;156(5):1633–1639.
22. Jain N, Brown R, Tun C, Gagnon D, Garshick E. Determinants of forced expiratory volume in 1 second (FEV₁), forced vital capacity (FVC), and FEV₁/FVC in chronic spinal cord injury. *Arch Phys Med Rehabil*. 2006;87(10): 1327–1333.
23. Linn W, Spungen A, Gong HJ, Bauman W, Adkins R, Waters R. Smoking and obstructive lung dysfunction in persons with chronic spinal cord injury. *J Spinal Cord Med*. 2003; 26(1):28–35.
24. Kang SW, Shin JC, Park CI, Moon JH, Rha DW, Cho DH. Relationship between inspiratory muscle strength and cough capacity in cervical spinal cord injured patients. *Spinal Cord*. 2006;44(4):242–248.
25. Tzeng A, Bach J. Prevention of pulmonary morbidity for patients with neuromuscular disease. *Chest*. 2000;118(5): 1390–1396.
26. Fine M, Auble T, Yealy D, et al. A prediction rule to identify low-risk patients with community-acquired pneumonia. *N Engl J Med*. 1997;336(4):243–250.