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Compensatory muscle activation during forced respiratory tasks in individuals with chronic spinal cord injury

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ABSTRACT

When lesions in the spinal cord occur, the neural activation of respiratory muscles is compromised (De Troyer and Heilporn, 1980; De Troyer et al., 1986, 1990; Estenne et al., 2000a) resulting in significant respiratory dysfunction (De Troyer and Heilporn, 1980; Linn et al., 2000, 2001; Yokoba et al., 2003). However the underlying mechanisms that contribute to this dysfunction remain unclear. The aims of this study were: (1) to investigate whether a correlation exists between pulmonary function and the International Standards for the Neurological Classification of Spinal Cord Injury (ISNCSCI) examination scores for sensory and motor function; (2) to evaluate whether compensatory muscle activation plays a role in pulmonary function after spinal cord injury (SCI). We recorded Forced Vital Capacity (FVC); Forced Expiratory Volume in 1 s (FEV_1); and electromyography (EMG) of respiratory muscles during maximum respiratory tasks in 36 with SCI and 15 neurologically intact participants. Results indicate that pulmonary function (FVC, FEV_1) was strongly correlated with motor and sensory scores from the ISNCSCI exam and maximal expiratory pressure (MEP) was also significantly related to ISNCSCI sensory scores ($\rho = 0.73$, $p < .001$) and moderately, but significantly correlated to motor scores ($\rho = 0.41$, $p = .04$). After SCI, there is a compensatory recruitment of accessory muscles upper trapezius during maximal inspiratory pressure (MIP) and pectoralis and latissimus dorsi during MEP that is significantly higher than in non-injured ($p < .001$).

1. Introduction

When lesions in the cervical or thoracic segments of the spinal cord occur, the neural activation of respiratory muscles can be compromised (De Troyer and Heilporn, 1980; Baydur et al., 2001; Branco et al., 2007; De Troyer et al., 1986, 1990; De Troyer and Estenne, 1990; Estenne et al., 2000b) resulting in significant respiratory dysfunction (Linn et al., 2000, 2001; Cotton et al., 2005; DeVivo, 2012; DeVivo et al., 1999a,b). A clinical relevant aspect of impaired respiration in individuals with spinal cord injury (SCI) is the inability to cough adequately. Although cough reflex is preserved even after SCI (Dicpinigaitis et al., 1999), these individuals suffer from ineffective coughing due to paralyzed or weak respiratory muscles, resulting in accumulation of secretions that can cause airway obstruction and provide growth media for the development of pneumonia (Cotton et al., 2005). In fact, this is a common secondary complication after injury and is among the leading causes of death in acute (DeVivo et al., 1999a) and chronic (Garshick et al., 2005) SCI. Previous reports indicate that pulmonary function parameters, including forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), and maximal inspiratory and expiratory pressures (MIP and MEP, respectively) are negatively correlated with the injury level (Linn et al., 2001; Baydur et al., 2001; Estenne et al., 2000b; Garshick et al., 2005; Kelley et al., 2003). However, the effects of the severity of injury determined by the International Standards for the Neurological Classification of Spinal Cord Injury (ISNCSCI) examination (Waring et al., 2010) on these parameters remain unclear.

A number of investigations have suggested that there is a correlation between pulmonary function and the neural activation of muscles involved in respiration (Linn et al., 2000; De Troyer et al., 1986). Peak expiratory flow rate is correlated with the EMG activity of pectoralis major and latissimus dorsi (De Troyer et al., 1986; Estenne and De Troyer, 1990; Fujiwara et al., 1999). EMG amplitude

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of intercostal muscles show significant increases with incremental respiratory loads in inspiratory muscle endurance tests in healthy individuals (Yokoba et al., 2003). However, the literature is limited in addressing the compensatory action of accessory muscles when primer movers for inspiration or expiration are weak or paralyzed as in SCI.

We hypothesize that FVC, FEV_1, MEP and MIP show a positive correlation to the ISNCSCI sensory and motor scores for the spinal cord injury. Additionally, we suggest that lower pulmonary function values are associated to higher EMG amplitude of the respiratory muscles above the level of the injury (i.e. accessory muscles).

2. Materials and methods

2.1. Demographic and clinical characteristics

This study was approved by the University of Louisville's Institutional Review Boards in compliance with all the institutional and federal regulations concerning the ethical use of human volunteers for research studies. Fifty-one volunteers, including 36 participants with chronic traumatic SCI and 15 neurologically intact individuals, participated in this study (Table 1). SCI participants were classified using the American Spinal Injury Association impairment scale (AIS) as follows: 12 were cervical motor complete (AIS grade A–B), 11 were cervical motor incomplete SCI (AIS grade C–D), 8 cervical motor incomplete, 8 thoracic motor complete, 5 as thoracic motor incomplete and 15 participants were neurologically intact participants. Evaluations were performed within 7 days of an ISNCSCI examination. All the 36 SCI subjects participated on the pulmonary function portion of the study. However, only 25 of the SCI (6 cervical motor complete AIS grade A–B, 7 cervical motor incomplete AIS grade C–D, 7 thoracic motor complete AIS grade A–B and 5 thoracic motor incomplete AIS grade C–D) participated on the EMG assessment during MEP and MIP. Eight of the SCI and 5 of the neurologically intact participants were female, and all were between 20 and 54 years of age (37.1 ± 13.5). One SCI participant was diagnosed as central cord syndrome.

Non-injured participants had no history of neuromuscular disease, back or join pain, were in stable medical condition without cardiopulmonary disease and were non-smokers. SCI participants were in stable medical condition without cardiopulmonary disease, had no painful musculoskeletal dysfunction, unhealed fracture, contracture, pressure sore or urinary tract infection; had no clinically significant depression, psychiatric disorders or ongoing drug abuse; showed clear indications that the period of spinal shock is concluded determined by presence of muscle tone, deep tendon reflexes or muscle spasms; had a non-progressive SCI above T6; were classified as International Standards for the Neurological classification of Spinal Cord Injury (ISNCSCI) A,B,C or D; were not ventilator dependent for respiration; had a sustained SCI at least 6 months prior to entering the study and were at least 18 years of age. Persons with clinically recognizable concomitant head injury were not enrolled in this study. Six of the SCI participants were undergoing locomotor training, and the rest either have standard physical therapy or not therapy at the time of the recordings. Participants' characteristics are shown in Table 1.

2.2. Neurological assessment

The AIS based on the ISNCSCI was used to determine the neurological level and clinical motor completeness severity of the spinal cord lesion (Waring et al., 2010; Marino et al., 2003). The ISNCSCI categorizes SCI severity and motor level based on the evaluation of voluntary contraction strength for five upper limb (C_5 to T_1) and five lower limb (L_2 to S_1) muscles bilaterally. The AIS also determines a sensory level from the perception of light touch and pin prick for C_2 through S_5 dermatomes. The ISNCSCI has been shown to be a reliable estimate for use in clinical assessment of SCI (Waring et al., 2010; Marino et al., 2003; Marino and Graves, 2004).

2.3. Pulmonary function test

FVC and FEV_1 were obtained and expressed as the percent of predicted value for each subject based on a large database of healthy, neurologically intact individuals with no known pulmonary complaints that was derived based on gender, age, and height (Kelley et al., 2003; ATS/ERS, 2002). Three acceptable spirograms were obtained and the result of the best attempt was used. A Differential Pressure Transducer (MP45-36-871-350) with UPC 2100 PC card and software from Validyne Engineering (Northridge, CA) was used to measure MIP and MEP. MIP was measured during maximal inspiratory effort beginning at near residual volume and MEP was measured during maximal expiratory effort starting from near total lung capacity (Black and Hyatt, 1969). Subjects were asked to use a three-way valve system with rubber tube as mouthpiece (Airlife 001504). The pressure meter incorporated a 1.5 mm diameter leak to prevent glottic closure and to reduce buccal muscle contribution during measurements. The assessment required that a sharp, forceful effort be maintained for a minimum of 2 s. The maximum pressure was taken as the highest value that is sustained for 1 s (Black and Hyatt, 1969). The maximum

Table 1
Clinical characteristics of participants by neurological level and injury severity; values are counts or mean ± SD.

Group	Gender	Age (years)	Weight (Lb.)	Height (in)	Time since SCI (months)
Cervical motor complete (*n* = 12)	4F; 8M	37 ± 13	169 ± 47	70 ± 3	52 ± 35
Cervical motor incomplete (*n* = 11)	2F; 9M	30 ± 8	184 ± 33	71 ± 3	22 ± 11
Thoracic motor complete (*n* = 8)	1F; 7M	37 ± 17	175 ± 53	69 ± 5	102 ± 75
Thoracic motor incomplete (*n* = 5)	1F; 4M	40 ± 13	160 ± 26	70 ± 4	92 ± 50
Non-injured (*n* = 15)	7F; 8M	39 ± 10	165 ± 34	68 ± 3	N/A

Table 2
Summary statistics (mean ± SD) for pulmonary function (FEV_1, FVC, MEP, MIP) by neurological level and injury severity.

SCI Level	Severity	FVC (% predicted)	FEV_1 (% predicted)	MEP (cm H20)	MIP (cm H20)
Cervical	Complete	52 ± 17	50 ± 19	43 ± 20	62 ± 27
	Incomplete	73 ± 17	69 ± 16	63 ± 16	93 ± 19
Thoracic	Complete	79 ± 26	72 ± 25	52 ± 22	54 ± 20
	Incomplete	94 ± 7	85 ± 13	65 ± 30	79 ± 31
Non-injured	N/A	109 ± 14	100 ± 10	100 ± 29	78 ± 25