CASE REPORT

Respiratory muscle training may improve respiratory function and obstructive sleep apnoea in people with cervical spinal cord injury

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STUDY DESIGN: This is a double-blind crossover case study series.

OBJECTIVES: The objective of this study was to assess the feasibility of respiratory muscle training (RMT) as an effective intervention to improve lung function and obstructive sleep apnoea (OSA) in cervical spinal cord injury (SCI) patients.

SETTING: This study was conducted in Australia.

METHODS: Three adults (C5–6, AIS A–C) participated in this study. They trained with an RMT device (active or sham) for 4 weeks followed by 2 weeks of rest, and then trained with the alternate device for 4 weeks. RMT occurred twice daily, 5 days a week, and it consisted of three sets of 12 inspirations and three sets of 12 expirations. Training intensity commenced at 30% maximal inspiratory pressure (MIP) and 30% maximal expiratory pressure (MEP), which was increased every second day by 10%. Spirometry, MIP, MEP, polysomnography and Epworth Sleepiness Scale (ESS) were measured before and after every 4 weeks of training.

RESULTS: After active RMT, vital capacity and inspiratory capacity improved from baseline in all participants (by 44%, 60% and 18% and by 18%, 46% and 5%, respectively); MIP improved by 40 and 17% from baseline in two subjects; and MEP improved in all participants. Two participants had OSA, and after active training their obstructive apnoea–hypopnoea index improved from 30 to 21 events per hour and from 72 to 18 events per hour, and ESS marginally improved. Sham RMT resulted in minimal changes in all measures.

CONCLUSION: RMT is feasible and likely effective to increase respiratory muscle strength, to improve lung function, and to reduce the severity of OSA and sleepiness in people with cervical SCI. A randomised controlled trial is planned to validate these findings and to examine respiratory-related morbidity and quality of life.

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INTRODUCTION

After cervical spinal cord injury (SCI), inspiratory and expiratory muscles are often weak or completely paralysed. There are two major clinical consequences: the capacity to get air into the lungs is diminished as is the ability to cough to remove secretions. The result is recurrent respiratory complications such as pneumonia. As many as 28% of people with an SCI die within the first year after injury from respiratory complications.¹ Respiratory-related illness remains the leading cause of mortality and morbidity in people with cervical or high thoracic injuries.¹ Respiratory muscle strength is a predictor for respiratory complications that are important to individuals with SCI. Weak respiratory muscles may also be a major contributor to the high prevalence of obstructive sleep apnoea (OSA) after SCI. The prevalence of OSA is ~60% in people with chronic SCI, which is 4- to 10-fold higher than in the general population.² Health consequences of OSA are likely to further increase the morbidity and mortality and to decrease the quality of life. The first-line treatment for OSA after SCI is continuous positive airway pressure. However, for people with SCI, this treatment is poorly tolerated even more than in the able-bodied. Compliance is estimated at only 35%.² Accordingly, alternative effective treatments for OSA are required. This pilot study tests the feasibility of respiratory muscle training as an

effective intervention to increase the respiratory muscle strength and to improve OSA after cervical SCI.

MATERIALS AND METHODS

Four non-ventilated adults consented to participate (C5–6, AIS A–C; Table 1), and one declined participation after initial measures and withdrew. Participants trained with a threshold-resistive trainer (Respiro-nics, Murrysville, PA, USA; active or sham device, random allocation) for 4 weeks followed by 2 weeks of rest, and then trained with the alternative device for 4 weeks. Respiratory muscle training occurred twice daily, 5 days a week, and it consisted of 3 sets of 12 inspirations and then 3 sets of 12 expirations. Training intensity began at 30% maximal inspiratory pressure (MIP) and 30% maximal expiratory pressure. Training intensity was increased on alternate days by 10%, if tolerated, and was capped at 70% of the highest weekly MIP/maximal expiratory pressure. Polysomnography, Epworth Sleepiness Scale, spirometry, MIP and maximal expiratory pressure were performed before and after each 4-week training period. Participants performed the respiratory function tests seated upright in their wheelchair. No abdominal binders were used. Polysomnography was recorded in participants' usual sleep position. All repeat tests were performed in the same position. Assessors, participants and trainers were blinded to treatment allocation. All relevant institutional and governmental regulations concerning the ethical use of human volunteers were followed.

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Table 1. Participant characteristics

Participant number	Level of injury	AIS	Time since injury (years)	Order of training	Study completed
1	C5	C	0.4	Sham–active	Yes
2	C5	B	0.2	Active–sham	Yes
3	C5	A	25	Active–sham	Yes
4	C6	A	19	Sham–active	No

Abbreviation: AIS, American Spinal Injury Association Impairment Scale.

Figure 1. Individual data from three participants with cervical SCI: participant 1—square, participant 2—triangle, and participant 3—circle. Pre- and post-training values are connected by a line. Order of respiratory muscle training is presented along the x axis: active training in the middle panel and sham training in the left panel for participant 1 and right panel for participants 2 and 3. Graph **a**: obstructive apnoea–hypopnoea index (central events excluded); graph **b**: vital capacity; graph **c**: maximal inspiratory pressure; and graph **d**: maximal expiratory pressure.

RESULTS AND DISCUSSION

After active training, MIP improved from baseline in two participants and maximal expiratory pressure improved in all participants (Figure 1); vital capacity, forced expiratory volume in 1 s, peak expiratory flow and inspiratory capacity improved from baseline in all participants (Table 2). Participants 1 and 3 had OSA (apnoea–hypopnoea index > 15). After active training, apnoea–hypopnoea index improved (Figure 1) and Epworth Sleepiness Scale decreased slightly for both participants. Participant 1 received oxycodone for unrelated pain during active training, accounting for the increased central apnoea index. Poor compliance and motivation were observed for participant 1 during active training and post testing, which may account for a lack of increase in MIP despite increases in measures of lung function. After 2 weeks of wash-out, there was a residual training effect for participants 2 and 3. In all three participants, sham training produced no improvements in any measure.

Respiratory muscle training is known to improve muscle strength in healthy individuals and in people with neuromuscular disorders.³ We have shown increases in respiratory muscle strength that can translate to functional respiratory-related improvements in people with SCI.

A primary reason proposed for the high prevalence of OSA after cervical SCI is weak respiratory muscles, although the exact mechanisms remain unknown. Maintaining ventilation through a patent airway requires well-coordinated contraction of both the upper airway dilator muscles (for example, genioglossus) and inspiratory pump muscles (for example, the diaphragm). Weak inspiratory muscles are likely to predispose to hypoventilation during sleep.⁴ Although upper airway dilator muscles are not affected directly by the SCI, they may have become unable to maintain an adequate open airway during sleep in the supine posture, the posture in which most people with tetraplegia sleep. There is some evidence that strength training by didgeridoo playing and oropharyngeal exercises can improve OSA in able-bodied individuals.⁵ We propose that our threshold loading trains both the respiratory pump muscles and upper airway muscles such that there is a net improvement in patency of the upper airway during sleep.

Our data confirm that the respiratory muscle training intervention is feasible and likely effective to increase respiratory muscle strength. The training has also improved lung function and reduced sleep apnoea severity. A large randomised controlled trial is needed to determine whether our protocol is

Table 2. Maximum values measured from each participant (P1, P2 and P3) for MIP, MEP, FEV₁, FVC, Vt, IC, VC and PEF before and after training with the sham and active respiratory muscle training device

	Active						Sham					
	P1		P2		P3		P1		P2		P3	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
MIP (cm H ₂ O)	39	32	52	73	69	81	38	32	73	71	87	62
MEP (cm H ₂ O)	21	47	18	25	36	38	17	18	25	19	39	40
<i>Spirometry measures</i>												
FEV ₁ (l)	0.91	1.12	1.17	1.38	2.03	2.04	0.61	1.25	1.36	1.38	1.91	2.03
FVC (l)	1.23	1.57	1.24	1.74	2.52	2.48	0.69	1.41	1.77	1.64	2.28	2.35
Vt (l)	0.75	0.67	0.41	0.65	0.65	0.83	0.7	0.75	0.8	0.52	0.96	0.8
IC (l)	0.89	1.05	1.14	1.67	2.34	2.46	0.9	1.03	1.71	1.43	2.3	1.98
VC (l)	1.06	1.53	1.15	1.84	2.15	2.53	1.1	1.25	1.97	1.51	2.23	2.2
PEF (l s ⁻¹)	1.52	1.63	2.71	2.91	4.47	4.58	1.21	2.12	3.3	3.1	4.51	4.61
<i>Sleep parameters</i>												
AHI (events per hour)	80	66	0.4	0.5	30	23	91	67	0.6	4.5	14	17
CAI (events per hour)	8	48	0	0	0	1	9	3	0	0	0.2	0.4
OAI (events per hour)	57	17	0.1	0	2	0.2	69	57	0	0.4	0	0.9
HI (events per hour)	15	1	0.3	0.5	28	21	13	7	0.6	4.1	13	15
ESS (score)	12	9	7	8	10	9	11	10	8	10	5	6

Abbreviations: AHI, apnoea–hypopnoea index; CAI, central apnoea index; ESS, Epworth sleepiness scale; FEV₁, forced expiratory volume in 1 s; FVC, forced vital capacity; HI, hypopnoea index; IC, inspiratory capacity; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; OAI, obstructive apnoea index; PEF, peak expiratory flow; VC, vital capacity; Vt, tidal volume. Similarly shown are each participant's overall AHI, CAI, OAI, HI and ESS.

effective to increase respiratory muscle strength, improve sleep health and quality of life and decrease respiratory-related morbidity.

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COMPETING INTERESTS

The authors declare no conflict of interest.

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