Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2016;97:964-73

ORIGINAL RESEARCH

Respiratory Training Improves Blood Pressure Regulation in Individuals With Chronic Spinal Cord Injury

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Abstract

Objective: To investigate the effects of respiratory motor training (RMT) on pulmonary function and orthostatic stress−mediated cardiovascular and autonomic responses in individuals with chronic spinal cord injury (SCI).

Design: Before-after intervention case-controlled clinical study.

Setting: SCI research center and outpatient rehabilitation unit.

Participants: A sample of (N=21) individuals with chronic SCI ranging from C_3 to T_2 diagnosed with orthostatic hypotension (OH) (n=11) and healthy, noninjured controls (n=10).

Interventions: A total of 21±2 sessions of pressure threshold inspiratory-expiratory RMT performed 5d/wk during a 1-month period.

Main Outcome Measures: Standard pulmonary function test: forced vital capacity, forced expiratory volume in one second, maximal inspiratory pressure, maximal expiratory pressure, beat-to-beat arterial blood pressure, heart rate, and respiratory rate were acquired during the orthostatic sit-up stress test before and after the RMT program.

Results: Completion of RMT intervention abolished OH in 7 of 11 individuals. Forced vital capacity, low-frequency component of power spectral density of blood pressure and heart rate oscillations, baroreflex effectiveness, and cross-correlations between blood pressure, heart rate, and respiratory rate during the orthostatic challenge were significantly improved, approaching levels observed in noninjured individuals. These findings indicate increased sympathetic activation and baroreflex effectiveness in association with improved respiratory-cardiovascular interactions in response to the sudden decrease in blood pressure.

Conclusions: Respiratory training increases respiratory capacity and improves orthostatic stress−mediated respiratory, cardiovascular, and autonomic responses, suggesting that this intervention can be an efficacious therapy for managing OH after SCI.

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Approximately 60% of people with chronic spinal cord injury (SCI) exhibit symptoms of orthostatic hypotension (OH),[1,2] which is associated with an inability to participate in activities of daily life[3,4] and rehabilitation[5,6] with an increased risk of stroke[7] and cognitive dysfunctions.[8,9]

Respiration affects hemodynamics by supporting cardiac output[10-12] and by participating in autonomic regulation of heart rate and blood pressure via baroreflex modulations.[13-16] These respiratory-cardiovascular interactions[17,18] are compromised after SCI.[1,11,19-22] Currently, there is no standardized management strategy for blood pressure dysregulation after SCI.[5,23,24] Respiratory

Supported by the Kentucky Spinal Cord and Head Injury Research Trust (grant no. 9-10A), the Christopher and Dana Reeve Foundation (grant no. OA2-0802), the Craig H. Neilsen Foundation (grant no. 1000056824), and the National Institutes of Health (grant nos. R01HL103750 and P30GM103507).

Disclosures: none.

0003-9993/16/$36 - see front matter © 2016 by the American Congress of Rehabilitation Medicine
http://dx.doi.org/10.1016/j.apmr.2015.11.018

Table 1 Characteristics of patients with SCI and NI individuals

Participant		Age (y)	Sex	Height (cm)	Weight (kg)	Level of SCI	AIS Category	Time After SCI (mo)
SCI (n=11)	B06	41	F	170	56	C4	B	72
	A38	37	F	175	51	C4	A	252
	A43	30	M	188	95	T2	A	11
	B11	23	M	173	84	C5	B	96
	B13	31	M	180	97	C7	C	36
	B17	42	M	191	99	C5	B	15
	C30	18	F	168	42	C4	C	12
	B19	39	M	188	82	C6	B	7
	C26	33	M	183	75	C7	C	6
	A58	40	M	178	104	C3	A	22
	C34	20	M	193	64	C4	C	55
	Mean ± SD	32±9	3 F and 8 M	181±8	77±21	NA	NA	53±72
NI (n=10)	Mean ± SD	33±10	2 F and 8 M	173±10	75±12	NA	NA	NA

NOTE. AIS categories A and B represent motor complete and C and D represent motor incomplete SCI.
Abbreviations: AIS, American Spinal Cord Injury Association Impairment Scale; F, female; M, male; NA, not available; NI, noninjured.

training is a widely used technique in clinical practice, but the consistent benefits of this intervention are somewhat contentious because of poor understanding of the underlying therapeutic mechanisms.[25-27] The objective of this study was to investigate the effects of pressure threshold inspiratory-expiratory training, termed here as a *respiratory motor training* (RMT), on pulmonary function and orthostatic stress−mediated cardiovascular and autonomic responses. It was hypothesized that RMT improves baroreflex responses and respiratory-cardiovascular interactions in patients with SCI-induced OH. This technique has never been evaluated for its ability to improve blood pressure regulation in individuals with SCI.

Methods

Material

Informed consent was obtained as approved by the Institutional Review Board for Human Research of the University of Louisville according to the inclusion criteria: at least 18 years of age; a minimum of 6 months since SCI; no ventilatory dependence; and OH defined as a decrease in arterial systolic blood pressure (SBP) of at least 20mmHg or a decrease in diastolic blood pressure (DBP) of at least 10mmHg or more upon changing from the supine position to the upright posture.[2] Individuals with painful musculoskeletal dysfunction; unhealed fracture; contractures; clinically significant depression or ongoing drug abuse; cardiovascular, respiratory, bladder, or renal diseases unrelated to SCI; human immunodeficiency virus/AIDS-related illness; anemia, hypovolemia, pregnancy, endocrine, and neurological diseases were excluded from this study.

List of abbreviations:

DBP diastolic blood pressure
HF high-frequency
LF low-frequency
OH orthostatic hypotension
PSD power spectral density
RMT respiratory motor training
SBP systolic blood pressure
SCI spinal cord injury

Clinical assessment

Eleven participants with SCI and 10 physically (age, sex, height, weight) matched noninjured controls participated in this study. The neurological level and completeness of the spinal cord lesion were determined using the American Spinal Cord Injury Association Impairment Scale.[28] Seven participants were classified as having motor complete SCI, and 4 participants were diagnosed with motor incomplete SCI ranging from C_3 to T_2 (table 1).

Pulmonary function test

Standard spirometrical measurements (forced vital capacity, forced expiratory volume in one second, maximal inspiratory pressure, maximal expiratory pressure)[13,29,30] were assessed as described previously.[31]

Orthostatic stress test

A sit-up test with continuous recordings of blood pressure, heart rate, and respiratory rate was used for the diagnose of OH and for beat-to-beat data acquisition at 1000Hz, and those recordings were analyzed using MATLAB software.[32,33,a] SBP and DBP were acquired from a finger cuff using Portapres-2[b] and ML880 PowerLab 16/30[c] systems. Brachial blood pressure measurements using a Dinamap V100[d] were acquired at the beginning and end of each position phase to calibrate the beat-to-beat blood pressure values. The ML132 3-lead II electrodes[c] and Inductotrace system bands[e] were used to record electrocardiograms and to assess the respiratory rate.[32]

Hemodynamic variables (presented as mean ± SD) were calculated for 5-minute intervals from 15 minutes of the supine position, 1-minute intervals from the first 3 minutes of sitting, and 3-minute intervals from 3 to 15 minutes of the sitting position. Power spectral density (PSD) of heart rate, PSD of blood pressure, and respiratory rate were calculated for 5-minute intervals in both positions. Each interval was linearly detrended, and power spectral density was estimated using Welch's averaged periodogram method (500-point windows with 50% overlapping segments). Mean power spectral density was calculated for low-frequency (LF) (.04−.15Hz) and high-frequency (HF) (.15−.40Hz) regions