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Case Report

Metabolic and cardiopulmonary responses to acute progressive resistive exercise in a person with C4 spinal cord injury

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Study Design: Single-subject (female, 38 years of age) case.
Objectives: To describe metabolic and cardiopulmonary responses to progressive resistive exercise in an individual with C4 ASIA A tetraplegia, and to review the relationship between level of spinal cord injury (SCI) and exercise responses.
Setting: Large, urban mid-western city rehabilitation hospital in United States of America.
Methods: Bilateral shoulder elevation/depression (shoulder shrug) exercise with two different resistances (0.7 kg/shoulder, 1.4 kg/shoulder) at two different frequencies (20 min., 40 min.), for 2 min per bout, deployed in a discontinuous protocol.
Results: Compared to rest heart rate (HR), exercise HR increased the greatest (13 bpm) for the 1.4 kg resistance at 40 min. and the least (6 bpm) during the 0.7 kg at 20 min. Blood pressure (BP) response was lower than resting BP for all four exercise conditions with the lowest (74/56 mmHg) at 1.4 kg at 40 min. Oxygen uptake was highest (4.6 $ml \cdot kg^{-1}\ min^{-1}$) during 1.4 kg at 20 min and V_E was greatest (18.2 L/min) during 1.4 kg at 40 min. Rate of perceived exertion (RPE) was the highest (17) during the 1.4 kg at 40 min.
Conclusions: Progressive resistance exercise provoked intense perceived physical effort, but only small metabolic and cardiopulmonary increases in a person with C4 SCI. Exercise recommended at a 'somewhat hard' intensity should avoid significant hypotension and still impressively increase oxygen uptake and ventilation compared to rest. An inverse relation between level of injury and aerobic responses may extend rostrally to the C4 level.
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Introduction

Cervical spinal cord injury often results in profound impairment of exercise capacity. Most devastating is injury above the 5th cervical segmental which reduces skeletal muscle mass innervation to only the head, neck, and proximal shoulder.[1] Although reduced muscle mass is a fundamental contributing factor in diminished exercise cardiopulmonary and metabolic responses, autonomic dysfunction compounds the problem particularly in cervical segmental level injury. Failure of sympathetically driven cardiac acceleration and contractility mechanisms along with venous pooling results in severely reduced cardiac output. This further results in decreased blood volume and oxygen delivery to exercising muscle.[2]

Level of injury appears to be strongly associated with maximum oxygen uptake (VO_2 max).[3,4] At least 60% of VO_2 max is contingent upon the availability of innervated skeletal muscle mass in untrained persons.[5] Although injuries above the 5th cervical segment could be expected to follow this inverse relationship, and be considerably less, there are no published data. Consequently, the purpose of this single-subject case study was to describe metabolism (oxygen uptake) and the cardiopulmonary system responses (heart rate, blood pressure, ventilation) to voluntary exercise in a person with C4 (ASIA A) tetraplegic, and review the relationship between level of SCI and exercise responses.

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Case description

The subject was a 38-year-old woman who sustained a traumatic SCI in a motor vehicle accident over 3 years ago. During the past year the subject has been more fatigued than usual and complained of occasional lightheadedness and visual disturbances. Additional history was remarkable for sedentary lifestyle, weight gain of 9.1 kg over the past year and recent diagnosis of hypercholesterolemia. The subject used an electric wheelchair for mobility, controlled by head movements.

Physical examination showed the subject was 155 cm tall, weighed approximately 82 kg, blood pressure was 98/68 mmHg, and respirations 16 min. Auscultation of heart in a seated position found S_1-S_2 normal, no S_3-S_4 sounds with an apical sinus rate of 98 bpm. Auscultation of the lungs revealed reduced breath sounds with no abnormal or adventitious sounds. Shoulder range of motion for elevation and depression were within normal limits and painless, bilaterally, Clinically, complete motor and sensory loss were evident below the C4 segmental level.

Resting pulmonary values included tidal volume of 380 ml thus producing an expired ventilation volume of 6.1 $l{\cdot}min^{-1}$. Her resting oxygen uptake was 2.3 $ml{\cdot}kg^{-1}\ min^{-1}$ (see Table 1).

This single-subject case study design, approved by the Wayne State University Human Investigation Committee as part of an aerobic capacity project, used a discontinuous exercise protocol. Study was conducted in the Rehabilitation Physiology Laboratory of the Brasza Clinical Rehabilitation Research Unit at the Rehabilitation Institute of Michigan.

Methods

Before exercise, the subject was seated with the trunk at 70° angle relative to horizontal and forearms supported with shoulders in fully depressed position. Exercise included bilateral shoulder elevation and depression or commonly termed 'shoulder shrug.' This exercise was used since it appeared to maximize the most available voluntary musculature. Resistance was added by weighted sleeves of 0.7 and 1.4 kg, draped over the trapezeii musculature without contacting wheelchair seat back. Repetitive shoulder shrugging was performed in four stages of exercise with approximately a 3-min recovery period between each stage. The 3-min recovery period was sufficient between each exercise stage to minimize residual fatigue. The first stage was done at a shoulder shrug movement frequency of 20 min with 0.7 kg/shoulder as resistance. The second stage was done at 40 min., again with 0.7 kg/shoulder resistance. The third and fourth stages followed the same movement frequency pattern respectively, but with 1.4 kg/shoulder resistance. Each shoulder shrug movement stage lasted approximately two minutes except for the last stage, which secondary to excessive fatigue, was 1 min and 2 s.

Oxygen uptake (VO_2) was determined via gas analysis with open circuit spirometry. O_2 and CO_2 were continuously sampled and measured for each breath by a Jaeger, Oxygon Alpha metabolic system. Values were averaged and recorded every 30 s. Heart rate (HR) was determined by 12-lead electrocardiogram, which was continuously monitored. Blood pressure (BP) was measured by the ausculatory method using the brachial artery and with the first and last sounds recorded immediately after each stage of exercise. Ventilation volume (V_E) was determined for each breath by a pneumotach (triple V volume transducer by Jaeger) and the average was recorded every 30 s. Rate of perceived exertion (RPE), a measure of overall exercise effort, was determined by asking the subject how difficult the exercise was after each stage.

Results

Results showed that all parameters increased except BP (see Table 1) with VO_2 peaking (4.6 $ml{\cdot}kg^{-1}\ min^{-1}$) during the 3rd stage. HR was elevated the greatest (113 bpm) during the 4th stage while BP was the greatest (82/60 mmHg) during the 1st stage. Blood pressure during exercise decreased in every stage compared to rest. V_E (18.2 liters min^{-1}) and RPE (17) were the greatest during the 4th stage of exercise.

Discussion

The person with C4 (ASIA A) tetraplegia increased oxygen uptake 100% greater during the most strenuous exercise as compared to rest. However, the difference between these two oxygen uptake values achieved was less than 150 $ml{\cdot}min^{-1}$. Metabolic variations of less than 150 $ml{\cdot}min^{-1}$ between increasing workloads are

Table 1 Metabolic and cardiopulmonary values during rest and exercise

Metabolic and cardiopulmonary parameters	*Rest*	*Exercise 0.7 kg @ 20 min*	*Exercise 0.7 kg @ 40 min*	*Exercise 1.4 kg @ 20 min*	*Exercise 1.4 kg @ 40 min*
VO_2 ($ml{\cdot}kg^{-1}\ min^{-1}$)	2.3	3.1	3.6	4.6	4.1
HR (bpm)	98	106	110	112	113
BP (mmHg)	98/68	82/60	80/60	78/60	74/56
V_E ($liters{\cdot}min^{-1}$)	6.1	10.4	14.9	17.4	18.2
RPE (6–20)	N/A	9	13	15	17

suggestive of steady and similar output. Although the RPE to complete the exercise was rated as 'hard' the small oxygen variation between rest and strenuous exercise was probably secondary to very limited muscle mass under corticospinal control. A further reduction in oxygen uptake during exercise was observed during the final resistive stage and was suggestive of decreased stroke volume secondary to minimal venous return. Peripheral and central fatigue probably were hastened by the progressive order of resistance employed in the study which required greater metabolism and skeletal muscle tension as the stages increased in resistance/workload.

The peak oxygen uptake ($4.6\ ml \cdot kg^{-1}\ min^{-1}$) during shoulder elevation resistive exercise was at least 15% lower than reported for C5 or C6 lesions during arm pedaling ergometry.[5] Peak exercise VO_2 values for sedentary persons with C5–C8 cervical lesion injuries were up to 75% greater than the subject in this study.[5,6] Together these data suggested an inverse relation between lesion level and aerobic capacity extending to the C4 level. This appeared to be the same type of relationship existing within the remaining cervical cord segmental levels.

The 113 bpm peak exercise heart rate, during the greatest workload (1.4 kg shrugged at 40 min.), was 15% greater than rest heart rate and was within 5% of the mean maximum seen in comparable cervical injury regardless of prior exercise training.[5,6] The difference in exercise heart rate was similar to the minimum 15% VO_2 difference observed for lower cervical lesions[5] suggesting that exercise muscle mass is equally or perhaps more critical for oxygen uptake elevation than heart rate response. Exercise heart rate elevation has been linearly related to oxygen uptake.[7] This relationship was even observed when neuro-intact subjects were paralyzed but still showed an increase in heart rate probably secondary to unblocked small type III, IV fiber metabolic demand.[8] Consequently, during metabolic demand, heart elevation attempts to maintain sufficient oxygen delivery. However, in cervical level SCI the primary mechanism for heart rate increase during exercise is withdrawal of vagal inhibition, in the absence of sympathetic innervation.[9]

Interestingly the progressive and consistent fall in exercise blood pressure with increasing workloads is similar to what has been observed in lower cervical segmental injuries.[8] The subject concomitantly reported mild to moderate lightheadedness as the exercise increased in intensity from stages 1 to 4, suggesting autonomic dysfunction. Normally BP rises during exercise accommodating increased metabolic demand by the skeletal muscle.[10] However, the small exercise muscle mass not only minimized demand but also diminished venous return.[11] Subsequently, low stroke volume, secondary to venous pooling and diminished venous return, probably further reduced left ventricular outflow and systolic pressure. Failure of adequate systolic pressure further exacerbated poor exercising muscle perfusion and resulted in a hypotensive response. The subject's performance was likely reduced by decreased arterial pressure. However, the fall in systolic pressure was less than the 29 mmHg reported to diminish performance.[12] Perhaps in a subject with a greater muscle mass without corticospinal control where arterial pressures increases are limited, a threshold value less than 29 mmHg may be critical.

Minute ventilation (V_E) increased as the exercise intensity increased. V_E was almost three times greater than resting level during the most resistance (1.4 kg) at the greatest frequency (40 min.). Since these values showed the greatest variation of any metabolic or cardiopulmonary parameter, at least the shoulder shrug exercise appears to be an effective breathing exercise. Although exercise V_E increased more than any other parameter it was low when compared to persons with C5–C6 injury.[9]

RPE appeared correlated with V_E. That is, as RPE increased with exercise intensity, minute ventilation also increased. RPE was highly correlated with work intensity and V_E in persons without SCI.[13] Consequently, even though the subject had limited working muscle mass it appeared that RPE was a reliable indicator of lung function and work intensity during exercise.

Conclusions

Bilateral shoulder shrug progressive resistive exercise performed at self-perceived 'hard to very hard' levels provoked small increases in metabolism and cardiopulmonary function for a sedentary person with a C4 SCI (ASIA A). These limited findings are also suggestive of hypotensive symptoms in spite of peak exercise oxygen uptake and ventilation responses being two or three times greater than rest levels. However, the results suggest that even with a C4 SCI, resistive exercise was completed without major problems. Consequently, recommending similar 'shoulder shrug' resistive exercise movements, cognizant of the minimal potential gains in cardiopulmonary and skeletal muscle fitness, appears warranted. A suggested exercise intensity RPE of 'somewhat hard' should provide a relative overload stimulus without significantly risking hypotensive symptoms.

An inverse relationship between level of injury and metabolic and cardiopulmonary responses to exercise may extend rostrally to the C4 segmental level. Further longitudinal study is needed to confirm whether several months of acute exercise described in this study would be sufficient to elicit physiological training effects.

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