Research article

Feasibility for developing cardiovascular exercise recommendations for persons with motor-complete paraplegia based on manual wheelchair propulsion; A protocol and preliminary data

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Background: The Center for Disease Control, American Heart Association, and American College of Sports Medicine recommendations for duration and intensity of exercise are based on the amount of energy expenditure required to maintain cardiovascular health in able body individuals; 1000 Kilocalories (Kcals) per week of energy expenditure has been demonstrated to achieve this effect. Manual wheelchair propulsion (MWP) represents a practical and accessible form of exercise for individuals with paraplegia.

Objective: To describe a method to determine the duration of MWP required to expend 1000 Kcals, when performed by individuals with paraplegia due to motor-complete spinal cord injury (SCI).

Study Design: Cross-sectional study.

Setting: Rehabilitation Research Laboratory.

Participants: Sixteen adults with motor complete T3-T12 paraplegia (body mass index < 35, duration of paraplegia > 3 months).

Interventions: Not applicable.

Main Outcome Measures: Indirect calorimetry during MWP was measured in order to calculate caloric expenditure per minute. These data were used to calculate the number of minutes of MWP required to expend 1000 Kcal in one week.

Results: During MWP, participants expended 3.3 ± 1.0 Kcal/minute. Based on this figure, 1000 Kcal of energy expenditure in one week would require 303 minutes of MWP per week, or 43.3 minutes per day, 7 days per week.

Conclusions: Our data suggest that it is feasible to create a practical and accessible exercise recommendation based on manual wheelchair propulsion for individuals with paraplegia due to motor-complete SCI. Larger studies are needed in order to develop accurate exercise recommendations for persons with SCI.

Keywords: Exercise, Guideline, Spinal cord injuries, Paraplegia, Wheelchairs

Introduction

Cardiovascular disease (CVD) is the leading cause of death in the United States; and the benefits of physical

activity for the maintenance of cardiovascular health are well described.¹ The Center for Disease Control (CDC), the American Heart Association (AHA), and the American College of Sports Medicine (ACSM) recommend 30 minutes of moderate intensity activity performed most days of the week in order to maintain

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cardiovascular health in able bodied individuals.¹⁻³ Brisk walking is the most frequently referenced form of moderate intensity physical activity.¹ The ACSM further highlights a significant benefit in cardiovascular health when an individual expends 1000 Kilocalories (Kcals) of energy per week through exercise.³ For the able-bodied individual, brisk walking should be done at least 30 minutes a day for five or more days a week, which equates to at least 150 minutes of moderate intensity activity each week. This activity can be accumulated in 10 minute bouts throughout the day in order to meet the 1000 Kcal weekly energy expenditure requirement.^{1,3}

Epidemiological data suggest that CVD has now surpassed renal and respiratory complications as the leading cause of death in persons with chronic spinal cord injury (SCI).⁴ The high risk for CVD can be explained, in part, by the reduced daily energy expenditure in individuals with SCI compared to the able-bodied population. Reasons for this lack of equivalency in energy expenditure in SCI include organic factors such as reduced active muscle mass, lower resting metabolic rate, decreased sympathetic activity, and lower thermal effect of food.⁴⁻⁶ This is compounded by reduced physical activity, lack of opportunity to exercise, limited access to exercise equipment, and a paucity of formal exercise guidelines for this population.⁴ Collins and colleagues demonstrated that resting oxygen consumption (VO_2) is lower in individuals with SCI, such that 1 metabolic equivalent (MET) should be defined as 2.7 ml $\text{O}_2/\text{kg}/\text{min}$, rather than standard 1 MET = 3.5 ml $\text{O}_2/\text{kg}/\text{min}$ in able-bodied adults.⁷ Therefore, quantification of physical activities in SCI must be approached differently than for able-bodied individuals.

There are few well-defined cardiovascular fitness recommendations for people with SCI. ACSM published aerobic exercise guidelines for people with paraplegia and quadriplegia that were extrapolated from exercise recommendations for able-bodied individuals.⁸ None of these physical activity recommendations take into account the differences in energy expenditure between people with SCI and able-bodied individuals. Abel *et al.*⁹ used specific calorie expenditure amounts of various recreational activities to develop target durations of training sessions of each activity, for individuals with SCI. Activities included wheelchair racing, arm cranking, and assorted wheelchair ball sports. These guidelines have limited generalizability because they apply only to individuals who participate in sports or have access to specialized equipment. Ginis and colleagues created exercise guidelines specifically designed for individuals with SCI. While these are

based on systemic review of the literature, the authors emphasize that they are limited by the quality of the component studies on which they are based, which are methodologically flawed in general.¹⁰ They also do not provide suggestion as to a practical means of achieving physical activity goals.

Manual wheelchair propulsion (MWP) represents a readily available and commonly used form of physical activity for people with SCI. Collins and colleagues reported on energy expenditure data during manual wheelchair propulsion, though this was done in a heterogeneous population of individuals with cervical to lumbar SCI with both complete and incomplete injuries.⁷ The purpose of this communication is to describe the duration of MWP required to expend 1000 Kilocalories (Kcals) of energy per week in individuals with paraplegia due to motor-complete thoracic SCI. By calculating caloric expenditure instead of energy utilization based on METs multiplied by duration of time, our study avoids the confounding factor of the inherent lower resting energy expenditure in individuals with SCI, and the uncertainty of how many MET-minutes or "SCI" MET-minutes (as defined by Collins *et al.*)⁷ are required for cardiovascular benefit. We report preliminary data that is not meant to serve as an exercise recommendation, but rather to create a foundation and a description of a protocol for larger studies that could establish accurate, practical exercise recommendations for individuals with SCI, analogous to the CDC, AHA, and ACSM guidelines for able-bodied individuals.

Methods

This study was approved by the Institutional Review Board at the university associated with the academic rehabilitation center where this study was performed.

Study sample

Participants with motor-complete (American Spinal Injury Association A or B) SCI below T2 level injury were recruited for the study. Participants were included if they were age 18 years or older, had paraplegia of either traumatic or non-traumatic origin, had duration of paraplegia more than 3 months, were able to use a manual wheelchair in the community, had ability to transfer from a wheelchair to level surface independently, and had a body mass index (BMI) of less than 35. Exclusion criteria included: presence of active wounds or pressure sores, known cardiac disease, or upper limb weakness or injury. Participants were recruited through flyers posted in the hospital, phone calls, mailings, and direct contact from primary investigators.

Procedures

All data were collected in a research lab within a rehabilitation center. Level of injury, weight, and height were recorded per chart review. Participants were not specifically instructed to eat or fast, exercise or not exercise prior to data collection. An investigator performed a physical exam at the start of each session. Metabolic activity data was collected during a single trial at rest, and during two MWP trials on a hard level surface. The COSMED K4b2 (COSMED, Rome, Italy), a portable device that measures pulmonary gas exchange and caloric expenditure by indirect calorimetry, was used for data collection. It has been utilized in other similar studies for the measurement of energy expenditure during various physical activities.⁷ Calibration of the COSMED K4b2 was done prior to each participant data collection session. The participant's height, weight, and age were entered into the device, and the maximum HR was automatically set. The mask of the K4b2 device was secured over the participant's mouth and nose. The device itself was fastened to the participant's back. The participant was instructed to breathe at a comfortable rate for a total of 6 minutes while seated upright in his or her own wheelchair. The first 0 to 3 minutes were allotted to reach steady state. Resting energy expenditure data was collected during the 3 to 5 minute interval, and the total resting period was completed by 6 minutes.

For the MWP task, participants were instructed to propel themselves in their own manual wheelchair along a hard-tiled level surface hallway for 6 minutes. It was emphasized that the participant should perform the task at his or her normal comfortable speed for any comparable hallway. Similar to the resting session, the first 3 minutes of MWP were allotted to reach steady state. Data were collected during the 3 to 5 minute interval, and the task was completed at 6 minutes. After the first trial, participants were allowed to rest for 10 minutes sitting upright in his or her own wheelchair, in order to return to baseline. No data were collected during this interval rest period. At the completion of 10 minutes of rest, the participant repeated the MWP task for a second time. Instructions to the participant for the data collection during MWP are provided below.

Instructions to participant for manual wheelchair propulsion—

Once the portable metabolic device and heart rate monitor are in place, push your wheelchair at a comfortable pace through the hallway. You should propel your wheelchair at the usual speed that you normally propel your wheelchair down

a typical hallway. This is not a race. Continue to push your wheelchair continuously for 6 minutes. After 6 minutes, the investigator will instruct you to stop. You will then rest for 10 minutes sitting upright in your wheelchair quietly. After 10 minutes of rest you will then repeat the wheelchair propulsion task a second time.

Statistical analysis

Upon completion of each participant testing session, the metabolic testing device was reconnected to the computer, and the COMS MED K4b2 software was used to produce a summary of the results. Energy expenditure data across the two MWP testing sessions was averaged for each individual participant, and the intraclass correlation coefficients were calculated to determine the reliability between the two testing sessions. The mean and standard deviation (SD) for age, time since injury, and BMI were calculated. The mean caloric expenditure in Kcals per minute of the single resting session and the two testing sessions for each participant and SD were determined. The mean number of Kcals/minute was used to derive the total number minutes per week of MWP needed to expend 1000 Kcals. Correlation coefficients with P-values were used to compare level of injury, age and BMI with energy expenditure (Kcal/min).

Results

Participants included 13 males and 3 females with SCI between the T3 and T12 levels, with an average age $\pm$ standard deviation (SD) of 36.0 ± 12.3 years, average time since injury of 12.1 ± 11.4 years, and average BMI of 27.2 ± 5.3 (Table 1). During MWP, participants demonstrated a mean heart rate of 103.1 ± 18.1 beats per minute, a $\text{VO}_2/\text{Kg}/\text{min}$ of 8.3 ± 2.0 , and expended 3.3 ± 1.0 Kcal/minute. The metabolic data at rest and during MWP is summarized in Table 2. The energy expenditure in Kcal/min for each individual participant is shown in Fig. 1. Based on this figure, 1000 Kcal of energy expenditure in one week would require 303 (range 233–435) minutes of MWP per week, or 43.3 (range 33.3–62.1) minutes per day, 7 days per week. Neither the level of thoracic SCI, age, or BMI significantly correlated with energy expenditure ($P > 0.05$, $P > 0.05$, $P > 0.05$, respectively).

Discussion

Cardiovascular disease (CVD) is now the leading cause of death in persons with chronic SCI.⁴ The existing literature focuses on changes in metabolic factors, including active muscle mass, autonomic nervous system

Table 1 Descriptive data of participants

Participant	Level Injury	Age (years)	BMI (kg/m ²)	Years Since Injury
1	T12	47	34.9	17.8
2	T10	26.4	24.8	1
3	T10	46.7	30.4	16.7
4	T11	37.8	25	20.9
5	T9	52.7	32.6	37.4
6	T3	29.1	23.7	8.8
7	T4	53.6	31.9	32.1
8	T10	29.3	31.9	6.3
9	T10	52.6	26.6	11.3
10	T4	25.7	28.7	0.6
11	T3	20	23.7	2.1
12	T11	47.7	19.2	11.3
13	T10	37	32.6	0.4
14	T6	23.3	24.6	5.7
15	T6	23.2	29	20.5
16	T10	23.2	15.7	0.9
Mean ± SD	—	36.0 ± 2.3	27.2 ± 5.3	12.1 ± 11.4
Range	T3 – T12	23 – 54	15.7 – 34.9	0.4 – 37.4

BMI—body mass index

cm—centimeters

Kg—kilograms

m²—meters squared

SD—standard deviation

activity, and resting metabolic rate, as an explanation for the elevated prevalence of CVD in individuals with chronic SCI.^{4–6} However, psychosocial factors also must be considered. In most communities, there is a lack of fitness resources that enable physical activity for people with SCI. Many physicians fail to counsel patients about the importance of exercise or provide concrete recommendations, particularly with regard to patients with SCI. Given the extraordinary importance of cardiovascular health in individuals with SCI, there is a need for specific exercise guidelines.

In order to achieve 1000 Kcal of weekly energy expenditure, the amount established to reduce the risk of

Table 2 Energy expenditure (mean ± SD) during rest and manual wheelchair propulsion

	Rest	Manual wheelchair propulsion
Heart rate (bpm)	80.7 ± 13.9	103.1 ± 18.1
Kcal/min	1.2 ± 0.5	3.3 ± 1.0
CO ₂ expelled (ml)	12.6 ± 6.6	31.5 ± 8.0
VO ₂ /weight (ml/kg/min)	3.0 ± 0.9	8.3 ± 2.0
VCO ₂ /VO ₂	0.75 ± 0.7	0.78 ± 0.07
MET ^a	0.9 ± 0.3	2.4 ± 0.6
SCI MET ^b	1.1 ± 0.4	3.1 ± 0.7
ICC	—	0.54

ICC = intraclass correlation coefficient of VO₂ measurements between the two trials of manual wheelchair propulsion.

^aBased on the standard for able-bodied individuals of 1 MET = 3.5 mlO₂/kg/min.

^bBased on 1 SCI MET = 2.7 mlO₂/kg/min proposed for individuals with motor complete SCI proposed by Collins *et al.*⁷

Figure 1 Caloric expenditure in Kilocalories per minute during manual wheelchair propulsion. The x-axis shows Kilocalories expended per minute. Each bar along the y-axis represents an individual participant, except the top bar, denoted “*Mean,” which shows the mean number of Kilocalories expended per minute of all participants.

cardiovascular disease,^{1,3} our data suggest that an average increase of 303 minutes per week of MWP at a self-selected comfortable pace per week would be adequate. This equals 43.3 minutes per day, 7 days per week of additional MWP in order to achieve cardiovascular benefit. To be commensurate with the CDC, AHA, and ACSM recommendations, this activity would have to be performed in bouts of at least 10 minutes. In order to maintain generalizability, we did not measure, nor would we propose a specific speed at which MWP should be performed. We again emphasize that this report of preliminary data is not meant to serve as an exercise recommendation, but rather to create a foundation and a protocol for larger studies that could establish accurate, practical exercise recommendations for individuals with SCI. Additionally, our data must be viewed within the context of certain limitations. We only studied participants with complete SCI. We would postulate that individuals with incomplete thoracic SCI may expend more than 3.3 Kcal/min given a greater lean muscle mass and potentially faster comfortable MWP speed compared to those with complete injuries. It also must be noted that these findings cannot be applied to individuals with cervical injuries as we only studied those with thoracic SCI. To speculate, individuals with complete cervical injuries may expend less than 3.3 Kcal/min given a lower lean muscle mass and potentially slower MWP speed compared to individuals with thoracic SCI, but this must be confirmed through further study. There was a fair amount of

variation in energy expenditure during MWP between participants. This could potentially be related to fasting versus fed state or whether a participant had exercised in close temporal proximity to the time of data collection. Another possible explanation is the presence of baseline differences in general cardiovascular conditioning. Some of the subjects may have had more lean body mass. We measured BMI, but this metric does not perfectly represent lean body mass. While we found no significant correlation between level of injury, age, or BMI and energy expenditure during MWP, in a larger sample, differences may have reached statistical significance. VO_2 data during a symptom-limited test such as arm-cycling was not collected prior to MWP testing, so we are unable to make comparisons of our data with peak exercise capacity. Finally, it must be considered that 1000 Kcal of energy expenditure per week could be too little or inadequate for the population with spinal cord injury. Additional studies will be needed to establish whether exercise surpassing 1000 Kcal of energy expenditure per week results in cardiovascular benefit specifically in individuals with SCI, as this has currently only been demonstrated in the able-bodied population.

Conclusion

Our data suggest that creating a practical and accessible exercise recommendation based on manual wheelchair propulsion for individuals with paraplegia due to motor-complete SCI is feasible. Larger studies are needed in order to develop an accurate exercise recommendation for persons with SCI.

Disclaimer statements

Contributors All of the authors participated in study design, data analysis, and manuscript preparation. Brian Liem and Peter Hwang additionally were responsible for subject enrollment and data collection.

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Conflicts of interest None of the authors have a conflict of interest.

Ethics approval Ethical approval was not required in addition to IRB protocol approval which was granted by Northwestern University.

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