Energy Cost of Lower Body Dressing, Pop-Over Transfers, and Manual Wheelchair Propulsion in People with Paraplegia Due to Motor-Complete Spinal Cord Injury

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Background: Energy required for able-bodied individuals to perform common activities is well documented, whereas energy associated with daily activities among people with spinal cord injury (SCI) is less understood. **Objective:** To determine energy expended during several basic physical tasks specific to individuals with paraplegia due to motor-complete SCI. **Methods:** Sixteen adults with motor-complete SCI below T2 level and duration of paraplegia greater than 3 months were included. Oxygen consumption (Vo_2), caloric expenditure, and heart rate were measured at rest and while participants performed lower body dressing (LBD), pop-over transfers (POTs), and manual wheelchair propulsion (MWP) at a self-selected pace. These data were used to calculate energy expenditure in standard metabolic equivalents (METs), as defined by 1 MET = 3.5 mL O_2 /kg/min, and in SCI METs using the conversion 1 SCI MET = 2.7 mL O_2 /kg/min. **Results:** Vo_2 at rest was 3.0 ± 0.9 mL O_2 /kg/min, which equated to 0.9 ± 0.3 standard METs and 1.1 ± 0.4 SCI METs in energy expenditure. LBD required 3.2 ± 0.7 METs and 4.1 ± 0.9 SCI METs; POTs required 3.4 ± 1.0 METs and 4.5 ± 1.3 SCI METs; and MWP required 2.4 ± 0.6 METs and 3.1 ± 0.7 SCI METs. **Conclusion:** Resting Vo_2 for adults with motor-complete paraplegia is 3.0 mL O_2 /kg/min, which is lower than standard resting Vo_2 in able-bodied individuals. Progressively more energy is required to perform MWP, LBD, and POTs, respectively. Use of the standard METs formula may underestimate the level of intensity an individual with SCI uses to perform physical activities. **Key words:** activities of daily living, metabolic equivalent, oxygen consumption, paraplegia, spinal cord injury

The amount of energy consumed by able-bodied individuals during performance of common daily activities is well defined,¹⁻⁴ but the energy cost of the performance of basic daily activities among people with spinal cord injury (SCI) is not well documented. Recent literature describes discrepancies between energy cost both at rest and during physical activities when able-bodied individuals are compared with people with chronic SCI.^{5,6} Bauman et al⁷ found a 10% lower baseline caloric expenditure in 13 individuals with SCI compared with their respective able-bodied monozygotic twins. Buchholz, McGillivray, and Pencharz⁵ and Buchholz and Pencharz⁸ reported

that the resting metabolic rate in individuals with SCI is overestimated by 5% to 32% when the standard conversion factor for calculating metabolic equivalents (METs) from measured oxygen consumption (Vo_2) is used, as this constant was designed for able-bodied individuals. Collins et al⁹ found a lower resting Vo_2 of 2.7 mL O_2 /kg/min in individuals with SCI, compared with the documented standard resting Vo_2 of 3.5 mL O_2 /kg/min in able-bodied individuals.

Because individuals with chronic SCI have a lower baseline metabolism, there is interest in defining the energy cost of various tasks in these individuals for the purpose of writing

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exercise prescriptions and potentially creating physical activity recommendations to improve cardiovascular health. Collins et al⁹ created a compendium of energy costs of various tasks commonly performed by individuals with paraplegia and quadriplegia due to both complete and motor-incomplete SCI with injury levels ranging from C5 to L4. Energy use data were reported for 27 different tasks that largely included sports activities such as arm cranking, weight training, and ball sports; between 2 and 20 subjects were studied for each task. Manual wheelchair propulsion (MWP) tasks on a hard surface, carpet, and grass were included. Measurements of the energy use during transfers or activities of daily living (ADLs) were not included.

The purpose of this study was to determine the Vo_2 and energy expenditure associated with common tasks in individuals with SCI — lower body dressing (LBD) and pop-over transfers (POTs) — that have never been reported in scientific literature and to provide additional data on MWP, specifically for people with motor-complete paraplegia.

Methods

Institutional review board approval was obtained, and all participants gave informed consent before the start of the investigation.

Study sample

Participants with motor-complete (American Spinal Injury Association Impairment Scale [AIS] A or B) SCI below T2 level were recruited for this study. Inclusion criteria were as follows: 18 years of age or older, paraplegia from either a traumatic or nontraumatic cause, ability to use a manual wheelchair in the community, ability to transfer from a wheelchair to level surface independently, and body mass index (BMI) less than 35. Individuals were excluded if they had active wounds or pressure sores, known coronary artery disease (CAD), heart failure, valvular or pulmonary disease, or upper extremity weakness or injury. Additionally, individuals with duration of paraplegia of 3 months or less were excluded to ensure resolution of spinal shock at the time of

testing. Participants were recruited through flyers posted in the hospital, phone calls, mailings, and direct contact by primary investigators.

Procedures

All data were collected in a research laboratory within a rehabilitation center. Level of injury, body mass, and stature were obtained from the most recent clinic visit (within 1 month). A single investigator performed a brief physical examination at the start of each participant session and conducted all testing.

Metabolic activity data were collected during a single baseline resting period while participants were sitting and during 2 trials each of LBD, POTs, and MWP on a hard level surface hallway. The COSMED K4b² (COSMED, Rome, Italy), a portable device that measures pulmonary gas exchange and calorie consumption, was used for data collection. It has been used in other similar studies and validated as a reliable measure of oxygen uptake.⁹⁻¹¹ Gas exchange was measured breath by breath. All breaths were included in analysis, and no breaths were excluded. This was recommended by the COSMED protocol and utilized in previous studies.^{11,12} The COSMED K4b² software was used to produce a summary of data, including our primary outcome measures: heart rate (HR), Vo_2 (expressed in $\text{mL O}_2/\text{kg}/\text{min}$), and caloric expenditure (in kcal/min). The first 3 minutes of activity were allotted to reach steady-state Vo_2 , and data for each activity were collected over the second 3-minute interval. The time required to reach steady-state Vo_2 was based on previously published data in individuals with SCI performing continuous aerobic activity.^{11,12} Although repeated performance of LBP and POTs could arguably be considered intermittent rather than continuous aerobic activity and therefore not requiring 3 minutes for a steady state to be achieved, we chose to collect the metabolic data in the same manner as the protocol used for the MWP task, allowing 3 minutes to achieve a steady state for consistency purposes.

Calibration of portable metabolic measurement device

Calibration of the COSMED K4b² mobile device was performed before each participant data

collection session using room air and a reference gas mixture with a known composition (16% O₂ and 5% CO₂).

Data collection at rest

Baseline initial resting data were collected while each participant was seated upright in his or her own manual wheelchair, as per previous protocols, rather than supine.¹¹⁻¹³ The mask of the COSMED K4b² device was secured in place over the participant's mouth and nose, and the device itself was strapped to the participant's back. The participant's stature, body mass, and age data were entered into the unit, and maximum HR was automatically set. The participant was instructed to breathe at normal resting rate while seated upright in his or her own wheelchair for a total of 6 minutes. The first 0 to 3 minutes were allotted to reach steady state. Primary data were collected during the 3- to 5-minute interval, and the total resting period was completed by 6 minutes. The participant then proceeded to the 2 trials of LBD, POTs, and MWP; the order of experimental trials was randomized for each subject. Instructions to the participants for the data collection at rest are shown below.

Instructions to participant. Rest—Once the portable metabolic device and heart rate monitor are in place, sit upright in your wheelchair quietly for 6 minutes and breathe at a normal resting pace. The investigator will tell you when the task is complete.

Data collection during LBD

Participants were instructed to continuously put on and remove their pants, shoes, and socks for 6 minutes. It was emphasized to the participants that they should perform the task at their normal comfortable pace. The first 3 minutes of LBD 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, the participants were allowed to rest for 10 minutes sitting upright in their 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 participants repeated the LBD task.

Instructions to participant. Lower body dressing—Once the portable metabolic device and heart rate monitor are in place, remove your pants, shoes, and socks as you would normally do at home for lower body dressing and then put your pants, socks, and shoes back on. You should simulate the normal pace that it takes you to perform this task at home. Perform this sequence of removing your pants, shoes, and socks and then putting these items back on as many times as you can comfortably during a 6-minute period. This is not a race to see how many you can do. 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 lower body dressing task a second time.

Data collection during POT

This protocol was identical to that described for LBD, except that LBD was replaced with continuously performed POTs.

Instructions to participant. Pop-over transfers—Once the portable metabolic device and heart rate monitor are in place, perform a pop-over transfer from your wheelchair to this [point to] level-surface exam table and then back from the exam table to your wheelchair. You should simulate the normal pace that it takes you to perform this transfer at home. Perform this transfer as many times as you can comfortably during a 6-minute period. This is not a race to see how many times you can transfer. 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 pop-over transfer task.

Data collection during MWP

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 participants should perform the task at their 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, the participants were allowed to rest for 10 minutes sitting upright in their 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 participants repeated the MWP task.

Instructions to participant. 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.

Statistical analysis

On completion of each participant testing session, the metabolic testing device was reconnected to the computer, and the COSMED K4b² software was used to produce a summary of the results. Primary data collected from the COSMED K4b² software included HR (beats/minute), Vo_2 ($\text{mL O}_2/\text{kg}/\text{min}$), and caloric expenditure (kcal/min). These data were then transferred to an Excel spreadsheet (Microsoft Excel, Microsoft Corp, Seattle, WA). The data from the 2 trials of each activity task—LBD, POTs, and MWP—were averaged for each participant.

Energy expenditure, as presented in both standard METs and SCI METs, was calculated from the primary data at rest and for the LBD, POTs, and MWP averages for each participant. Conversion of Vo_2 to METs was based on the definition of the standard 1 MET = $3.5 \text{ mL O}_2/\text{kg}/\text{min}$ for able-bodied individuals and 1 SCI MET = $2.7 \text{ mL O}_2/\text{kg}/\text{min}$, as proposed for individuals with paraplegia and quadriplegia.⁹ The SCI MET conversion has been utilized in several studies of energy expenditure in SCI.^{9,14,15} The mean and standard deviation (*SD*) for each of the outcome measures (HR, caloric expenditure, Vo_2 , METs, and SCI METs) for all 16 participants were calculated.

All statistical analyses were performed using IBM SPSS Software (IBM, Armonk, NY). Single-measure intraclass correlation coefficients (ICCs) were calculated to assess the reliability of Vo_2 between the 2 trials for each physical activity task. Analysis of variance (ANOVA) with post hoc Tukey-Kramer test was used to assess statistical differences in SCI METs across all of the activity tasks including rest, with the significance level set at $P < .05$. Correlation coefficients with

P values were used to compare age and BMI with the primary outcome measures (HR, caloric expenditure, Vo_2), standard METs, and SCI METs. A Kolmogorov-Smirnov test was used to confirm normal distribution of data. A t test was used to determine any association between gender and the primary outcomes, standard METs, and SCI METs. Linear regression was used to determine correlation between level of injury and Vo_2 at rest and for each task. The SCI METs results for each participant were additionally grouped by age; t test and ANOVA with post hoc Bonferroni correction were used to look for significant differences between age groups.

Results

Our study included individuals with motor-complete SCI between the T3 and the T12 levels. Thirteen of the 16 participants were male (81%). Demographic description of the sample is displayed in **Table 1**. Mean HR, caloric expenditure, Vo_2 , standard METs, and SCI METs at rest and during LBD, POTs, and MWP are displayed in **Table 2**. Reliability ICCs for the 2 trials for each physical activity are additionally displayed in **Table 2**. Average resting energy expenditure of participants with paraplegia was $3.0 \text{ mL O}_2/\text{kg}/\text{min}$. LBD required 4.1 ± 0.9 SCI METs; POTs required 4.5 ± 1.3 SCI METs; and MWP required 3.1 ± 0.7 SCI METs. Progressively more energy was required to perform MWP, LBD, and POTs, respectively. POTs required approximately 4 times the amount of energy as sitting quietly at rest. ANOVA with post hoc Tukey-Kramer test showed statistically significant

Table 1. Descriptive data of participants

	Mean $\pm$ SD	Range
Level of injury		T3-T12
Age, years	36.0 ± 12.3	23-54
Weight, kg	83.3 ± 19.4	47.6-125.0
Height, cm	174.6 ± 10.5	157.5-196.0
BMI, kg/m^2	27.2 ± 5.3	15.7-34.9
Years since injury	12.1 ± 11.4	0.4-37.4

Note: BMI = body mass index.

Table 2. Energy expenditure (mean $\pm$ SD) for rest and selected tasks in individuals with motor-complete thoracic paraplegia SCI

	Rest	LBD	POTs	MWP
HR, beats/min	80.7 $\pm$ 13.9	108.0 $\pm$ 19.6	107.7 $\pm$ 20.4	103.1 $\pm$ 18.1
Energy expenditure, kcal/min	1.2 $\pm$ 0.5	4.3 $\pm$ 1.0	4.6 $\pm$ 1.3	3.3 $\pm$ 1.0
Vo ₂ per weight, mL O ₂ /kg/min	3.0 $\pm$ 0.9	11.1 $\pm$ 2.3	12.1 $\pm$ 3.6	8.3 $\pm$ 2.0
MET [*]	0.9 $\pm$ 0.3	3.2 $\pm$ 0.7	3.4 $\pm$ 1.0	2.4 $\pm$ 0.6
SCI MET ^{**}	1.1 $\pm$ 0.4	4.1 $\pm$ 0.9 ^{a,b}	4.5 $\pm$ 1.3 ^{a,b}	3.1 $\pm$ 0.7 ^{a,c,d}
ICC ^{***}	—	0.87	0.92	0.54

Note: HR = heart rate; ICC = intraclass correlation coefficient; LBD = lower body dressing; MET = MWP = manual wheelchair propulsion; POTs = pop-over transfers; SCI = spinal cord injury; Vo₂ = oxygen consumption.

^{*}Based on the standard for able-bodied individuals of 1 MET = 3.5 mL O₂/kg/min.

^{**}Based on 1 SCI MET = 2.7 mL O₂/kg/min proposed for individuals with motor-complete SCI.

^{***}Intraclass correlation coefficient assessing reliability of Vo₂ between the 2 trials for each physical activity task.

^aSignificant difference between the physical task and resting ($P < .05$).

^bSignificant difference between the physical task and manual wheelchair propulsion ($P < .05$).

^cSignificant difference between the physical task and lower body dressing ($P < .05$).

^dSignificant different between the physical task and pop-over transfers ($P < .05$).

differences between energy expenditures of all tasks, with the exception of no significant difference between LBD and POTs. There were no significant correlations between age or BMI and any of the energy expenditure measures, nor were there significant differences between each age group and SCI METs, displayed in **Table 3**. **Table 4** displays the results by gender. Females had a lower resting energy expenditure than male participants and females expended higher SCI METs in order to complete each of the physical tasks compared to males, although these differences were not statistically significant. There were additionally no correlations between level of injury and Vo₂ at rest or during any of the activity tasks.

Discussion

We report a lower resting Vo₂ in individuals with SCI of 3.0 mL O₂/kg/min as compared with the commonly accepted value in able-bodied individuals of 3.5 mL O₂/kg/min. Thus, when energy requirements for physical tasks are calculated, the standard MET based on studies in the able-bodied population underestimates the level of intensity

required for individuals with SCI to complete a task and overestimates resting energy expenditure in individuals with SCI. This is consistent with results of multiple prior studies that confirm lower resting metabolism in individuals with SCI.⁵⁻⁹ Our value of Vo₂ at rest in individuals with SCI (3.0 mL O₂/kg/min) exceeds that which was published by Collins et al⁹ (2.7 mL O₂/kg/min). The authors of previous studies based their value on averaged data from individuals with motor-complete and motor-incomplete SCI and either paraplegia or quadriplegia, whereas our results are specific to individuals with motor-complete paraplegia.

We report an energy expenditure for MWP at a self-selected speed on a hard surface that is similar to that previously reported by Collins et al⁹ in individuals with upper level paraplegia. We also report novel energy expenditure for LBD and POTs at a self-selected pace. These data have implications for guiding health care professionals and trainers during continuous repetition of these functional tasks. Additionally, these data provide a foundation for creating exercise recommendations.

Our data demonstrate that continuously performing POTs requires more energy than LBD

Table 3. Results of energy expenditure in SCI METs (mean $\pm$ SD) for each physical activity by age group

Age, years	N	Rest	LBD	POTs	MWP
20-29	8	1.13 $\pm$ 0.47	4.13 $\pm$ 0.81	4.84 $\pm$ 1.03	3.42 $\pm$ 0.75
30-39	2	1.08 $\pm$ 0.22	4.37 $\pm$ 1.18	3.98 $\pm$ 1.25	2.57 $\pm$ 1.04
40-49	3	1.05 $\pm$ 0.24	3.81 $\pm$ 1.31	4.42 $\pm$ 2.72	3.07 $\pm$ 0.40
50-59	3	1.08 $\pm$ 0.15	4.15 $\pm$ 0.79	3.85 $\pm$ 0.26	2.43 $\pm$ 0.19

Note: LBD = lower body dressing; METs = metabolic equivalents; MWP = manual wheelchair propulsion; POTs = pop-over transfers; SCI = spinal cord injury.

Table 4. Results of energy expenditure in SCI METs (mean $\pm$ SD) for each physical activity by sex

Sex	n	Rest	LBD	POTs	MWP
Female	3	0.95 $\pm$ 0.35	4.15 $\pm$ 0.86	5.38 $\pm$ 1.60	3.23 $\pm$ 0.79
Male	13	1.14 $\pm$ 0.35	4.09 $\pm$ 0.89	4.25 $\pm$ 1.24	3.02 $\pm$ 0.76

Note: LBD = lower body dressing; METs = metabolic equivalents; MWP = manual wheelchair propulsion; POTs = pop-over transfers; SCI = spinal cord injury.

and that each requires significantly more energy than MWP. The greater involvement of trunk muscles and proximal stabilizers during LBD and POTs, compared with MWP, may account for this difference. Given the prevalence of cardiovascular disease (CVD) in the SCI population,¹⁶⁻²⁰ it is important to keep these relative energy costs in mind when functional training, therapy programs, and exercise protocols are designed. For example, during inpatient and outpatient SCI rehabilitation directed at training for independence in ADLs, the rehabilitation professional may encounter patients with a medical history of CVD who may be at risk for angina during physical exertion. Based on our findings, these patients should be able to complete MWP comfortably without symptoms or vital sign changes before attempting POTs or LBD independently.^{21,22} Further research is needed to determine whether and to what extent cardiovascular restrictions should be applied during therapy sessions and physical activity, particularly with respect to the intensity of each physical task.

CVD has surpassed renal and respiratory disease as the leading cause of mortality in individuals with chronic SCI.^{17,19,20} Epidemiological studies have estimated that approximately one-third of the population with SCI has CVD. This is thought to be

due to a greater frequency of risk factors including hyperlipidemia, diabetes, and metabolic syndrome in individuals with chronic SCI compared with the able-bodied population.¹⁶ Lack of accessibility to exercise, decreased thermal effect of food, and a lower resting metabolic rate due to reduced active muscle mass and decreased sympathetic activity have been cited as possible reasons for lower daily energy expenditure and the high rates of CVD risk factors in individuals with chronic SCI.^{5,6,8,19} In addition to these risk factors, sensory- and motor-complete SCI itself is an independent risk factor for CAD.^{16,18}

These preliminary MWP data could be used as a foundation on which to create exercise recommendations for individuals with paraplegia due to motor-complete thoracic SCI, analogous to the recommendations that have been published by the US Department of Health and Human Services (HHS), the American Heart Association (AHA), the Centers for Disease Control and Prevention (CDC), and the American College of Sports Medicine (ACSM) for able-bodied individuals.²³⁻²⁶ MWP is a relatively accessible and inexpensive activity on which to base exercise recommendations for individuals with SCI, in contrast to using wheelchair treadmills or arm-cycling devices for exercise, which require

access to specialized equipment or gyms. This concept is similar to the use of brisk walking as moderate-intensity physical activity for fitness as recommended by the HSS, AHA, CDC, and ACSM for able-bodied individuals. However, we must acknowledge that MWP is not necessarily always realistic or safe for all persons with SCI, because of the condition of sidewalks or outdoor environments in which some individuals live. A large-scale study of the energy requirement of MWP is warranted to establish generalized exercise recommendations for individuals with SCI.

Multiple studies in able-bodied individuals show a lower resting metabolic rate in women than in men that is independent of differences in body composition.^{27,28} We observed a similar relationship in our study population, although the result was not statistically significant. Female participants in our study expended higher energy during each of the physical activities compared with their male counterparts. It is difficult to make any conclusion from this, as again these results did not reach statistical significance and outcomes of separate studies assessing gender differences in energy expenditure during physical activities are inconsistent.²⁹⁻³¹ Our study only included 3 female participants. A larger sample size with a greater female-to-male ratio would be necessary to further assess these gender differences in energy metabolism in individuals with SCI. With the natural decline in muscle mass with increasing age, one would have anticipated age-related differences in energy expenditure as well. We did not observe any statistically significant differences in age for our primary outcomes. This again could be attributed to the small sample size, although little is known about how metabolic energy expenditure in adults living with SCI changes with aging. In our study, we did not ask participants to rate their exertion on a Borg Rating of Perceived Exertion scale,³² and we did not record distance traveled during MWP or repetitions performed during LBD or POTs. These are limitations of our study, as we cannot be certain that a “comfortable pace/effort” was consistent or equivalent in intensity between participants. However, we do not expect that all participants’

Borg scores or quantified output during these tasks would be equivalent. We believe that measuring energy expenditure with instructions to complete each task at a consistent self-perceived level of comfort, rather than at a particular Borg level or output goal, makes our results more generalizable. Peak VO_2 data from a symptom-limited test such as arm cycling were not obtained before our testing, so we are unable to make comparisons of our data with peak exercise capacity. Our study sample included individuals with paraplegia for less than 3 months such that the window of spinal shock was avoided; however, individuals with both subacute and chronic SCI were included. Our sample was too small to stratify with regard to subgroup difference based on duration of SCI. Thus, future study investigating differences between subacute and chronic SCI is warranted. Our criterion for inclusion of individuals with duration of paraplegia of more than 3 months was broad, so that we were able to recruit more participants, while still confidently excluding any individuals in spinal shock. We did not measure body mass at the time of testing, which may have affected the accuracy of our reported VO_2 as measured in $\text{mL O}_2/\text{kg}/\text{min}$, though these measures were typically taken less than 1 month before testing.

Conclusion

The resting VO_2 for adults with motor complete paraplegia from SCI is $3.0 \text{ mL O}_2/\text{kg}/\text{min}$, which is lower than that in able-bodied individuals. When performed continuously at self-selected effort levels, MWP (3.1 SCI METs), LBD (4.1 SCI METs), and POTs (4.5 SCI METs), respectively, require progressively more energy.

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The authors declare no conflicts of interest.

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