Effect of standing and sitting positions on energy expenditure in people with transtibial amputation compared to age- and sex-matched controls

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Abstract

Background: Energy expenditure (EE) is often greater in people with lower-limb amputation, compared with healthy controls, because of the biomechanical compensations needed to walk with a prosthesis. Compensatory movements are required to stand with a prosthesis; however, little is known about whether standing with a prosthesis also requires greater EE.

Objective: The goal of this study was to examine the effect of standing and sitting positions on EE in people with transtibial amputation and matched controls.

Study Design: This is a secondary analysis.

Methods: Energy expenditure data from people with unilateral, transtibial amputation because of nondysvascular causes were compared with data from age- and sex-matched controls without amputation. Energy expenditure was defined as the mean volumetric rate of oxygen consumed over the last 2 of 5 minutes in each position and measured with a portable breath-by-breath metabolic analyzer. Repeated-measures analysis of variance was used to examine the effects of position (sitting and standing) and group (amputation and control) on EE.

Results: A significant interaction effect indicated participants with amputation showed a significantly greater increase in standing EE relative to sitting EE (26.2%) than did controls (13.4%). Simple main effects showed EE in standing was significantly greater than EE in sitting for both groups, but there were no significant differences in EE between groups during sitting or standing.

Conclusions: Energy expenditure in standing, when measured relative to EE in sitting, is significantly greater in people with amputation. This result indicates that additional energy may be required to maintain an upright position with a lower-limb prosthesis.

Keywords

amputee, artificial limb, basal metabolism, energetics, prosthesis

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Background

Transtibial amputation results in the removal of physiological tissues that are integral to a person's ability to stand and walk. Although the structure of the foot and ankle can be replaced with a prosthesis, functionality and efficiency of movement with an artificial limb are limited when compared with an intact, healthy limb. A large number of studies over the past few decades have investigated whether the metabolic demands required to ambulate with a prosthesis are increased relative to healthy controls.[1-13] Predominantly, these studies have shown that transtibial prosthesis users require up to 30% more energy expenditure (EE) to walk than controls without amputation.[2-8,10-13] However, results from 2 recent studies also suggest that younger and more physically fit individuals with transtibial amputation, such as injured service members, may not require more energy to walk with a prosthesis than matched controls.[1,9] Although seemingly contrary to previous studies, the investigators suggested that the training, motivation, and extensive rehabilitation provided to these individuals might have contributed to their unique outcomes.[1,9]

The increase in walking EE reported in previous energetic studies is generally attributed to biomechanical factors such as the altered gait that is often adopted by people who walk with a prosthesis.[14-16] Although compensatory movements are more pronounced during walking, people with transfemoral and transtibial amputation also exhibit increased postural sway and greater imbalance during quiet standing.[17,18] Displacement of the center of mass in people with lower-limb amputation is higher in both the anterior–posterior and medial–lateral directions compared with controls without amputation.[17,19] It has also been noted that balance in people with lower-limb amputation is maintained through increased movements of the nonamputated limb and trunk,[18] likely because of the loss of proprioception and ankle control on the prosthetic limb. Thus, the energy required to stand may be greater in people with than without amputation because increased postural sway and increased center of mass displacement will require greater muscular activation and metabolic effort to maintain the standing position.[20]

To the best of our knowledge, there is limited evidence available to determine whether standing with a transtibial prosthesis requires greater EE than standing with a healthy, intact limb. One study of 10 transtibial prosthesis users conducted more than 45 years ago found that standing EE was increased by nearly 30%

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relative to controls.[4] However, the difference in standing EE between groups was not statistically significant, suggesting large variability within the study sample. Data from 2 more recent studies found small (<10%) but nonsignificant increases in standing EE in people with amputation compared with controls.[2,6] Results of these later studies are challenging to interpret as the investigators did not report whether EE was scaled to the participants' biological mass or mass with the prosthesis.[2,6] Another recent study, which scaled EE to participants' biological mass, found that service members with transtibial amputation required less energy when standing compared with controls.[1] The authors suggested that this unexpected finding might have been due to differences in cardiovascular fitness between the groups.[1]

One approach to addressing limitations in previous studies may be to evaluate differences between standing EE and sitting EE for each participant. Measuring changes in EE between positions could help to account for differences in individual participants' cardiovascular fitness. Consequently, we undertook this study to assess the effect of standing and sitting positions on EE in people with and without amputation. We also measured variability in EE to determine whether the groups were in a comparable steady state. We hypothesized that participants with transtibial amputation would require significantly greater EE in standing relative to sitting, when compared with control participants matched by age and sex.

Methods

A secondary analysis was conducted to evaluate sitting and standing EE in people with unilateral transtibial amputation compared with age- and sex-matched controls. Energy expenditure data from people with transtibial amputation were collected as part of a randomized crossover study conducted previously to assess EE associated with using energy-storing and crossover prosthetic feet.[21] Energy expenditure data from the session in which participants wore the energy-storing foot were used in this study because they are more generally prescribed to and used by lower-limb prosthesis users. Control participants without amputation were recruited for purposes of this study and tested using the same methods and metabolic measurement equipment. Data were collected from participants with amputation between May 2015 and January 2017, and from control participants between February 2018 and April 2018. Standardized surveys and physical measurements were used to characterize and compare participants with and without amputation.

Participants

Convenience sampling was used to identify volunteer participants with unilateral transtibial amputation and age- and sex-matched controls. Participants with amputation were recruited from local prosthetic clinics using posted flyers. Control participants were recruited from the local community using flyers posted in common areas throughout our university and through word of mouth with the investigators' personal and professional contacts. Eligibility criteria for all participants included aged 18 years or older; ability to walk for 6 minutes without assistance; no known metabolic, vascular, or respiratory diagnoses; and good health. All eligibility criteria were screened through self-report before enrollment. Additional eligibility criteria for the participants with amputation included unilateral transtibial amputation, nondysvascular etiology, at least 1 year postamputation, and use of a prosthesis with an energy-storing or crossover foot. To ensure that control participants had similar activity levels to participants with amputation, who were all classified as community ambulators or active adults, individuals were asked verbally to describe their activity level as "sedentary," "somewhat active," "active," or "very active." Those individuals who reported their activity level as "sedentary" were excluded from participation in this study. An endoskeletal prosthesis with a carbon-fiber socket, pin or vacuum suspension system, elastomeric liner, and energy-storing foot (Össur Variflex, Össur hf, Reykjavik, Iceland) was fabricated for participants by their prosthetist as part of our previous study.[21] A clinical investigator (ie, a certified clinical prosthetist) confirmed the fit, alignment, and function of each participant's prosthesis before testing. Participants with amputation were each provided one month of accommodation to the prosthesis before energetic testing. All participants (ie, with and without amputation) wore their own shoes during testing. Control participants were matched to participants with amputation in age (±5 years) and sex. All participants provided informed consent for the procedures, which were approved by a University of Washington Institutional Review Board.

Equipment

The volumetric rate of oxygen consumption (VO_2 in ml O_2/min) was collected through indirect calorimetry using a portable breath-by-breath metabolic analyzer (Cosmed K4b2, Rome, Italy).[22] The analyzer was calibrated before each session according to the manufacturer's recommendations.

Table 1. Participant demographics and clinical characteristics

Characteristic	Amputation (n = 27)		Control (n = 27)		*P*
	Mean	SD	Mean	SD	
Age, y	42.6	11.0	42.1	11.6	.87
Mass, kg	82.9	16.5	79.7	14.4	.44
Stature, cm	177.8	8.9	177.0	8.5	.74
Time since amputation, y	12.2	11.3			

	n	%	n	%
Sex, male	22	81.5	22	81.5
Smoking status	5	18.5	5	18.5

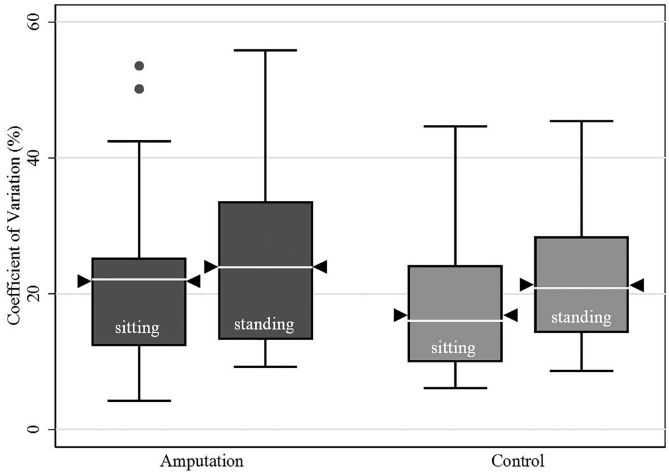

Figure 1. Energy expenditure variation in people with transtibial amputation and matched controls without amputation. Coefficients of variation are calculated over the final 2 minutes of a 5-minute trial in each resting position (ie, sitting and standing). Lines indicate median values, carets denote mean values, and dots indicate outliers

Procedures

Participants were asked to refrain from eating or exercising and from consuming caffeine one hour before their scheduled session to mitigate the immediate thermic effect of food on energy expenditure. Participants were otherwise encouraged to follow their normal daily routine in an attempt to capture representative variation in energy expenditure across the study sample.

Study visits were scheduled from 7:00 AM to 6:00 PM at a time convenient for each participant. Participants first completed a short survey that included demographic questions and 2 standardized self-report instruments (ie, the Charlson Comorbidity Index[23] and the Patient Reported Outcome Measurement Information System [PROMIS] Fatigue scale[24]). The survey administered to participants with amputation included additional questions about the participant's amputation and prosthesis. Stature (cm) and mass (kg) were measured with a height rod (Doran Scales DS1100) and digital scale (Eatsmart Precision Plus), respectively. Participants with amputation were weighed without their prosthesis.

The researcher then helped the participant to don the metabolic analyzer. Participants were asked to relax and refrain from activity (ie, moving or fidgeting) or interaction with the researcher during EE data collection. The participant was instructed to sit in a comfortable position for 5 minutes. Participants all sat in the same, standard height guest chair with a straight back and arms (43 cm height, 47.5 cm depth). After 5 minutes, the participant was asked to stand slowly and move into a comfortable standing position. Participants were allowed to stand in their desired standing position; exact placement of the feet was not controlled. One minute was allowed for transition, and then, the participant was asked to remain standing in position for 5 minutes. The researcher monitored the data telemetered from the metabolic analyzer to ensure proper operation of the equipment throughout the data collection period and verify that each participant achieved steady state (ie, a level plateau in the VO_2 data).

Analysis

Participant groups (ie, people with and without amputation) were compared to assess differences in age (years), mass (kg), stature (cm), smoking status (nonsmoker/smoker), comorbidities (none/1 or more), and self-reported fatigue (PROMIS T-score). Differences in continuous variables (age, mass, stature, and fatigue) were assessed with 2-tailed, independent *t* tests; differences in nominal variables (smoking status and presence of comorbidities) were assessed with chi-square tests.

Breath-by-breath VO_2 was averaged over 10-second intervals and extracted for analysis. Data from the last 2 minutes of sitting and standing were used for the analyses presented below. A 2-minute analysis period was selected because it has been used by other investigators who have assessed EE associated with rest or activity in people with lower-limb amputation.[1,7,11,25-27] Other steady-state periods (eg, last 1, 3, or 4 minutes) were also examined but produced the same outcomes as the last 2 minutes. Results of those analyses were therefore not reported.

Energy expenditure was defined as the VO_2, in ml O_2/min. The coefficient of variation (CV) in VO_2 was calculated to determine the variability of EE during sitting and standing. We deemed it important to characterize the variability in the EE data to assess whether the participants had achieved similar variation in EE during the last 2 minutes of the 5-minute sample period for each posture. Although we did not expect participants to achieve a true "steady state," that is, a minimal amount of EE variation as might be observed after resting in a prone position,[28,29] we wanted to ensure participants with and without amputation were in a similar state of variability so that we could compare differences in standing and sitting EE between groups.

Differences between standing EE and sitting EE were calculated to determine the increase in EE because of position. Differences between standing EE and sitting EE have been reported previously

Table 2. EE during sitting and standing activities

Characteristic	Amputation			Control		
	Mean	SD	95% CI	Mean	SD	95% CI
Sitting CV (%)	22.0	12.5	17.0-26.9	18.5	9.7	14.7-22.4
Standing CV (%)	23.9	11.8	19.2-28.6	21.6	9.6	17.9-25.4
Sitting EE (mL O_2/min)	305.0	84.2	271.7-338.4	317.5	62.3	292.9-342.1
Standing EE (mL O_2/min)	376.4	85.5	342.6-410.2	357.7	69.6	330.2-385.2
Standing–sitting EE difference (mL O_2/min)	71.4	61.1	47.2-95.6	40.2	38.4	25.0-55.4

Abbreviations: CV, coefficient of variation; CI, confidence interval; EE, energy expenditure.
Note that EE differences and ratios are calculated as mean of individual differences/ratios, rather than the difference/ratio of the mean sitting EE and mean standing EE.

for healthy controls and other clinical populations.[30] A 2-way repeated-measures analysis of variance (ANOVA), with one within-subject factor (ie, position: sitting and standing) and one between-subject factor (ie, group: participants with amputation and participants without amputation), was used to assess the effect of position and group on EE CV and EE. Energy expenditure and EE CV data were checked to ensure they met assumptions of the 2-way ANOVA (ie, presence of outliers, normality, and sphericity). Simple main effects analysis with a Bonferroni correction was conducted in cases where a statistically significant interaction effect was observed. A simple effects analysis is needed in these situations because the presence of an interaction affects the generalizability of the main effects. A cutoff of $\alpha = .05$ was used as an indicator of statistically significant differences for all comparisons.

Results

Twenty-seven participants with unilateral transtibial amputation and 27 controls without amputation were included in this study (Table 1). Most participants were male (n = 22 of 27 in each group). There were no significant differences in age ($P = .87$), mass ($P = .44$), stature ($P = .74$), or smoking habits ($P = 1.00$) between groups. Participants with amputation reported significantly higher fatigue compared with controls (PROMIS T-score = 49.3 vs 44.9, $P = .03$). A significantly greater number of participants with amputation also reported minor comorbidities (eg, asthma and arthritis) compared with controls (n = 6 vs n = 1, $P = .04$). Pretest routines did not seem to differ substantially between groups.

No significant interaction effects ($F(1,52) = 0.110$, $P = .741$, $\eta_p^2 = 0.002$) or main effects by group ($F(1,52) = 1.392$, $P = .244$, $\eta_p^2 = 0.026$) or position ($F(1,52) = 2.040$, $P = .159$, $\eta_p^2 = 0.038$) were observed for EE CV, indicating that EE variability was similar between groups and between positions (Figure 1, Table 2). The repeated-measures ANOVA revealed a statistically significant interaction between the effects of position and group on energy expenditure, ($F(1,52) = 5.031$, $P = .029$, $\eta_p^2 = 0.088$), indicating that participants with amputation showed a significantly greater increase in standing EE relative to sitting EE (26.2%) than participants without amputation (13.4%) (Figure 2, Table 2). Simple main effects analysis showed that standing EE was significantly greater than sitting EE in both participants with and without amputation ($P < .001$ for both group comparisons), but there were no significant differences between groups in sitting EE ($P = .54$) or standing EE ($P = .38$). Individual participant data are provided as an online supplement (Supplement Digital Content, http://links.lww.com/POI/A3).

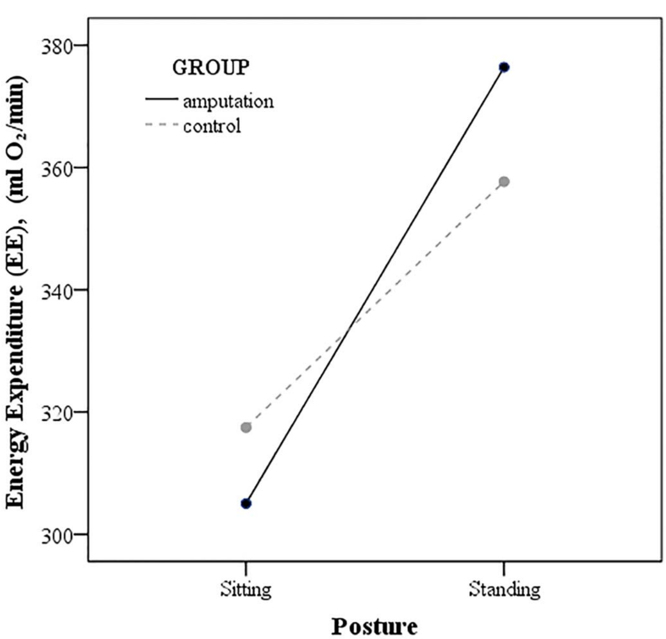

Figure 2. Estimated marginal means for EE in sitting and standing by group (participants with and without amputation). Compared with controls, participants with amputation experienced a significantly greater increase in standing EE relative to sitting EE (13.4% increase vs 26.2% increase, $P = .029$). EE, energy expenditure

Discussion

In this study, we evaluated the effect of sitting and standing positions on EE in people with and without amputation. Mean sitting and standing EE were similar between groups. However, we found a significantly greater increase in standing EE, relative to sitting EE, in people with amputation compared with controls. To the best of our knowledge, standing EE has not been compared with sitting EE in this population, so the 26.2% increase we measured in that group is difficult to place in context. However, the 13.4% increase measured in our control group was consistent with results reported previously for people without amputation. For example, Betts et al[31] found a 12.4% increase in energy expenditure from sitting to standing, using a resting protocol similar to this study (ie, sitting and standing in a comfortable position). A recent meta-analysis of 46 studies by Saeidifard et al[30] also concluded that adults, on average, expend 11.6% more energy in standing than sitting.

The significantly greater increase in standing EE, relative to sitting EE, in our group with amputation when compared with the control group suggests that maintaining an upright position requires greater energy when using a prosthesis. By contrast, other investigators have suggested that standing with a prosthesis does not affect energy expenditure[6,32] primarily because previous studies found no significant differences in standing EE between people with transtibial amputation and controls.[2,6,33] We also did not find a significant difference in standing EE between participants with and without amputation. However, because we measured EE in both positions, we found a disproportionate increase in EE between sitting and standing in participants with amputation. This increase might have been overlooked in previous studies that measured EE in only one position (ie, sitting or standing). The 26.2% increase in standing EE, relative to sitting EE, in our group with amputation is similar to the 25.6% increase found by Levine et al[34] in able-bodied participants when they were allowed to fidget while standing, relative to when they were seated. Like the fidgeting movements described by Levine et al, increased postural sway and center of mass displacement in people with amputation may illustrate how subtle movements can adversely affect EE.[35] This increase in EE seems to reflect the higher postural and balance demands required when standing with a prosthesis. Future studies are needed for further evaluation and should include the assessment of center of pressure and postural sway using simultaneous kinematic and kinetic analyses.

Given the results of our study, we suggest that additional research is needed to determine whether the increase in oxygen consumption in standing, relative to sitting, we observed in people with unilateral transtibial amputation, is clinically meaningful (eg, do people with amputation who stand for large portions of their day experience greater daily fatigue). Future research is also warranted to assess if the disproportionate increase in oxygen consumption between standing and sitting is magnified in people with higher levels of amputation (eg, transfemoral amputation) or in people with bilateral amputation.

We also calculated and compared CV in sitting and standing to assess whether EE variability was similar between groups. Energy expenditure CVs have not previously been reported in people with amputation but may serve as means by which investigators can assess comparable testing conditions (ie, other than visual observation of plateaus in the VO_2 data). We considered the possibility that people with altered metabolic processes, such as people with amputation, might require more time than controls to achieve similar levels of EE variability. However, we found that people with unilateral transtibial amputation did not exhibit significantly greater EE CV than controls in the last 2 minutes of a 5-minute test period. Consequently, this length of testing seems sufficient to achieve similar “steady states” in people with and without transtibial amputation. It is important to note that although the EE variability was not significantly different between groups, the mean CVs for both groups (ie, 22.0%-23.9% for people with amputation and 18.5%-21.6% for controls) were above the ≤10% threshold recommended for resting metabolic rate studies.[28,29] Similar to our results, Popp et al[36] reported a CV of 19.9% over 5 minutes in healthy, young adults. Ten minutes were needed to achieve a variability of ≤10% in that study.[28,36] Future study would be needed to determine whether 10 minutes would be sufficient to achieve this level of variability in people with transtibial amputation.

Limitations of this study include the relatively small sample size of 54 participants, most of whom were male. As our participants with amputation included mostly people classified as unlimited community ambulators or active adults (ie, n = 26 of 27 were K3 or K4 level ambulators), our results may not generalize to people with greater mobility restrictions (eg, those classified as limited community or household ambulators). Because all participants with amputation had amputation because of nondysvascular causes, the results may also not generalize to people with amputation because of dysvascular disease. Although participants in the study exhibited or reported similar activity levels (ie, they were all deemed to be community ambulators or active adults), participants were not individually matched by activity level. Furthermore, there are limitations because this study was performed as a secondary analysis. Additional information about participants’ body composition, such as fat-free and fat mass, would be useful to explain our results. A study of people without amputation showed that fat-free mass explains more variation in resting EE than fat mass.[37] Thus, it may be worthwhile in future studies to measure both fat and fat-free mass in participants with amputation to determine if a similar relationship exists. We did not assess body composition in either group because body composition was not assessed in the primary study that was the source of our EE data for participants with amputation.[21] Given that people with the same mass can have different body compositions, our ability to understand differences in EE between groups is limited. We also did not collect data regarding participants’ physical fitness. As fitness has been suggested as a possible reason why active individuals with transtibial amputation do not exhibit significant differences in EE relative to controls,[1,9] future studies should include variables associated with overall fitness (eg, VO_2max and muscular strength).

Finally, the mean sitting and standing EE values reported in this study are not truly minimum resting values because the pretest conditions were not strictly controlled through fasting and activity restriction. Participants were asked only to refrain from eating, exercising, or consuming caffeine one hour before the study. The original study from which we obtained participants’ with amputation data was intended to evaluate the walking energy expenditure of individuals engaged in typical activities.[21] As the goal of measuring sitting and standing EE in that study was just to capture a realistic baseline energy expenditure before the walking trials, participants’ pretest routines were not strictly controlled. However, as noted in this study, using the last 2 minutes of a 5-minute period of sitting or standing was sufficient to obtain a similar plateau and variability in EE data in both groups (ie, people with and without amputation). Thus, a 5-minute EE protocol may be sufficient for these purposes.

Conclusions

People with transtibial amputation showed a significantly greater increase in EE while standing relative to while sitting, when compared with age- and sex-matched controls without amputation. This may reflect the energy required to maintain an upright position with a prosthesis, but future research is needed to determine how the increased energetic demands of standing with a prosthesis may affect a user over the course of a day.

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Disclaimer

Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the University of Washington or the U.S. Department of Defense.

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