Assessment of Free-Living Daily Physical Activity in Older Claudicants: Validation Against the Doubly Labeled Water Technique

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Background. The purpose of this study was to compare physical activity assessed by monitoring devices and questionnaires with the criterion method of physical activity using doubly labeled water (DLW) in free-living peripheral arterial occlusive disease (PAOD) patients.

Methods. Twenty-two older nonsmoking PAOD patients with intermittent claudication (age = 68.7 ± 7.3 years, ankle/brachial index = 0.67 ± 0.21) were recruited from the Vascular Clinic at the Baltimore Veterans Affairs Medical Center. The energy expenditure of physical activity (EEPA) was calculated using DLW. Physical activity values were also obtained by activity monitors (an accelerometer and a pedometer worn on each hip over a 48-h period) and by three activity questionnaires (the Minnesota Leisure-Time Physical Activity, the Peripheral Arterial Disease Physical Activity Recall, and the NASA Johnson Space Center questionnaire).

Results. As expected, the claudicants were sedentary, as EEPA was 378 ± 190 kcal/day. The activity value from the accelerometer was highly correlated with EEPA, yielding a regression equation of EEPA (kcal/day) = 81.6 + (0.599 × accelerometer kcal/day); R = 0.834, R² = 0.696, standard error of estimate = 77 kcal/day, p = 0.001. The activity value from the pedometer was also correlated with EEPA, yielding a regression equation of EEPA (kcal/day) = 76.6 + (0.048 × pedometer steps/day); R = 0.614, R² = 0.377, standard error of estimate = 124 kcal/day, p = 0.002. None of the physical activity questionnaires was significantly correlated with EEPA, as the correlation coefficients ranged between 0.037 and 0.326.

Conclusion. Free-living daily physical activity of older PAOD patients with intermittent claudication can be accurately predicted with an accelerometer, and to a lesser extent with a pedometer, worn over a 48-h period.

A low level of physical activity is associated with increased risk of cardiovascular morbidity and mortality in apparently healthy subjects (1–3). The poor prognosis of a sedentary lifestyle may be further compounded in peripheral arterial occlusive disease (PAOD) patients with intermittent claudication, who have an 11-fold higher mortality rate than individuals free of PAOD (4). Consequently, the combination of low physical activity and the presence of atherosclerosis in the peripheral arteries may place claudicants in one of the highest at-risk groups for subsequent cardiovascular events.

Accurate measurement of daily physical activity in elderly claudicants is necessary before interventions can be designed to increase activity to a specific target level. Although questionnaires (5–7) and monitoring devices (8,9) are frequently used to determine activity levels, these instruments may not be sensitive enough to provide valid data in elderly PAOD patients, because claudicants are typically at the extreme low end of the activity spectrum (10). Therefore, a need exists to validate physical activity monitors and questionnaires against the technique of doubly labeled water (DLW), considered to be the criterion measure of free-living daily physical activity (11). Using this approach, the most valid activity monitors and questionnaires can be identified for assessing the physical activity of elderly claudicants in an expeditious and inexpensive manner.

The purpose of this study was to compare physical activity assessed via monitoring devices and questionnaires with the criterion method of physical activity using DLW and indirect calorimetry techniques in PAOD patients.

Methods

Patients

Recruitment.—A total of 22 PAOD patients from the Vascular Clinic at the Baltimore Veterans Affairs Medical Center were recruited. The gender and racial composition of the sample consisted of 20 men, 2 women, 10 Caucasians, and 12 African-Americans. All patients lived independently at home and were current nonsmokers. The smoking history of the group consisted of 5 patients who had never smoked and 17 patients who were former smokers, defined as not having smoked over the preceding year. The former smokers quit smoking 14 ± 13 years (mean ± SD; range 1–50 years) prior to investigation. None of the
patients was enrolled in an exercise rehabilitation program at the time of testing.

The inclusion criterion for entry into the study was a history of claudication pain secondary to PAOD. Claudicants were excluded for the following medical conditions: (a) leg pain while at rest, (b) ST-segment depression greater than 2 mm at rest, (c) exercise tolerance limited by factors other than claudication (e.g., dyspnea, fatigue, dizziness, arthritis), (d) exercise-induced leg pain not of cardiovascular origin. These criteria have been used in previous investigations (12–14). The procedures used in this study were approved by the Institutional Review Board for research involving humans at the University of Maryland at Baltimore. Written informed consent was obtained from each patient prior to investigation.

Measurements

Total daily energy expenditure.—Free-living daily energy expenditure was determined over a 10 day period using the DLW technique. Baseline urine samples were obtained and an oral dose of $^{3}H_2O$ and $^{18}O$ (0.075 and 0.15 g/kg body mass, respectively) was administered during the morning of Day 1. A weighed 1:400 dilution (dose:tap water) of the dose and water used for the dilution were saved and analyzed with each patient’s sample set. Two urine samples were obtained on the following morning (Day 2) and on the final day of the dosing period (Day 10). All samples were obtained between 0800 and 1200 h.

Samples were prepared for isotopic analysis of $^{3}H_2O$ and $H_2^{18}O$, as described previously (15). The time-zero extrapolated dilution spaces and turnover rates of the two isotopes were determined from the intercept and slope, respectively, of the semilogarithmic plot of isotopic enrichment versus time in days. These values were used to calculate the rate of carbon dioxide production from Equation 2 of Speakman et al. (16) assuming a dilution space ratio of 1.0472. Oxygen consumption was obtained by dividing rates of carbon dioxide production by a fixed respiratory quotient of 0.85, and this value was used to calculate daily energy expenditure from Equation 12 of de Weir (17).

Resting energy expenditure.—Oxygen consumption and carbon dioxide production were measured over 45 min of supine rest with a computerized open-circuit indirect calorimeter (Deltatrac Sensorsmedics Metabolic Monitor model 125, Anaheim, CA). Measurements were obtained between 0700 and 0900 h after an overnight fast. The oxygen consumption and carbon dioxide production were used to calculate resting energy expenditure (17).

Energy Expenditure of Physical Activity (EEPA).—After obtaining the daily and resting energy expenditures, EEPA was calculated as [(0.9 × daily energy expenditure) – resting energy expenditure], assuming that the thermic effect of food constitutes 10% of daily energy expenditure (18).

Physical activity monitors.—Physical activity level was monitored over two consecutive weekdays by a Caltrac accelerometer (Muscle Dynamics, Torrance, CA) and a pedometer (Omron Health Care Corporation, Vernon Hills, IL) attached to the belt of each patient and worn slightly anterior over both hips. Patients were instructed to wear the devices during their waking hours and to remove them before retiring to bed. The accelerometer assessed daily physical movements by recording vertical accelerations and decelerations of the body, and converted these movements into caloric expenditure during the 48-h monitoring period (8,9). The pedometer recorded the number of steps taken during this period. We have previously shown that these measures are highly reliable for assessing the physical activity level of PAOD patients, as the test–retest intraclass reliability coefficients between two 48-h monitoring periods separated by 1 week were $R = 0.84$ and $R = 0.86$ for the accelerometer and pedometer, respectively (10). Both monitors are easy to wear and do not interfere with the ability to perform activities of daily living. However, it is important for the monitors to be attached securely to the belt of each patient so that they are not inadvertently lost by slipping off the waist.

Physical activity questionnaires.—Physical activity habits over the past week, month, and year were assessed by three validated questionnaires. The Stanford 7-day physical activity questionnaire (6), modified specifically for PAOD patients (19), was administered to assess the amount of physical activities performed in work, leisure, and household settings. Specifically, the activities for each category were recorded and combined to yield a total duration (hours per week) and intensity (MET-hours per week) of physical activities performed during the preceding week.

The Johnson Space Center (JSC) physical activity scale was used to assess the activity level of the participants over the preceding month (5,20). The scale ranges from 0 (avoid physical activities whenever possible) to 7 (heavy physical activities done regularly for more than 3 hours per week). The participants were asked to select the number (0 to 7) that best described their general level of physical activity for the previous month. The JSC physical activity scale has a strong, independent relationship with maximal oxygen uptake in men and women between the ages of 20 and 79 years (5,21).

The Minnesota Leisure Time Physical Activity Questionnaire (LTPA) was administered to determine the activity level of the participants over the preceding year (7). The Minnesota LTPA yields an average daily energy expenditure of physical activity (kilocalories per day). During a structured interview, participants were asked whether they had performed various activities over the past year. For each activity performed, the frequency, duration, and intensity were multiplied to obtain a yearly total of energy expenditure (calories), which was subsequently divided by 365 to convert to a daily value. The Minnesota LTPA is highly correlated ($r = .83$) with the energy expenditure of physical activity (EEPA) derived by the DLW and indirect calorimetry methods in apparently healthy, elderly (67 ± 6 years) individuals (22). No relationship existed between the activity values obtained from each questionnaire and body weight, race, and gender of the patients.
Ankle/brachial index (ABI).—Participants refrained from drinking caffeinated beverages during the morning of testing. Participants rested supine for 10 min, after which ankle systolic blood pressure, brachial systolic pressure, brachial diastolic blood pressure, and heart rate were obtained. From these blood pressure measurements, ABI was calculated as follows: ankle systolic pressure/brachial systolic pressure.

Ankle systolic pressure was measured with a Parks Medical Electronics, Inc., nondirectional Doppler flow detector (model 810-A, Aloha, OR), a pencil probe (9.3 MHz), and standard-size ankle blood pressure cuffs (10 cm width). Measurements were taken from the posterior tibial and dorsalis pedis arteries in both legs. The higher of the two arterial pressures from the more severely diseased leg was recorded as the resting ankle systolic pressure. The test-retest intraclass reliability coefficient and coefficient of variation were \( R = 0.97\%\) and 12.8\% for ankle systolic pressure and \( R = 0.96\%\) and 12.5\% for ABI in a previous investigation (14).

Brachial blood pressures and heart rate were measured from both arms with a Critikon Dinamap Vital Signs Monitor (Tampa, FL; model 1846-SX), using either a standard adult-size blood pressure cuff (14 cm width) or a large adult-size cuff (17 cm width). Brachial systolic pressure, diastolic pressure, and heart rate were recorded from the arm yielding the higher systolic pressure. In a subsample of 44 participants tested twice in our laboratory within 2 weeks, the test-retest intraclass reliability coefficient and coefficient of variation were \( R = 0.84\) and 11.5\% for systolic pressure, \( R = 0.85\) and 8.9\% for diastolic pressure, and \( R = 0.88\) and 12.2\% for heart rate.

Body composition.—Height was recorded from a stadiometer (SECA, Berlin, Germany) and body weight was recorded from a balance-beam scale (Health-O-Meter, Inc., Bridgeview, IL) without shoes. From these measurements, body mass index was calculated as follows: weight (kg)/height \(^2\) (m\(^2\)). The minimal waist and maximal hip circumference values were obtained by trained exercise technicians with a steel measuring tape according to recent recommendations (23). The circumference values represent the mean of three consecutive measurements. From these measurements, the waist-to-hip ratio was calculated as follows: waist circumference/hip circumference. The percentage of body fat was determined by a total body scan with dual-energy X-ray absorptiometry (model DPX-L, LUNAR Radiation, Madison, WI) while patients rested supine after a 12-h overnight fast. All scans were analyzed by the same investigator using the LUNAR Version 1.3 DPX-L extended analysis program for body composition. The coefficient of variation for the measurement of percentage of body fat is 0.9\% using this technique (24).

Statistical Analyses

Pearson product moment and Spearman rank correlation coefficients \((r)\) were calculated to determine the relationship between EEPA and the activity values obtained from activity-monitoring devices and questionnaires. For each significant relationship, a regression equation was generated to estimate EEPA from the monitoring devices and questionnaires. Paired \(t\) tests were conducted to determine if the estimated mean energy expenditure values from the activity monitoring devices and questionnaires were significantly different from EEPA. Because the sample included only two women, the above analyses were run with and without them to determine if the physical activity level of the women altered the results of the entire group. Similar results were obtained when the women were included or excluded from the analyses, probably because their physical activity level measured by the monitoring devices and questionnaires approximated the average activity values of the men. Consequently, the results of the entire sample are reported for this investigation. All analyses were performed using the SPSS-PC statistical package (25). Statistical significance was set at \(p < .05\). Measurements are presented as means ± standard deviations.

RESULTS

The clinical characteristics of the claudicants are shown in Table 1. As a group, the patients were elderly, obese, and had ABI values approximately 33\% below normal due to low ankle systolic blood pressures. Total daily energy expenditure was approximately 2,300 kcal/day, of which the resting energy expenditure was approximately 1,700 kcal/day, or 74\% of the total.

The physical activity values obtained from monitors and questionnaires and their correlation with EEPA are shown in Table 2. As a group, the claudicants were sedentary, as EEPA was on average less than 380 kcal/day. The activity value determined by the accelerometer was highly correlated with EEPA, but overestimated the amount of physical activity by an average of 117 kcal/day \((p = .083)\). The daily number of steps recorded from the pedometer was also correlated with EEPA. None of the physical activity questionnaires were significantly correlated with EEPA, as the correlation coefficients ranged between -0.037 to -0.326. Additionally, the Minnesota LTPA underestimated EEPA by an average of 218 kcal/day \((p = .001)\), whereas the caloric expenditure associated with the 7-day physical activity

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>69 ± 7</td>
<td>53-88</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>88.6 ± 13.7</td>
<td>60.2-122.0</td>
</tr>
<tr>
<td>Body mass index (weight/height(^2))</td>
<td>30.2 ± 5.1</td>
<td>20.4-41.2</td>
</tr>
<tr>
<td>Waist/hip ratio</td>
<td>0.96 ± 0.07</td>
<td>0.75-1.08</td>
</tr>
<tr>
<td>Percent body fat (%)</td>
<td>30.6 ± 3.6</td>
<td>25.9-39.2</td>
</tr>
<tr>
<td>Total daily energy expenditure (kcal/day)</td>
<td>2,312 ± 435</td>
<td>1,526-3,151</td>
</tr>
<tr>
<td>Resting energy expenditure (kcal/day)</td>
<td>1,702 ± 286</td>
<td>1,180-2,250</td>
</tr>
<tr>
<td>Ankle/brachial index</td>
<td>0.67 ± 0.21</td>
<td>0.28-0.95</td>
</tr>
<tr>
<td>Ankle systolic blood pressure (mmHg)</td>
<td>91 ± 30</td>
<td>40-141</td>
</tr>
<tr>
<td>Brachial systolic blood pressure (mmHg)</td>
<td>136 ± 19</td>
<td>104-183</td>
</tr>
<tr>
<td>Brachial diastolic blood pressure (mmHg)</td>
<td>70 ± 10</td>
<td>42-92</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>66 ± 11</td>
<td>51-91</td>
</tr>
</tbody>
</table>
recall (658 kcal/day) overestimated EEPA by an average of 280 kcal/day (p < .001). The caloric expenditure associated with the pedometer reading and the JSC physical activity score could not be estimated. The interrelationships among the physical activity monitors and questionnaires are shown in Table 3. The only measures that were significantly correlated with each other were the accelerometer and the pedometer, and the Minnesota LTPA and the 7-day physical activity recall.

The relationship between EEPA and the daily physical activity from the accelerometer is depicted graphically in Figure 1. The regression equation to predict EEPA from the accelerometer data is EEPA (kcal/day) = 81.6 + (0.599 × accelerometer kcal/day); \( R = .834, R^2 = .696, \) standard error of estimate = 77 kcal/day, \( p < .001. \) The relationship between EEPA and the daily number of steps from the pedometer is shown in Figure 2. The regression equation to predict EEPA from the pedometer data is EEPA (kcal/day) = 76.6 + (0.048 × pedometer steps/day); \( R = .614, R^2 = .377, \) standard error of estimate = 124 kcal/day, \( p = .002. \)

DISCUSSION

The major findings in this investigation were that: (a) PAOD patients with intermittent claudication expend on

Table 2. Physical Activity Measurements of 22 Peripheral Arterial Occlusive Disease Patients With Intermittent Claudication

<table>
<thead>
<tr>
<th>Measurements of Physical Activity*</th>
<th>Mean ± SD (Range)</th>
<th>Correlation With EEPA (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEPA (kcal/day)</td>
<td>378 ± 190 (102-836)</td>
<td>—</td>
</tr>
<tr>
<td>Accelerometer (kcal/day)</td>
<td>495 ± 265 (145-1,172)</td>
<td>.834 (&lt;.001)</td>
</tr>
<tr>
<td>Pedometer (steps/day)</td>
<td>6,344 ± 2,454 (1,396-10,907)</td>
<td>.614 (.002)</td>
</tr>
<tr>
<td>Minnesota LTPA (kcal/day)</td>
<td>160 ± 167 (11-618)</td>
<td>.326 (.276)</td>
</tr>
<tr>
<td>PAD-PAR (h/week)</td>
<td>70 ± 25 (30-109)</td>
<td>.158 (.519)</td>
</tr>
<tr>
<td>PAD-PAR (MET-h/week)</td>
<td>122 ± 39 (54-193)</td>
<td>.106 (.667)</td>
</tr>
<tr>
<td>JSC PAS (activity code)</td>
<td>1.4 ± 1.0 (0-3)</td>
<td>.037 (.872)</td>
</tr>
</tbody>
</table>

*EEPA = energy expenditure of physical activity, LTPA = leisure-time physical activity, PAD-PAR = peripheral arterial disease physical activity recall, JSC PAS = Johnson Space Center physical activity scale.

Table 3. Interrelationships Among the Physical Activity Values Obtained From Monitors and Questionnaires in 22 Peripheral Arterial Occlusive Disease Patients With Intermittent Claudication*

<table>
<thead>
<tr>
<th>Accelerometer</th>
<th>Pedometer</th>
<th>Minnesota LTPA</th>
<th>PAD-PAR†</th>
<th>JSC PAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedometer</td>
<td>.692 (.&lt;.001)</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Minnesota LTPA</td>
<td>.068 (.771)</td>
<td>.022 (.926)</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>PAD-PAR†</td>
<td>.061 (.811)</td>
<td>.055 (.828)</td>
<td>.477 (.045)</td>
<td>—</td>
</tr>
<tr>
<td>JSC PAS</td>
<td>.147 (.524)</td>
<td>.187 (.418)</td>
<td>.313 (.167)</td>
<td>.392 (.108)</td>
</tr>
</tbody>
</table>

*Values are correlation coefficients (p values)
LTPA = leisure-time physical activity, PAD-PAR = peripheral arterial disease physical activity recall, JSC PAS = Johnson Space Center physical activity scale.
†MET-h/week.
average less than 380 kcal/day in physical activity, as deter-
mained from the criterion method of DLW; and (b) EEPA was
highly correlated with the activity value obtained from an
accelerometer, but not from physical activity questionnaires.

The non-smoking PAOD patients in this investigation were
functionally limited by claudication pain, resulting in EEPA
values below 380 kcal/day. This physical activity level is
51% lower than that of 46 healthy sedentary men of com-
parable age, who had an EEPA value of 769 ± 412 kcal/day
(15). Furthermore, the elderly claudicans expended only
160 kcal/day (1,120 kcal/week) in leisure-time physical
activities. It is not clear whether this level of activity is ade-
quate to elicit a cardiovascular protective effect, as the mini-
mal threshold of activity may range between 700 kcal/week
(26) and 2,000 kcal/week (3,27–29). However, since PAOD
patients with intermittent claudication have an 11-fold
higher risk of mortality than those who do not have PAOD
(4), it is prudent to use the high end of the range as the goal
that claudicans should strive to achieve to aggressively
modify their cardiovascular risk. Consequently, non-smoking
PAOD patients with intermittent claudication should in-
crease their leisure-time physical activity by approximately
125 kcal/day to reach the level of 2,000 kcal/week (285
cal/day). This activity level could be accomplished by an
additional 20–30 min of walking each day, or by exercising
for approximately 1 h three times per week in a structured
exercise program under medical supervision.

The high correlation between the activity value obtained
from an accelerometer and EEPA suggests that accelerome-
try is a promising technique to measure free-living daily
physical activity accurately in elderly PAOD patients with
intermittent claudication. The EEPA values of the claudicans
were estimated to within 77 kcal/day by the accelerometer,
thus providing clinicians a field method to measure activity
levels. Furthermore, accelerometer monitoring is highly reli-
able over a 48-h period in elderly claudicants (10). The
pedometer was also correlated with EEPA, although it
yielded a less precise estimate (within 124 kcal/day).

The low relationship between EEPA and the physical
activity questionnaires suggests that the questionnaires
provide less precise measurements of activity in PAOD
patients with intermittent claudication. This is probably due
to recall error and to the small range in activity scores in
this population, as the questionnaire values of the patients
were clustered at the extreme low end of the physical
activity spectrum. It is possible that a higher correlation would
exist between the activity questionnaires and EEPA in a
group having a wider range of daily physical activity. Low
 correlations also were evident between the physical activity
questionnaires and the physical activity monitors. Specifi-
cally, the relationship between the accelerometer and Min-
nesota LTPA questionnaire (r = .068) was lower than that
found in a younger population of healthy men and women
(r = .21) (30), most likely because the patients in the pre-
 sent study were clustered at the low end of the physical
activity spectrum with narrower ranges in activity values.

The physical activity questionnaires are still valuable
instruments for use with PAOD patients, however, for sev-
eral reasons. First, the activity questionnaires are positively
related to ABI in patients having a wide range in PAOD
severity, with activity level decreasing progressively with a
reduction in ABI (31). Second, the questionnaires can
detect differences in activity between PAOD patients and
healthy age-matched controls (31). Third, the question-
naires provide information that PAOD patients with clau-
dication are quite sedentary, and consequently fall in the
highest risk group for subsequent cardiovascular morbidity
and mortality (3,27–29).

Although this study provides encouraging preliminary
data on the validity of an accelerometer to assess free-living
daily physical activity in elderly claudicants, several limita-
tions deserve mention. First, the correlation coefficients
between the accelerometer and EEPA may be relatively
unstable due to the small sample size. Second, the group
was relatively homogeneous, as all of the claudicans were
nonsmokers. Because the daily physical activity of smoking
claudicans is even lower than that of non-smoking PAOD
patients (32), it is possible that the relationship between the
accelerometer and EEPA may not be as strong in smokers.
On the other hand, a population consisting of both smoking
and non-smoking claudicans combined may yield a higher
 correlation than that found in this study because of the
wider range in free-living daily physical activity.

This is the first study to validate physical activity moni-
tors and questionnaires against the criterion method of
DLW in elderly PAOD patients. In summary, PAOD pa-
tients with intermittent claudication expend on average less
than 380 kcal/day in physical activity, determined from the
criterion methods of DLW and indirect calorimetry, and
EEPA was highly correlated with the activity value ob-
tained from an accelerometer, but not from physical activity
questionnaires. It is concluded that the free-living daily
physical activity of older PAOD patients with intermittent
claudication can be accurately estimated with an accele-
rometer, and to a lesser extent with a pedometer, worn over
a 48-h duration.

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