Energy Expenditure During Ambulation with Ortho Crutches and Axillary Crutches

Catherine A. Hinton and Karen E. Cullen

Thirteen normal male college students were studied during unassisted ambulation and nonweight-bearing ambulation with Ortho crutches and axillary crutches to determine energy expenditure. Subjects walked at self-selected velocities. Energy expenditure was determined by analyzing expired air collected by a calorimeter. Heart rate was monitored by telemetry. During the first 2.5 minutes of walking, heart rate and energy expenditure were significantly greater for ambulation with axillary crutches than with Ortho crutches. After 11.5 minutes of walking, no difference in energy cost was found between crutch types; however, heart rate increased significantly (p < .01) during ambulation with axillary crutches. Differences in energy cost and heart rate were attributed to increased upper extremity work performed when using axillary crutches. We concluded that during nonweight-bearing ambulation for short periods of time or over a short distance, the Ortho crutch is less taxing in terms of energy cost and heart rate demands.

Key Words: Energy metabolism, Crutches, Gait.

For patients required to walk with a nonweight-bearing (NWB) gait, the choices of assistive ambulatory devices are limited to crutches and walkers. Because of the greater mobility they afford, crutches are generally chosen over walkers for both young patients and older patients with adequate balance. Nonweight-bearing ambulation with crutches requires more energy expenditure than normal, unassisted ambulation.1, 2 Energy costs of different types of crutches are not reported as a clinical consideration, however, in the selection of a particular type for a specific patient. The traditional wooden axillary crutch and the Ortho* crutch are two types of crutches frequently used. Currently, no published evidence indicates a difference in energy cost between the use of Ortho crutches and axillary crutches.

A number of investigators have examined energy expenditure during ambulation with assistive devices.1, 2, 12 In any ambulation study, walking speed must be taken into consideration because there is a linear relationship between energy expenditure and velocity.3, 4 Some investigators have examined energy costs of subjects walking at fixed velocities. Others have allowed subjects to select their own comfortable walking speeds because normal subjects have been found to select velocities that are least costly in terms of energy expenditure.4 Pagliarulo and associates found that during ambulation with both crutches and prostheses, energy expenditure was lowest when the subject was allowed to select his own walking speed.5 McBeath and associates examined the energy cost of self-selected velocity ambulation with axillary crutches, Loftstrand forearm crutches, and canes using four gaits with a group of normal subjects.1 No difference was found in the amount of energy required to use each type of crutch in the various gaits.

If the use of a certain type of crutch requires less energy expenditure, it follows that energy can be saved during a patient’s rehabilitation by having him use that crutch. Examples of patients who could benefit include those who have become deconditioned from extended bed rest;6 those with chronic disabilities who are required to ambulate with a NWB gait; those with unilateral, lower extremity amputations; those who are required to use crutches or ambulate with a NWB gait for long periods of time; and those with chronic respiratory or cardiovascular problems.

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The purpose of this investigation was to determine whether significant differences exist in energy cost (measured by oxygen consumption), heart rate, and blood pressure during three-point NWB ambulation with axillary crutches and Ortho crutches and during unassisted ambulation. Responses were measured at the subject's self-selected speed for each mode of ambulation. In this study, we hypothesized that there would be no difference in oxygen consumption, heart rate, or blood pressure during the three modes of ambulation.

METHOD

Subjects

Thirteen normal male college students were studied. Means and standard deviations for age, weight, and height of the subjects were as follows: age, 26.0 ± 1.3 years; weight, 74.2 ± 11.5 kg (163.6 ± 25.4 lb); and height, 181.9 ± 7.5 cm (71.6 ± 3.0 in). No subjects reported histories of chronic or acute musculoskeletal, cardiovascular, or respiratory disorders. Five of the subjects had used crutches in the past, but no subjects had used crutches within the previous year. Subjects had consumed neither food nor beverages other than water for at least four hours before testing.

Instrumentation

The Kofranyi-Michaelis calorimeter† was used to measure volume of expired air and to collect 0.06 percent of this air as a sample for subsequent analysis (Fig. 1). The use of this device has been described previously.7 Analysis of the gas samples was performed using a Beckman E2 oxygen analyzer‡ and a Beckman LB2 carbon dioxide analyzer.§ The gas analyzers were calibrated for each subject using gases of known concentration determined by a micro-Scholander apparatus.§ All volumes were corrected for standard temperature, pressure, and water vapor.

Heart rate was recorded on an ECG strip by telemetry‡ from three electrodes placed in a modified V5 position on the subject's chest. A sphygmomanometer attached to the subject's left arm was used to measure blood pressure between walking trials.

Two types of crutches were used in this study (Fig. 2). The axillary crutches were made of lightweight wood with double uprights and weighed 1.9 kg (4.2 lb). The Ortho crutches were made of aluminum with single uprights and weighed 2.0 kg (4.4 lb).

Procedure

After each subject completed the screening form and signed the informed consent form, the procedure was explained and questions were answered. Both types of crutches were fitted to the subject while standing. The crutches were adjusted to a height approximately 5 cm (2 in) below the subject's axillae with the handgrip positioned to allow approximately 25 degrees of elbow flexion. The process of NWB ambulation was reviewed. Each subject received a five-minute training period with each type of crutch.

The ECG electrodes and telemetry unit were placed on the subject. The Kofranyi-Michaelis calorimeter

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Fig. 1. Front and rear views of subject wearing Kofranyi-Michaelis calorimeter.

Fig. 2. Ortho crutch and axillary crutch.
was placed on the subject's back like a knapsack. After a two-minute rest period in the sitting position, resting heart rate and blood pressure values were obtained.

All subjects walked for 11.5 minutes in each mode of ambulation: unassisted, NWB with Ortho crutches, and NWB with axillary crutches. The trial order was randomized for each subject. For each mode of ambulation, subjects walked at self-selected velocities on a level floor in a 91.4-m (300-ft) circular hallway. Four samples of expired air were collected during set time intervals over the 11.5-minute walking trials: 0 to 2.5 min, 3 to 5.5 min, 6 to 8.5 min, and 9 to 11.5 min, respectively (referred to as Periods 1–4). During the 30-second intervals between collection periods, volumes were recorded and gas collection bags changed. During the last 10 seconds of every minute of ambulation, heart rate was determined from the ECG strip using a rate stick. The peak heart rate during each period of gas collection was used for analysis. Velocity was determined by using a stopwatch to measure the time required to pass between markers taped every 10 ft on the floor. During each of the four periods of gas collection, velocity was determined and the average of the four values was recorded as the velocity for that mode of ambulation. Immediately after each walking trial, blood pressure was measured with the subjects standing. Also, after each walking trial, each subject was seated to rest for at least 10 minutes, which allowed his heart rate and blood pressure to return to resting values.

**TABLE 1**

<table>
<thead>
<tr>
<th>Analysis of Variance for Mean Oxygen Consumption over Time (ml O$_2$·kg$^{-1}$·min$^{-1}$)</th>
</tr>
</thead>
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<td>Error</td>
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<td>Error</td>
</tr>
<tr>
<td>Interaction</td>
</tr>
<tr>
<td>Error</td>
</tr>
</tbody>
</table>

$^a$ p < .01.

**Data Analysis**

Oxygen consumption over time (ml O$_2$·kg$^{-1}$·min$^{-1}$), oxygen consumption over distance (ml O$_2$·kg$^{-1}$·m$^{-1}$), and heart rate were analyzed with separate two-way analyses of variance with two repeated measures. Separate one-way analyses of variance with one repeated measure were performed for analysis of blood pressure and velocity. Where significant $F$ values were found, the Newman-Keuls multiple comparison test was performed, with an acceptance level set at .05, to identify significant differences.

**RESULTS**

**Velocity**

The mean velocity for unassisted ambulation (UA) was 66 ± 12 m/min. For ambulation with Ortho
crutches (OCA) and axillary crutches (ACA), the respective mean velocities were 43 ± 11 m/min and 42 ± 6 m/min. Velocity of ambulation with both types of crutches was significantly less than that of unassisted ambulation ($F = 46.66; df = 2,24; p < .01$). No significant difference in walking speed was found between the two types of crutches.

**Oxygen Consumption**

Table 1 summarizes the results of the analysis of oxygen consumption over time. The results revealed steady state was achieved by Period 2 during all modes of ambulation. Subjects continued in steady state throughout the remainder of each trial.

The multiple comparison tests revealed the mean oxygen consumption during periods 1 to 4 for both OCA and ACA was significantly greater ($p < .01$) than that for UA (Fig. 3). Additionally, during Period 1 of ACA, the mean oxygen consumption (13.6 ml O$_2$·kg$^{-1}$·min$^{-1}$) was significantly greater ($p < .01$) than the mean oxygen consumption (11.0 ml O$_2$·kg$^{-1}$·min$^{-1}$) during OCA. During Periods 2 to 4, no significant differences in mean oxygen consumption over time were found between OCA and ACA.

Similar findings were observed in mean oxygen consumption over distance (Tab. 2). The multiple comparison further indicated that mean oxygen consumption over distance for OCA and ACA was significantly greater ($p < .01$) than for UA during all collection periods (Fig. 4). During Period 1, the mean oxygen consumption during ACA (0.33 ml O$_2$·kg$^{-1}$·m$^{-1}$) was significantly greater ($p < .01$) than the mean oxygen consumed (0.26 ml O$_2$·kg$^{-1}$·m$^{-1}$) during OCA. During Periods 2 to 4, no significant differences in mean oxygen consumption over distance were found between OCA and ACA.

**Heart Rate**

Results of the analysis of heart rate are shown in Table 3. Comparison of the three modes of ambulation during each collection period showed that mean heart rates during OCA and ACA were significantly greater ($p < .01$) than during UA for all four periods (Fig. 5). Additionally, significant differences ($p < .01$) in mean heart rates were found between OCA and ACA during Periods 1 and 4. During Period 1 of ACA, the mean heart rate was 124 bpm, which was significantly greater ($p < .01$) than the mean heart

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**Table 2**

Analysis of Variance for Mean Oxygen Consumption over Distance (ml O$_2$·kg$^{-1}$·m$^{-1}$)

<table>
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<td>Error</td>
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<td>0.15</td>
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<tr>
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<tr>
<td>Error</td>
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</table>

$^a p < .01$. 

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![Graph](image-url)  

Fig. 4. Mean oxygen consumption over distance for three modes of ambulation during four consecutive collection periods.

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rate of 118 bpm during OCA. During Period 4 of ACA, the mean heart rate was 142 bpm, which was significantly greater \(( p < .01)\) than the mean heart rate of 135 bpm during OCA.

**Blood Pressure**

Analysis of mean systolic blood pressure data for the three modes of ambulation revealed a significant difference between them \((F = 20.47, df = 2.24, p < .01)\). Multiple comparison showed that for ambulation with both types of crutches, mean systolic blood pressure was significantly higher than that for UA. There was no significant difference between mean systolic blood pressure for OCA and ACA. The mean systolic blood pressures were 120 mmHg for UA and 135 mmHg for both OCA and ACA. No significant differences in mean diastolic blood pressure were found among the three modes of ambulation. The mean diastolic blood pressures were 77 mmHg for UA, 77 mmHg for OCA, and 76 mmHg for ACA.

**DISCUSSION**

The finding that mean oxygen consumption, heart rate, and blood pressure were significantly greater in NWB ambulation with crutches than in UA is in agreement with findings of other investigators.\(^1\)\(^-\)\(^8\) All walking trials were performed at the subject’s self-selected velocity as this speed has been found to require the least energy expenditure during both assisted and unassisted ambulation.\(^2\)\(^-\)\(^9\) Thus, the assumption was made that, for a given mode of ambulation, each subject was expending the least amount of energy possible, and that modes of ambulation could be compared at this point of minimal energy expenditure. The mean velocity selected by subjects during UA (66 m/min) was slower than self-selected velocities reported by other investigators.\(^1\)\(^-\)\(^4\) The mean velocities selected by subjects during NWB ambulation with both types of crutches were also slower than those in other studies.\(^1\)\(^-\)\(^8\) Lack of familiarity with experimental equipment and conditions could have contributed to the selection of slower mean velocities during both assisted and unassisted ambulation. Even though all subjects had a short training period with

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**TABLE 3**

Analysis of Variance for Mean Heart Rate

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<td>72</td>
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</table>

\( ^* p < .01\)
both types of crutches, lack of proficiency in walking with crutches also could have contributed to selection of slower mean velocities during those trials.

Subjects in this investigation were in steady state during all periods of UA, and values for oxygen consumption per minute were comparable to those found by other researchers. During Period 1 of OCA and ACA, however, the subjects were not in steady state. No previous studies were available for comparison of oxygen consumption values for subjects not in steady state during NWB ambulation with crutches.

A number of possible reasons exist for the significantly greater mean oxygen consumption that occurred with ACA during Period 1. Because subjects were equally untrained in the use of both types of crutches and because the order of mode of ambulation was randomized, differences in adaptation during Period 1 are not sufficient to explain the higher energy cost of the ACA. Possible reasons for the varied energy expenditure include differences in the work required to do the following: perform an isometric handgrip, stabilize the scapula or thorax, balance, lift, or extend the elbows during push-off. Investigation of these possible differences was beyond the scope of this study.

During ambulation with both types of crutches, subjects reached steady state during Period 2 and remained in steady state throughout the remainder of each trial. Values of oxygen consumption are similar to those reported by other investigators for steady-state ambulation with crutches at self-selected velocities.

When considering mean oxygen consumption over distance, values during UA were similar to those reported in other studies. In the present study, the mean oxygen consumption during Period 1 of OCA was similar to results reported for ambulation with other types of crutches, whereas the mean oxygen consumption during ACA was higher than reported values. The same reasons suggested for greater mean oxygen consumption over time with ACA may also explain the greater mean oxygen consumption over distance with this crutch. During Periods 2 to 4, mean oxygen consumption values for ambulation with both types of crutches did not differ significantly from each other and both values were greater than those found in studies cited previously. The higher values probably resulted from the slower self-selected velocities in this study.

During all four periods of UA, mean heart rate did not vary significantly and was similar to reported values. Mean heart rate values during all four periods of OCA and during the first three periods of ACA were also similar to those found in the literature. The mean heart rate during Period 4 of ACA, however, was higher than any previously reported values.

In comparing mean heart rate for ambulation with the two types of crutches, the significantly higher heart rate for ACA during Period 1 was to be expected because mean oxygen consumption was greater for ACA during this period. During Periods 2 and 3, no difference in mean oxygen consumption was found between ambulation with the two crutches and, as expected, no significant difference in mean heart rate was observed.

The most unusual finding in this study was seen in comparison of mean heart rates between OCA and ACA during Period 4. Although no significant difference in mean oxygen consumption existed, a significantly higher mean heart rate occurred during ACA. Other studies have demonstrated that upper extremity work may cause a disproportionate increase in heart rate in relation to oxygen consumption. Because ambulation with crutches requires upper extremity work, it is possible that ambulation with one type of crutch may result in a more disproportionate heart rate response than another because of a greater amount of upper extremity work. This seems to be the case during ACA. Some of the reasons that were previously proposed for differences in mean oxygen consumption during Period 1 may also serve as possible explanations for the mean heart rate differences during Period 4. Possibilities for varying degrees of upper extremity work include differences in handgrip, in elbow extensor activity during push-off, in shoulder or scapular stabilization, or in dynamic forward movement of the crutches.

Mean systolic and diastolic blood pressures during UA were similar to those reported for a group of men aged 20 to 29. Few investigators have reported blood pressure responses to crutch ambulation, and the reported values are higher than the ones found in the present study. However, the results may not be comparable because subjects in the other studies differed from ours; in one study subjects were elderly individuals and in the other study they were amputees. Several investigators have demonstrated that upper extremity work results in a higher blood pressure response than does lower extremity work. Although crutch ambulation involves a combination of upper extremity and lower extremity work, the fact that upper extremity work is involved in the activity may explain why blood pressure responses during ambulation with both types of crutches is significantly greater than blood pressure responses during UA.

The results of this study suggest several considerations for patients who must walk with a NWB gait for the selection of an assistive ambulatory device. The lower mean heart rate and oxygen consumption with Ortho crutches during Period 1 suggest that for
walking over a short distance or for a short time, the Ortho crutch would be less taxing for an untrained patient. Patients with cardiovascular problems would certainly benefit from an assistive device that results in a lower heart rate. During Period 4, OCA resulted in lower heart rates than did ACA. This finding is not as functionally relevant as the differences between the two in Period 1, because few patients would need to maintain 9 to 11.5 minutes of continuous NWB ambulation. It is possible, however, that some patients, such as those with no complicating medical problems other than amputation or young patients with acute medical-surgical problems requiring NWB gait, could benefit from the selection of Ortho crutches for continuous, extended walking.

Because the Ortho crutch has not been investigated in previous studies, further study of the energy costs of this device with patients would be desirable. Possible subjects include patients with orthopedic problems, amputations, or cardiovascular diseases and elderly patients. Another possible aspect of crutch ambulation that could be examined is the oxygen debt incurred during walking. Suggested changes for future study include familiarizing subjects with experimental conditions so that data are not artificially affected and using a longer training period to ensure proficiency with crutches.

**SUMMARY**

Mean oxygen consumption over time and distance, mean heart rate, and mean blood pressure were all significantly greater during four collection periods for OCA and ACA than for UA. During Period 1, mean heart rate, mean oxygen consumption over time, and mean oxygen consumption over distance were significantly greater for ACA than for OCA. No difference between the two crutches for these variables was seen in Periods 2 and 3. In Period 4, no difference in mean oxygen consumption over time and distance was found. During this period, however, mean heart rate was significantly greater for ACA. Differences in mean heart rate and mean oxygen consumption were attributed to a greater amount of upper extremity work performed with axillary crutches. No significant differences in mean blood pressure were found between OCA and ACA. The results indicate that during NWB ambulation for short periods or over short distances, the Ortho crutch is less taxing in energy cost and heart rate demands.

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