Energy costs of walking in lower-extremity plaster casts

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Energy Costs of Walking in Lower-Extremity Plaster Casts


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ABSTRACT: The energy cost of walking with axillary crutches and each of three types of plaster casts (long, short, and cylinder) on the lower extremity was measured in twenty normal adult men. The knee and ankle joints were immobilized unilaterally in the neutral positions. Oxygen uptake was measured using a modified Douglas-bag technique. Heart rate, respiratory rate, and step frequency were telemetered from transducers that were attached to the subjects.

When walking and bearing full weight on a cast without the use of crutches, the average rates of energy expenditure for subjects wearing the three varieties of casts did not significantly differ from the value for normal walking. Velocity, however, was reduced depending on the extent of immobilization. The average velocity of the subjects was fifty-six meters per minute in a long cast, sixty-four meters per minute in a cylinder cast, and seventy meters per minute in a short cast, compared with seventy-eight meters per minute without immobilization of the limb. The subjects' average oxygen cost per meter was 0.24 milliliter per kilogram in a long cast, 0.20 milliliter per kilogram in a cylinder cast, and 0.19 milliliter per kilogram in a short cast, compared with 0.15 milliliter per kilogram for normal walking.

Using a unilateral non-weight-bearing swing-through gait, the average rate of oxygen uptake for subjects wearing the three types of casts did not differ from the mean value without a cast (21.2 milliliters per kilogram per minute). All values were at least 60 per cent higher than the average for normal level walking.

Clinical Relevance: These findings support the conclusion that weight-bearing on an injured limb following trauma to the lower extremity should be allowed at the earliest possible time to minimize the high energy cost of walking with crutches. When a subject walks bearing a weight-bearing cast without crutches, the gait velocity and the energy cost depend on the extent of immobilization. Walking with a free knee or ankle (in a short cast or a cylinder cast) is more rapid and less costly than walking with combined restriction of the knee and ankle (in a long cast).

The patient with lower-extremity trauma frequently is required to wear a cast and may depend on crutch assistance to walk. Clinical experience suggests that the physiological energy expenditure during walking is a significant factor that should be considered in the therapeutic plan. Previous investigators have documented high energy consumption and heart rates during crutch-assisted walking. This study was undertaken to determine the effects on the energy expenditure required for walking of long, short, and cylinder casts on the lower extremity, with and without the use of crutches.

Methods

Twenty normal male volunteers between the ages of twenty-two and thirty-eight years (mean age, 27.2 years) were selected. None reported any history of cardiopulmonary or orthopaedic disease. Each subject was instructed by a physical therapist in the performance of a non-weight-bearing, swing-through crutch-assisted gait. The dominant lower limb was determined by observing which leg the un instructed subject used to step onto a stool. That limb was then placed in a long plaster cast, with the knee and ankle immobilized in the neutral positions. A cast boot was placed on the foot portion of the cast.

The initial testing was performed with the subject wearing a long cast. The cast then was modified into a short cast (for ten subjects) or a cylinder cast (for ten subjects). The subjects were instructed to become accustomed to walking with the modified cast. Two tests were performed in random order: walking with crutches without weight-bearing on the limb in the cast, and walking without crutches with full weight-bearing on the limb in the cast. Finally, after removal of the cast, all subjects were tested to determine their normal gait performance. During each walking trial, with or without crutches, the subjects were instructed to choose a comfortable pace.

Testing was conducted on a level outdoor track, 60.5 meters in circumference. A modified Douglas-bag collection technique, described in previous reports, was used for gathering expired air for the data on oxygen consumption. The light-weight air-collection system was harnessed to the subject's shoulders, and a two-way J valve allowed inspiration of ambient air and collection of expired air in a non-porous polyethylene bag. Heart rate, respiratory rate, and cadence were monitored and transmitted by a portable frequency-modulation radio telemetry system during the first and last thirty seconds of a continuous two-minute period of gas collection. Data were recorded on a Visicorder.

Gas collection immediately followed a three-minute warm-up. During gas collection, the subjects were checked to determine if they achieved a steady state, defined as not more than a twelve beat-per-minute difference in heart rate between the first and last thirty-second measurement period. The subjects rested for a minimum of fifteen minutes after each test, or until they felt ready to proceed. Each sample of gas was analyzed for oxygen content with a paramagnetic oxygen analyzer (Heath and Taylor Servomex, type OA-250), for carbon dioxide content with an electromagnetic capnograph (Godhart, type 146), and for volume with a dry-gas flowmeter (American Meter). All single-gas volumes were corrected to standard values of temperature, saturation, and pressure (STPD units), and mixed-gas volumes were corrected to values of body temperature, pressure, and saturation (BTPS units).

Energy expenditure was expressed in two ways, both normalized to body mass. The first determination was the rate of oxygen uptake (milliliters per kilogram per minute) and the second was the oxygen cost per unit of distance traveled (milliliters per kilogram per meter). The latter is an indicator of the efficiency of gait.

Results

The two test conditions, weight-bearing on the limb with the cast and non-weight-bearing walking using a
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Table I

Walking without Crutches — Bilateral Full Weight-Bearing*

<table>
<thead>
<tr>
<th></th>
<th>Long Cast (N = 20)</th>
<th>Cylinder Cast (N = 10)</th>
<th>Short Cast (N = 10)</th>
<th>No Cast (N = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen uptake (ml/kg/min.)</td>
<td>13.0 ± 2.7</td>
<td>12.7 ± 1.8</td>
<td>13.0 ± 1.4</td>
<td>12.5 ± 2.1</td>
</tr>
<tr>
<td>Heart rate (beats/min.)</td>
<td>92.0 ± 12.1</td>
<td>92.8 ± 12.0</td>
<td>92.8 ± 11.3</td>
<td>91.6 ± 12.0</td>
</tr>
<tr>
<td>Net oxygen cost (ml/kg/m)</td>
<td>0.24 ± 0.03</td>
<td>0.20 ± 0.01†</td>
<td>0.19 ± 0.02</td>
<td>0.15 ± 0.02†</td>
</tr>
<tr>
<td>Velocity (m/min.)</td>
<td>55.5 ± 10.5</td>
<td>63.7 ± 8.1†</td>
<td>69.9 ± 6.3†</td>
<td>77.9 ± 7.5</td>
</tr>
</tbody>
</table>

* All values are mean and standard deviation.
† A significant difference (p < 0.05) from the same parameter in the column on the left.

crutch-assisted gait proved to be a significantly stressful experience compared with weight-bearing walking in a cast. Energy demands were high and were not notably modified by the presence of any one of the three types of cast. The heart rate with or without any type of cast was at least 132 beats per minute (range, 132 to 141 beats per minute) (Table II). This represents at least a 48 per cent increase above the average value during normal walking (ninety-two beats per minute). The difference was statistically significant (p < 0.01).

Paralleling the results with regard to heart rate, the rate of oxygen expenditure also was elevated during walking with crutches. Swing-through gait with a free knee (no cast or a short cast) did not require a significantly higher rate of oxygen uptake (21.2 and 21.6 milliliters per kilogram per minute for normal walking without a cast.

The reduced gait velocity resulted in gait efficiency that was significantly lower than normal, depending on the extent of immobilization. The average oxygen cost per meter was 0.24 milliliter per kilogram for the long cast, 0.20 milliliter per kilogram for the cylinder cast, and 0.19 milliliter per kilogram for the short cast, compared with 0.15 milliliter per kilogram for normal level walking.

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Non-weight-bearing swing-through gait proved to be a significantly stressful experience compared with weight-bearing walking in a cast. Energy demands were high and were not notably modified by the presence of any one of the three types of cast. The heart rate with or without any type of cast was at least 132 beats per minute (range, 132 to 141 beats per minute) (Table II). This represents at least a 48 per cent increase above the average value during normal walking (ninety-two beats per minute). The difference was statistically significant (p < 0.01).

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gram per minute, respectively) than when the knee was immobilized in a cylinder cast or long cast (20.4 and 20.0 milliliters per kilogram per minute, respectively). However, all values were significantly (p < 0.01) higher than the mean for normal walking (12.5 milliliters per kilogram per minute).

During walking with crutches, gait velocity was influenced by the type of cast. Having a free knee — that is, no cast or a short cast — allowed the subjects to walk at a rate of sixty-two and sixty-one meters per minute, respectively. When the knee was immobilized in a long cast or cylinder cast, the average comfortable gait velocity was reduced significantly (p < 0.01) to fifty-one and fifty-three meters per minute, respectively. All of these values were significantly lower than the mean for normal level walking (seventy-eight meters per minute).

The combination of reduced velocity and increased energy expenditure during walking with crutches resulted in a significantly increased energy cost per unit of distance walked.

Differences in oxygen cost related to immobilization of the knee were not significant: 0.35 and 0.36 milliliter per kilogram per minute when the knee was free compared with 0.39 and 0.40 milliliter per kilogram per minute when the knee was immobilized in a cylinder cast or long cast. Hence, all modes of walking with crutches resulted in at least a 133 per cent increase in oxygen cost per meter walked beyond the value for normal walking, which is 0.15 milliliter per kilogram per meter.

Discussion

Several investigators have studied the energy costs of normal and pathological gait by performing energy-cost analyses while the subject walked either on a treadmill or at a regulated velocity, or both. These imposed conditions frequently present a difficult barrier for the disabled patient, particularly when crutch assistance is required, and thus the collected data may not reflect true physiological status during normal walking conditions. The modified Douglas-bag method that we used, which allowed the subject to select his own comfortable speed on a stationary level surface, permitted testing during the subjects' customary walking conditions.

When the subjects walked without crutches, fully weight-bearing on any of the three types of casts, the rate of energy consumption and the heart rate did not increase beyond those for normal walking. The subjects slowed their walking speed (which depended on the extent of immobilization) and kept the rate of energy expenditure from rising above normal.

Exercise performed at this work rate (approximately 30 per cent of the maximum aerobic capacity for normal subjects who are twenty to thirty years old) can be sustained for many hours, with no easily definable point of exhaustion. Most customary sustained activities of daily living, domestic work, and light industry are performed at or below this level. Practical experience has indicated that workloads that tax as much as 40 per cent of the individual's maximum oxygen capacity are the reasonable and average upper limit for physical work performed on a regular basis throughout an eight-hour workday.

The length of time that an individual can perform prolonged exercise at a work rate above the anaerobic threshold (approximately 50 per cent of the maximum aerobic capacity of an untrained subject) decreases inversely with the rate of energy expenditure, expressed as a fraction of maximum aerobic capacity. Endurance time shortens and fatigue occurs earlier as the intensity of the work load rises due to the restricted availability of the anaerobic energy supply and the accumulation of lactate in the muscle.

Crutch-walking using a unilateral non-weight-bearing swing-through gait caused a 66 per cent rise in the rate of energy expenditure (from 12.5 to 21.2 milliliters per kilogram per minute) and a 48 per cent increase in heart rate compared with the values for normal walking. The values remained approximately the same regardless of whether a long, short, or cylinder plaster cast was added to the non-weight-bearing limb. These findings are in agreement with the results of Imms et al., who measured energy expenditure during walking in patients with lower-extremity fractures.

The physical exertion experienced during crutch-walking can be compared with that during other types of exercise on the basis of rate of oxygen uptake and cardiac response. The rate of energy expenditure required for non-weight-bearing swing-through walking is above the anaerobic threshold of the typical adult and is equivalent to the energy expenditure for a variety of recreational and athletic pursuits and for industrial activities classified as heavy work, such as shoveling coal. While the physical demands of crutch-walking are rigorous, the orthopaedic patient often has a diminished capacity for exercise due to the sequelae of trauma. A fall in serum hemoglobin, a state of negative nitrogen balance, and depletion of muscle glycogen commonly follow skeletal injury. Bed rest for an extended time further decreases the capacity for exercise.

These findings account for the common clinical experience that patients who previously led a sedentary life may limit crutch-walking to short intervals to avoid physical exertion. Patients whose exercise capacity is reduced by trauma, bed rest, age, or associated cardiovascular disease may be unable to meet the energy demands of non-weight-bearing crutch-walking. Care should be used in prescribing crutches for older patients. We have found cardiac monitoring to be of assistance when there is a history of cardiovascular disease. An endurance-training program may be beneficial to prepare the older patient for crutch-walking, since the capacity for upper-extremity exercise can be increased by physical conditioning.

The patient should, at the earliest possible time, be allowed to bear weight on an injured limb to the greatest extent feasible, in order to minimize cardiac stress and the energy expenditure associated with supporting the body.
weight on crutches.

After a ligament injury to the knee or ankle, it may be preferable to protect the injured extremity in a cast and to allow full or partial weight-bearing, rather than providing protection by prescribing crutches and recommending no weight-bearing.

References