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Energy cost of walking measurements in subjects with lower limb amputations: A comparison study between floor and treadmill test

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Abstract

Measuring the energy cost of walking (ECW) is a valid way of assessing the walking efficiency of subjects who were prosthetic users following lower limb amputation. The aim of this study was to determine whether, in these subjects, treadmill and floor ECW measurements are comparable.

We tested 24 subjects who had undergone unilateral lower limb amputations for vascular diseases as they walked at a self-selected comfortable speed on the floor and on a treadmill. The tests were conducted at the end of rehabilitative treatment to fit prosthesis. Eight subjects underwent transtibial and 16 transfemoral amputation. The measurements were taken with a portable gas analyzer.

The self-selected comfortable speed on the treadmill was significantly lower than that on the floor, where the patients adopted the aid they normally used for walking; oxygen consumption was the same in the two tests. Therefore, for both transtibial and transfemoral patients, ECW was greater during walking on the treadmill.

Steady-state heart rate did not differ in the two tests.

The data show that the ECW values of the amputated subjects obtained on the treadmill at the end of rehabilitation did not correspond with those they obtained on the floor. The floor test is the one that may better reflect walking with prostheses and aids in everyday life, in subjects with dysvascular lower limb amputation, using the prosthesis for a short time.
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Keywords: Amputees; Walking; Oxygen consumption; Human locomotion

1. Introduction

Energy cost measurement, which is a functional evaluation method adopted for studying the physiology of physical exercise, is used in rehabilitation to determine the effect of disability on walking [1]. In the literature there are several reports on energy cost of walking (ECW) measurement for functional evaluation of subjects with unilateral amputation and who use prostheses [2–10].

Measuring ECW in the amputated subject is an established method for quantifying the actual effort exerted [2,3,6–8,11–13] and for comparing the effectiveness of different prosthetic devices [4,5,9,10,14–16]. This measurement has significant clinical importance, since ECW affects the subject's ability to use the prosthesis and acquire the necessary motor abilities, thus influencing level of autonomy and quality of life. Reports in the literature show that ECW is greater in the amputated individuals compared to healthy controls [1,6,7] and increases with a higher level of amputation [2,6]. Transtibial and transfemoral vascular disease amputees have higher ECW than traumatic amputatees [2,7,12,13].

In previous studies, measurements were taken on the treadmill [5,10,12,14–18], or during overground walking [7–9,11,19], as in field tests or methods were used in the same study [14].

Patients who use aids to walk on flat surface use the equipment supports on the treadmill instead, because of difficulty keeping their balance. They also acquire adequate levels of coordination and specific motor abilities for walking on the treadmill only after consistent training. In the literature

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the studies that compared the energy cost of walking on the floor and on the treadmill were conducted with non-amputated subjects [20]. We are not aware of any previous studies on this topic conducted in lower limb amputatees. Therefore, the aim of this study was to verify whether ECW tests on a treadmill and during free walking are really equivalent, or whether there are measurement differences in patients with lower limb amputations who use prostheses.

2. Materials and methods

2.1. Subjects

The subjects recruited for the study had to meet the following inclusion criteria: (i) unilateral amputation of a lower limb for peripheral vascular disease due to diabetes or atherosclerosis; (ii) no pathological stump conditions that could impede prosthesis fitting (open surgical wound, ulcers or infections); (iii) no functional impairment of the sound limb; (iv) no cognitive disorders or other significant medical conditions.

We recruited 24 consecutive patients admitted to our rehabilitation unit who were referred from surgical wards. Eight patients had undergone transtibial amputation (3 related to diabetes, 5 to atherosclerosis) and 16 transfemoral amputation (8 related to diabetes, 8 to atherosclerosis). Table 1 reports the characteristics of the population examined.

2.2. Rehabilitation treatment

A physician led the rehabilitation team, which developed a program based primarily on practical locomotor skills with prostheses. Subjects underwent physiotherapy for 180 min once a day, 5 days a week, for 2 months.

All above-knee amputees used a modular prosthesis with quad socket, polycentric knee joint and S.A.C.H. foot. Below-knee amputees used a modular patellar tendon bearing hard socket and energy storing foot.

When the patients were able to walk independently on the floor with an aid they also began to exercise on the treadmill. The subjects walked on the device at a comfortable speed, progressively increasing the length of the sessions until they were able to walk on it continuously for at least 15 min. Training on the treadmill was carried out without aids, using the available supports and patients were trained to adjust velocity by themselves.

2.3. Measurement of energy cost of walking

For all patients ECW measurement was obtained at the end of rehabilitation. In the same testing session each patient was measured first on the floor and then on the treadmill, with a rest interval that lasted as long as necessary to return to basal heart rate and oxygen consumption.

Table 1
Subjects' characteristics

	No. of subjects	M/W	Age	Height (cm)	Weight[a] (kg)
TT	8	6/2	56 ± 17	170 ± 13	77 ± 18.9
TF	16	11/5	61 ± 11	169 ± 7	65 ± 11.6

TT, transtibial amputation; TF, transfemoral amputation; M, man; W, woman.

[a] Weight was measured on the day of the test, without the prosthesis.

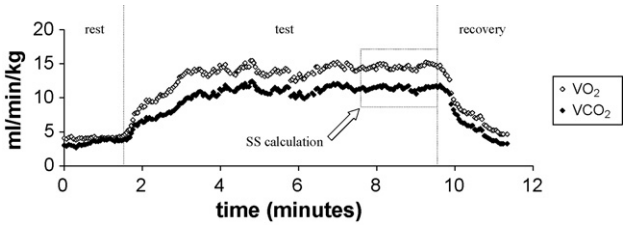

Fig. 1. Breath-by-breath oxygen consumption (VO_2) and carbon dioxide production (VCO_2) during floor test. The patients were asked to walk at their own self-selected comfortable speed. The test lasted at least 7 min to enable them to reach and maintain steady-state (SS) conditions. Data obtained during the last 2 min were assumed to be the steady state and mean value of these 2 min was used. Verification that the patients had reached steady state occurred in real time by means of data acquisition and graphic visualization, in telemetry (this figure is example for a single subject).

2.3.1. Floor measurement

The test was conducted indoors, in a hallway with a regular floor surface. We chose a 61 m rectilinear course the subjects had to walk back and forth on. The patients were asked to walk at their own self-selected comfortable speed, with the aid they normally used. The test lasted at least 7 min to enable them to reach and maintain steady-state conditions. Data obtained during the last 2 min were assumed to be the steady state and mean value of those was used [21] (Fig. 1). Steady state was defined as a condition in which, after some minutes of exercise at a constant and sub-maximal workload, the rate of oxygen consumption reaches a level sufficient to meet energy demands. In this condition oxygen consumption and other physiological parameters (cardiac output, heart and respiratory rate) maintain a plateau. Verification that the patients had reached steady state occurred in real time by means of data acquisition and graphic visualization, in telemetry (Fig. 1).

2.3.2. Treadmill measurement

A Technogym treadmill (RUNRACE model), adapted for rehabilitation needs (the lowest speed was .1 m/s), was used. The test was carried out without aids and with a treadmill inclination of 0°. The subject, with upper limbs forward, grasped the bar at the height of the treadmill display and could easily push the button to change speed. The speed indicator was covered and patients chose their own comfortable speed without knowing the speed indicated on the treadmill. Once the speed was chosen, the test lasted for at least 7 min.

The parameters recorded on both tests were the following: walking speed, steady-state oxygen consumption, resting heart rate and, finally, steady-state respiratory exchange ratio (carbon dioxide production/oxygen consumption). Oxygen consumption was expressed in milliliters per minute per kilogram of body weight (ml/min kg), and speed was expressed in meters per second (m/s). Energy cost (ECW), expressed in milliliters of oxygen consumed per meter walked for kilogram of body weight (ml/m kg), was calculated using the formula: ''oxygen consumption/speed''.

Breath-by-breath gas exchange was measured using the portable system K4b^2 (COSMED) [22], and heart rate using a POLAR heart rate monitor applied to the patient's thorax.

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