An Evaluation of Mechanical Energy Transfer During Spring-loaded and Traditional Crutch Ambulation

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Abstract

Context: Spring-loaded crutches may decrease metabolic energy expenditure during ambulation, relative to traditional crutch use, by transferring additional mechanical energy from a compressed spring in the crutch post to the patient. Prior to the present study, this idea had not been comprehensively evaluated. **Objective:** The purpose of this study was to determine whether spring-loaded crutches provide additional kinetic energy to patients, relative to traditional crutches. We hypothesized that subjects utilizing spring-loaded crutches would exhibit greater peak velocity (Kinetic Energy = ½ · mass · velocity^2), in the forward direction during crutch-ground contact, than subjects using traditional crutches. **Design:** Within-subjects. **Setting:** Controlled biomechanics laboratory. **Participants:** Twenty healthy volunteers (10 males, 10 females; Age = 23 ± 2 yrs; Height = 1.73 ± 0.10 m; Mass = 69.2 ± 13.7 kg). **Interventions:** The independent variable was crutch type. Subjects performed five randomized ambulation trials with traditional and spring-loaded crutches; the order of crutch use was randomized. Subjects were required to ambulate at a standardized speed (0.97 m/s ± 5%); immediate feedback regarding ambulation speed was provided to subjects using an opto-electronic timing device. Whole-body center of mass velocity was derived from center of mass position; center of mass position was determined using six video cameras and 35 reflective markers placed over various anatomical landmarks. Mean differences in peak velocity between crutch type were evaluated using a paired *t*-test ($\alpha = 0.05$). **Main Outcome Measures:** The dependent variable was peak whole-body center of mass velocity, in the forward direction during crutch-ground contact. **Results:** Peak velocity during crutch-ground contact was 5% greater ($p < 0.001$; $t_{0.05,19} = -4.598$) for subjects using spring-loaded crutches (1.29 ± 0.08 m/s) than for subjects using traditional crutches (1.23 ± 0.10 m/s). **Conclusions:** The present data supported our hypothesis, indicating that instantaneous kinetic energy, in the forward direction, is greater for subjects using spring-loaded crutches than for subjects using traditional crutches. However, these differences were relatively small and should be interpreted with caution. The direction of the difference supports the notion that spring-loaded crutch use may require less metabolic energy expenditure than ambulation using traditional crutches. However, reduced metabolic energy expenditure should not be inferred from these data alone, as other factors influence metabolic energy expenditure rate. A direct measure of metabolic costs for patients utilizing spring-loaded and traditional crutches would further clarify this issue.

Introduction

Approximately 600,000 Americans use crutches to ambulate,[1] and crutch ambulation requires significantly more energy than able-bodied gait.[2] A novel spring-loaded crutch design (Figure 1) may reduce energy expenditure during crutch ambulation. A spring in the crutch post compresses during crutch-ground contact, storing strain energy; this strain energy is then converted into kinetic and gravitational energy upon spring decompression. Theoretically, the additional kinetic energy that results from spring decompression may be transmitted to the patient in the forward direction and reduce energy expenditure during crutch ambulation. The purpose of this study was to objectively evaluate the aforementioned theorized energy transfer. We hypothesized that subjects using spring-loaded crutches would exhibit greater peak velocity and kinetic energy in the forward direction than subjects using traditional crutches.

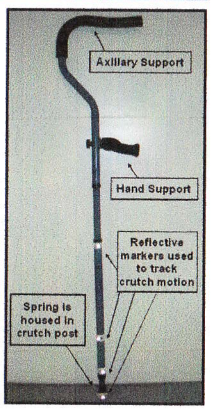

Figure 1. The spring-loaded crutch that was tested.

Methods

Twenty healthy subjects participated (10 male, 10 female; Age = 23 ± 2 yrs; Height = 1.73 ± 0.10 m; Mass = 69.2 ± 13.7 kg). We applied reflective markers to subjects and crutches in order to determine whole-body center of mass position during crutch-ground contact (Figure 2). Subjects performed five ambulation trials using spring-loaded crutches and five trials using traditional crutches at a standardized speed (0.97 m/s ± 5%). Video was used to determine center of mass and crutch position during the trials. Peak center of mass velocity in the forward direction was derived from the position data, and peak kinetic energy for the center of mass in the forward direction was calculated using a standard equation: Kinetic Energy = ½ · mass · velocity^2. We used paired *t*-tests to compare mean ambulation velocity, and peak velocity and kinetic energy for the whole-body center of mass in the forward direction between crutch types.

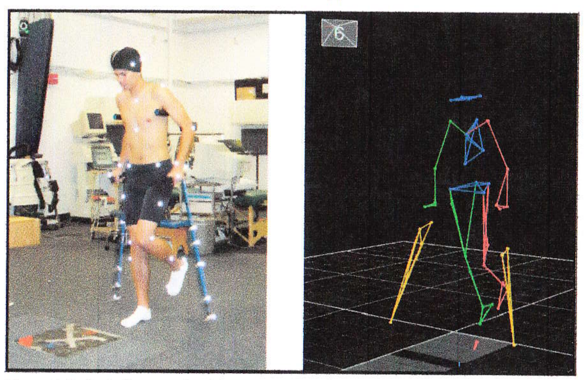

Figure 2. Left: A photograph of the reflective marker arrangement for the spring-loaded crutch trials. Right: The computer reproduction of the subject. Traditional-crutch ambulation was observed in a similar fashion.

Results & Discussion

Center of mass peak velocity and peak kinetic energy in the forward direction were 5% ($p < 0.001$; $t_{0.05,19} = -4.598$) and 9.6% ($p = 0.001$; $t_{0.05,19} = -4.157$) greater for subjects using spring-loaded crutches than for subjects using traditional crutches (Table 1).

	Spring-loaded Crutches	Traditional Crutches
Peak Velocity (m/s)	1.29 ± 0.08	1.23 ± 0.10
Peak Kinetic Energy (J)	57.3 ± 12.0	52.3 ± 11.6

Table 1. Means and standard deviations for peak center of mass velocity and kinetic energy in the forward direction during spring-loaded and traditional crutch ambulation.

The results confirmed our hypothesis and indicate that individuals possess more kinetic energy in the forward direction at the end of crutch-ground contact while using the tested spring-loaded crutches. Some of this additional kinetic energy probably results from the strain energy (2.50 ± 1.96 J) that is stored via spring compression during crutch-ground contact. Part of this stored strain energy is converted into kinetic energy and is likely transmitted to the individual, in the forward direction. The observed differences for kinetic energy were relatively small, however, and should be interpreted with caution. The results support the notion that these spring-loaded crutches provide additional kinetic energy and may decrease metabolic energy expenditure, yet reduced metabolic energy expenditure should not be assumed from these data alone. A comprehensive comparison of metabolic costs while using these spring-loaded crutches and traditional crutches would further clarify this issue.

References

1. Russell et al. (1997), Vital & Health Stats for CDC, 292, 1-10.
2. Fisher (1981), Arch Phys Med & Rehab, 62, 250-256.

Acknowledgements

We gratefully acknowledge Millennial Medical Incorporated, the BYU Office of Research and Creative Activities, and the Mary Lou Fulton Chair for the College of Health and Human Performance at BYU for funding this project.