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The influence of a polymer damper on swing-through crutch gait biomechanics

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ABSTRACT

Forearm crutch technology has evolved slowly compared to other assistive mobility devices, despite the highly repetitive nature of forearm crutch gait and the high incidence of overuse injuries. Using 13 able-bodied volunteers between the ages of 19 and 27, we compared the ground reaction forces of a novel crutch design featuring an elastomeric polymer situated below the handle to an identical design without a damper system and to a commercially available generic rigid forearm crutch model. There were no differences in peak vertical force or impulse between crutches. The crutch with the damper system demonstrated a significantly smaller peak braking force and impulse compared to the generic forearm crutch model. However, the crutch with the damper system demonstrated a significantly larger peak propulsive force and impulse compared to both crutch models. This finding indicates that a forearm crutch with a damper system may help to propel the crutch forward when walking on level surfaces, which could impact forward momentum.

1. Introduction

Although the forearm crutch has existed for nearly 5000 years [1], its design and technology has advanced slowly compared to other forms of assistive mobility devices. Many assistive walking devices have historically been characterized as a ‘rigid support with an underarm crosspiece’ in reference to the early axillary crutch [2]. Problems associated with this primitive crutch design were identified as early as the 1900s and have included compression neuropathy of the radial nerve, brachial plexus, and axillary artery [3–5]. The forearm crutch, also known as the Lofstrand or Canadian crutch, is thought to enhance control during gait [6]. However, long-term use of the forearm crutch has been associated with overuse injuries of the upper extremities such as ulnar neuropathy at the wrist and elbow and ulnar fractures [7–11].

Crutch-assisted gait requires significantly more energy compared to unassisted gait in able-bodied individuals and consequently many crutch users may also experience fatigue [12–14]. Swing-through gait is the most energy-demanding form of crutch gait and has been reported to require 78% more energy compared to unassisted gait [13]. An additional study found that ambulating using swing-through gait with axillary crutches expended twice as much energy compared to unassisted gait [12]. Swing-through gait consists of the individual simultaneously advancing both crutches forward, swinging the torso past the crutches, and then bearing weight on the foot or feet (Fig. 1) [15], thus resulting in repetitive loading of the upper limbs and leg(s).

The reliance on crutches for mobility requires repetitive joint loading of the upper extremities, therefore any reductions in vertical ground reaction forces and impulses may help to reduce impact on the body. Many forearm crutches are made of rigid materials such as steel, aluminum, and hard plastics, which are not designed to absorb impulse (i.e. dissipate kinetic energy). Although these rigid materials are less expensive, they likely do little to reduce joint impact. Shock absorption systems have been used in a variety of devices such as bicycles, prosthetics, wheelchair forks, and footwear for many years, but have only been implemented into commercially available crutch designs over the past few decades

Abbreviations: % BW, percent body weight; s, seconds; sd, standard deviation; η_p^2, partial eta squared.

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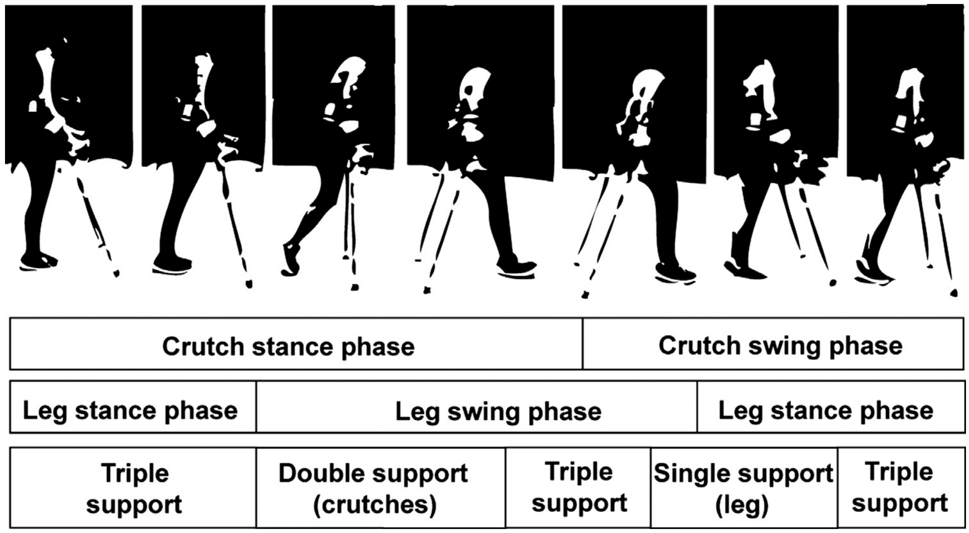

Fig. 1. Schematic of swing-through crutch gait. The schematic of swing-through crutch gait identifies the main phases of this gait pattern including crutch stance and swing phases.

[16–21]. The use of damping materials in crutch designs may help to reduce overall impact and consequently repetitive overuse injuries.

Minimal research has evaluated the influence of a shock absorption system on swing-through forearm crutch gait kinetics (i.e. peak forces and impulses). Kinetic characteristics of a conventional aluminum axillary crutch were compared to a crutch model with a helical compression spring (spring constant 22.4 kN/m, preload 10 N) at the distal end of the shaft in ten able-bodied individuals [22]. The authors discovered that while the spring-loaded crutch decreased vertical crutch impulse, it also slowed walking velocity and increased peak vertical crutch ground reaction force. The authors hypothesized that their results might be a result of a 'bottoming-out' effect of the spring although the kinematic data did not confirm this [22]. An additional study found that spring-loaded axillary crutches (spring constant 12.95 kN/m, preload 220 N) increased peak forward velocity by 5% but did not change preferred ambulation speed, compared to standard axillary crutches [18]. An extensive spring study conducted by Shortell et al. found a spring constant of 21.9 kN/m to be suitable for individuals between 53–90 kg based on interviewing participants regarding their preference following trials with 30 different linear compression springs [19].

The focus of this research was to evaluate a new forearm crutch, designed to decrease overall impact to improve joint health (see Patent # 20110240077) [23]. Among other design features (e.g. rotating footpad, carbon tube in lower shaft, and ergonomic design), this crutch model incorporated a centrally positioned elastomeric damper-system (Fig. 2). The system is inserted below the handle to (1) reduce the moment of inertia caused by the weight of the damper system by keeping it close to the body (reducing the lever arm); (2) reduce environmental contaminants from interfering with the damper system; and (3) allow for easier height adjustment. The damper includes interchangeable polyurethane elastomers (polymers) with varying spring constants for different weight ranges which were selected based on the work by Shortell et al. [19].

It is postulated that the elastomeric damper would dissipate kinetic energy upon crutch loading and thus reduce peak vertical ground reaction forces and impulse. The purpose of this study was to determine the influence of the damper system on swing-through crutch gait ground reaction forces. We hypothesized that the crutch with the elastomeric damper system would reduce peak vertical force and impulse compared to a similar crutch model without a damper system and a generic rigid forearm crutch.

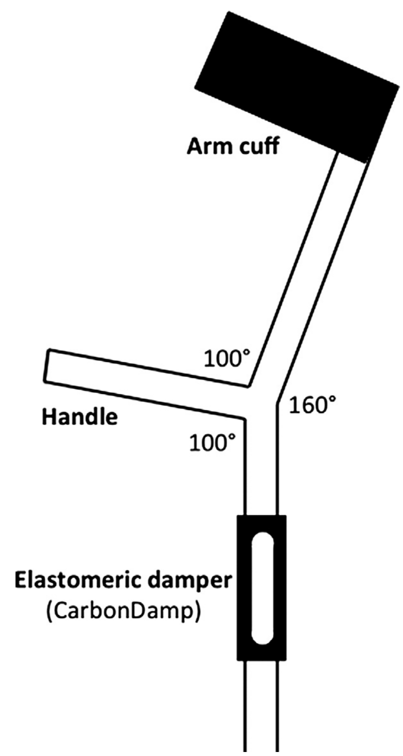

Fig. 2. Schematic of the CarbonDamp crutch model. The specific geometry of the Carbon and CarbonDamp crutches is indicated in the diagram. The damper system is located below the handle and the elastomeric polymer is situated within the shaft of the crutch (white cylinder).

2. Methods

2.1. Participant recruitment

Thirteen healthy able-bodied individuals (age range 19–27 years; mean height (sd) 174 (9.6) cm; mean body mass (sd) 66.3 (11.6) kg) were recruited. Ten participants reported being