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Analysis of hand pressure in different crutch lengths and upper-limb movements during crutched walking

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ABSTRACT

Hand pressure in crutch is important as it is directly related to the comfort of the patients using crutches. However, little research has been done on dynamical hand pressure during crutched walking. This study investigated hand pressures and joint movements in the upper limb with the different crutch lengths during crutched walking. Twelve healthy male adults participated in the study, and performed crutch-supported walking at bi-crutch and single-foot way. A specific mat of pressure sensors was designed to measure the hand pressure of the palm and fingers and a motion capture system used to capture the movements at the shoulder and elbow. It was found that when walking speeds were between 0.5 and 1.0 m/s, maximum pressure and force were approximately 120 kPa and 100 N respectively in the hand; the ranges of motion were from 28 to 60 deg at the shoulder and from 15 to 30 deg at the elbow. The results showed that the pressure-time integral and force-time integral in the hand are higher when using a traditional standard crutch length than using longer or shorter lengths. The visual analogue scores of conformable degree showed that the participants are favourite for a traditional standard crutch length. The pressure and kinematic data collected provide a set of database available for crutch manufacturer, glove designer and clinicians as reference when they need.

Relevance to industry: Crutched walking usually causes hand uncomfortable or injury. Our study provides the first experimental data of hand pressures and the joint movements in the upper limbs at different crutch lengths. These results are valuable for devising gloves for patients, thus improving the life quality of the patients using crutch.

1. Introduction

Injuries of the lower extremities following a fall or an accident are very common. Such injuries make walking difficult because the lower limbs cannot bear the body weight properly. Elbow crutches are designed for the ambulation of injured patients allowing weight bearing via the arms and hands until full recovery. The handle position or crutch length and pressure distribution on the hands are directly related to the comfort of the patients using crutches, thus should be investigated.

Walking with different crutch lengths during non-weight bearing, swing-through axillary crutch gait showed no significant effect on the forces exerted on the hand, however while changing gait speed from slow to normal it did have a significant effect (Stallard et al., 1980; Sala et al., 1998; Reisman et al., 1985; Aldien et al., 2005). These gait patterns are a common practice following orthopaedic operations or leg injury, and involve leaning on crutches, extending hips and spine, raising the body free from the ground and swinging forward through the crutches. There is full transfer of body weight to the crutches during the stance phase of the gait cycle (Sala et al., 1998). There has been no published literature studying the relationships among crutch length, hand pressure, upper limb kinematics and walking speeds.

What crutch length is suitable for the patients using crutches? Previous authors have recommended specific criteria for optimal length of crutches during ambulation (Mulley, 1988). They have placed particular emphasis on the effect of energy expenditure and activity intensity during non-weight bearing walking (Mullis and Dent, 2000) or on metabolic intensity by measuring oxygen consumption (Smith and Enright, 1996). However these studies have not investigated the relationship

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between hand pressure and crutch lengths during crutched walking.

Previous studies have reported different hand forces and pressures in different situations, e.g. hand forces in griping cylindrical handles (Aldien et al., 2005), max griping strengths (Rossi et al., 2012), and male griping strength (Seo et al., 2007); also the pressures in handgrip measurements (Ugurlu and Ozdogan, 2011) and in falling down (Choi and Robinovitch, 2011). Aldien et al. (2005) observed a high peak pressure in the thenar area following an application of high grip and push force on a large diameter cylindrical handle, or low grip and high push force on a smaller diameter handle. Sala et al. (1998) reported that palmar load distributions for cylindrical and wide elbow crutch handle design were similar during ambulation through modified three-point partial weight-bearing gait pattern. Nicholas et al. (2012) measured the static pressures of the hand grasping cylinders. Recently, Kabra et al. (2015) measured hand pressure during wheelchair propelling, and Medola et al. (2014) used a glove instrumented system with ten force sensors to assess how different handrim designs influence the force distribution on hands. However, there was little research directly measuring hand pressures on the crutch handle during walking and associated with upper limb movements.

Therefore, this study aimed to investigate the effect of different crutch heights on hand pressure and on the movement of shoulder and elbow joints during single leg and bi-crutch supported gait. The particular objectives were to measure hand pressure at different crutch heights, and collected and analysed the movements of the shoulder and elbow joints during crutch-supported walking. Hopefully, the data measured would benefit manufactures of crutch, designers of glove, and clinicians who guide patients using crutches, ultimately to improve the quality of patient comfort during ambulation.

2. Methods

2.1. Participants

Twelve healthy male subjects participated in the study. Their ages were between 22 and 45 years (mean: 35.2 years, standard deviation [S.D.] 7.7) with a mean height of 175.6 cm (S.D. 7.6) and a mean weight of 77.6 kg (S.D. 9.8). Subjects had no previous injuries, dysfunction or surgeries to the upper limbs and hands. The study was approved by the university research ethics committee. All subjects signed the consent forms prior to data collection.

2.2. Crutch length

The standard elbow crutch was selected in this study. This crutch is adjustable, light-weight, and is commonly used in clinical practice. The crutch height was measured according to Mulley's guidelines (Mulley, 1988) which suggest that both the distance from the floor to the handle and from the floor to the ulnar styloid should be equal with elbow joint in 15° of flexion. In this study, this crutch height was defined as the standard length; 5 cm higher being defined as long length and 5 cm lower as short length. All subjects were instructed on how to walk with single supported leg on bi-crutch, and were allowed to practice several times before recording data.

2.3. Equipment

The main apparatus used for data collection was the Vicon® motion capture system with 12 high resolution digital cameras covering a 25 m walkway. The Novel Pliance® matrix sensors were specifically designed to measure hand pressure distribution and contact forces while gripping a cylinder during walking. The individual sensor elements were elastic and arranged in a matrix which conformed to three-dimensional shapes. The matrix typed S2022-44 was calibrated on a cylinder of 28 mm diameter up to 400 kPa then connected to the Pliance® X32 analyser via the CX2032 cable as shown in Fig. 1. The calibration procedure is given in Appendix.

2.4. The model to calculate joint angles

A model was developed in-house to calculate the joint angles in the shoulder and elbow. This model employed a set of reflective markers attached over bony landmark on the body to construct three segments, the trunk, arm and forearm.

These marker placements were:

- the acromioclavicular joint
- the manubrium sterni
- the xiphisternum
- the seventh cervical and tenth thoracic vertebrae
- the contralateral acromioclvicular joint
- the greater tuberosity of the humerus
- the medial and the lateral epicondyle of the humerus
- the radial and the ulnar styloid processes

Each foot had two makers applied, one over the 5th metatarsal shaft and the other on the posterior aspect of the heel. Two more markers were used for each crutch, one at the upper end close to handgrip. These markers enabled us to calculate joint angles at the shoulder and elbow and also to analyse walking parameters such as speed, cadence and phase proportion (Fig. 2). A similar model was used and validated in several studies (Kolwadkar et al., 2011; Kabra et al., 2015; Jafri et al., 2015). This model has been modified by adding a couple of markers on the trunk and thus worked more reliably than previous ones during movement.

2.5. Data collection

Firstly, the Vicon® motion capture system was calibrated statically and dynamically by using the Vicon® standard calibration frame. Then subjects stood still while all markers on the body were captured in order to calculate the joint angles for subject standing situations. Then, the dynamic trial was carried out by requesting the subject to walk with single supported leg and bi-crutch within the motion capture area. Each subject was required to walk under the three different crutch lengths, standard, long and short, in a randomised order. Each subject walked six trials for each crutch length, and from these, three respective trials were analysed.

2.6. Stance and swing phases

Stance phase was defined as the period when the crutches made contact with the ground. Swing phase was defined as the period when the crutches had no contact with the ground. A cycle of crutch walking was defined from an initial strike of the crutch on the ground to the next initial strike. Only one cycle on the centre area of walking way was analysed as the speed there was more stable than beginning and finishing phases.

2.7. Visual analogue score (VAS)

After the subjects had walked with three different crutch lengths, they were asked to complete a 10 point scoring scale for