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The effect of stroke on foot kinematics and the functional consequences

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ABSTRACT

Background: Although approximately one-third of stroke survivors suffer abnormal foot posture and this can influence mobility, there is very little objective information regarding the foot and ankle after stroke.
Objective: As part of a programme of research examining foot and ankle biomechanics after stroke, we investigated multi-planar kinematics and the relationship with function.
Methods: In a single assessment session, static foot posture (Foot Posture Index); mobility limitations (Walking Handicap Scale) and multi-segment foot and ankle kinematics during stance phase of walking were measured in 20 mobile chronic stroke survivors and 15 sex and age-matched healthy volunteers.
Results: Compared to the healthy volunteers, the stroke survivors demonstrated consistently reduced range of motion across most segments and planes, increased pronation and reduced supination, disruption of the rocker and the timing of joint motion. Changes in pronation/supination were associated with limited walking ability.
Conclusions: This study provides evidence of structural and movement deficiencies in the intrinsic foot segments affected by stroke. These would not have been detectable using a single segment foot model. Data do not support common clinical practices that focus on correction of sagittal ankle deformity and assumed excessive foot supination. Some of these abnormalities were associated with limitation in functional ability. Biomechanical abnormalities of foot and ankle are modifiable and there is potential for clinical studies and future developments of interventions to help prevent or treat these abnormalities which may improve functional ability post stroke.

1. Introduction

Regaining safe, independent mobility is a priority for many stroke survivors and is a primary goal in stroke rehabilitation [1]. There is an extensive literature about the mechanisms of hemiplegic gait and the rehabilitation of walking after stroke, but this concentrates on hip and knee movements. There is a particular paucity of information about foot and ankle function. As the only source of direct contact with the ground, the function of the foot is important for weight bearing tasks and there is already some evidence of foot and ankle problems after stroke. Foot deformities which could influence walking have been reported in ~50% of people with chronic stroke [2]. Approximately 30% suffer abnormal, asymmetric foot posture while standing (with almost equal numbers of pronation and supination abnormality) [3], and foot posture abnormalities are associated with walking limitations [3].

Most stroke related foot and ankle literature focuses on sagittal plane function [4–7]. The deviations most commonly reported are initial contact on areas other than the heel, reduced ankle plantarflexion after initial contact, reduced dorsiflexion during midstance and reduced plantarflexion at toe off [8–10]. Varus foot deformities are said to be common in swing phase [5]. However these descriptions are based on a single segment model of the foot and ankle in which all the bones distal to the tibia are assumed to act as a single unit. This fails to take movement in the frontal and transverse planes in to account [5,8] and ignores the coupling between foot joints and movements across planes of motion [11]. These coupled movements are influenced by extrinsic and intrinsic multi-joint muscles that are affected by stroke [12]. Indeed there already some evidence that stroke affects the rearfoot, midfoot and forefoot during walking [6,12,13]. However, the limited information

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available may lead to incorrect diagnosis and inappropriate clinical interventions. For example, using the single segment foot model to describe the commonly reported plantarflexed ankle (equinus) and excessive midfoot dorsiflexion (the so called midfoot break) may lead to motion at the tarso-metatarsal and midfoot joints to be interpreted as ankle motion. This would indicate clinical use of an ankle–foot orthosis, whereas a foot orthosis would more effectively address abnormal intrinsic foot movements. Three dimensional multi-segment foot and ankle kinematics have been used to simplify the complex structure of the foot and yet successfully identify disease-related abnormalities of foot and ankle kinematics [14,15]. They have yet to be implemented in stroke populations.

Thus, we undertook a programme of research

- To examine foot and ankle biomechanics after stroke using a tri-planar multi-segment model.
- To explore the impact of any abnormalities on functional walking ability.

2. Methods

Subsequent to ethical approval from the University and National Health Service, sample size was decided after a pilot study. Based on rearfoot eversion and inversion data from ten stroke and ten control participants, a minimum sample of 14 subjects per group was required to detect differences with 80% power. To improve clinical relevance, the final sample was twenty stroke survivors who could walk independently without an assistive device for at least 10 m. These were recruited from in and out-patient stroke services of the local hospital and a stroke support group (7 men, mean age 65.0 ± 10.2 years, height 1.65 ± 0.1 m, weight 73.2 ± 18.2 kg, the right side was affected for 8 survivors and median time after stroke 6.9 months, IQR: 10.4 months). Fifteen healthy sex and age-matched (within 5 years) volunteers were also recruited from stroke participants' relatives and staff of the university and their relatives, which provided 20 side-matched feet (10 men, mean age 67.1 ± 8.6 years, height 1.64 ± 0.9 m and weight 72.6 ± 8.5 kg).

For each participant, static foot posture (Foot Posture Index (FPI) [16]); mobility limitations (Walking Handicap Scale [17]); multi-segment foot and ankle kinematics and spatio-temporal gait parameters during stance phase were recorded in a single measurement session at the University's gait analysis clinic. A ten camera Qualysis Proreflex system (Qualisys Medical, 2003, 100 Hz) was used to obtain the kinematic data. Eighteen reflective markers were attached to the forefoot, midfoot, rearfoot and shank on affected side of stroke survivors and the same sides of healthy control group (Table 1). The Calibrated Anatomical System Technique (CAST) was adopted to establish a suitably anatomical four segmental model of foot and shank [18]. First a static trial was recorded during relaxed standing in which position participants placed their feet in a natural, self-selected posture, attempting equal weight bearing on both feet. Participants walked barefoot along the walkway while the Qualysis system tracked the movements of the reflective markers indicating the movement of the foot and ankle segments. A minimum of ten walking trials were collected. Data from the markers were smoothed (4th order Butterworth, low-pass filter with 6 Hz cut off) and individual segment coordinate systems were defined using the anatomical markers and joint centre calculations with the positive *X*-axis to the right, positive *Y*-axis facing anteriorly, and positive *Z*-axis pointing superiorly. Vertical velocity of the midpoint between the heel and toe markers derived the point of initial contact (IC) and toe off (TO) of stance phase [19]. After detection of gait events, processed kinematic data were normalised to 100 percent of stance phase to enable averaging across trials.

The variables measured were maximums, minimums and range of motion of the rearfoot (i.e. the calcaneus relative to the shank), the midfoot (i.e. the midfoot relative to the rearfoot) and the forefoot (i.e. the forefoot relative to the midfoot) in the three anatomical planes (sagittal, transverse and frontal). Angular

Table 1
Anatomical and tracking markers in our multi-segments foot and shank model.

Segments	Anatomical (calibration) markers	Tracking markers
Shank	1- Two markers on the medial and lateral femur epicondyles 2- Two markers on the most medial and lateral aspects of malleolus	1- A cluster of four markers on the distal and anterior aspect of shank
Rearfoot	1- A cluster of four markers on calcaneus (two markers on the bisection line of the posterior aspect of heel, distally and proximally (ICAL and SCAL, respectively). Two markers on the medial and lateral aspects of heel at the same distance from the posterior bisection line (MCAL and LCAL, respectively)	1- The same as calibration markers
Midfoot	1- A cluster of three markers (one marker on the navicular tuberosity (NAV), one marker on the cuboid tuberosity (CUB) and one marker on the dorsal aspect of second cuneiform (SCN2))	1- The same as calibration markers
Forefoot	1- SCN2 2- One marker on the distal head of first metatarsal (D1MT) 3- One marker on the distal head of fifth metatarsal (D5MT)	1- D1MT 2- The head of second metatarsal (D2MT) 3- D5MT
Total foot	1- Two markers on the most medial and lateral aspects of malleolus 2- D1MT 3- D5MT	1- SCAL 2- D1MT 3- D5MT