**A cross-sectional observational study comparing foot and ankle characteristics in people with stroke and healthy controls.**

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**Abstract**

**Purpose:** The purpose of this study was to explore and compare foot and ankle characteristics in people with stroke and healthy controls; and between stroke fallers and non-fallers.

**Methods:** Participants were recruited from community groups and completed standardised tests assessing sensation, foot posture, foot function, ankle dorsiflexion and first metatarsal phalangeal joint range of motion (1st MPJ ROM), hallux valgus presence and severity.

**Results:** Twenty three stroke participants (mean age 75.09 ± 7.57 years; 12 fallers) and 16 controls (mean age 73.44 ± 8.35 years) took part. Within the stroke group, reduced 1st MPJ sensation (P=0.016) and 1st MPJ ROM (P=0.025) were observed in the affected foot in comparison to the non-affected foot; no other differences were apparent. Pooled data (for both feet) was used to explore between stroke/control (n=78 feet) and stroke faller /non-faller (n=46 feet) group differences. In comparison to the control group, stroke participants exhibited reduced sensation of the 1st MPJ (p=0.020), higher Foot Posture Index scores (indicating greater foot pronation, p=0.008) and reduced foot function (p=0.003). Stroke fallers exhibited significantly greater foot pronation in comparison to non-fallers (p=0.027).

**Conclusions**: Results indicated differences in foot and ankle characteristics post stroke in comparison to healthy controls. These changes may negatively impact functional ability and the ability to preserve balance. Further research is warranted to explore the influence of foot problems on balance ability and falls in people with stroke.

**Background**

Approximately one in three community dwelling older people report problems with their feet [1, 2, 3]. Ageing contributes to foot problems such as: pain, increased pronation, reduced range of motion (ROM) at the ankle and first metatarsal phalangeal joint (1st

MPJ), higher incidence of hallux valgus; toe deformities as well as sensation problems and reduced toe strength [1, 4-5]. Foot problems are associated with functional problems such as reduced walking speed, difficulty with activities of daily living (ADL) and increased risk of falls [1].

Maintenance of balance depends on interaction of multiple sensory, motor and integrative systems [2]. Alteration in foot posture, sensation, strength or flexibility could lead to impairments in the foot and ankle’s ability to maintain these functions [3]. Foot sensation and proprioception have been associated with postural sway and balance in the elderly [3] and post stroke [6]. Reduced sensation can lead to increased caution during weight acceptance throughout the gait cycle [4] and consequently a reduction in duration of stance phase of the affected limb [7].

People with stroke often present with motor and sensory deficits that impact on their ability to perform functional tasks [8-10]. A stroke can affect different functions in each individual leaving residual impairments of varying severity and a number of compensatory strategies [11] and can alter physiological characteristics including those of the foot and ankle which may negatively impact on gait and balance. Few studies have explored foot and ankle problems specifically in people with stroke [12-14]. Forghany etal. [12] used the Foot Posture Index (FPI) to assess foot posture and reported that approximately 30% of participants had abnormal foot posture with pronation more common than supination; foot abnormalities were more common among less mobile participants. A later study highlighted that people with stroke had reduced ROM in the foot across most segments and planes and a more pronated foot position was observed [13]. In contrast, others reported FPI scores indicative of greater supination particularly in the affected foot and concluded that supinated foot postures were linked to increased levels of spasticity [14].

Among the elderly population, foot problems were significantly more common in fallers and a number of studies highlighted the importance of toe plantar flexion strength as a potential predictor of falls [5, 15-16]. People with stroke are at higher risk of falling than people among the general population [17-18]. Current research highlights a relationship between foot and ankle characteristics and falls in the elderly population and an increased fall risk in stroke patients. However, to date few researchers have explored foot and ankle characteristics among chronic people with stroke and it is unknown whether foot and ankle problems contribute to fall risk within the stroke population. Therefore the primary aim of this study was to explore if a) there are differences between the foot and ankle characteristics of stroke patients and healthy controls and b) whether foot and ankle problems differ between stroke fallers and non-fallers.

**Methods**

**Study Design**

This cross-sectional observational investigation was approved by the Faculty of Health

Sciences Ethics Board at the University of Southampton and was completed as part of an

MSc-Physiotherapy (Pre*-*registration) - course. Community dwelling older people (with no history of stroke) and people with stroke were recruited from community and stroke groups around Hampshire. Permission was gained to attend a group meeting from group leaders prior to initial contact with any potential participants. The inclusion criteria were

(1) live within 30 mile radius of Southampton, (2) able to mobilise independently at least

10m (with or without an aid), (3) to be ≥ 1 year post stroke and satisfy the definition of stroke according to World Health Organisation (stroke participants only) [19], (4) be able to give informed consent and follow instructions and (5) must not have suffered a stroke (control participants only). People with other neurological impairments, systemic illness that could affect foot and ankle characteristics, lower limb amputations or current foot or ankle injuries were excluded. All participants provided written informed consent prior to commencement of testing.

**Participants**

Twenty three individuals with a history of stroke volunteered to participate in this study.

Twelve participants reported left hemiplegia, 10 a right hemiplegia and for one participant neither side was affected. The mean time post stroke was 8 years (±6.38), mean age of the stroke group 75.09 ± 7.57 years. Sixteen individuals who had no history of stroke volunteered to take part to serve as a control group (mean age 73.44 ± 8.35 years).

Participant characteristics are presented in Table 1.

**Table 1**: Mean ± standard deviation of stroke and control group characteristics

|  |  |  |
| --- | --- | --- |
|  | **Stroke (n=23)** | **Control (n=16)** |
| Gender (Male/Female) | 13/10 \* | 3/13 |
| Age | 75.09 ± 7.573 | 73.44 ± 8.350 |
| BMI# | 27.76 ± 6.21 | 26.79 ± 3.64 |
| FAC score | 4.52 ±0.51 | 4.81 ± 0.403 |
| Fallers | 12\* | 3 |
| Side of weakness (L/R/None) | 12/10/1 | n/a |

\* p =0.024 for Gender and p=0.049 for Fallers

#Body Mass Index calculated: height2 (cm)/weight (kg)

FAC=Functional Ambulation Category score

**Assessments**

Participants were visited in their own home on one occasion and asked to complete a battery of tests in a standardised order on both feet. The foot and ankle tests included in this study have previously demonstrated acceptable reliability [20-23]. Sensation of the plantar aspect of the 1st MPJ was assessed using a 10g retractable monofilament (Bailey

Instruments, Manchester, UK). The monofilament was applied to test sites until it bowed and sensitivity was determined (yes/no answer) according to online American College of Physicians Clinical 2007 guidelines for diabetic foot care; updated guidelines have been published after data collection was completed [24]. Foot posture was assessed using the Foot Posture Index (FPI) [20]. For this test participants were asked to stand still (with double limb support) in a relaxed position, with arms by their side, looking straight ahead and foot posture was rated using six validated criteria of the foot and ankle on a five point scale (-2 to +2) with summed scores providing a measure of the degree of foot pronation or supination in a static position with larger scores indicating more pronation. The Foot Function Index (FFI) [21] was used to measures the impact of foot pathology on function by quantifying pain, disability and activity limitations in the form of visual analogue scales for each sub-scale (higher scores indicate worse foot function). Active ankle dorsiflexion ROM was measured using a universal goniometer with the participant resting their knee on a stool using anatomical landmarks as previously described [22]. Similarly active 1st MPJ extension ROM was measured in a non-weight bearing position using methods adapted from Hopson [25]. ROM measures were completed three times and a mean was calculated. Hallux valgus presence and severity was observed in standing and rated according to the Manchester Scale [26]. This instrument consists of four standardised photographs grading hallux valgus severity from 1-4. Participants were asked questions about the frequency and circumstances of any falls in the last 12 months using the Falls Events Questionnaire [27].

**Data Analysis**

The data for foot and ankle characteristics did not satisfy the assumption of normality; therefore non-parametric analyses were completed. Wilcoxon Signed Ranks tests were used to complete within group analysis and Mann Whitney U tests were used to determine if any significant differences existed between the stroke and control (and stroke faller/stroke non-faller group). For some measures (Manchester scale, FPI and ROM) data from both feet for of all participants (stroke and control) were pooled to give a total sample size of 78 feet to explore differences between the stroke and control group. Pooling of data is not always appropriate in clinical investigations [28] however it was justified in this study as it allowed comparison of the entire group and would account for any compensatory changes that could have occurred in the non-affected foot and ankle in response to stroke. Data was also pooled for the stroke group (giving a total sample size of 46 feet) for the Foot Posture Index score comparison between stroke fallers and non-fallers. Chi squared analysis was used to detect differences for the dichotomous variable of sensation for the plantar aspect of 1st MPJ (yes/no answer). A *p*-value of 0.05 was set as the criterion for statistical significance. SPSS (Version 22.0) was used to perform the analysis.

**Results**

The stroke and control group participants were comparable for age and Body Mass Index (BMI). Although there were trends towards a higher functional ambulation score in the control group this did not reach significance. More men than women made up the stroke group (13/10) in comparison to the male/female ratio in the control group (3/13) (p = 0.024) and a greater number of people with stroke had experienced falls in the previous 12 months (p = 0.049), see table 1.

**Within group analysis**

There were no differences between the stroke affected and non-affected foot and ankle on the Manchester scale, FPI and FFI scores or ankle dorsiflexion ROM (p>0.05) but there was less 1st MPJ extension ROM (p =0.025) and reduced sensation (p = 0.016) on the affected side in comparison to the non-affected side, see table 2. There were no significant differences between the left and right feet of the control group for all variables except for greater extension ROM at the 1st MPJ in the right foot (p =0.002, data not shown,).

**Between group analysis**

Table 2 presents group medians (range) for the stroke and control participants’ foot and ankle characteristics; pooled data is presented for Manchester scale, FPI scores and ROM. Comparisons between the stroke versus the control group highlighted a greater proportion of stroke participants who presented with reduced sensation in the plantar aspect of the 1st MPJ (p = 0.020), higher FPI scores (p=0.008, see Fig. 1a) and higher FFI total scores (p = 0.003, Fig.1b). Both the activity and disability FFI scores demonstrated greater impairment in the stroke group (p< 0.001 and p = 0.006 respectively) but no difference was demonstrated in the pain scores (but a variability and wide range in scores) was observed. There were no significant differences between the stroke and control groups for ankle dorsiflexion and 1st MPJ extension ROM or Manchester scale.

**Table 2:** Within and between group comparison of foot and ankle variables.

*Numbers*, Median (range)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Stroke (n=23)** | **p value**within stroke group | **Control (n=16)** | **p value**stroke vs control |
| Sensation Plantar aspect 1st MPJ intact (yes/no) | *9/14* |  | *13/3* | 0.020 |
| Unaffected foot# | *13/9* | 0.016 |  |
| Affected foot# | 8/14 |
| FPI \* | 8 (-7-12) |  | 4.5 (-4-10) | 0.008 |
| Unaffected foot# | 8 (-7-11) | ns |  |
| Affected foot# | 8 (-6-12) |
| Stroke faller\* | 9.5 (-7-12) | 0.027 |
| Stroke non-faller\* | 6 (-3-10) |
| FFI Total score  | 17 (0-64) |  | 0 (0-20) | 0.003 |
| FFI Pain  |  0 (0-90) | 0 (0-49) | ns |
| FFI Disability  | 10.0 (0-76)  | 0 (0-16) | 0.006 |
| FFI Activity  | 29.0 (0-80) | 0 (0-4) | <0.001 |
| ROM DF\* (degrees)  | 9.6 (0-21) | 10.5 (0-24) | ns |
| Unaffected foot# | 10.3 (0-21) | ns |  |
| Affected foot# | 9.5 (0-19) |
| 1st MPJ extension ROM\* | 36.83 (0-68) |  | 36.17 (9-71) | ns |
| Unaffected foot# | 38.7 (0-68) | 0.025 |  |
| Affected foot# | 27.0 (0-64) |
| Manchester scale score\* | 2 (1-4) |  | 2 (1-4) | ns |
| Hallux Valgus Y/N | *13/10* | *13/3* | ns |
| Unaffected foot# | *13/9* | ns |  |
| Affected foot# | *11/11* |

|  |
| --- |
|  ns= not significant (p>0.05)\* Median score based on pooled data (both feet n=46 stroke feet and n=32 control feet)# Missing data for one participant who did not have a left or right sided weakness  |



**Stroke Fallers and non-fallers**

Within the stroke group there were 12 fallers and 11 non-fallers. Within these two groups no significant differences were observed in the foot posture when comparing the affected and unaffected side. However, comparison of pooled FPI data (for both feet n=46 for all stroke group participants) revealed a significant difference between stroke-fallers and stroke-non-fallers (p = 0.027). The FPI score of fallers was 9.5 (-7-12) and 6 (-3-10) for non-fallers, suggesting that fallers presented with significantly greater foot pronation (Fig. 2). In all other foot and ankle characteristics no differences were apparent.



**Discussion**

This study adds to the emerging body of evidence and a growing awareness that foot and ankle problems may impact on balance performance and well-being in people with stroke [12-14, 29]. We reported that people with stroke presented with foot and ankle problems such as altered sensation, altered (more pronated) foot posture, reduced foot function and activity to a greater extent than people of a similar age who have not had a stroke. Our findings also suggested that people with stroke who have fallen exhibited significantly higher FPI scores (indicating greater foot pronation) in comparison to stroke non-fallers which may indicate that foot problems and specifically altered foot posture may contribute to an increased fall risk among people with stroke.

Altered sensation

Firstly, findings suggested that sensation of the plantar aspect of the 1st MPJ was significantly impaired in stroke participants (both with regards to the stroke affected side in comparison to the non-affected side and when comparing sensation in the stroke and control group). Somatosensory impairments are common post stroke [8-10] and as such it is unsurprising that results indicate a significant reduction in sensation of the foot in stroke participants, in particular the plantar sensitivity of the 1st MPJ in the affected foot. Sensory input from the plantar aspect of the foot is thought to contribute to postural stability and provides information on body position via plantar mechanoreceptors [3] contributing to an awareness of foot position sense [30]. The presence of sensation was assessed using a 10g monofilament due to pragmatic reasons (student project). While this is consistent with routine clinical practice, this method may be less sensitive to change in sensation than the use of an incremental method as used by other researchers [24].

Altered foot posture

Secondly, significant differences in foot posture, with a greater degree of foot pronation, were apparent in people with stroke in comparison to the control group (and when comparing stroke fallers with stroke non-fallers). It is plausible that changes in foot posture following stroke could occur secondary to a reduction in sensory input through the foot. Foot pronation might increase in an attempt to increase the plantar area of the foot in contact with the ground to increase the sensory information received by the foot. This might be a compensatory strategy in order to gain functionally important information regarding body position [31]. Increased pronation can lead to decreased lateral loading of the foot [4] and an increase in pressure exerted through the toes [31]; the increased force through the toes may be an attempt to stabilise standing posture [32]. As stroke fallers presented with significantly greater levels of pronation than non-fallers, the question arises, whether over-compensation can occur. It is possible that extreme foot postures such as the pronation observed among fallers in this study are counterproductive and thus might actually reduce the ability to preserve balance or to react to perturbations. Foot Posture Index scores for stroke fallers in the present study were higher than scores reported among elderly fallers [15]. Menz et al. [3] highlighted that high foot postures scores can be linked to reduced standing balance; which might suggest that alterations in foot posture could contribute to increased fall risk. Our findings are in line with other studies who also reported a tendency towards pronated foot postures in people with stroke [12-13] but in contrast to one study who reported a more supinated posture [14]. Interestingly, comparison of actual FPI scores between studies showed that participants in our study presented with much greater FPI scores than previously reported [12-14] whilst FPI scores in our control group were comparable to the normative values reported for a healthy elderly population [33]. An explanation could be the chronic nature of the stroke sample in the present study as previous studies assessed people at 7 [13], 16 [12] and 25 [14] months post stroke. During recovery and rehabilitation following a stroke, there may be an alteration in the demands placed upon the non-affected limb. Further investigation is required to determine the impact of stroke upon foot posture in both the affected and non-affected feet in the early and later stages post stroke.

Reduced foot function

Thirdly, people with stroke in this sample presented with reduced foot function. Differences were most apparent for the FFI activity limitation and disability sub-scales in comparison to control group FFI scores. Existing evidence suggests that reduced foot function can impact on the performance of functional tasks [5], functional status measures [2] and stability [3]. No direct comparison to other stroke specific studies is possible as previous studies did not assess foot function in people with stroke.

Reduced ROM

Within the stroke group 1st MPJ extension ROM was significantly reduced in the affected limb in comparison to the non- affected limb and slightly lower (not significantly different) scores for dorsiflexion (DF) ROM. No significant difference between the stroke and control group was apparent for 1st MPJ extension ROM was or dorsiflexion (DF) ROM.

Reduced 1st MPJ extension ROM and the concurrent reduced sensation in the plantar aspect of this joint may have led to reduced movement caused by a lack of awareness of the position of the great toe. Hopson et al. [25] reported 65° of 1st MPJ ROM was required for normal gait. This was not achieved in the present sample populations. Similarly reduced 1st MPJ ROM values have been reported in an elderly population [3, 4, 15]. Differences therefore could also be partially explained by advancing age [4].

In our study 9 (39%) of stroke participants achieved a DF ROM 5° of DF ROM. It has been previously suggested that in order to achieve foot clearance during the swing phase of gait at least 5-10° of DF ROM are required [34]. Lamontagne et al. [35] reported that more than 50% of stroke participants had reduced DF in swing phase in their paretic side. Reduction in DF ROM may be due to stiffness and spasticity of plantar flexors, ankle joint pathology and dorsi-flexor weakness [36]. In addition to foot clearance in gait, reduced ankle ROM can also be associated with impaired performance in tests of function and postural sway [3]*.* Values of DF in the current study are comparable to studies that assessed DF using non-weight bearing methods [35]. However the majority of recent studies into foot and ankle characteristics use an alternative weight bearing technique to produce passive DF to provide insight into movements that occurs in the stance phase of gait [3, 4, 16]. It may be pertinent to recommend that future research includes both active and passive measures of DF to better reflect the requirements of normal gait.

Big toe deformity

Thirteen (81%) people our control and 13 (57%) in the stroke group presented with a hallux valgus; in line with similar percentages reported by others [37]. We did not identify any significant differences between affected and non-affected feet in our stroke group. When comparing control and stroke groups, a high proportion of people in both groups demonstrated mild deformity, possibly suggesting prevalence increases with age rather than being related to stroke, consistent with Scott et al. [4]. Hallux valgus is reported to be more common and severe in females [38]. Therefore findings have to be viewed with caution as the similarity in scores between the groups may be influenced by the fact that our male/female ratio differed between the stroke and control group; possibly masking any difference.

It is acknowledged that there are several factors limiting generalisability of the current study including the small sample size, recruitment from community groups, and reliance on retrospective self-reporting of falls events. Despite these limitations, findings from this small study support that people with stroke have problems with their feet, which may contribute to an increased fall risk among this population. Results suggest that further research is warranted to further explore foot problems and identify possible interventions to address foot and ankle problems in people with stroke. We are currently undertaking a study exploring footwear and foot problems in relation to balance and falls in people with stroke and Parkinson disease (NIHR PB-PG-0212-27001) with the aim to develop and explore interventions to address foot problems in rehabilitation.

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**Declaration of Interest**

The authors report no conflicts of interest.

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