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# Relationship between hip flexion and ankle dorsiflexion during swing phase in chronic stroke patients

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ABSTRACT

*Background:* During the clinical examination of stroke patients, it is common to observe that involuntary hip flexion occurs during voluntary ankle dorsiflexion (synkinesia). This suggests that there is a relationship between these two joints. We hypothesized that there may be a relationship between hip and ankle flexion during swing phase of the gait cycle. The objective of this study was to determine if there is a biomechanical relationship between peak hip flexion and peak ankle dorsiflexion during the swing phase of the gait cycle following stroke.
*Method:* The paretic lower limbs of 60 patients with stroke were evaluated using clinical tests and 3D-gait analysis. The clinical assessment included muscle strength, spasticity and passive range of ankle motion. The gait analysis focused on sagittal frontal and transverse kinematic gait parameters during swing.
*Findings:* A stepwise-linear-regression indicated that peak hip flexion and gait speed were the only 2 parameters which accounted for peak ankle dorsiflexion. There was also a significant negative correlation between peak hip flexion and peak ankle dorsiflexion during swing, and a significant positive correlation between hip flexor and ankle dorsiflexor muscle strength.
*Interpretation:* These results suggest that the biomechanical behaviour of hip and ankle joints during the swing phase of the gait cycle is linked in patients with stroke. They also suggest that two strategies exist: if sufficient ankle dorsiflexion is present, less hip flexion is required (distal-strategy) whereas if dorsiflexion is reduced, it is compensated for by an increase in peak hip flexion (proximal-strategy).


## 1. Introduction

The paresis and spasticity which frequently occur following stroke alter the gait pattern and reduce gait capacity. This is a public health issue since gait-related disorders have been shown to have the greatest impact on independence in activities of daily living (Veerbeck et al., 2011). It is probably also why an estimated 25–74% of the 50 million stroke survivors worldwide require some assistance or are fully dependent on care givers for activities of daily living (Lloyd-Jones et al., 2010). Stroke patients' gait is characterized by a decrease in cadence, stride length and speed (Bohannon, 1987; Brandstater et al., 1983; Olney et al., 1994; Pinzur et al., 1987; Von Schroeber et al., 1995). These changes in spatiotemporal parameters are often related to kinematic deficits, particularly during the swing phase of the gait cycle. Decreases in peak hip flexion (Pinzur et al., 1987), peak knee flexion (Kerrigan et al., 1991) and peak ankle dorsiflexion (Pittock et al., 2003) are frequently observed. The main cause of decreased peak hip flexion is weakness of the hip flexor muscles (Kerrigan et al., 1991), although spasticity of the hip extensor muscles may also reduce hip flexion. Spasticity can cause other kinematic alterations such as decreased peak knee flexion in swing. Several studies (Hutin et al., 2010; Robertson et al., 2009; Stoquart et al., 2008) have demonstrated that spasticity of the rectus femoris muscle is one of the main causes of decreased peak knee flexion in swing in stroke patients. Decreased peak ankle dorsiflexion in swing seems to be one of the parameters which most affect the quality of gait and is a problem in the majority of stroke patients (Lamontagne et al., 2002). Two mechanisms generally cause this: paresis of the ankle dorsiflexor muscles (Tibialis Anterior) and spasticity, stiffness or contracture of the triceps surae (Dietz et al., 1981; Lamontagne et al., 2002; Mancini et al., 2005; Pittock et al., 2003; Pradon et al., 2011). Lamontagne et al. (2002) showed that in some stroke patients with passive plantarflexor stiffness, the activity of the ankle dorsiflexors was increased during swing and dorsiflexion was reduced but not significantly compared with values in control subjects. In contrast, other patients with excessive passive plantarflexor stiffness were unable to increase the activity of the dorsiflexor muscles and thus dorsiflexion was reduced.

During the gait cycle, ankle dorsiflexion occurs following toe off to ensure sufficient toe clearance and constitutes a critical component of the gait cycle (Dobkin et al., 2003). Indeed, insufficient dorsiflexion

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leads to a risk of falls. It also interferes with gait velocity since Lin et al. (2006) showed that gait velocity was particularly related to dorsiflexion capacity in stroke patients (Lin et al., 2006). However, although many patients have impaired dorsiflexion during swing, only a few fall. This fact led Lamontagne et al. (2002) to suggest that compensatory strategies involving other joints of the paretic lower limb might compensate for this deficit. However, their interpretation was limited since their analysis focused only on the ankle (Lamontagne et al., 2002). Olney et al. (1991) showed that the hip flexor muscles are the major contributors to gait following stroke (Olney et al., 1991). It would therefore seem logical that of all the more proximal joints, the hip might play a key role in compensating for decreased ankle dorsiflexion during swing.

This hypothesis is also partly supported by clinical observations. Indeed, it is not rare to observe synkinesia of the paretic lower limb in stroke patients. Synkinesia is characterized by a loss of movement selectivity. When the patient attempts to selectively contract a given muscle on the paretic side, co-contraction of other muscles occurs. Among the different kind of synkinesia that can be observed in stroke patients, the coordination synkinesia which associates voluntary ankle dorsiflexion with hip flexion is the most common (Thibaut et al., 2013). This synkinesia suggests that there may be a neurological, and thus also a biomechanical, relationship between ankle dorsiflexion and hip flexion. Indeed during a static clinical exam, patients unable to achieve a sufficient voluntarily ankle dorsiflexion, frequently use a compensatory strategy relying on performing a concomitant hip flexion called coordination synkinesia. In contrast, if they are able to perform a sufficient voluntarily dorsiflexion, they do not recruit hip flexors muscles. Therefore, it may be hypothesized that, during gait, hemiplegic patient who exhibits a lack of ankle dorsiflexion during swing phase, are liable compensate this kinematic alteration by simultaneously increasing hip flexion. In this last case, this phenomenon similar to what is observed in a static situation would represent a “synkinesia” during gait. In contrast, patients with sufficient ankle dorsiflexion during static clinical exam do not need an increase of hip flexion suggesting that they do not use this specific neurological mechanism. To our knowledge, this hypothesis has never been tested.

The aim of this study was therefore to evaluate the relationship between: i) peak ankle dorsiflexion and peak hip flexion during the swing phase of the gait cycle in stroke patients using a biomechanical approach (3D-gait analysis system); ii) the maximal voluntary strength of the hip and ankle dorsiflexor muscles evaluated clinically and the respective peak hip flexion and peak ankle dorsiflexion in swing; and iii) the spasticity of ankle plantarflexor muscles and ankle kinematics in the sagittal plane during swing.

## 2. Methods

### 2.1. Patients

Sixty stroke patients (mean age: 50.3 (13.1) years, 30 with right hemiparesis, 30 with left hemiparesis, 45 men and 15 women, time post stroke: 5.8 (6.7) years) were included in this study. The inclusion criteria were: age over 18 years, hemiparesis due to stroke, ability to walk 10 m without an assistive device and sufficiently medically stable to participate in the protocol. All subjects gave written consent before participation. This study was performed in accordance with the ethical codes of the World Medical Association (Declaration of Helsinki) and was approved by the local ethics committee (CPP Ile de France—Ambroise Paré).

### 2.2. Experimental protocol

The patients underwent 2 types of evaluation: a clinical assessment and 3D-gait analysis. The gait analysis was carried out at the patients' self-selected walking speeds.

To limit inter-investigator variability, the same physiotherapist carried out all assessments.

#### 2.2.1. Clinical assessment

The clinical assessment included:

- ➢ Hip flexor, knee flexor and extensor, and ankle dorsiflexor and plantarflexor muscle strength assessed using the Medical Research Council (MRC) scale.
- ➢ Evaluation of spasticity of the triceps surae using the Modified Ashworth Scale (MAS).
- ➢ Passive range of ankle motion using a manual goniometer (with the knee in flexion and in extension)
- ➢ The new Functional Ambulation Classification (nFAC).

#### 2.2.2. Gait analysis

3D-Gait analysis was carried out using the Motion Analysis System with a recording frequency of 100 Hz (Motion Analysis Corporation, Santa Rosa, CA, USA). The subjects wore their own shoes and were asked to walk at their own comfortable gait speed. A minimum of 10 gait trials were averaged. The trajectories of 30 reflective markers placed on anatomical land marks based on the Helen Hayes marker set were collected and filtered using a low-pass Butterworth filter with a cut off frequency of 6 Hz (Kadaba et al., 1990; Winter et al., 1974). Spatio-temporal parameters and joint kinematics were calculated using Orthotrack 6.5 software (Motion Analysis Corporation, Santa Rosa, CA, USA). The phases of the gait cycle were defined according to Perry (1992).

In addition to gait speed, the following kinematic gait parameters were analysed during the swing phase of the gait cycle on the paretic side: i) peak anterior pelvic tilt; ii) peak pelvic obliquity; iii) peak pelvic rotation; iv) peak hip flexion; v) peak hip abduction; vi) peak knee flexion and vii) peak ankle dorsiflexion. The magnitude of the ankle and the hip joints angle changes from toe-off to their respective peaks in swing phase were also assessed.

In addition, it should be note that the movement of ankle either in dorsiflexion or in plantarflexion was defined as follow: The zero line set was between the foot longitudinal axis perpendicular to the tibia longitudinal axis.

### 2.3. Statistical analysis

Descriptive statistics including means and standard deviations were calculated for each parameter and each subject. Then, values were averaged across subjects and expressed as the mean and the standard error.

Moreover, different types of multiple linear regression analysis were carried out in order to identify the variables which were the most highly correlated with peak ankle dorsiflexion in swing. A stepwise method with variables entered in the model at a significance level of $P < 0.01$ was used.

Multiple linear regression analysis is an extension of simple linear regression used to assess the association between two or more independent variables and a single continuous variable. The results of a multiple linear regression are expressed by the following equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots + b_pX_p$$

where Y is the predicted or expected value, $X_1$ through $X_p$ are p distinct predictor variables, $b_0$ is the value of Y when all the independent variables ($X_1$ through $X_p$) are equal to zero and $b_1$ to $b_p$ are the estimated regression coefficients. Each regression coefficient represents the change in Y relative to a one unit change in the respective independent variable.

The first regression was performed with data from all the patients ($N = 60$) and all the clinical parameters were used to identify the, or