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## Transverse plane rotation of the foot and transverse hip and pelvic kinematics in diplegic cerebral palsy

M.S. Gaston<sup>a,\*</sup>, E. Rutz<sup>b</sup>, T. Dreher<sup>c</sup>, R. Brunner<sup>b</sup>

<sup>a</sup>Royal Hospital for Sick Children, Edinburgh, UK

<sup>b</sup>University Children's Hospital, Basel, Switzerland

<sup>c</sup>Department of Orthopaedic Surgery, Heidelberg, Germany

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### ABSTRACT

External rotation of the foot associated with mid-foot break is a commonly observed gait abnormality in diplegic CP patients. Previous studies have shown a correlation between equinus and internal hip rotation in hemiplegic patients. This study aimed to determine if there was a correlation between the amount of transverse plane rotation in diplegic CP patients using kinematic data from standardised gait analysis.

Lower limb data of 134 ambulant children with diplegic CP was analysed retrospectively determining the maximum change in foot, hip and pelvis rotation during loading response. Highly significant negative correlations ( $P = <0.001$ ) were found between foot and hip movements and foot and pelvic movements. Equinus at initial contact diminished the foot:hip correlation while it enhanced the foot:pelvic correlation. There was less external rotation of the foot in equinus patients ( $P = 0.012$ ) and more external rotation of the pelvis in the equinus group ( $P = <0.001$ ).

This data reveal a correlation between transverse plane rotation at foot level to that at the hip and pelvis. The likely biomechanical explanation is relatively excessive transverse external rotation of the foot due to abnormalities such as mid-foot break. When under load, where the foot is fixed to the floor, internal rotation of the entire leg occurs. This is due to lever arm disease as a result of the relatively shortened foot and inefficiency of the plantar-flexion knee-extension couple. Equinus modulates the effect. When treating such patients, lever arm deformities at all levels must be considered to result in the best outcome and prevent recurrences.

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### 1. Introduction

Diplegic cerebral palsy (CP) gait is often associated with a plano-valgus deformity of the feet. Anatomically this equates to the foot rotating externally with respect to the shank when dorsiflexed during clinical examination. Similarly the plano-valgus foot is characterised by external rotation of the foot in relation to the shank in kinematic data from standard gait analysis [1]. Other characteristic irregular gait patterns in CP are hip internal rotation and pelvic retraction (external rotation) [2]. Pelvic retraction is commonly seen as a compensation for the increased internal hip rotation [3,4]. These proximal deviations at hip level may however be secondary to distal deformities at foot level or abnormal muscular activity lower in the limb. Indeed plantar flexion of the foot in hemiplegic CP due to overactivity of the triceps surae has shown proximal effects of this increased activity, namely increased

pelvic retraction and hip internal rotation, even in patients where there was no proximal muscle involvement (Winters types I and II) [5].

In diplegic CP the gait pattern is often typically seen as dynamic changes which are most evident in the first 20% of stance i.e. the feet move into external rotation and the hips move into internal rotation during initial contact and loading response [6,7]. The results of correcting femoral torsion in isolation can lead to early recurrence and poor results and there is evidence emerging that all deformities including the pes plano-valgus should be corrected in a single event multilevel surgery to produce optimal results [8].

Malalignment of the lower extremities in these patients in the transverse plane consisting of external foot rotation combined with hip internal rotation will result in lever arm disease. The dynamic foot instability known as 'mid-foot break' is a potential causative factor in the occurrence of internal rotation of the hip under load. Mid-foot break is the external rotation of the foot that occurs when abducted, valgus feet are dorsiflexed under load. The aim of this study was to determine if there was a correlation between the changes in foot position and hip and pelvis position in

\* Corresponding author. Tel.: +44 7811103381.

E-mail address: [Mark.gaston@ed.ac.uk](mailto:Mark.gaston@ed.ac.uk) (M.S. Gaston).

associated with plano-valgus deformity under load. As the foot is fixed to the floor under load, it is actually the tibia which moves into internal rotation. The internal rotation of the tibia will result in an internal rotation of the upper parts of the leg thus producing an internal rotation of the hip independent of femoral anteversion. The pelvis also moves internally or protracts as the entire limb segment is affected, effectively lurching forward. Due to the relative shortening of the foot due to the rotation, the triceps surae also loses its lever arm and the plantar-flexion knee-extension couple becomes inefficient. This causes the knee to move into excessive flexion as the leg rotates internally and will also cause additional hip flexion resulting in the characteristic pathological rotational profile seen in crouch gait. This concept may also account for failures when femoral osteotomies are carried out without consideration for distal abnormalities or not as part of a multilevel procedure [15,16]. These results also suggest the hypothesis that femoral rotational abnormalities in these patients are potentially secondary to other rotational abnormalities at a more distal level.

The strength of the correlation between foot movements and hip movements was reduced by separating the diplegic patients who also had an equinus posture of 5° or more at initial contact. While still statistically significant the equinus at initial contact is likely to have reduced the strength as it will have maintained knee extension to a better degree through the plantar-flexion knee-extension couple, preventing the collapse into crouch and the ensuing effect on hip kinematics. The correlation between foot and pelvic movements was increased in patients with equinus. With regard to this we noted that when looking at the mean values of change, the equinus patients had a significantly less change into external rotation at the foot, with a mean approaching zero when compared to the non-equinus group. The equinus patients also had a significantly higher change of pelvic rotation with a mean value of change into external rotation or retraction. It is likely therefore in the equinus patients that the correlation is explained in the opposite direction i.e. as the foot moves less into external rotation, the pelvis will move less in internal rotation and on average will retract or externally rotate. Combining this finding with those previously described by us [5], we hypothesise that the degree of pelvic rotation is modulated by the equinus of the foot with two mechanisms working against each other: External rotation of the foot results in pelvic protraction while foot equinus leads to pelvic retraction. The severity and duration of each deformity will then result in the current position of the pelvis of that patient.

In this group of patients, the change in movement of the hip and pelvis showed no correlation. This is in contrast to hemiplegic patients where it is known that the hip and pelvis shared an inverse relationship [3,4]. However it should be noted overall that the pelvic motion during this phase is not of a large scale as the values are clustered around 5° of change (Fig. 3) and this confirms that transverse pelvic motion overall in diplegic CP is limited.

In conclusion we have shown that there is a highly significant correlation between dynamic foot external rotation and internal hip and pelvis rotation in diplegic CP in the first 20% of the gait cycle and this effect on the hip is diminished when an equinus posture at initial contact is present and in the pelvis it is enhanced by equinus. As this effect probably represents a distal to proximal phenomenon there are implications for clinical practice. When treating these patients all segments must be considered and not

only sagittal but transverse planes of movement also must be considered and examined with instrumented gait analysis. With regard to the management of transverse plane deformities the length of the lever arm of the foot should be restored with attention to the external rotation deformity. Femoral torsional deformities should also be dealt with concurrently, rather than in isolation, if optimal results and the least chance of recurrences are to be achieved. The results of this study may also explain gait patterns with internal hip rotation and external rotation at the foot but without clinically apparent pathological femoral torsion. In these cases correcting the foot deformity alone may be sufficient for a satisfactory result.

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### Conflict of interest statement

There were no conflicts of interest in the preparation of this paper, in particular no financial or personal relationships with other people or organisations that could inappropriately influence (bias) this work.

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