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Full length article

“Children with cerebral palsy experience greater levels of loading at the low back during gait compared to healthy controls”

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ABSTRACT

Excessive trunk motion has been shown to be characteristic of cerebral palsy (CP) gait. However, the associated demands on the lower spine are unknown. This study investigated 3-dimensional reactive forces and moments at the low back in CP children compared to healthy controls. In addition, the impact of functional level of impairment was investigated (GMFCS levels). Fifty-two children with CP (26 GMFCS I and 26 GMFCS II) and 26 controls were recruited to the study. Three-dimensional thorax kinematics and reactive forces and moments at the low back (L5/S1 spine) were examined. Discrete kinematic and kinetic parameters were assessed between groups. Thorax movement demonstrated increased range for CP children in all 3 planes while L5/S1 reactive forces and moments increased with increasing level of functional impairment. Peak reactive force data were increased by up to 57% for GMFCS I and 63% for GMFCS II children compared to controls. Peak moment data were increased by up to 21% for GMFCS II children compared to GMFCS I and up to 90% for GMFCS II compared to control. In addition, a strong correlation was demonstrated between thorax side flexion and L5/S1 lateral bend moment ($r = 0.519$, $p < 0.01$) and medial/lateral force ($r = 0.352$, $p < 0.01$). Children with CP demonstrated increased lower spinal loading compared to TD. Furthermore, GMFCS II children demonstrated significantly more involvement. Intervention should be aimed at reducing excessive thorax movement, especially in the coronal plane, in order to reduce abnormal loading on the spine in this population.

1. Introduction

The trunk makes up a large proportion of body mass and has been shown to be dominant in the production of external forces during gait [1]. When cerebral palsy (CP) gait in particular is considered, an increased lateral lean, known to be characteristic of this population [2,3], reduces the hip abductor moment during stance and aids stabilization of the pelvis [4,5]. Additionally, a forward trunk tilt increases the hip extensor moment arm and may be used to increase the knee flexor moment arm in a subject experiencing quadriceps deficiency to reduce the risk of knee flexion [5]. In general, while the importance of the trunk on lower limb net joint kinetics has been considered [5], the effects of excessive trunk movement further up the kinematic chain, in particular at the lower spine, are unknown.

Mechanical loads at the spine and the surrounding areas are influenced by gravity, inertia and externally applied loads and, consequently, excessive trunk movement may increase lower lumbar spinal loading. In a recent study examining the effects of amputee gait on loads at the lumbar spine, positive correlations were found between increased trunk movements and increased reactive forces and moments [6]. While reactive force and moment data at the lower spine in normal subjects have been reported in the literature [6–8], no data exists for people with CP. Prolonged exposure to pathological changes in the mechanics of motion of the trunk during CP gait may result in changes to the structural tissue within and surrounding the lumbar spine [9,10]. Indeed, it has been suggested that the formation of osteophytes along the junction of vertebral bodies and intervertebral discs are a consequence of altered stresses applied to the spine [9,10]. Additionally, increased spinal loads have also been highlighted as an important contributor to lower back pain [11], with a higher reported incidence of low back pain (ranging from 50% to 63% higher) in people with CP from early age into adulthood [12–14]. With this in mind, there is a need to better understand the impact of pathological gait, in particular

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excessive trunk movement, on loading at the lumbar spine in this population.

Levels of functional impairment in CP are also a consideration. Excessive movements have been shown to increase with increasing levels of gross motor function classification system (GMFCS) score [15]. As functional demand increases, the potential exists for increased demands on the lower spine. At the very least, reactive forces and moments at the lower spine during CP gait, and the relationship with excessive trunk movement and functional level of impairment, need to be better understood and be given consideration in the clinical decision making process. Following from this, the aims of this study were: (1) to investigate three-dimensional reactive forces and moments at the low back in paediatric cerebral palsy subjects compared to healthy controls and (2) to investigate the relationship between three-dimensional reactive forces and moments at the low back and level of functional impairment, expressed using the GMFCS levels I & II [16].

2. Materials and methods

2.1. Subjects

Ethical approval was granted by the Central Remedial Clinic's Ethical Committee. Fifty-two children with CP were recruited from a cohort attending the gait analysis laboratory over a period of 9 months (GMFCS I: $n = 26$, 15 M, 11F, mean age 11.65 (2.91) yrs; GMFCS II: $n = 26$, 18 M, 8F, mean age 10.38 (3.02) yrs). Inclusion criteria were: (1) diagnosis of hemiplegic or dipelgic cerebral palsy and (2) GMFCS levels I or II. Subjects were excluded if they had surgery or Botox within 1 year of presenting to the gait laboratory or if they attended for a repeat assessment during the course of the study. Typically developed (TD) children were recruited from the local community ($n = 26$, 15 M, 11F, mean age 10.15 (3.17) yrs). A participant information leaflet was provided to parents and guardians who then gave written informed consent. Full participant data and sample size calculations are provided as supplementary material.

2.2. Data Collection

A full barefoot 3-dimensional analysis was performed using the CODA cx1 active marker system (Charnwood Dynamics Ltd., Leicestershire). The lower limb marker placement protocol and underlying mathematical model followed implementation as previously described [17]. Trunk kinematic data were recorded using a recently validated single cluster [18]. Previous studies from our group demonstrated that the anthropometric estimates of Jensen et al. [19], and the hip joint centre regression equations of Bell et al. [20], were suitable for the kinematic model [21,22]. In order to determine the L5/S1 joint, a marker was placed on the skin at the L5/S1 joint space. A virtual point was then created, corresponding to 5% of the length of the line from the L5/S1 marker to the mid-point of the Anterior Superior Iliac Spines (ASISs), at which L5/S1 reactive forces and moments were calculated [23] .

Subjects walked unassisted at a self-selected pace. Two Kistler 9281B and two AMTI Accugait force platforms, embedded into the laboratory walkway, were used to measure ground reaction force data. One representative walking trial, containing both left and right feet completely inside the boundary of two consecutive force platforms during successive initials contacts of the same foot, was recorded for each subject. Due to the replication of data at the L5/S1 joint during double support phase, data were analysed for one limb only, namely the involved limb of the children with hemiplegia and a random limb (selected by coin toss) for TD and children with diplegia.

Data were collected using Codamotion ODIN software (v1.06 Build 01 09) at capture rates of 100 Hz (kinematic) and 200 Hz (kinetic) respectively. Kinematic and kinetic data were filtered with a 4th order Butterworth filter with a cut-off frequency of 8 Hz and 20 Hz respectively. All kinematic and kinetic analysis and data filtering were performed in Visual 3D v4.96.0 software (C-Motion Inc., Germantown, MD, USA).

2.3. Data analysis

Thorax movement (w.r.t pelvis) and L5/S1 reactive forces and moments were the measures of interest. The phrases "ipsilateral" and "contralateral" refer to positive and negative direction. Walking speed (m/s) and a number of discrete parameters were assessed between groups. Discrete parameters were: value at initial contact (IC), root mean square (RMS), peak value (Peak), time to peak (TTP) and range of movement (RoM).

Data were checked for distribution using the Shipiro-Wilk normality test. For data that followed a normal distribution, differences between children with GMFCS I, GMFCS II and TD children were assessed using a one-way analysis of variance (ANOVA) with Bonferroni post-hoc tests for comparisons between groups. Dunnett's tests were also used to compare each GMFCS level with the TD control group. For data that did not follow a normal distribution, differences were assessed using a Kruskal-Wallis test and post hoc Mann-Whitney *U*-tests. A Pearson correlation coefficient was used to assess the relationship between thorax kinematic patterns and L5/S1 reactive forces and moments. All statistical analyses were performed using IBM SPSS Statistics (v23.0.0.2). Additionally, ensemble average kinematic and kinetic profiles were visually analyzed for deviations between groups. Ensemble average profiles and corresponding discrete parameters for the pelvis are provided as supplementary material.

3. Results

3.1. Subject data

Walking speed was significantly reduced for both GMFCS I and GMFCS II groups compared to typically developed controls (−0.12 m/s, $p = 0.004$). No significant differences were recorded for mean walking speed between GMFCS I (1.07 m/s) and GMFCS II groups (1.07 m/s). Additionally, no significant differences were present for age, height or weight between groups (available as Supplementary Data).

3.2. Thorax kinematics (w.r.t Pelvis)

In the sagittal plane, the thorax demonstrated a slight forward flexion for TD and GMFCS I groups while the GMFCS II group tended to alternate between flexion and extension throughout the gait cycle (Fig. 1). For discrete parameters, only RoM was statistically significant between all 3 groups ($p < 0.001$). Both GMFCS I and II demonstrated higher RoM compared to TD (≈2° and 5.6° respectively) (Table 1). No significant differences were recorded between groups for RMS or peak flexion values.

In the coronal plane, GMFCS II was significantly increased compared to GMFCS I and TD (≈7°) for ipsilateral peak. Contralateral peak, occurring during swing, demonstrated no significant differences between groups. Timings to peak values were similar across groups. RMS and RoM parameters were statistically significant for both GMFCS I and II compared to TD (increased by 1.1° and 3.6° for RMS and 1.9° and 8.6° for RoM).

In the transverse plane, similar kinematic patterns were present for the thorax for all 3 groups (Fig. 1). The thorax started in a backwards position moving forwards until late stance where