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Short communication

The influence of estimated body segment parameters on predicted joint kinetics during diplegic cerebral palsy gait $\stackrel{\star}{\sim}$



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ABSTRACT

Inverse Dynamic calculations are routinely used in joint moment and power estimates during gait with anthropometric data often taken from published sources. Many biomechanical analyses have highlighted the need to obtain subject-specific anthropometric data (e.g. Mass, Centre of Mass, Moments of Inertia) yet the types of imaging techniques required to achieve this are not always available in the clinical setting. Differences in anthropometric sets have been shown to affect the reactive force and moment calculations in normal subjects but the effect on a paediatric diplegic cerebral palsy group has not been investigated. The aim of this study was to investigate the effect of using different anthropometric sets on predicted sagittal plane moments during normal and diplegic cerebral palsy gait. Three published anthropometric sets were applied to the reactive force and moment calculations of 14 Cerebral Palsy and 14 Control subjects. Statistically significant differences were found when comparing the different anthropometric sets but variability in the resulting sagittal plane moment calculations between sets was low (0.01–0.07 Nm/kg). In addition, the GDI-Kinetic, used as an outcome variable to assess whether differences were clinically meaningful, indicated no clinically meaningful difference between sets. The results suggest that the effects of using different anthropometric sets on the kinetic profiles of normal and diplegic cerebral palsy subjects are clinically insignificant.

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1. Introduction

Inverse dynamic analysis during gait allows for the estimation of joint forces and moments (Davis et al., 1991; Kingma et al., 1996). It is a procedure routinely used in gait laboratories where measured kinematic and ground reaction data are combined with estimated body segment parameters (BSP), such as mass, centre of mass and moments of inertia (MoI), to determine intersegmental forces and net joint moments during gait. The various concerns associated with the use of estimated BSPs have been widely discussed throughout the literature, in particular when subject age and sex fall outside the population originally used to estimate the BSPs (Damavandi et al., 2009; Kingma et al., 1996; Pearsall and Costigan, 1999; Rao et al., 2006). Some authors have shown inverse dynamic calculations to be sensitive to the BSP set used (Chen et al., 2011; Jensen., 1989; Rao et al., 2006), while others report the effect to be negligible (Ganley and Powers, 2004). Concerns have also been raised for pathological groups where limb asymmetry is common such as cerebral palsy (CP) (Chen

 $^{\ast}All$ authors were fully involved in the study and preparation of the manuscript and the material within has not been and will not be submitted for publication elsewhere except as an abstract.

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et al., 2011: Damavandi et al., 2009: Niiler and Riad, 2012). Asymmetries that may exist within this subject group, such as limb length discrepancy or reduced muscle volume (Lampe et al., 2006; Moreau et al., 2009; Shortland, 2009), could result in significantly altered reactive forces and moments during gait when different BSPs are applied. However, no study has examined the effects of different BSP sets on the kinetic profiles of a CP population. Ideally, when dealing with a pathological group such as CP, the BSPs specific to the subject would be directly measured. However, it is not always feasible for most gait laboratories to access the types of imaging techniques required to achieve this. For this reason the use of published BSP sets acts as an acceptable compromise. Following from this, the aim of this study is to determine whether any clinically meaningful difference may exist in the predicted kinetic profiles of a cohort of CP subjects when different published BSP sets are used in the reactive force and moment calculations during gait.

2. Materials and methods

2.1. Subjects

Fourteen subjects (n=28 limbs) presenting for routine gait analysis with a diagnosis of diplegic cerebral palsy and 14 healthy controls (n=28 limbs) participated in the study (Table 1). Informed written consent was obtained from all





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participants and from their parents when legally minor. The study was approved by the Central Remedial Clinic's Ethical Committee.

2.2. Data collection

A full barefoot 3-dimensional kinematic analysis was performed using the CODA mpx-30 active marker system (Charnwood Dynamics Ltd., Leicestershire). The marker placement protocol and underlying mathematical model followed implementation as previously described (Newman et al., 2007). Additionally, the foot segment was calculated from the ankle joint centre and the heel and toe markers. Subjects walked unassisted at a self-selected pace. One representative walking trial containing a clean strike of the left and right force plate was recorded for each subject. Subject specific clinical examination data, required for the kinematic and kinetic models, were recorded for each subject (Table 1). Segment lengths were measured using a measuring tape. Thigh length was measured from a mark representing the hip joint centre (adjacent to the greater trochanter) to a mark representing the knee joint centre (adjacent to the lateral epicondyle). Shank length was measured from the knee joint centre mark to the ankle joint centre mark (adjacent to the lateral malleolus). Foot length was measured from the midpoint of the posterior plantar aspect of the foot to the tip of the third toe. For each representative trial, three separate sets of proportional BSPs from the literature were applied and the corresponding joint moments calculated. A cut-off frequency of 10 Hz was set for force data. All kinetic calculations were performed using Codamotion v6.78.9 software. For the purposes of this study only sagittal plane kinetic data were reported. Summary tables of the proportional BSP sets are reported (Table 2). Walking speed was calculated from kinematic data.

2.3. Anthropometric models

Three proportional anthropometric sets, Set 1–Jensen (Jensen, 1989), Set 2– Ganley and Powers (Ganley and Powers, 2004) and Set 3–Cadaveric (Dempster, 1955) (adapted from (Winter, 1990)) were used.

2.4. Data analysis

The mean absolute variability (MAV) is the difference between the maximum and minimum of a measure for all subjects at each point in the gait cycle, averaged over the complete gait cycle (Ferrari et al., 2008). The MAV gives a direct measure of variability of a repeated measure and was calculated for each joint moment in the

Table 1

Mean anthropometric data for cerebral palsy and control groups. Note that only walking speed was significantly different (p < 0.01).

CP mean (SD) $N=14$	Control mean (SD) $N = 14$	<i>p</i> -Value
9.43 (1.91)	8.29 (1.20)	0.069
10/4	10/4	
1.34 (0.15)	1.33 (0.10)	0.832
29.41 (7.44)	28.38 (5.81)	0.685
345.36 (37.9)	344.32 (32.73)	0.939
316.07 (43.02)	322.43 (33.33)	0.666
195.71 (25.26)	192.50 (19.88)	0.711
348.21 (33.26)	340.71 (34.47)	0.563
316.79 (43.17)	326.43 (31.71)	0.507
196.79 (26.50)	193.21 (20.25)	0.692
1.11 (0.13)	1.33 (0.14)	< 0.01*
	CP mean (SD) N=14 9.43 (1.91) 10/4 1.34 (0.15) 29.41 (7.44) 345.36 (37.9) 316.07 (43.02) 195.71 (25.26) 348.21 (33.26) 316.79 (43.17) 196.79 (26.50) 1.11 (0.13)	CP mean (SD) N=14 Control mean (SD) N=14 9.43 (1.91) 8.29 (1.20) 10/4 10/4 1.34 (0.15) 1.33 (0.10) 29.41 (7.44) 28.38 (5.81) 345.36 (37.9) 344.32 (32.73) 316.07 (43.02) 322.43 (33.33) 195.71 (25.26) 192.50 (19.88) 348.21 (33.26) 340.71 (34.47) 316.79 (43.17) 326.43 (31.71) 196.79 (26.50) 193.21 (20.25) 1.11 (0.13) 1.33 (0.14)

sagittal plane. An ensemble average of lower limb joint moments was calculated and visually analyzed for deviations across BSP sets.

The gait deviation index kinetic (GDI-Kinetic) score (Rozumalski and Schwartz, 2011) was calculated for each leg. The GDI-kinetic was used as an additional tool to determine whether any clinically meaningful important difference (CMID) existed in the kinetic profiles between groups. The GDI-kinetic is an index which scales the difference in pathological gait to normal gait and it is used to quantify the pathology present in the kinetic profiles of patients. A threshold of clinical significance of 3.6 points (CMID) was calculated for this study. The relationship of the GDI-Kinetic has only been examined with respect to the Gilette functional assessment questionnaire (FAQ) (Rozumalski and Schwartz, 2011). The authors report the mean decrement from FAQ levels 10 to 7 as 2.4 points (Standard Deviation of 1.2 points). For the purpose of this paper, the mean change in FAQ level plus one standard deviation will be considered clinically meaningful (CMID=3.6 points). Recalling that the GDI-Kinetic is measured in 10-fold standard deviation units, this implies that BSP sets can differ by 0.36 standard deviations before being deemed clinically significant using the GDI-Kinetic approach.

Subject anthropometric values were compared between the cerebral palsy and control groups using a Student's *t*-test with significance level set at p < 0.05. GDI-Kinetic scores were statistically compared using a one-way repeated measures analysis of variance (ANOVA). Mean BSP estimates were calculated for each BSP set for both groups and visually analyzed. A one-way repeated measures ANOVA was used to determine whether any statistical difference existed between BSP estimates. MAV scores were calculated in Microsoft Excel while GDI-kinetic scores and all statistical calculations were performed in MATLAB 8.10.604 (The MathWorks, Natick, Massachusetts, U.S.A).

3. Results

3.1. Subject anthropometric data

Subject anthropometric data were examined and no statistical significant difference existed between the CP and Control groups (Table 1). Walking speed demonstrated a significant difference between groups with the Control group on average 0.22 m/s faster (p < 0.01) than the CP group (Table 1).

Table 3

Results of a one-way repeated measures ANOVA of BSP estimates for all 3 sets for control and CP groups. Statistically significant differences were found for each variable for each group.

Measure	Segment	Control	СР
Mass	Thigh Shank Foot	$F(2,54) = 87.93, p < 0.01^{a}$ $F(2,54) = 58.85, p < 0.01^{a}$ $F(2,54) = 683.8, p < 0.01^{a}$	$\begin{array}{l} F(2,54) \!=\! 99.36, \ p < 0.01^{a} \\ F(2,54) \!=\! 53.04, \ p < 0.01^{a} \\ F(2,54) \!=\! 351.42, \ p < 0.01^{a} \end{array}$
CoM Radius	Thigh Shank Foot	$\begin{array}{l} F(2,54) \!=\! 199.39, \ p < 0.01^{a} \\ F(2,54) \!=\! 34.54, \ p < 0.01^{a} \\ F(2,54) \!=\! 122.18, \ p < 0.01^{a} \end{array}$	$\begin{array}{l} F(2,54) = 208.97, \ p < 0.01^{a} \\ F(2,54) = 114.02, \ p < 0.01^{a} \\ F(2,54) = 182.87, \ p < 0.01^{a} \end{array}$
ΜοΙ	Thigh Shank Foot	$F(2,54) = 29.07, p < 0.01^{a}$ $F(2,54) = 16.52, p < 0.01^{a}$ $F(2,54) = 178.9, p < 0.01^{a}$	$\begin{split} F(2,54) = & 57.42, \ p < 0.01^{a} \\ F(2,54) = & 111.1, \ p < 0.01^{a} \\ F(2,54) = & 137.77, \ p < 0.01^{a} \end{split}$

^a Statistically significant at p < 0.01.

Table 2

Proportional body segment parameter data used in the reactive force and moment calculations. (Mass is calculated as a % of body mass while CoM radius and radius of gyration are calculated as a % of segment length). Ganley and Powers–(Ganley and Powers, 2004), Jensen–(Jensen, 1989), Cadaver–(Dempster, 1955) adapted from Winter (1990).

Parameter		Ganley ar	nd Power		Jensen							Cadaver
Age		7-8	9–10	11-13	7	8	9	10	11	12	13	N/A
Mass CoM Radius Radius Cyr	Thigh Shank Foot Thigh Shank Foot Thigh Shank Foot	0.11 0.0462 0.0137 0.463 0.415 0.482 0.256 0.256 0.274 0.259	0.114 0.0473 0.0149 0.465 0.416 0.488 0.252 0.252 0.274 0.259	0.117 0.0483 0.0149 0.468 0.415 0.483 0.256 0.256 0.276 0.259	0.0919 0.0464 0.0195 0.4609 0.4295 0.4161 0.2909 0.2880 0.2437	0.0967 0.0484 0.0201 0.4609 0.4274 0.4161 0.2909 0.2873 0.2437	0.1009 0.0500 0.0205 0.4609 0.4253 0.4161 0.2909 0.2866 0.2437	0.1046 0.0512 0.0207 0.4609 0.4232 0.4161 0.2909 0.286 0.2437	0.1077 0.0521 0.0209 0.4609 0.4211 0.4161 0.2909 0.2853 0.2437	0.1103 0.0526 0.0208 0.4609 0.4190 0.4161 0.2909 0.2846 0.2437	0.1124 0.0527 0.0207 0.4609 0.4169 0.4161 0.2909 0.2839 0.2437	0.1 0.0465 0.0145 0.433 0.433 0.5 0.323 0.302 0.47

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