Gait & Posture 45 (2016) 133–136

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Short Communication

Is adult gait less susceptible than paediatric gait to hip joint centre regression equation error?☆

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ARTICLE INFO

Article history:
Received 28 September 2015
Received in revised form 30 November 2015
Accepted 21 January 2016

Keywords:
Hip joint centre
Regression equation error
Adult gait
Kinematics
Kinetics

ABSTRACT

Hip joint centre (HJC) regression equation error during paediatric gait has recently been shown to have clinical significance. In relation to adult gait, it has been inferred that comparable errors with children in absolute HJC position may in fact result in less significant kinematic and kinetic error. This study investigated the clinical agreement of three commonly used regression equation sets (Bell et al., Davis et al. and Orthotrak) for adult subjects against the equations of Harrington et al. The relationship between HJC position error and subject size was also investigated for the Davis et al. set. Full 3-dimensional gait analysis was performed on 12 healthy adult subjects with data for each set compared to Harrington et al. The Gait Profile Score, Gait Variable Score and GDI-kinetic were used to assess clinical significance while differences in HJC position between the Davis and Harrington sets were compared to leg length and subject height using regression analysis. A number of statistically significant differences were present in absolute HJC position. However, all sets fell below the clinically significant thresholds (GPS $<1.6^{\circ}$, GDI-Kinetic <3.6 points). Linear regression revealed a statistically significant relationship for both increasing leg length and increasing subject height with decreasing error in anterior/posterior and superior/inferior directions. Results confirm a negligible clinical error for adult subjects suggesting that any of the examined sets could be used interchangeably. Decreasing error with both increasing leg length and increasing subject height suggests that the Davis set should be used cautiously on smaller subjects.

1. Introduction

Regression equations, based on pelvic anatomy and sometimes leg length, are widely used during gait analysis to estimate the position of the Hip Joint Centre (HJC) [1–5]. However, the associated errors, in some cases reported to be as large as 31 mm in absolute position, have been well documented [6]. In most gait laboratories, it is common to use the same set of regression equations on both paediatric and adult subjects [6]. During paediatric gait, errors have been reported to have both statistical and clinical importance [7]. Comparable errors in absolute HJC position have been reported for adult subjects [6]. However, larger pelvic size may in fact reduce the clinical significance of this error [6]. Consequently, the potential also exists for the effects of error to decrease with respect to increased subject size. The clinical impacts of reduced error on adult gait, and any correlation with subject size, have not been reported. Following from this, the aims of this study are: (1) to assess the clinical impact of HJC regression equation error on kinematics and kinetics during adult gait and (2) to assess the relationship between HJC position error and subject size, for an older commonly used regression equation set [2], previously reported to be least accurate for HJC estimation during gait [3,7].

2. Materials and methods

2.1. Subjects

Twelve healthy adult subjects were recruited to the study (Table 1). Informed written consent was obtained from all participants. Ethical approval was obtained from the Central Remedial Clinic's ethical committee. In addition, paediatric data

☆ Each of the authors has read and concurs with the content in the final manuscript. The material within has not been and will not be submitted for publication elsewhere except as an abstract.

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http://dx.doi.org/10.1016/j.gaitpost.2016.01.023
0966-6362/

Table 1
Mean subject anthropometric data for adult and paediatric groups including pelvic width, depth and leg length required for regression equation offset calculations. "Whole" data refers to both adult and paediatric data combined, required to assess the relationship between HJC position error and subject size.

Parameter	Age (yrs)	M/F	Height (m)	Weight (kg)	Pelvic width (mm)	Pelvic depth (mm)	Leg length (L) (mm)	Leg length (R) (mm)
Adult	29.11 (4.88)	7/5	1.72 (0.84)	68.83 (11.44)	238.75 (20.13)	128.17 (13.77)	898.50 (49.70)	901.25 (50.84)
Paediatric	10.83 (2.45)	7/11	1.45 (0.14)	40.17 (12.65)	216.67 (30.05)	128.22 (20.45)	727.78 (80.24)	731.39 (79.87)
Whole	18.14 (9.77)	14/16	1.56 (0.18)	51.65 (18.66)	225.50 (28.36)	128.20 (17.80)	796.07 (109.31)	799.33 (109.01)

Source: Paediatric data referenced from Kiernan et al. [7].

published in Kiernan et al. [7], were used to explore the relationship between HJC position error and subject size (Table 1).

2.2. Data collection

Data collection was implemented as previously described [7]. A detailed description of the model is available in Supplementary data. Four commonly used predictive hip joint centre (HJC) regression equation sets from the literature were applied and the corresponding kinematics and kinetics calculated. The regression equations sets were as follows: Harrington [6], Bell [1], Davis [2] and Orthotrak [6]. The equations of Harrington et al. are described as the closest alternative to the best performing functional calibration technique [3,4,8,9]. With this in mind, the equations described by Harrington [6] were used as the reference standard against which the three other commonly used sets were compared.

2.3. Data analysis

Data analysis was implemented as previously described [7]. In short, the co-ordinate distances for the HJC position between the reference standard (Harrington – baseline zero) and the Bell, Davis and Orthotrak regression equation sets were calculated for one side only (Right). Ensemble average kinematic and kinetic profiles were visually analysed for deviations between sets. The gait profile score (GPS) and GDI-kinetic were calculated for each subject and used as measures of *kinematic* (threshold 1.6°) and *kinetic* (threshold 3.6 points) clinically meaningful important difference (CMID) [10–13]. The gait variable score (GVS) [10] was calculated for hip kinematic data to assess effects specifically at the hip joint. Mean values for left and right were utilised for ensemble averages, GPS, GVS and GDI-kinetic data. As the same exact trials were used for each subject with only regression equation variables changed, any differences in outcome variables will solely be as a result of the different regression equation sets.

To explore the relationship between HJC position error and subject size, the adult data collected in this study were combined with previously reported paediatric data [7]. Differences in HJC position between the Davis set and Harrington reference in the anterior/posterior (x-axis), medial/lateral (y-axis) and superior/inferior (z-axis) directions were compared with leg length and subject height using regression analysis.

The HJC co-ordinate difference, GPS, GVS and GDI-kinetic scores for Bell, Davis and Orthotrak regression sets were all individually compared to the Harrington reference set using a Student's t-test with a significance level set at $p < 0.05$. All variables were found to have a normal distribution following a Shapiro–Wilk normality test.

3. Results

HJC location estimates demonstrated a number of statistically significant differences for each set compared to the Harrington reference (Table 2). Of note, both Bell (MD = −4.46 mm, $p < 0.01$) and Orthotrak (MD = −11.87 mm, $p < 0.01$) were statistically different in the anterior/posterior direction while statistical differences were present for all three sets in the medial/lateral direction. GPS and GDI-kinetic scores demonstrated no statistical or clinical significant difference for any set when compared to the Harrington reference (Table 2). No statistically significant differences were recorded for GVS data for any set (Table 2).

Kinematic ensemble average graphs demonstrated almost identical curve displacements for the hip in all three planes for Bell, Davis and Orthotrak sets when compared to the Harrington reference (Supplementary Data). However, a number of differences were present in the kinetic profiles, such as a decreased hip abduction moment for Davis and Orthotrak sets during mid and terminal stance (approximately 0.05 Nm/kg) (Supplementary Data).

Linear regression revealed a statistically significant relationship between the difference in HJC position with both leg length and subject height. HJC error decreased between the Davis set and Harrington reference in the anterior/posterior and superior/inferior directions as both leg length and subject height increased (Fig. 1). No statistically significant relationship was identified in the medial/lateral direction for either variable (Fig. 1).

Table 2
Statistical relationship of the GPS, GVS, GDI-kinetic and HJC position in the pelvic coordinate frame for Bell, Davis and Orthotrak regression equation sets compared to the Harrington reference. Mean difference (Mean Diff.) and 95% confidence intervals [95% CI] are reported for each variable. In addition, the clinical relationship for the GPS and GDI-kinetic is reported between sets (mean difference + 1SD). *Note*: No clinically meaningful differences were present for GPS or GDI-kinetic scores (GPS clinical threshold = 1.6°; GDI-kinetic clinical threshold = 3.6 points).

Measure	Har-Bell	Mean Diff. [95% CI]	Har-Davis	Mean Diff. [95% CI]	Har-Ortho	Mean Diff. [95% CI]
GPS (deg)	$p = 0.74$	−0.01 [−0.07, 0.05]	$p = 0.09$	−0.06 [−0.13, 0.01]	$p = 0.28$	−0.08 [−0.22, 0.07]
$GVS^{Hip\ Flex/Ext}$ (deg)	$p = 0.69$	0.04 [−0.19, 0.28]	$p = 0.47$	−0.11 [−0.42,0.21]	$p = 0.96$	−0.02 [−0.66, 0.63]
$GVS^{Hip\ Add/Abd}$ (deg)	$p = 0.19$	0.13 [−0.08, 0.34]	$p = 0.17$	−0.18 [−0.45, 0.09]	$p = 0.91$	−0.01 [−0.24, 0.22]
$GVS^{Hip\ Int/Ext}$ (deg)	$p = 0.62$	−0.01 [−0.03, 0.02]	$p = 0.91$	−0.002 [−0.03, 0.03]	$p = 0.55$	0.01 [−0.03, 0.05]
GDI-kinetic	$p = 0.74$	0.14 [−0.75, 1.02]	$p = 0.22$	0.42 [−0.29, 1.14]	$p = 0.37$	0.72 [−0.97, 2.42]
HJC_x (mm)	$p < 0.01$[a]	−4.46 [−6.63, −2.30]	$p = 0.64$	0.71 [−2.551, 3.92]	$p < 0.01$[a]	−11.87 [−14.29, −9.44]
HJC_y (mm)	$p < 0.01$[a]	−3.96 [−6.35, −1.58]	$p < 0.01$[a]	5.03 [2.07, 7.99]	$p < 0.01$[a]	5.59 [3.42, 7.76]
HJC_z (mm)	$p < 0.01$[a]	9.62 [8.19, 11.04]	$p < 0.01$[a]	−12.84 [−15.25, −10.43]	$p = 0.94$	0.07 [−1.76, 1.89]
$GPS^{(clinical)}$	0.08	–	0.05	–	0.15	–
$GDI\text{-}kinetic^{(clinical)}$	1.53	–	1.55	–	3.39	–

[a] Statistically significant at $p < 0.05$.