Gait & Posture 41 (2015) 175–179

Contents lists available at ScienceDirect

Gait & Posture

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

The clinical impact of hip joint centre regression equation error on kinematics and kinetics during paediatric gait

D. Kiernan [a,b,*], A. Malone [a], T. O'Brien [a], C.K. Simms [b]

[a] Gait Laboratory, Central Remedial Clinic, Clontarf, Dublin 3, Ireland
[b] Trinity Centre for Bioengineering, Parsons Building, Trinity College Dublin, Dublin 2, Ireland

ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form 26 September 2014
Accepted 29 September 2014

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

ABSTRACT

Regression equations based on pelvic anatomy are routinely used to estimate the hip joint centre during gait analysis. While the associated errors have been well documented, the clinical significance of these errors has not been reported. This study investigated the clinical agreement of three commonly used regression equation sets (Bell et al., Davis et al. and Orthotrak software) against the equations of Harrington et al. Full 3-dimensional gait analysis was performed on 18 healthy paediatric subjects. Kinematic and kinetic data were calculated using each set of regression equations and compared to Harrington et al. In addition, the Gait Profile Score and GDI-Kinetic were used to assess clinical significance. Bell et al. was the best performing set with differences in Gait Profile Score (0.13°) and GDI-Kinetic (0.84 points) falling below the clinical significance threshold. Small deviations were present for the Orthotrak set for hip abduction moment (0.1 Nm/kg), however differences in Gait Profile Score (0.27°) and GDI-Kinetic (2.26 points) remained below the clinical threshold. Davis et al. showed least agreement with a clinically significant difference in GDI-Kinetic score (4.36 points). It is proposed that Harrington et al. or Bell et al. regression equation sets are used during gait analysis especially where inverse dynamic data are calculated. Orthotrak is a clinically acceptable alternative however clinicians must be aware of the effects of error on hip abduction moment. The Davis et al. set should be used with caution for inverse dynamic analysis as error could be considered clinically meaningful.

1. Introduction

The accurate quantification of skeletal motion is hugely important for the assessment of both normal and pathological gait [1]. In lower limb gait analysis the location of the hip joint centre (HJC) is needed to define the thigh coordinate frame for kinematic analysis and it is the point at which inverse dynamics at the hip are calculated. As a result, accurate definition of this point is essential. Ideally the HJC location specific to the subject would be directly measured. However, the imaging techniques required to achieve this would not be available to most gait laboratories. As the HJC cannot be directly palpated, its position is usually estimated using one of two approaches. The first, referred to as functional calibration, relies on relative movement of the segments usually during a number of calibration trials [2–4]. This approach has been shown to yield the best results, however it may be difficult to implement when dealing with pathological groups such as cerebral palsy where function is impaired [5]. As a result, implementation in the clinical setting has been limited. The second approach is the use of regression equations based primarily on the anatomy of the pelvis [6–8]. These types of regression equations will usually have been derived from radiographic or cadaveric measurements and are by far the most widely used in clinical gait analysis [5,9,10]. However, while their use is considered an acceptable compromise, regression equations have their limitations. Most rely on accurate identification and measurement of pelvic bony landmarks and the subject populations on which they were originally based may be quite different to subject populations on which they are used.

The errors associated with the use of regression equations have been well documented in the literature [5,10–13]. Errors up to 31 mm have been reported between true and estimated HJC position [8,12]. Recent studies examining the accuracy of a number of regression based and functional methods for HJC location report that in the case where functional calibration is not an option, such as where subjects find it difficult to perform functional calibration exercises, the regression equations reported by Harrington and

* Corresponding author at: Central Remedial Clinic, Vernon Avenue, Clontarf, Dublin 3, Ireland. Tel.: +353 1 8542467; fax: +353 1 8542570.
E-mail address: dkiernan@crc.ie (D. Kiernan).

http://dx.doi.org/10.1016/j.gaitpost.2014.09.026
0966-6362/

moment graph (Fig. 3). When the GDI-Kinetic is considered, no statistically significant ($p = 0.96$) or clinically significant (2.26 points) differences were present. A similar trend was demonstrated for GPS score (Fig. 2) with very little deviation in the kinematic graphs (Fig. 3). It has been suggested that HJC estimation methods with minimal anterior/posterior error should be preferred [12]. Taking this into consideration, along with the findings of no statistical or clinical differences in GDI-Kinetic or GPS, it is concluded that the Orthotrak set could be used confidently in the clinical setting as an alternative to the Harrington set. Results suggest that associated errors would not be incorrectly mistaken as a clinically meaningful difference.

The Bell regression equation set was the best performing set compared to the Harrington reference across all measured variables. No statistically significant differences were present for HJC coordinate distance in either the anterior/posterior or medial/lateral directions. However, there was a difference in the superior/inferior direction (MD = 5.95 mm, $p < 0.01$) (Fig. 1) (Table 2). The ensemble average moment graphs were almost identical to the Harrington reference graphs for all three measures at the hip (Fig. 3). When the GDI-Kinetic and GPS are considered, no statistically significant ($p = 0.57$ and $p = 0.57$ respectively for GDI-Kinetic and GPS) or clinically significant (0.84 points and 0.13° respectively for GDI-Kinetic and GPS) were present. Kinematic graphs were identical for Bell compared to the Harrington reference (Fig. 3). Consequently, it is concluded that the Bell regression equation set could also be used confidently in the clinical setting as an alternative to the Harrington set.

The current findings suggest that the use of the Bell regression equation set [6] is equally as valid as using the Harrington regression equation set [8] for HJC location during paediatric gait analysis. While differences in HJC location were statistically significant in all three axes for the Orthotrak set, there were no clinically significant differences and it is unlikely any error would be incorrectly considered clinically meaningful. However, when using the Orthotrak set, clinicians must be aware of the increased error in the medial/lateral direction and the consequences on the hip abduction moment. The Davis set performed poorly compared to the Harrington set with respect to the kinetic output and the potential exists for error to be incorrectly considered clinically meaningful. Therefore it should be used with caution, particularly when comparing data derived using other regression equation sets. Consequently, it is proposed that the Harrington or Bell regression equation sets are used during paediatric gait analysis especially where inverse dynamic data are calculated. While not tested in this study, it is not expected that results would significantly differ for cerebral palsy or adult subjects. In a recent study assessing actual HJC position, measured using MRI scans in adults, healthy children and children with cerebral palsy, absolute measurement errors were shown to be comparable across groups [8]. The authors infer that in relative terms the errors would in fact be less significant for adults due to larger pelvises.

Acknowledgements

Part funding was provided by the Scientific and Research Trust of the Central Remedial Clinic, Dublin. The funders had no role in the study design, collection, analysis or interpretation of data.

Conflict of interest statement

None of the authors had any financial or personal conflict of interest with regard to this study.

References

[1] Ehrig RM, Heller MO, Kratzenstein S, Duda GN, Trepczynski A, Taylor WR. The SCoRE residual: a quality index to assess the accuracy of joint estimations. J Biomech 2011;44(7):1400–4.
[2] Camomilla V, Cereatti A, Vannozzi G, Cappozzo A. An optimized protocol for hip joint centre determination using the functional method. J Biomech 2006;39(6):1096–106.
[3] Leardini A, Cappazzo A, Catani F, Toksvig-Larsen S, Petitto A, Sforza V, Cassanelli G, Giannini S. Validation of a functional method for the estimation of hip joint centre location. J Biomech 1999;32:99–103.
[4] Piazza S, Okita N, Cavanagh P. Accuracy of the functional method of hip joint center location: effect of limited motion and varied implementation. J Biomech 2001;34:967–73.
[5] Sangeux M, Pillet H, Skalli W. Which method of hip joint centre localisation should be used in gait analysis? Gait Posture 2014;40(1):20–5.
[6] Bell AL, Brand RA, Pedersen DR. Prediction of hip joint centre location from external landmarks. Human Mov Sci 1989;8(1):3–16.
[7] Davis R, Ounpuu S, Tyburski D, Gage J. A gait analysis data collection and reduction technique. Human Mov Sci 1991;10:575–87.
[8] Harrington ME, Zavatsky AB, Lawson SE, Yuan Z, Theologis TN. Prediction of the hip joint centre in adults: children, and patients with cerebral palsy based on magnetic resonance imaging. J Biomech 2007;40(3):595–602.
[9] Peters A, Baker R, Morris ME, Sangeux M. A comparison of hip joint centre localisation techniques with 3-DUS for clinical gait analysis in children with cerebral palsy. Gait Posture 2012;36(2):282–6.
[10] Sangeux M, Peters A, Baker R. Hip joint centre localization: evaluation on normal subjects in the context of gait analysis. Gait Posture 2011;34(3):324–8.
[11] Kirkwood R, Culham E, Costigan P. Radiographic and non-invasive determination of the hip joint centre location: effect on hip joint moments. Clin Biomech (Bristol Avon) 1999;14:227–35.
[12] Stagni R, Leardini A, Cappazzo A, Benedetti MG, Cappello A. Effects of hip joint centre mislocation on gait analysis results. J Biomech 2000;33:1479–87.
[13] Andersen MS, Mellon S, Grammatopoulos G, Gill HS. Evaluation of the accuracy of three popular regression equations for hip joint centre estimation using computerised tomography measurements for metal-on-metal hip resurfacing arthroplasty patients. Gait Posture 2013;38(4):1044–7.
[14] Newman CJ, Walsh M, O'Sullivan R, Jenkinson A, Bennett D, Lynch B, O'Brien T. The characteristics of gait in Charcot-Marie-Tooth disease types I and II. Gait Posture 2007;26(1):120–7.
[15] Kiernan D, Walsh M, O'Sullivan R, O'Brien T, Simms CK. The influence of estimated body segment parameters on predicted joint kinetics during diplegic cerebral palsy gait. J Biomech 2014;47(1):284–8.
[16] Baker R, McGinley JL, Schwartz MH, Beynon S, Rozumalski A, Graham HK, Tirosh O. The gait profile score and movement analysis profile. Gait Posture 2009;30(3):265–9.
[17] Baker R, McGinley JL, Schwartz M, Thomason P, Rodda J, Graham HK. The minimal clinically important difference for the Gait Profile Score. Gait Posture 2012;35(4):612–5.
[18] Rozumalski A, Schwartz MH. The GDI-Kinetic: a new index for quantifying kinetic deviations from normal gait. Gait Posture 2011;33(4):730–2.