ELSEVIER

Journal of Biomechanics 40 (2007) 595–602

JOURNAL OF BIOMECHANICS

www.elsevier.com/locate/jbiomech
www.JBiomech.com

Prediction of the hip joint centre in adults, children, and patients with cerebral palsy based on magnetic resonance imaging

M.E. Harrington[a], A.B. Zavatsky[b,*], S.E.M. Lawson[b], Z. Yuan[b], T.N. Theologis[a]

[a]*The Oxford Gait Laboratory, Nuffield Orthopaedic Centre, Oxford, UK*
[b]*Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, UK*

Accepted 1 February 2006

Abstract

The location of the hip joint centre (HJC) is required for calculations of hip moments, the location and orientation of the femur, and muscle lengths and lever arms. In clinical gait analysis, the HJC is normally estimated using regression equations based on normative data obtained from adult populations. There is limited relevant anthropometric data available for children, despite the fact that clinical gait analysis is predominantly used for the assessment of children with cerebral palsy. In this study, pelvic MRI scans were taken of eight adults (ages 23–40), 14 healthy children (ages 5–13) and 10 children with spastic diplegic cerebral palsy (ages 6–13). Relevant anatomical landmarks were located in the scans, and the HJC location in pelvic coordinates was found by fitting a sphere to points identified on the femoral head. The predictions of three common regression equations for HJC location were compared to those found directly from MRI. Maximum absolute errors of 31 mm were found in adults, 26 mm in children, and 31 mm in the cerebral palsy group. Results from regression analysis and leave-one-out cross-validation techniques on the MRI data suggested that the best predictors of HJC location were: pelvic depth for the antero-posterior direction; pelvic width and leg length for the supero-inferior direction; and pelvic depth and pelvic width for the medio-lateral direction. For single-variable regression, the exclusion of leg length and pelvic depth from the latter two regression equations is proposed. Regression equations could be generalised across adults, children and the cerebral palsy group.

Keywords: Gait; Hip joint centre; Motion analysis; MRI; Cerebral palsy

1. Introduction

In gait analysis, the hip joint centre (HJC) is the point about which hip moments are calculated, and it is often used in determining the location and orientation of the femur and in estimating the lengths and lever arms of muscles crossing the hip. Unlike prominent bony landmarks, such as the superior iliac spines, the HJC cannot be palpated and thus its location must be calculated. Errors in the location of the HJC can propagate down the limbs through kinematic and kinetic calculations.

Although clinical gait analysis is predominantly used for the assessment of children with cerebral palsy, the most common ways of estimating HJC rely on equations derived from average adult anthropometric data. These may not be appropriate for children, whose pelvic geometry is still maturing, and even less so for children with cerebral palsy who, almost invariably, have musculoskeletal deformities.

Previous studies found the error in HJC estimation in adults using a range of methods in living subjects (Kirkwood et al., 1999; Leardini et al., 1999) and cadaveric specimens (Seidel et al., 1995). Functional techniques, such as those proposed by Cappozzo (1984),

*Corresponding author. Tel.: +44 1865 273146; fax: +44 1865 273010.
E-mail address: amy.zavatsky@eng.ox.ac.uk (A.B. Zavatsky).

0021-9290/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2006.02.003

following *single* linear regression equations (in mm) are proposed for the right hip:

$$\hat{x} = -0.24\text{PD} - 9.9, \quad (5)$$

$$\hat{y} = -0.30\text{PW} - 10.9, \quad (6)$$

$$\hat{z} = 0.33\text{PW} + 7.3. \quad (7)$$

Results in this study indicate that these could improve estimates based on existing predictive methods by up to 7 mm, depending on method and direction considered. However, predictive methods do not account for pelvic asymmetry, which was found to average 6 mm in this study, and do not account for errors in marker placement or skin movement artefacts.

Acknowledgements

The authors wish to acknowledge the financial support of The Wishbone Trust (UK), the Engineering and Physical Sciences Research Council (UK), and The Leverhulme Trust (UK); the clinical support from Mrs. Nicky Thompson, Oxford Gait Laboratory, and the Radiology Department of the Nuffield Orthopaedic Centre NHS Trust; and the helpful suggestions of Dr. Alberto Leardini.

References

Bell, A.L., Pedersen, D.R., Brand, R.A., 1990. A comparison of the accuracy of several hip center location prediction methods. Journal of Biomechanics 23 (6), 617–621.

Cappozzo, A., 1984. Gait analysis methodology. Human Movement Science 3, 27–50.

Cappozzo, A., Catani, F., Leardini, A., Benedetti, M.G., Della Croce, U., 1996. Position and orientation in space of bones during movement: experimental artifacts. Clinical Biomechanics 11 (2), 90–100.

Charlton, I.W., Tate, P., Roren, L., 2004. Repeatability of an optimised lower body model. Gait and Posture 20 (2), 213–221.

Davis, R.B., Õunpuu, S., Tyburski, D., Gage, J.R., 1991. A gait analysis data collection and reduction technique. Human Movement Science 10 (5), 575–587.

Della Croce, U., Cappozzo, A., Kerrigan, D.C., 1999. Pelvis and lower limb anatomical landmark calibration precision and its propagation to bone geometry and joint angles. Medical and Biological Engineering and Computing 37 (2), 155–161.

Fieser, L., Quigley, E.J., Wyatt, M., Sutherland, D., Chambers, H., 2000. Comparison of hip joint centers determined from surface anatomy and CT scans: two case studies. Gait and Posture 11 (2), 119–120.

Jenkins, S.E.M., Harrington, M.E., Theologis, T.N., Zavatsky, A.B., O'Connor, J.J., 2001. Errors in the calculation of the hip joint centre location in children. In: Proceedings of the XVIIIth Congress of the International Society of Biomechanics, p. 365.

Jenkins, S.E.M., Harrington, M.E., Zavatsky, A.B., O'Connor, J.J., Theologis, T.N., 2003. Femoral muscle attachment locations in children and adults, and their prediction from clinical measurement. Gait and Posture 18 (1), 13–22.

Kirkwood, R.N., Culham, E.G., Costigan, P., 1999. Radiographic and non-invasive determination of the hip joint center location: effect on hip joint moments. Clinical Biomechanics 14 (4), 227–235.

Leardini, A., Cappozzo, A., Catani, F., Toksvig-Larsen, S., Petitto, A., Sforza, V., Cassanelli, G., Giannini, S., 1999. Validation of a functional method for the estimation of hip joint centre location. Journal of Biomechanics 32 (1), 99–103.

Piazza, S.J., Okita, N., Cavanagh, P.R., 2001. Accuracy of the functional method of hip joint center location: effects of limited motion and varied implementation. Journal of Biomechanics 34 (7), 967–973.

Ripley, B., 1996. Pattern Recognition and Neural Networks. Cambridge University Press, Cambridge, UK.

Rozumalski, A., Schwartz, M.H., 2004. The practicality of functional model calibration in a clinical setting. In: Proceedings of the 13th Annual Meeting of the European Society for Movement Analysis in Adults and Children, p. 125.

Schwartz, M.H., Rozumalski, A., 2005. A new method for estimating joint parameters from motion data. Journal of Biomechanics 38, 107–116.

Seidel, G.K., Marchinda, D.M., Dijkers, M., Soutas-Little, R.W., 1995. Hip joint center location from palpable bony landmarks—a cadaver study. Journal of Biomechanics 28 (8), 995–998.

Sokal, R.R., Rolf, F.J., 1995. Biometry—the Principles and Practice of Statistics in Biological Research, third ed. W. H. Freeman and Co., New York.

Stagni, R., Leardini, A., Cappozzo, A., Benedetti, M.G., Cappello, A., 2000. Effects of hip joint centre mislocation on gait analysis results. Journal of Biomechanics 33 (11), 1479–1487.

Wu, G., 2002. ISB recommendation on definitions of joint coordinate system for various joints for the reporting of human joint motion. Part I: ankle, hip, and spine. Journal of Biomechanics 35, 543–548.