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

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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 Orthotrac 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 Orthotrac 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. Orthotrac 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.

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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
moment graph (Fig. 3). When the GDI-Kinetic is considered, no statistically significant \((p = 0.96)\) or clinically significant \((2.26 \text{ points})\) 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 Orthotрак 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 \((MD = 5.95 \text{ mm}, p < 0.01)\) (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 \((p = 0.57 \text{ and } p = 0.57\) respectively for GDI-Kinetic and GPS) or clinically significant \((0.84 \text{ points and } 0.13^\circ \text{ respectively for GDI-Kinetic and GPS})\) 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 Orthotрак set, there were no clinically significant differences and it is unlikely any error would be incorrectly considered clinically meaningful. However, when using the Orthotрак 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 pelvies.

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Conflict of interest statement

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

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