Gait & Posture 48 (2016) 30–35

Contents lists available at ScienceDirect

Gait & Posture

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

ESMAC – Best Paper Award for 2015

Validation of hip joint center localization methods during gait analysis using 3D EOS imaging in typically developing and cerebral palsy children☆

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ARTICLE INFO

Article history:
Available online

Keywords:
Hip joint center
Cerebral palsy
EOS biplanar X-rays
Gait analysis
Children

ABSTRACT

Localization of the hip joint center (HJC) is essential in computation of gait data. EOS low dose biplanar X-rays have been shown to be a good reference in evaluating various methods of HJC localization in adults. The aim is to evaluate predictive and functional techniques for HJC localization in typically developing (TD) and cerebral palsy (CP) children, using EOS as an image based reference. Eleven TD and 17 CP children underwent 3D gait analysis. Six HJC localization methods were evaluated in each group bilaterally: 3 predictive (Plug in Gait, Bell and Harrington) and 3 functional methods based on the star arc technique (symmetrical center of rotation estimate, center transformation technique and geometrical sphere fitting). All children then underwent EOS low dose biplanar radiographs. Pelvis, lower limbs and their corresponding external markers were reconstructed in 3D. The center of the femoral head was considered as the reference (HJC_{EOS}). Euclidean distances between HJCs estimated by each of the 6 methods and the HJC_{EOS} were calculated; distances were shown to be lower in predictive compared to functional methods ($p < 0.0001$). Contrarily to findings in adults, functional methods were shown to be less accurate than predictive methods in TD and CP children, which could be mainly due to the shorter thigh segment in children. Harrington method was shown to be the most accurate in the prediction of HJC (mean error ≈ 18 mm, SD = 9 mm) and quasi-equivalent to the Bell method. The bias for each method was quantified, allowing its correction for an improved HJC estimation.

1. Introduction

Motion analysis has become an important asset during decision making for the treatment of musculoskeletal disorders, such as cerebral palsy [1,2]. Gait analysis is based on biomechanical models that use external skin markers in order to calculate joint kinematics and kinetics [3,4]. These external markers are used to associate a local coordinate system to each skeletal segment. The hip joint center (HJC) is an essential landmark for the creation of the local coordinate system of the thigh segment [5]. While this anatomical landmark is not directly accessible externally, a virtual marker is associated to this point. Two possible approaches exist in the localization of the HJC: either predictive techniques based on regression equations using anthropometric measurements [6–8] or functional calibration methods based on the movement of the thigh relative to the pelvis, where the center of rotation is determined [9–13].

The validation of these hip joint center localization techniques has been mainly based on cadaveric experiments or simulations [11,14]. Medical imaging techniques could be used in order to validate the HJC localization methods in vivo. Fluoroscopy has been previously used in some of the validation studies [9,15]. However, this method is known to deliver a considerable dose of radiation to the patient. Other studies have used three-dimensional (3D) ultrasound and have shown it to be effective [16,17]. However, this method cannot allow simultaneous acquisitions of both HJC and external markers. Magnetic Resonance Imaging could be an alternative [8], but is costly and time consuming.

☆ This paper underwent a regular peer-review process and was edited by Dr. Thomas Dreher.

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http://dx.doi.org/10.1016/j.gaitpost.2016.04.028
0966-6362/