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Reliability of functional and predictive methods to estimate the hip joint centre in human motion analysis in healthy adults

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ABSTRACT

In human motion analysis predictive or functional methods are used to estimate the location of the hip joint centre (HJC). It has been shown that the Harrington regression equations (HRE) and geometric sphere fit (GSF) method are the most accurate predictive and functional methods, respectively. To date, the comparative reliability of both approaches has not been assessed. The aims of this study were to (1) compare the reliability of the HRE and the GSF methods, (2) analyse the impact of the number of thigh markers used in the GSF method on the reliability, (3) evaluate how alterations to the movements that comprise the functional trials impact HJC estimations using the GSF method, and (4) assess the influence of the initial guess in the GSF method on the HJC estimation. Fourteen healthy adults were tested on two occasions using a three-dimensional motion capturing system. Skin surface marker positions were acquired while participants performed quite stance, perturbed and non-perturbed functional trials, and walking trials. Results showed that the HRE were more reliable in locating the HJC than the GSF method. However, comparison of inter-session hip kinematics during gait did not show any significant difference between the approaches. Different initial guesses in the GSF method did not result in significant differences in the final HJC location. The GSF method was sensitive to the functional trial performance and therefore it is important to standardize the functional trial performance to ensure a repeatable estimate of the HJC when using the GSF method.

1. Introduction

Three-dimensional (3D) motion analysis is a powerful clinical tool that can be used to objectively quantify the gait of individuals with movement disorders [1]. Clinical gait laboratories typically use conventional biomechanical models that calculate joint centres and kinematics directly from the 3D position of retro-reflective markers mounted on the skin surface [2,3]. The joint kinematics are used in combination with additional gait measures (*e.g.* joint moments and powers) and physical assessment to inform clinical interventions [4]. Therefore, it is imperative that gait analysis methods are both accurate and reliable.

The location of the hip joint centre (HJC) is crucial in biomechanical models of human gait. It influences the definition of the long axis of the thigh segment, and thus the calculation of the hip and knee joint kinematics. The HJC cannot directly be identified from the skin surface and is estimated relative to the pelvis segment using predictive or functional methods. Predictive methods use regression equations based on cadaveric [5] or medical imaging studies [2], to estimate the HJC location. Functional methods use the relative movement of femur and

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pelvis segments from functional calibration trials to calculate the centre of rotation, which is assumed to be the HJC [6–8]. A recent systematic review [9] indicated that the Harrington regression equations (HRE) [10] and the geometric sphere fit (GSF) [6,11] method were the most accurate predictive and functional methods, respectively. [9] also reported that only a small number of studies assessed the reliability of predictive and functional methods. Reliability of joint kinematics is important in clinical practice as the patient's gait is typically compared pre- and post-intervention. Functional methods have been shown to result in more reliable gait kinematics than regression methods [7,12], but other studies have not found notable differences between the approaches [13]. All these studies [7,12,13], however, included functional determination of the HJC together with functional determination of the knee joint axis. The reported reliability, therefore, was not an independent evaluation of functional HJC methods. To date, the reliability of the most accurate predictive (HRE) and functional (GSF) methods to estimate the HJC alone has not been compared.

Pelvis marker locations are not likely to impact on the accuracy of functional methods to estimate the HJC, but do affect reliability as the HJC is stored relative to the pelvic anatomical coordinate system (ACS), which is based on the 3D location of manually placed pelvis markers. The reliability of functional methods may be additionally affected by soft tissue artefacts (STA) associated with the number of thigh markers used to determine the centre of rotation and range of motion (RoM) used during the functional calibration trial. The reliability of predictive methods is dependent on the location of pelvis markers alone. In functional methods, however, the pelvic ACS does not impact on the reliability of the thigh ACS, whereas in predictive methods any errors in the definition of the pelvic ACS would propagate to the HJC, thigh ACS, and potentially reducing reliability of joint kinematics.

It is currently recommended that functional calibration trials for the GSF method should be performed in a 'StarArc' movement pattern [14] with a RoM as large as possible [15,16]. The effect of number and placement of markers on the precision of the HJC estimation has been previously evaluated, although not with respect to the GSF method [17]. The impact of the chosen functional method, movement pattern and number of markers on the accuracy of the HJC estimation has also been assessed [14,16,18,19]. To our knowledge no previous study has assessed the influence of the number of markers used on the reliability of HJC calculations. Furthermore, the influence of the initialization of the GSF method and the impact of movement asymmetry in the functional trials on HJC estimation has not been previously addressed.

The aims of this study were to (1) compare intra- and inter-session reliability between the HRE and GSF method, (2) analyse the influence of the number of markers used in the GSF method on the reliability of HJC estimates, (3) evaluate the influence of functional trial perturbations on HJC estimations using the GSF method, and (4) assess the influence of the initialization of the GSF method on the HJC estimation. Using predictive methods, the HJC estimation depends on the placement of the pelvis markers and how well the regression model, developed from small mostly healthy sample individuals, represents the pelvis of the individual. Functional methods depend on the number and placement of pelvis and thigh markers and functional movement trial performance [14,16,18,19]. The precision of the SCoRE functional method increased with the number of markers used [17], and functional trial performance has been shown to influence HJC estimation [16,18]. Thus, the following hypotheses were proposed: (1) there is no difference in the reliability of HJC estimates between the HRE and GSF method, (2) including more markers in the GSF method improves reliability of HJC estimates, (3) movement perturbations in functional trials will influence the results of the GSF method, and (4) HJC estimates from the GSF method are independent from the initial guess.

2. Methods

Fourteen healthy adults (10 males, 4 females; mean (standard deviation) age: 27.7(4.3)years; height: 1.74(0.09)m; BMI: 23.0(2.4) kg/m^2) free from musculoskeletal impairment were recruited. All participants gave informed, written consent prior to participation. The study protocol was approved by the University Human Research Ethics Committee. Testing was conducted on two occasions separated by at least one week.

Ten retro-reflective markers were placed on the pelvis and right thigh segments of each participant. Markers were placed on the left and right Anterior Superior Iliac Spine (ASIS), left and right Posterior Superior Iliac Spine (PSIS), lateral knee, medial knee, lateral to the distal third of the thigh (wand marker), and lateral to the thigh a triad (CL1, CL2, CL3). The distance between markers on the long axis of the triad (CL1-CL3) was 18 cm and the third marker of the triad (CL2) was perpendicular to the long axis 7 cm from the midpoint. The triad long axis was aligned with the long axis of the femur with the CL2 marker pointing anterior. The most distal triad marker (CL3) was approximately 8 cm proximal to the lateral knee marker. In all sessions, the same rater (MSc in Rehabilitation Engineering) performed marker placement and collected motion capture data. A motion analysis consultant with several years of experience in marker placement trained and supervised the rater. For each testing session, participants performed a static standing calibration trial, functional calibration trials as described below and 3 walking trials at preferred walking speed. Based on pilot testing, 70 beats per minute (bpm) was a natural velocity for the functional calibration trial. A metronome, set to 70bpm, was used to cue participants as they performed the StarArc motion for the functional calibration trials, as per [14]. Participants performed between two and four practice trials of the StarArc motion prior to data collection. All participants were able to confidently execute the task without any obvious limitations. The trial order for each session is described in Table 1.

Table 1
Overview of trials collected during both testing sessions. Normal functional full range of motion (RoM) and half RoM trials required participants to pause for 1 beat at each of the 7 StarArc end positions. Biased trials required participants to pause for 3 beats at the 2 most anterior StarArc end positions (Anterior bias), the 3 most lateral StarArc end positions (Lateral bias) and the 2 most posterior StarArc end positions (Posterior bias).

	Static	Functional trial description					Gait
		Full RoM	Half RoM	Anterior bias	Lateral bias	Posterior bias	
Session 1							
Trial 1	√						
Trial 2		√					
Trial 3			√				
Trial 4		√		√			
Trial 5		√			√		
Trial 6		√				√	
Trial 7	√						
Trial 8		√					
Trial 9–11							√
Session 2							
Trial 1	√						
Trial 2		√					
Trial 3	√						
Trial 4		√					
Trial 5–7							√