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Original article

The use of the greater trochanter marker in the thigh segment model: Implications for hip and knee frontal and transverse plane motion

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Abstract

Background: The greater trochanter marker is commonly used in 3-dimensional (3D) models; however, its influence on hip and knee kinematics during gait is unclear. Understanding the influence of the greater trochanter marker is important when quantifying frontal and transverse plane hip and knee kinematics, parameters which are particularly relevant to investigate in individuals with conditions such as patellofemoral pain, knee osteoarthritis, anterior cruciate ligament (ACL) injury, and hip pain. The aim of this study was to evaluate the effect of including the greater trochanter in the construction of the thigh segment on hip and knee kinematics during gait.

Methods: 3D kinematics were collected in 19 healthy subjects during walking using a surface marker system. Hip and knee angles were compared across two thigh segment definitions (with and without greater trochanter) at two time points during stance: peak knee flexion (PKF) and minimum knee flexion (MinKF).

Results: Hip and knee angles differed in magnitude and direction in the transverse plane at both time points. In the thigh model with the greater trochanter the hip was more externally rotated than in the thigh model without the greater trochanter (PKF: −9.34° ± 5.21° *vs*. 1.40° ± 5.22°, MinKF: −5.68° ± 4.24° *vs*. 5.01° ± 4.86°; $p < 0.001$). In the thigh model with the greater trochanter, the knee angle was more internally rotated compared to the knee angle calculated using the thigh definition without the greater trochanter (PKF: 14.67° ± 6.78° *vs*. 4.33° ± 4.18°, MinKF: 10.54° ± 6.71° *vs*. −0.01° ± 2.69°; $p < 0.001$). Small but significant differences were detected in the sagittal and frontal plane angles at both time points ($p < 0.001$).

Conclusion: Hip and knee kinematics differed across different segment definitions including or excluding the greater trochanter marker, especially in the transverse plane. Therefore when considering whether to include the greater trochanter in the thigh segment model when using a surface markers to calculate 3D kinematics for movement assessment, it is important to have a clear understanding of the effect of different marker sets and segment models in use.

Keywords: 3D motion analysis; Thigh segment model; Transverse plane motion

1. Introduction

In gait analysis using surface marker systems, the greater trochanter (GT) has been employed as a bony landmark for the orientation of the thigh segment,[1,2] and it is still commonly used.[3–9] However, some authors found poor intra- and inter-rater precision in the identification of the GT.[10] Inaccuracies in defining the GT position for the definition of the anatomical frame of reference of the thigh were found to cause variability in hip and knee joint kinematics across different estimated GT positions.[10,11]

Understanding the influence of GT marker on biomechanical calculations derived from hip and knee models is important when quantifying frontal and transverse plane hip and knee kinematics, parameters which are particularly relevant to investigate in individuals with conditions such as patellofemoral pain, knee osteoarthritis, anterior cruciate ligament (ACL) injury, and hip pain. The frontal and transverse plane motion

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of the hip and knee joints during gait is small, hence small differences across hip and knee models could lead to different or misleading clinical conclusions. For example, one model might reveal excessive hip internal rotation or knee valgus while another might not. This issue is particularly relevant when making clinical judgments on lower limb alignment in individuals with patellofemoral pain for the presence of dynamic knee valgus (i.e., excessive hip adduction and internal rotation, and knee abduction and external rotation) which is a proposed mechanism for patellofemoral pain.[12] Furthermore the GT marker included or excluded in the thigh definition may also have different effects on the knee angles. These effects may impact clinical judgments based on knee angles when examining individuals with knee pain or ACL injury.

The effect of the GT marker included *vs.* excluded in the thigh segment on both hip and knee angles is still unclear. Therefore the scope of this study was to evaluate the effect of including the GT in the construction of the thigh segment on hip and knee kinematics during gait. In the present study, we compared hip and knee angles using two thigh segment definitions (with and without GT) during walking.

Because the GT marker is used to define the orientation of the frontal plane of the thigh, we hypothesized that the GT would influence the magnitude and direction of hip and knee transverse plane angles to a greater extent than sagittal and frontal plane angles.

2. Methods

2.1. Participants

Nineteen subjects (10 males), with age 27.19 ± 5.66 years, height 1.70 ± 0.05 m, mass 71.41 ± 9.44 kg, and body mass index 24.57 ± 2.89 kg/m^2 (mean ± SD) participated in this study. Subjects reported no unresolved or recent musculoskeletal injuries, surgeries, or pain. The study was approved by the Institutional Review Board of Saint Louis University and all subjects read and signed an informed consent form before participating. The dominant leg was assessed by asking subjects which leg they would kick a ball with.[13] All subjects were right leg dominant.

2.2. Procedures

Kinematic data were collected (120 Hz) using an 8-camera 3-dimensional (3D) motion capture system (Vicon Nexus, Oxford, UK). Reflective markers were placed on: iliac crests, anterior and posterior superior iliac spines, the medial and lateral femoral epicondyles (approximating the knee flexion/extension axis), GTs (superior aspect), medial and lateral malleoli (approximating the ankle flexion/extension axis) (Fig. 1A). Quadrangular clusters with four markers on each were placed on thighs and shanks. The markers on the GTs, femoral epicondyles, and malleoli were removed after calibration (Fig. 1A). Subjects performed three walking trials on a 7-m walkway using their customary speed (mean 1.41 m/s). Data were collected in one session.

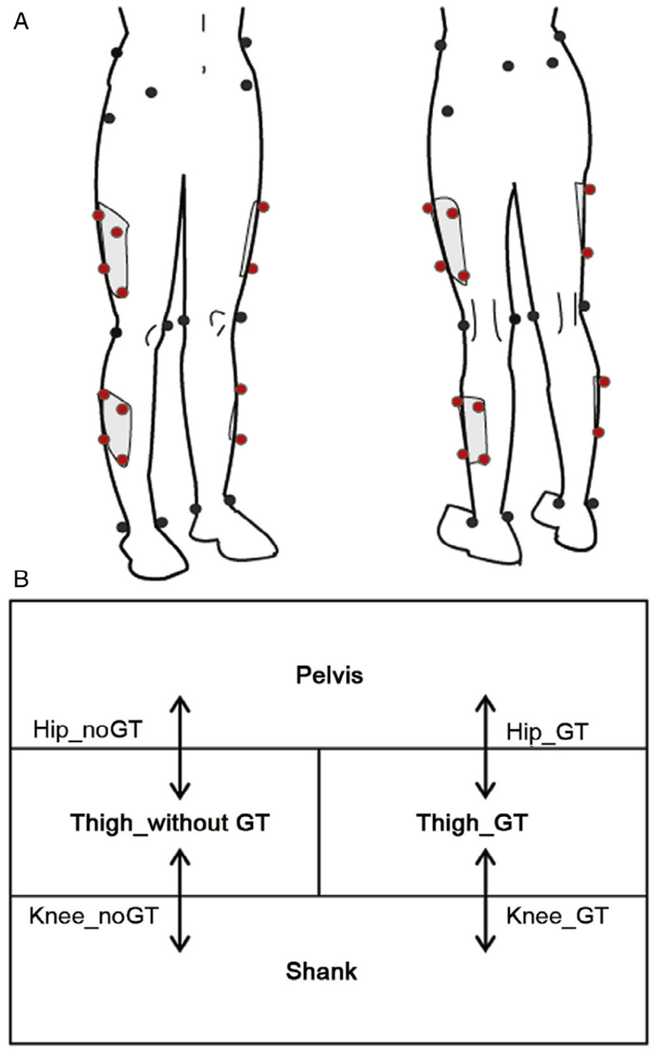

Fig. 1. (A) Schematic of the marker placements. Black points represent the markers that were used only for tracking the segment movement during walking. Red points represent the markers that were used also in the calibration trial for the construction of the 6-degree-of-freedom model. The markers on the greater trochanters (GT), femoral epicondyles, and malleoli were removed after calibration. (B) Schematic of the thigh and shank segment definitions and the hip and knee models used.

2.3. Data analysis

Visual3D (C-Motion, Inc., Germantown, MD, USA) was used to construct a 6-degree-of-freedom model that incorporated the pelvis, thigh, and shank segments. For the pelvis the CODA model (Charnwood Dynamics Ltd., Leicestershire, UK) was used. The coordinates of the hip joint center were calculated according to the Bell's method[14,15] as a percentage of the distance between anterior superior iliac spines (i.e., 36% in the sagittal plane, 19% in the frontal plane, and 30% in the transverse plane). We defined two thigh segments: 1) Thigh_without GT, where the frontal plane was defined by the hip joint center and femoral epicondyles, and 2) Thigh_GT, where the frontal plane was defined by the GT, hip joint center, and femoral epicondyles (i.e., a plane is fit to the four markers so that the sum of the squared distances between the targets and the frontal