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Soft tissue artifact causes significant errors in the calculation of joint angles and range of motion at the hip

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ABSTRACT

Soft tissue movement between reflective skin markers and underlying bone induces errors in gait analysis. These errors are known as soft tissue artifact (STA). Prior studies have not examined how STA affects hip joint angles and range of motion (ROM) during dynamic activities. Herein, we: 1) measured STA of skin markers on the pelvis and thigh during walking, hip abduction and hip rotation, 2) quantified errors in tracking the thigh, pelvis and hip joint angles/ROM, and 3) determined whether model constraints on hip joint degrees of freedom mitigated errors. Eleven asymptomatic young adults were imaged simultaneously with retroreflective skin markers (SM) and dual fluoroscopy (DF), an X-ray technique with sub-millimeter and sub-degree accuracy. STA, defined as the range of SM positions in the DF-measured bone anatomical frame, varied based on marker location, activity and subject. Considering all skin markers and activities, mean STA ranged from 0.3 cm to 5.4 cm. STA caused the hip joint angle tracked with SM to be 1.9° more extended, 0.6° more adducted, and 5.8° more internally rotated than the hip tracked with DF. ROM was reduced for SM measurements relative to DF, with the largest difference of 21.8° about the internal-external axis during hip rotation. Constraining the model did not consistently reduce angle errors. Our results indicate STA causes substantial errors, particularly for markers tracking the femur and during hip internal-external rotation. This study establishes the need for future research to develop methods minimizing STA of markers on the thigh and pelvis.

1. Introduction

Joint angle measurements provide insights into movement abnormalities for clinical gait analysis and scientific investigations [1,2]. Most often, tracking of markers adhered to the skin surface serve as the basis for calculating joint angles; however, skin marker motion capture suffers from soft tissue artifact (STA) [3]. Therefore, measuring STA and its influence on joint angles and range of motion (ROM) calculations are important for interpreting the results from clinical gait analysis and gait models.

Soft tissue artifact results from unequal movement of soft tissue layers, including muscle, tendon and dermis, between the bone and the skin surface. STA can arise from three main sources [3]—skin sliding relative to underlying bone, inertial effects of skin motion, and deformation caused by muscle contraction. Model constraints [4] and skin marker locations [5] have been purported to limit the effects of STA, but the effect of model constraints and marker locations on hip joint angles and ROM remain unclear as neither has been assessed in the hip relative to a true reference standard.

Historically, STA has been measured in-vivo using pins implanted in bone [6,7]. While these studies provided valuable information, bone pins require invasive procedures for placement and may affect tissue movement between the skin surface and bone by restricting sliding between the soft tissue interfaces. More recent advancements permit minimally invasive assessment of STA and its effects on joint kinematics using X-rays. X-ray studies to-date have often focused on imaging the knee joint [8] or only obtained multiple static positions of the hip [9]. A more recent dynamic imaging technique, termed high-speed dual fluoroscopy (DF), has been utilized to measure in-vivo joint motion. The advantage of DF as a reference standard is that bone motion is measured dynamically with sub-millimeter and sub-degree accuracy without the need to implant pins [10].

The purposes of this study were to: 1) measure STA of skin markers on the pelvis and thigh during walking, hip abduction and hip rotation,

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