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Quantification of pelvic soft tissue artifact in multiple static positions☆

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ABSTRACT

Soft tissue artifact (STA) has been identified as the most critical source of error in clinical gait analysis. Multiple calibration is a technique to reduce the impact of STA on kinematic data, which involves several static calibrations through the range of motion of the joint of interest. This study investigated how skin markers at the pelvis were displaced in relation to anatomical body landmarks in multiple static calibration positions. The magnitude and direction of the pelvic marker displacement was assessed in nine different body positions including 90° and 45° hip flexion, maximum hip extension, and pelvic tilt in 20 healthy young adults. ASIS markers were found to be more susceptible to relative displacement than PSIS markers, with displacement particularly evident in positions where the hip was flexed (up to 17 mm). A strong correlation was found between the hip flexion angle and marker displacement ($r^2 = 0.70$). While the estimated impact of pelvic STA on gait kinematics was relatively small, the findings suggest that activities with large hip flexion would cause larger STA with a greater impact on pelvic kinematics. The skin surface located over the ASIS differed by a mean of 17 mm between standing and supine positions, which could affect the inter-ASIS distance and the location of hip joint center (HJC) by up to 20 mm and 10 mm, respectively.

1. Introduction

Gait analysis has been used in treatment decision-making or outcome assessment of pathological conditions, and the accuracy of the data is of critical interest. Soft tissue artifact (STA) refers to the movement of surface markers associated with deformation of subcutaneous tissues due to muscle contraction, skin movement and inertial effects. It has been identified as the most critical source of error within predictive models in clinical gait analysis [1].

The most commonly used biomechanical models within clinical gait analysis use the position of anatomical landmarks identified by skin-mounted markers in conjunction with geometrical equations to estimate the location of joint centers, track the motion of the underlying bone during walking, and calculate joint kinematics [2,3]. The location of pelvic markers is critical in these hierarchical models as the pelvic segment is the origin of the kinematic chain and errors within this segment propagate to all distal segments.

There have been efforts to quantify STA or tracking true bone movement, using bone pins [4,5], external fixators [6], X-ray or fluoroscopy [7–9], or MRI [10]. Although many studies have investigated STA of the thigh, shank, or foot [4–13], knowledge of STA at the pelvis is particularly scarce. Despite its potential significance, investigations of pelvic STA are limited, perhaps due to the practical and ethical considerations associated with those investigative techniques particularly around the pelvis. Only one study was found to have quantified STA at the pelvis, using bone pins in the S1 vertebrae [14]. Significant STA was noted in a sit-to-stand task (over 35 mm) and gait (over 25 mm). Although the presence of pelvic STA was identified, its detailed characteristics and effects on pelvis kinematics remain unknown.

Double calibration is one technique previously used to reduce the impact of STA on kinematic data. Double calibration procedures typically involve two static calibrations at end-range positions of the joint of interest as a reference [15]. Knee STA was effectively reduced with this technique compared to single calibration [13,16].

The current study aimed to investigate how skin-mounted pelvic markers were displaced in relation to anatomical bony

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One of the limitations of the current study was that it included only healthy young adults with regular BMI. Gait analysis is generally used for patients with pathology, and clinicians often regard STA as more prevalent and problematic among people with higher BMI. The findings of the current study are not directly applicable to those with gait pathology or higher BMI. However, this was the first study to quantify STA using multiple calibration positions, and the focus was on establishing the profile of pelvic STA in individuals with typical anthropometric characteristics. Quantification of pelvic STA is particularly complex due to the motions of the two joints attached in conjunction with its own segment movement under the skin. The use of multiple calibration positions allowed the systematic isolation of these movements and quantification of the static STA. Soft tissue artifact due to dynamic muscle contraction, inertial effects, or wobbling of markers was not quantified in this project. Although STA measured in this study may differ from STA that occurs during activities such as walking, the results of this study provide reference information of pelvic STA, which may lead to application in kinematics and kinetics data as a function of joint angle.

5. Conclusion

Evidence of relative displacements of the pelvic markers with respect to their bony landmarks was shown in multiple calibration positions. ASIS markers were more susceptible to displacement than PSIS markers, particularly in hip flexion positions. Although the estimated impact of pelvic STA on gait kinematics was relatively small, a larger influence was observed in position which involved 90° hip flexion (up to 6°). Inter-ASIS distance measured in supine was found to be smaller than the distance measured in standing, which may place the HJC more medially in the Plug-in-gait model.

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Conflict of interest statement

None of the authors have any financial or personal relationships with other people or organizations that could inappropriately influence this work.

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