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Non-invasive assessment of soft-tissue artifact and its effect on knee joint kinematics during functional activity

Massoud Akbarshahi [a], Anthony G. Schache [a], Justin W. Fernandez [a], Richard Baker [a,b], Scott Banks [c], Marcus G. Pandy [a,*]

[a] Department of Mechanical Engineering, University of Melbourne, Victoria 3010, Australia
[b] Murdoch Childrens Research Institute, Parkville, Victoria 3010, Australia
[c] Department of Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL 32611, USA

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ABSTRACT

The soft-tissue interface between skin-mounted markers and the underlying bones poses a major limitation to accurate, non-invasive measurement of joint kinematics. The aim of this study was twofold: first, to quantify lower limb soft-tissue artifact in young healthy subjects during functional activity; and second, to determine the effect of soft-tissue artifact on the calculation of knee joint kinematics. Subject-specific bone models generated from magnetic resonance imaging (MRI) were used in conjunction with X-ray images obtained from single-plane fluoroscopy to determine three-dimensional knee joint kinematics for four separate tasks: open-chain knee flexion, hip axial rotation, level walking, and a step-up. Knee joint kinematics was derived using the anatomical frames from the MRI-based, 3D bone models together with the data from video motion capture and X-ray fluoroscopy. Soft-tissue artifact was defined as the degree of movement of each marker in the anteroposterior, proximodistal and mediolateral directions of the corresponding anatomical frame. A number of different skin-marker clusters (total of 180) were used to calculate knee joint rotations, and the results were compared against those obtained from fluoroscopy. Although a consistent pattern of soft-tissue artifact was found for each task across all subjects, the magnitudes of soft-tissue artifact were subject-, task- and location-dependent. Soft-tissue artifact for the thigh markers was substantially greater than that for the shank markers. Markers positioned in the vicinity of the knee joint showed considerable movement, with root mean square errors as high as 29.3 mm. The maximum root mean square errors for calculating knee joint rotations occurred for the open-chain knee flexion task and were 24.3°, 17.8° and 14.5° for flexion, internal–external rotation and abduction–adduction, respectively. The present results on soft-tissue artifact, based on fluoroscopic measurements in healthy adult subjects, may be helpful in developing location- and direction-specific weighting factors for use in global optimization algorithms aimed at minimizing the effects of soft-tissue artifact on calculations of knee joint rotations.

1. Introduction

Accurate *in vivo* measurement of knee joint kinematics is important for the evaluation of different surgical techniques, treatment methods and implant designs and for the development and validation of computer models capable of simulating normal and pathological movement (Pandy, 2001; Fernandez et al., 2008). Three-dimensional (3D) motion analysis using skin markers is the most common method for measuring knee joint kinematics *in vivo*. The accuracy of this approach is determined mainly by errors associated with the non-rigid movement of the soft-tissue interface between the skin markers and the underlying bone, commonly referred to as soft-tissue artifact (STA).

Numerous studies have investigated thigh and shank STA for a variety of different motor tasks, such as walking, running and sit-to-stand (Cappozzo et al., 1996; Wretenberg et al., 1996; Fuller et al., 1997; Reinschmidt et al., 1997; Stagni et al., 2005; Benoit et al., 2006; Tsai et al., 2009). All of these studies have found STA to be greater for the thigh than for the shank, with STA errors reaching values as high as 50 mm.

It is also important to quantify the propagation of STA to the estimation of knee joint kinematics. Previous studies have most often used intrusive techniques for their analyses, such as bone pins (Fuller et al., 1997; Reinschmidt et al., 1997; Benoit et al., 2006), external fixators (Cappozzo et al., 1996) and percutaneous tracking devices (Holden et al., 1997; Manal et al., 2000) to quantify joint motion *in vivo*. Unfortunately, these devices can restrict the movement of the subject and alter the normal, unimpeded sliding

* Corresponding author. Tel.: +61 3 8344 4054; fax: +61 3 9347 7717.
E-mail addresses: pandym@unimelb.edu.au, pandy@mail.utexas.edu (M.G. Pandy).

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Conflict of Interest

The authors do not have any financial or personal relationships with other people or organizations that could inappropriately influence this manuscript.

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Appendix A. Supporting materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jbiomech.2010.01.002.

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