Quantification of Soft Tissue Artifact in the Knee during Walking: Bi-plane Fluoroscopic Study

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Introduction: Accurate measurement of skeletal kinematics plays an important role in understanding musculoskeletal diseases such as osteoarthritis [1]. Reflective markers attached to the skin are frequently used to quantify joint angles during movements. For example, markers on greater trochanter, lateral epicondyle and medial epicondyle of the femur are used to locate the femoral coordinate system. Muscle and other soft tissue layers between the skin and bone degrade the accuracy of estimating skeletal movements from the skin markers [2]. Previously marker cluster methods [3] and soft tissue artifact correction methods [4] have been proposed to overcome the skin movement artifact. Bone-pins were attached to the femur and tibia to understand the knee kinematics during walking [5]. Recently bi-plane fluoroscopic (BPF) analysis has been adopted in biomechanics studies and could directly measure the skeletal movements almost non-invasively [6,7]. While the new x-ray based technique are available skin marker based motion capture system are widely used. Thus investigating the effect of soft tissue artifact on joint kinematics will increase our understanding on the predictability of conventional motion capture systems for skeletal kinematics during clinical gait measurements. The objective of the study was to quantify the soft tissue artifacts for the medial and lateral epicondyle markers on the femur and the medial and lateral plateau markers on the tibia.

Methods: Three healthy subjects (all males, 24±1 years, weight 64±7 kg, height 168±3 cm) volunteered for this study. Chung-Ang University IRB approval and informed consents were obtained prior to testing. Reflective markers including medial and lateral epicondyle markers on the femur, and medial and lateral plateau markers on the tibia were put on subjects' right lower limb. Subjects walked on a treadmill at 0.9 m/s. A BPF system were set-up to take a series of anterior-posterior x-ray images and lateral-posterior-medial-anterior x-ray images with 45 degree angles between the two views. The X-ray tubes were set with 55 kVp and 10 mA. CCD cameras attached to X-ray image intensifiers were set with shutter speed 4 ms and 27 frames per second. A Vicon motion capture system with five cameras was set up around the BPF system. Each subject walked on the treadmill continuously and the BPF system started manually in the middle of the swing phase of right leg and was up for 1.5 seconds. A static trial with normal standing pose was taken in the same way for 0.2 second.

The BPF system was calibrated using an in-house calibration phantom and software. A coordinate transformation matrix between the BPF and Vicon systems were calculated. The time synchronization between the BPF system and Vicon system was performed using two Vicon markers which were also visible in BPF system. The femur and tibia were registered to a series of X-ray images from the two views for both the static and walking trials. Coordinates of the markers identified with Vicon system at static trial were transformed to BPF coordinate system and used as the virtual markers of the underlying bones, the femur and...
tibia. The virtual markers moved along the femur and tibia in BPF coordinate system. The coordinates of virtual markers then transformed to the Vicon coordinate system. The movements between the virtual markers and Vicon markers were compared to quantify the pair-wise distance change from mid swing phase to the mid stance phase.

Results: The BPF and Vicon data were captured around heel strike. Capture durations were 592 ms, 518 ms and 444 ms, which were 51%, 45% and 43% of a gait cycle for the three subjects. The average position differences for the four markers between the BPF system and Vicon system were calculated for pre-heel-strike period and post-heel-strike period. We performed only descriptive statistics because of a small number of samples. The average position differences were 10.4 mm, 13.0 mm, 8.9 mm, and 6.4 mm for the pre-heel-strike period, and 6.2 mm, 7.3 mm, 6.2 mm, and 6.8 mm for the post-heel-strike period for the lateral condyle, medial condyle, lateral plateau, and medial plateau markers, respectively.

Discussion: The effect of soft tissue artifact on the four important markers around the knee was quantified using a BPF system and a conventional motion capture system. Average position differences were larger than 5 mm for all four markers around heel strike. The differences were generally larger during pre-heel-strike period than post-heel-strike period. The standard markers positions were determined at standing static position thus it is possible that the knee flexion during pre-heel-strike period could be affected the position difference. The position differences were larger in the femoral markers than in the tibial markers.
Muscle contractions during heel strike and attachment locations around the knee could cause relatively large movements for the femoral markers.

**Significance:** The study quantified soft tissue artifact around the knee during walking. It will increase our understanding on the predictability of conventional motion capture systems for skeletal kinematics during clinical gait measurements.

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**References:**

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