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In Vivo Knee Kinematics during Gait Reveals New Rotation Profiles and Smaller Translations

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In order to identify abnormal or pathological motions associated with clinically relevant questions such as injury mechanisms or factors leading to joint degeneration, it is essential to determine the range of normal tibiofemoral motion of the healthy knee. In this study we measured in vivo 3D tibiofemoral motion of the knee during gait and characterized the nonsagittal plane rotations and translations in a group of six healthy young adults. The subjects were instrumented with markers placed on intracortical pins inserted into the tibia and femur as well as marker clusters placed on the skin of the thigh and shank. The secondary rotations and translation excursions of the knee were much smaller than those derived from skin markers and previously described in the literature. Also, for a given knee flexion angle, multiple combinations of transverse and frontal plane knee translation or rotation positions were found. This represents normal knee joint motions and ensemble averaging of gait data may mask this important subject-specific information.

Based on normative joint profiles, it may be possible to identify knee injury mechanisms that exacerbate degenerative joint disorders and knee pathomechanics. For example, tibiofemoral joint instability has been implicated in the progression of osteoarthritis (OA) of the knee.[13,20,34] Knowledge of knee pathomechanics may facilitate improvements in surgical techniques, prosthetic design, injury prevention, and joint degeneration.[1] Additionally, biomechanical models of the knee have been used to identify the roles of joint ligaments and forces in controlling these motions.[28,32,47,50] However, to identify mechanisms of anterior cruciate ligament (ACL) and other ligament and soft tissue injuries, three dimensional (3D) in vivo kinematic data representing tibiofemoral motions under physiological conditions are needed to drive these models.[50] Furthermore, it is essential to determine the range of normal tibiofemoral motion of the healthy knee before identifying abnormal or pathological motions associated with clinically relevant questions such as injury mechanisms or factors leading to joint degeneration.

Stereophotogrammetry (multiple cameras) combined with surface markers placed on the thigh and shank is most commonly used to track lower limb kinematics. With advances in high resolution optoelectric motion analysis systems, 3D tibiofemoral joint profiles are readily derived. Internal/external tibial rotations have been reported to be 11° with concomitant anteroposterior tibial excursions of 22 mm during the stance phase of gait.[16] However, movement artifacts from markers affixed to the skin contribute up to 4.4° and 13 mm of error to knee rotations and anteroposterior tibial translations, respectively.[12] The magnitude of these artifact errors may mask tibiofemoral motions, thus limiting the conclusions drawn from nonsagittal plane observations.[12,25] To circumvent artifact associated errors, technologies have advanced the means by which skeletal tibiofemoral kinematics is measured. These include roentgenstereophotogrammetric analysis (RSA),[29] biplanar image-matching,[5] video fluoroscopy,[6,15,48,49] and cine phase-contrast magnetic resonance imaging (PC-MRI) techniques.[22,41,44–46] Although PC-MRI permits imaging of knee motion and has been useful in comparing populations with ACL injury,[7,8] transferring the kinematics of these cyclical knee flexion-extension motions to walking or other activities of daily living has not yet been established. Combined high-speed biplanar radiography

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Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research, and that informed consent was obtained.
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sition at heel strike be since healthy subjects show such variability? Generally, the joint excursions are more consistent across subjects throughout the cycle (with the exception of one subject) and may be a more robust indicator of normal, or conversely pathological, motion.

We have described the in vivo kinematics of the knee during the pre-foot strike and stance phases of gait. We found secondary rotations and translations were generally smaller then those described using skin markers. The smaller in vivo frontal, sagittal, and transverse plane rotations and translations, combined with inherent individual subject variability, indicates ensemble averaging of gait data may mask important individual gait characteristics.[3] The shape of the motion curves and the total joint excursions reported in this study can be used to indicate the validity of knee kinematic data collected using skin markers. In addition, this study provides data of the 3D in vivo tibiofemoral motions of the healthy knee during physiological conditions that may be integrated into biomechanical models.

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