KNEE ANATOMICAL METRICS PREDICT KINEMATICS DURING LOADED LANDINGS

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INTRODUCTION

Anatomical metrics of the tibiofemoral joint, such as tibial slope, are reportedly a predictor of soft tissue injury [1] and deleterious biomechanical patterns of of the knee [2]. Individuals with altered knee morphology may exhibit exacerbated injury risk by adding body borne load during certain activities. However, it is difficult to measure these anatomical metrics with high resolution and accuracy under weight-bearing conditions with standard imaging techniques. The ability to image a subject's knee geometry in a weight bearing state is facilitated through the use of a dedicated cone-beam CT (CBCT) scanner. The use of the CBCT scanner allows for a unique capability to image the knee morphology during weight bearing, which could provide the ability to identify individual's susceptibility of suffering a soft-tissue injury when bearing body borne loads, as common during military activities. Drop landing is an infantry relevant task and has been previously used to identify injury risk [3], particularly during weight-bearing military activities [4]. In this study, we determine if there is a relation between an individual's knee joint morphology and the knee biomechanics they exhibit during loaded and unloaded drop landings.

METHODS

We plan to recruit 36 healthy male and female soldiers between 18-39 yo. stationed at NSRDEC as Human Research Volunteers. Eligible volunteers had 3D knee joint biomechanical data recorded during a series of drop landings from a 30 cm platform. Each participant performed the drop landings for two conditions: unloaded and loaded (Figure 1). During the unloaded condition (Non-BBL), participants wore a helmet and carried a mock weapon (~ 6 kg). For the loaded condition (BBL), participants wore a weighted vest (WeightVest.com Inc. Rexburg, ID, USA), in addition to carrying the weapon and donning the helmet, such that the total load equaled 30% of their body weight. During each condition, participants performed five successful drop landings.

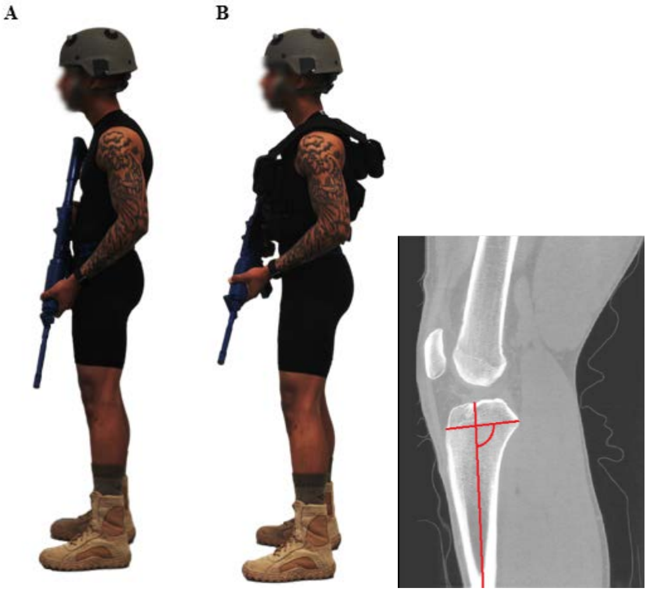

Figure 1. A) Non-BBL and B) BBL configurations for this study. BBL includes weighted vest, weighted mock weapon, helmet and boots. A representative image of a subject's tibiofemoral joint in sagittal view with the required points for MTS calculation.

During each drop landing, knee biomechanics were quantified based on the 3D coordinates of 36 reflective skin markers recorded with twelve high-speed (240 fps) optical cameras (Opus, Qualysis AB, Gothenburg, Sweden). A high-speed video recording of the subject standing in a stationary (neutral) position was taken following marker placement and used to define a kinematic model comprised of eight skeletal segments (bilateral foot, shank and thigh segments and the pelvis and trunk) with 24 degrees of freedom. The 3D marker trajectories recorded during each landing were low-pass filtered with a fourth-order Butterworth filter at a cut-off frequency of 12. The filtered marker trajectories were subsequently processed by the Visual 3D (C-Motion, Rockville, MD) software to solve for knee joint rotations.

After the landing protocol, the subject's dominant knee is imaged with the CBCT while standing. Each subject is imaged in a natural stance without load. To ensure a natural stance and even weight distribution, the subject's stood with each foot on a custom pressure mat (Novel GmbH, Munich, Germany) which allows for real time monitoring. The CBCT volumes are analyzed using conventional radiological metrics of joint morphology. To simplify analysis, custom software has been developed that allows for multi-planar rendering of CBCT volumes and then guides users through the selection of specific anatomical landmarks required for calculation of all specified metrics. The anatomical metrics calculated include: medial and lateral tibial slope and depth.

For analysis, knee flexion angles were assessed for the stance phase (0 – 100%) of each landing. Finally, the biomechanical and anatomical variables were submitted to multiple stepwise linear regression analyses ($P < 0.05$) to assess the relationship between lower extremity morphology and biomechanics exhibited during the Non-BBL and BBL drop landings.

RESULTS AND DISCUSSION

The study is ongoing with 8 out of 36 subjects having completed biomechanics testing and imaging, with another 20 subjects to be completed by summer of 2016. The landing biomechanics and mean anatomical morphologies calculated from CBCT images can be seen in Tables 1 and 2, respectively. At this time, only 8 subjects having completed all parts of the study. While there is low statistical power for most anatomical metrics, we found that lateral tibial slope was a significant predictor of peak knee flexion during the loaded ($p = 0.0380$, but not during the unloaded landings ($p > 0.05$).

MTS	LTS	M. Tib. Depth	L. Tib. Depth	Non-BBL Knee Flx	BBL Knee Flx
5.63 (3.31)	5.13 (1.80)	2.18 (0.62)	0.97 (0.63)	-58.4 (14.3)	-63.1 (8.6)

Table 1. Mean (SD) data for anatomical and biomechanical metrics .

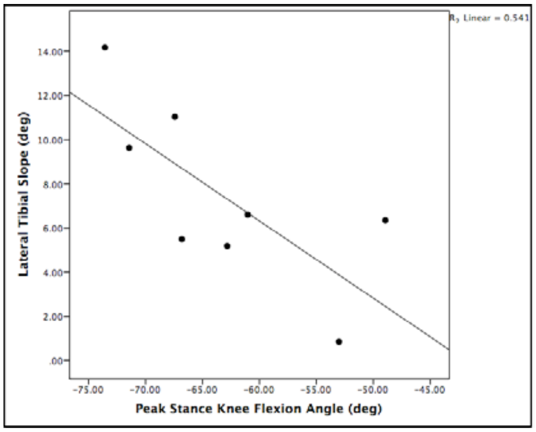

Figure 1. Scatter plot of lateral tibial slope and peak knee flexion exhibited during BBL landings.

CONCLUSIONS

The method of combining traditional biomechanics analyses with advanced imaging techniques allows for a better understanding of the effect of BBL *in vivo*. External joint measures may not always appropriately reflect the effect of load on the internal anatomy, thus requiring both internal and external measures. Ideally, identifying anatomical metrics using a consistent and standardized method will enable the capability to pre-screen Soldiers and athletes for susceptibility to BBL injuries. Ultimately, this will allow for performance optimization and extended musculoskeletal health.

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