# Variation in Femoral and Tibial Bony Morphology Correlates with Knee Kinematics During Walking

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## Introduction

### Background

- Variations in anatomy exist from person to person, such as bony morphology
- Certain morphological features have been related to kinematics and injury risk, but have been limited to 2D measurements utilizing radiographs or CT images[1], or estimated bone morphology using simple geometry[2]
- Statistical shape modeling (SSM) can be used to isolate and describe variations in surface geometry of subject specific 3D bone models[3–5]

### Aim

- To determine if femur and tibia morphology variation found with SSM correlates to tibiofemoral kinematics during walking
- Based upon previous 2D measurements[1,2], we hypothesize that shape modes pertaining to femoral condylar sphericity and tibial slope will correlate with knee kinematics

## Methods

### Subjects

- 46 subjects with IRB approval and informed consent were enrolled (31 males 22.4± 7.3 years, 15 females 22.1± 9.0 years)
- All subjects received unilateral Anterior Cruciate Ligament Reconstruction (ACL-R) and completed a 6-month standardized rehabilitation program

### Data Collection

- Biplane radiographs were collected at 100Hz during level walking (1.2 m/s) with Dynamic Stereo X-ray system (DSX)
- High resolution computed tomography (CT) acquired and used to build subject specific bone models (±10 cm from joint line)
- Foot strike recorded using instrumented treadmill

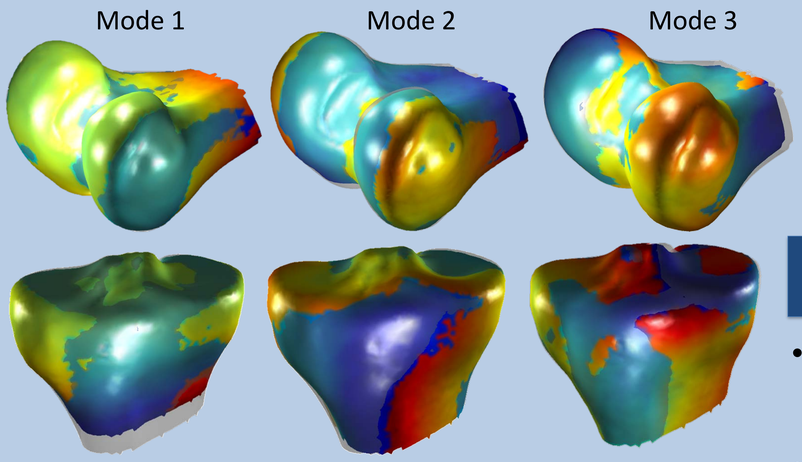


*Figure 1. Visual representations of the first 3 shape modes, +3SD (transparent grey is average shape). Cooler color represents surface under average shape, hotter color represents surface above average shape.*

### Data Processing

- Knee kinematics were determined using a validated volumetric model-based bone tracking techniques[6]
- Kinematics were calculated following the Grood and Suntay convention[7]
- Custom MATLAB code was used to interpolate kinematic results to function of percent gait cycle (0 to 15% of gait cycle)
- SSM using principal component analysis was performed using custom MATLAB code on the femur and tibia bone models of the contralateral uninjured knee for each subject, providing the modes of variation[8]
- Mode scores were calculated, which reflects the subject-specific bone model variation from the average bone model

### Statistics

- Mode scores that contributed to more than 5% of the overall variance were included in the correlation analysis
- Spearman's Rho used to test for correlations between mode scores and kinematics parameters (maximum and minimum values of anterior/posterior (AP) and medial/lateral (ML) translation, and internal/external (I/E), ab/adduction (Ab/Ad) and flexion/extension (F/E) rotation)
- Visual representations of the shape modes, obtained by varying each mode by ±3 standard deviations, were used to identify the physical attributes of each mode (Figure 1)

## Results

Femur shape mode 5

- 5.9% of femur shape variance
- Corresponds to the sphericity of the medial femoral condyle and the height of the lateral ridge of the trochlea (Figure 2A)
- Correlated to maximal knee extension (ρ=-0.402, p=0.006) (Figure 3A)

Tibia shape mode 4

- 8.0% of the tibia shape variance
- Corresponds to the height of the anterior aspect of the medial plateau (Figure 2B)
- Correlated to maximal internal rotation (ρ=-0.297, p=0.045) (Figure 3B)

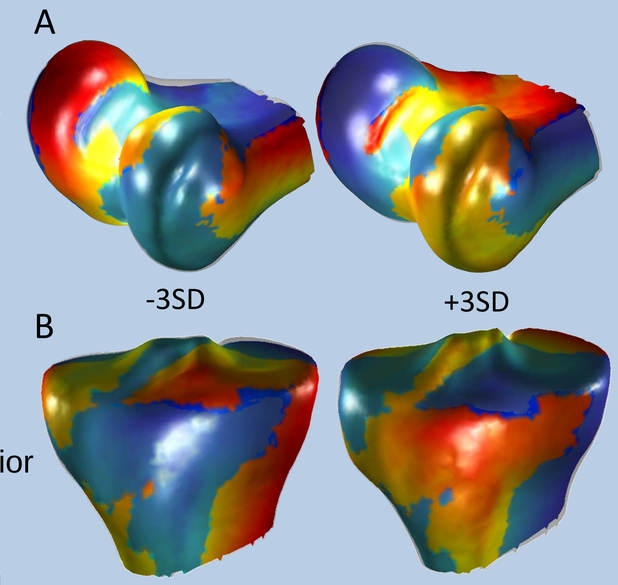


*Figure 2. Femur and tibia average model (transparent blue) with +/- 3SD variation (red) in mode 5 (Femur) and mode 4 (Tibia)*

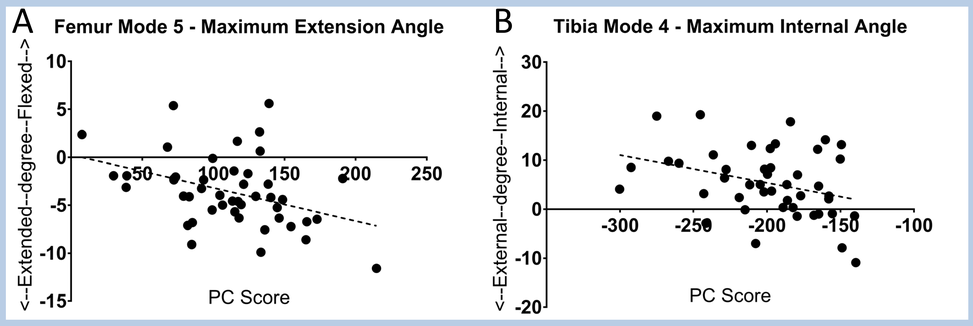


*Figure 3. Shape mode score vs Kinematic parameter. Dotted line represents linear trend.*

## Discussion

- Quantifiable morphological features that are correlated to tibiofemoral kinematics during the early support phase of walking in healthy, uninjured knees were found using SSM
- The results are in agreement with previous studies that correlated femoral condyle offset (which is related to the sphericity of the condyle) and tibial slope with kinematic differences[1,2]

### Limitations

- Physical interpretations of each shape mode are assigned by visualization, and therefore qualitative
- Contralateral knee of patients with ACL-R was used
- Only first 15% of gait cycle was assessed

### Significance

- SSM may provide a method for quantitatively identifying patients with increased risk of injury and osteoarthritis due to abnormal kinematics, using only 3D models obtained from a CT scan

## References and Acknowledgement

[1] Herbst et al, ISAKOS 2017. [2] Hoshino et al, KSSTA 2012. [3] Lansdown et al, Clin. Orthop. Relat. Res., 2017. [4] Bredbenner et al, J. Biomech., 2010. [5] Harris et al, J. Orthop. Res., 2013. [6] Anderst et al, Med. Eng. Phys., 2009. [7] Tashman et al, J. Biomech. Eng., 2003. [7] Grood et al, J. Biomech. Eng., 1983
[8] Cootes et al, Comput. Vis. Image Underst., 1995.

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