A Preliminary Study: Tracking 3D Kinematics of the Goat Knee Joint In-Vivo

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INTRODUCTION
ACL injury has reached epidemic levels. In the United States, it is estimated that 100,000-200,000 people sustain an ACL injury annually. ACL injury is thought to alter knee mechanics, disrupting cartilage metabolism. These changes in knee joint mechanics have been linked to increased incidence of osteoarthritis (OA); however, the precise mechanism is poorly understood (Tapper 2005). Developing an in vivo method for accurately tracking 3D bone kinematics during relative movements of articular surfaces during load-bearing movements in both healthy and injured knees may be useful for exploring the relationship between joint motion and OA. The goal of this study was to introduce a novel method for tracking 3D kinematics of the healthy and ACL-transected goat knee joint.

METHODS AND PROCEDURES

Surgical Technique: One Nubian goat (64.2 kg) received surgical ACL-transection, while another goat (53.1 kg) received a sham surgical procedure. A total of 12 spherical radiopaque tantalum markers were embedded in the distal femur and proximal tibia (6 markers per bone) of each goat during surgery.

Fluoroscope Motion Capture: Each goat knee joint was imaged using a high-speed, biplanar video fluoroscopy system comprised of two C-arm (OEC 9400) fluoroscope assemblies. Each C-arm assembly was retrofitted with an X-ray source opposite a 12-inch image intensifier optically coupled to a digital high-speed video camera (Photron Fastcam-X 1024pci, 250 frames/s). Each goat walked on a standard treadmill while video sequences were synchronously recorded with both video cameras at shutter speeds of 0.001 seconds. X-ray source voltage and current were independently set (camera one: 100 kVp 3.2 mA, camera two: 110 kVp 3.0 mA) to best visualize the bone markers during gait cycles. Markers were identified for each frame using marker digitization software (XrayProject; CTX Technology Development Project, Brown University, Providence, RI).

Anatomical Coordinate System Determination: 3D bone models were created from CT scans (LightSpeed; GE, Piscataway, NJ) for the tibia and femur of each goat knee. Manual segmentation software (Mimics 9.11; Materialise Ann Arbor, MI) was used to produce 3D models of bone. 3D bone features, including the surface of the tibial plateau, the volume between the most medial and most lateral points on the femoral condyles, and the femoral shaft were found using geometry analysis software (Geomagic Studio 9; Geomagic, Durham, NC). The FE axis of the femoral coordinate system was designated as the first axis, based on the best cylindrical fit of the volume between the femoral condyles. The AB/ADD axis was designated as the second axis, defined by taking the cross product of the cylindrical fit through the femoral shaft with the FE axis. Finally, the third axis of the femoral coordinate system was defined by crossing the FE axis with the AB/ADD axis (Figure 1). The tibial coordinate system was defined...
using the plane that was the best-fit to the surface of the tibial plateau. The plane was finite, with its corners approximating the length and width of the tibial plateau. Its normal vector approximated the tibial shaft, and the other two axes were defined by bisecting the plane perpendicular to its edges.

**3D Joint Kinematic Data Processing:** 3D modeling and animation software (Maya 8.5; Autodesk, San Rafael, CA) was used to link, rotoscope, and animate the digitized bone markers to the 3D bone models and the anatomical axes. The animated anatomical axes generated in Maya were loaded into motion analysis software (Visual3D; C-Motion, Germantown, MD) to perform kinematic analysis on local reference frames. A joint coordinate system was defined from the tibial and femoral anatomical axes using the method of Grood and Suntay (Grood, 1983). The ordered sequence of rotations was FE (x-axis), AB/ADD, (y-axis), and IE rotation (z-axis). AP translation of the femur relative to the tibia was also determined. The average ROM in each goat knee joint was defined as the difference between the maximum and minimum peaks of each rotation.

**RESULTS**

The kinematic rotational and translational patterns were similar for the sham and ACL-transected joints (Figure 2). The largest ROM was FE (sham 37.7°±2.43°, ACL-transected 32.7°±3.30°), followed by IE rotation (sham 18.1°±4.41°, ACL-transected 22.5°±3.33°), and then AB/ADD (sham 4.76°±1.29°, ACL-transected 8.37°±2.21°). The AP translations of the femur relative to the tibia were 5.76±0.138mm and 6.03±0.256mm for the sham and ACL-transected knees, respectively.

**DISCUSSION**

This study has introduced a novel method for tracking 3D kinematics of healthy and ACL-transected goat knee joints. The relative rotational and translational motion of the goat knee joint were quantified by determining ROM in a sham and ACL-transected goat knee. Any differences observed in kinematics between the two subjects tested may have been due to ACL-transection altering joint mechanics or to differences in the defined knee coordinate systems. Further studies are needed to validate the robustness this method. ROM measurements (Figure 2) are consistent with other more invasive marker tracking quadruped kinematic studies by Frank et al. (Tapper, 2008). The results of this preliminary study indicate the feasibility and repeatability of tracking 3D kinematics *in vivo*.

**REFERENCES**


![Figure 2. Bar chart depicting mean range of motion (left y-axis in mm, right y-axis in degrees) between goat gait strides with standard deviation bars.](image-url)