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Q&A

How did you become involved in doing research?
Engineering is about learning and applying. I wanted to take the engineering principles I learned in the classroom and apply them to something tangible. I researched what professors in my department were doing and found a lab that sparked my interest. I met with the professor and began doing small tasks with the graduate students. After exposure to the work going on in the lab, I developed my own research proposal and began working on an independent project.

How is the research process different from what you expected?
There is no clearly defined route to get to the results you are wanting to obtain. You have to continuously change your methods and process to get to the end result.

What is your favorite part of doing research?
I really enjoyed the bridging of engineering with other areas of science. Through my research I was exposed to areas of biology, orthopedic surgery, and a number of engineering backgrounds.

Displacement, Tension & Kinematic Properties of the Posterior Cruciate Ligament during Flexion-Extension with Applied Loads

Jamie Branch

INTRODUCTION
The objective of this research is to investigate the mechanical properties of the posterior cruciate ligament (PCL) at maximum extension angles. Tension and displacement of the PCL are two critical factors that will provide insight into how the PCL behaves in the knee joint. These parameters will be analyzed in reference to the kinematics of the knee and the loads being applied. This research seeks to better characterize the mechanical properties of the PCL to add to the existing literature and provide insight into how the PCL functions under tension.

BACKGROUND
The PCL is a ligament in the knee joint (Fig. 1) that is responsible for restraining the posterior translation of the tibia and prevents the femur from moving too far backward over the tibia. Its primary purpose is to stabilize the knee. The PCL originates from the femoral condyle and inserts into the back of the tibial plateau. The average length of the PCL from origin to insertion is 38 +/- 4 mm.[1]

Approximately 25,000 PCL injuries are diagnosed in the United States per year[7]. This is one-tenth the number of diagnosed ACL injuries. PCL tears are normally a result of high force impacts. These typically occur through vehicle accidents or contact sports. Extreme hyperextension of the leg is another form of trauma that may cause a PCL tear. Since fewer PCL incidents of damage (especially compared to the ACL) occur, there is less research literature available and repair techniques are not as developed. Surgical repair, while extremely common for an ACL tear, is much more complex when fixing the PCL. Patients may instead choose to sacrifice stable knee mechanics by opting out of surgery and seeking physical therapy rehabilitation.

METHODS

A cadaveric knee was obtained for experimentation. External fixings were attached to the femur and tibia. The PCL was accessed by making an incision just below the posterior center of the joint line and pulling back skin, fascia, and subcutaneous tissue to expose the deep anatomy near the PCL tibial insertion site. The PCL was located by manually pushing the knee into hyperextension and feeling for the tightening of the PCL fibers. The entirety of the PCL was exposed by removing surrounding tissue (Fig.2). Once identified, an implantable pressure transducer (IPT) was implanted and sutured into the fibers of the PCL. The IPT is a sensor that has a small strain gauge embedded in it to pick up deformations as the ligament constricts on it (Fig. 3). The sensor measures the transverse compression created by the PCL as it elongates and becomes tense. It does not measure tension directly, but can be used as a model where the ligament undergoes tension. The fixing of the femur was inserted into a contraption to secure the knee in a fixed position. Rigid body sensors were attached to the femur and tibia fixings to track their motion in 3D space. The tibia of the knee was manually moved through maximum extension to 110 degrees of flexion while either Varus-Valgus (VV), Anterior-Posterior (AP), or Interior-Exterior (IE) loads were applied (Fig. 4). An Optotrak 3020 infrared camera system captured the motion of the femur and tibia via the rigid bodies. The IPT sensed tension in the ligament as it underwent loads at different flexion angles. Labview software synchronized with the Optotrak and IPT recorded load, kinematic, and tension feedback. After the completion of kinematic testing, the femur, tibia, and PCL attachment sites were probed to obtain knee geometry data.

A Matlab computer program was written to compile and perform operations on the data recorded in Labview. A distance code used the probed PCL attachment sites to calculate the length of the PCL throughout the knee's range of motion. The kinematics, loads, distances, and tensions of the PCL were input into a different Matlab program to generate representative plots for analysis.

RESULTS

The PCL undergoes the least amount of load in a VV test. Because varus-valgus affects the PCL the least, the VV test was used to model the displacement of the PCL as it travels through the range of flexion and extension. The IPT sensor data is plotted next to this graph. This representation is depicted in Figure 5. It is important to note that the IPT sensor does not directly measure tension: the trend of the values correlate to tension.

Anterior-posterior loads affect the PCL the most since the PCL functions to stabilize the knee in the anterior-posterior direction. An AP test was used to analyze characteristics of the PCL and model how the PCL properties differ when under load. Figure 6 depicts the displacement, load, and IPT sensor data with respect to flexion extension.

It is necessary to relate all the parameters that may influence the PCL in one plot. Length, AP kinematics, flexion-extension angle, AP load, and tension are the variables that particularly influence the PCL. Figures 6 & 7 model the results of these variables against one another.

DISCUSSION

Figure 5 illustrates how the PCL is lengthening throughout the range of flexion extension in the absence of load. From this figure, it can be concluded that the PCL lengthens as the knee achieves greater extension until it hits a certain value (around 80 degrees) where the PCL length plateaus and remains relatively stable. In the area nearing maximum extension, the PCL begins to lengthen, which can be seen from 26-28mm range on Figure 5. This is most likely explained by the increasing distance between the two insertion sites in which the PCL has to stretch to prevent the knee from bending backward further.

The greatest tension correlates with the above described plateau region at deeper flexion angles, and in the region nearing maximum extension where the PCL reverses trend and begins to lengthen with smaller knee angle (length 33-35mm and 26-28mm).

From Figure 6, it can be seen that as load is applied, the PCL lengthens. The trend of the PCL displacing up to 8mm at a set flexion angle matches up with the anterior and posterior loads being applied at that angle. This shows that the load being applied to a knee greatly affects the displacement of the PCL length. The IPT sensor data indicates that the tension fluctuated with the load, and greatest tension (lower on y axis) is in the 80-100 degree of flexion-extension. It was surprising to find that tension did not appear to fluctuate from approximately 40 degrees to maximum extension like it did in the VV test. The greater the tension of the PCL, the more likely it is to tear. The figures model where these areas of high tension are.

Figures 7 and 8 represent the variables affecting the PCL in a multi-dimensional plot. Figure 7 indicates that greater load is seen at highest and lowest lengths of the PCL (dark red and dark blue). Figure 8, which incorporates the IPT data, shows that highest tension was recorded at maximum PCL lengths at the highest flexion angle achieved (dark blue). It also somewhat suggests that more tension is seen under anterior loads.

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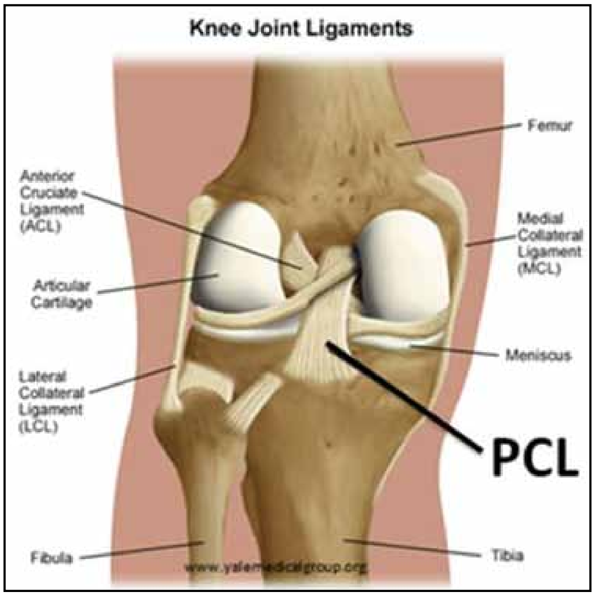
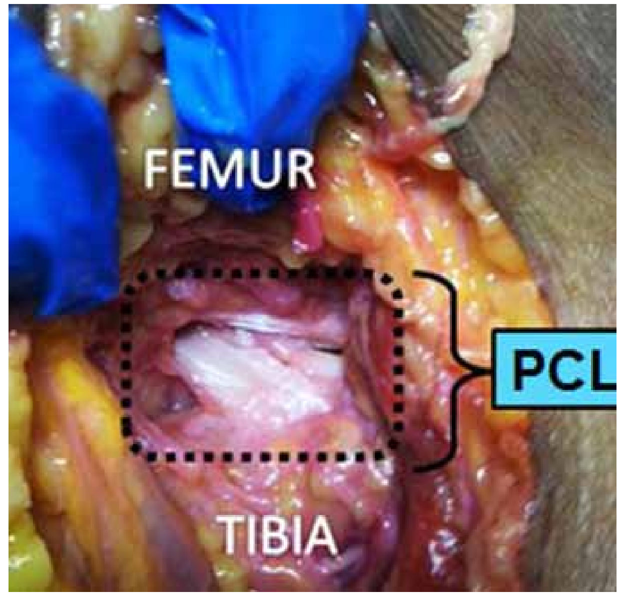
FIGURE 1.



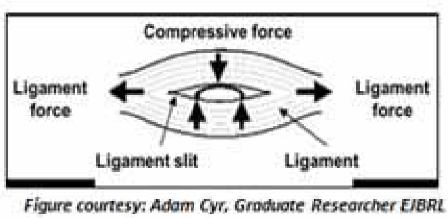
Anatomy of the knee joint

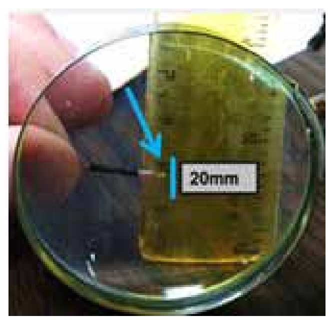
FIGURE 2.



Exposure and Identification of the PCL

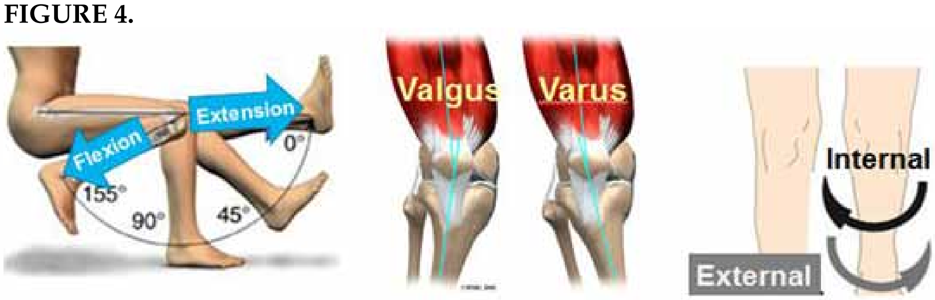
FIGURE 3.





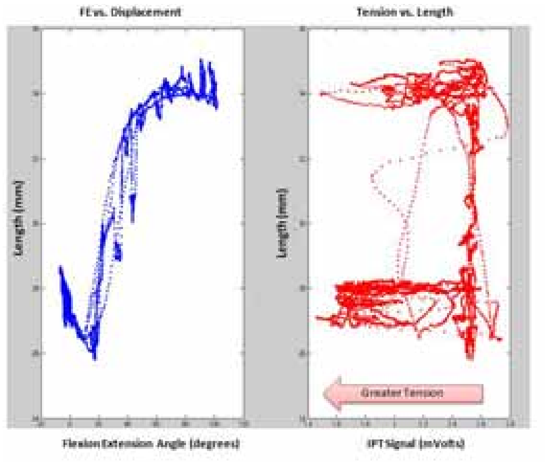
Implantable Pressure Transducer

FIGURE 4.



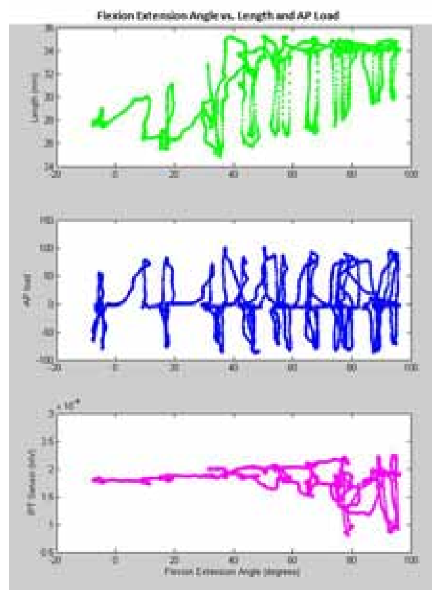
Directional terms

FIGURE 5.



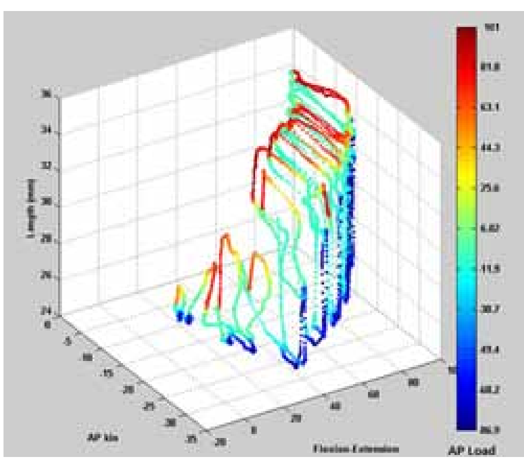
Length of PCL as it travels through flexion-extension in a minimal (VV) load test, modeled with tension.

FIGURE 6.



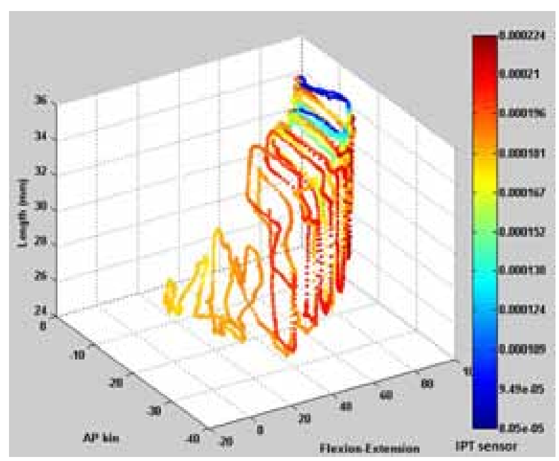
Length of the PCL as it travels through flexion-extension in an AP test, modeled with AP load and tension.

FIGURE 7.



3D plot of length, flexion-extension, and AP kinematic. Load is coded with color.

FIGURE 8.



3D plot of length, flexion-extension, and AP kinematic. IPT is coded with color.