Measurement of Tibial Translation in Dogs with Anterior Cruciate Ligament Rupture

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Client:

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Abstract:

Arthritis is the major cause of ACL rupture in canines and a quantitative, minimally invasive diagnostic device is needed to increase the quality of healthcare for canines as well as reduce costs. The device will measure tibial translation and force exerted on the canine's paw during the tibial thrust test. This data will be plotted and from this graph the state of the ACL will be determined. The design consists of two needles inserted at anatomical markers in line with the ACL. The distance that separates these two markers is measured by the Hall Effect sensor. In the future, a final prototype will be built and used in clinical cases and applications to humans will be explored.

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Problem Statement:

Arthritis in canines often leads to joint degeneration and rupture of the Anterior Cruciate Ligament (ACL). Diagnosis of this condition is often difficult because the current methods used are non-quantitative. The aim of this project is to quantify the amount of tibial translation in a canine's leg caused by a known applied force in order to determine the severity of an ACL rupture. Preliminary parts for a device that can accomplish this aim have been developed and it is the goal of this team to create and test a working model.

Background:

Dr. Peter Muir conducts research on the anterior cruciate ligament, ACL, in canines. He and his colleagues have come up with an apparatus to measure the displacement of a canine's tibia when a force is applied to the paw. This allows for an accurate reading of the severity of the ACL rupture. The ACL has an important biomechanical function; it prevents hyperextension, internal rotation and anterior-posterior translation (DeRooster 777). The ACL is located between the tibia and femur in the canine knee; it can be seen in the posterior view of the canine knee in Figure 1. The ACL is labeled cranial cruciate ligament in Figure 1. ACL rupture is a common medical diagnosis in canines. Dogs with ACL rupture usually have inflammation in the synovial membrane and fluid. This inflammation deteriorates the canine's ACL gradually over time. Current diagnosis of ACL rupture in dogs is only qualitative, and must be performed by an experienced veterinarian. The diagnosis is performed by applying a force on the paw, while holding the femur in place. This creates a displacement across the

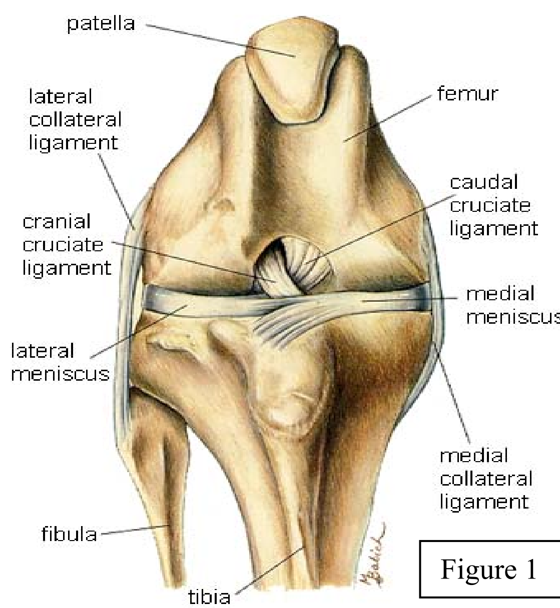


Figure 1

tibia and the experienced veterinarian must use his judgment on the severity of the canine's ACL rupture (Harasen 1). This is shown in Figure 2.

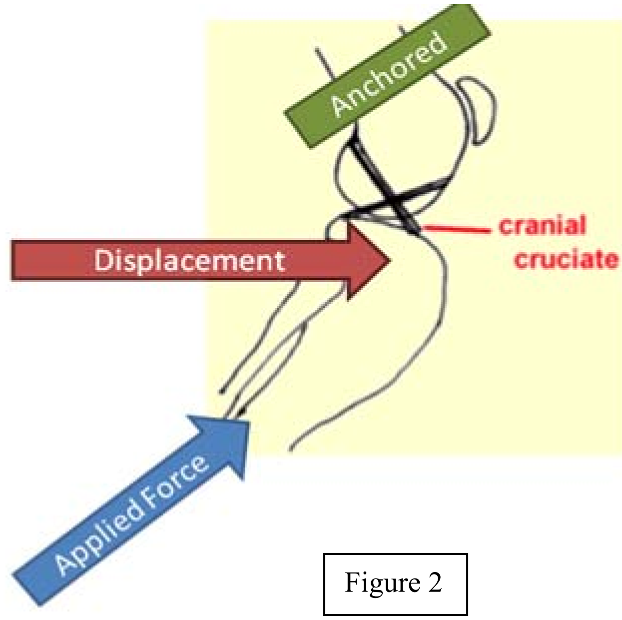


Figure 2

The device design allows it to be applicable to many different-sized canines. For example, the canines can range from a Yorkshire Terrier (1.5kg) to a Mastiff (up to 100kg). The designed apparatus will allow for a quantitative measurement of the severity of the ACL rupture, leading to intervention during earlier stages of the disease. Earlier diagnosis may help preserve ACL properties by preventing further collagen degradation (DeRooster 769). This will decrease the need for ACL surgery and reduce the financial burden of ACL rupture. The anatomical markers for the placement of the needles on the device are shown in Figure 3. They are located in between the fabella and femur, and between the top of the tibia and the femur. An experienced veterinarian would easily find these anatomical markers.

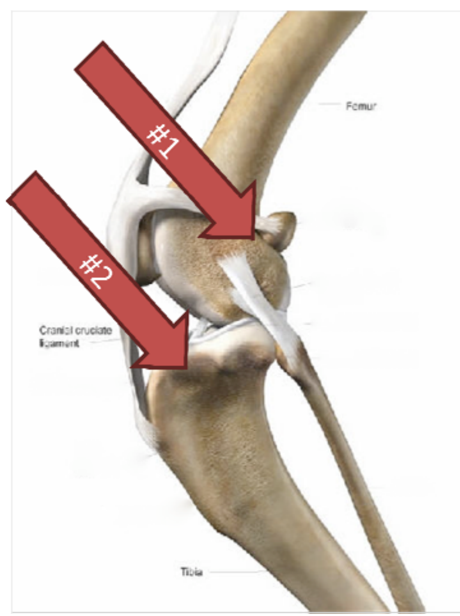


Figure 3

Current Methods of Diagnosis:

Non-invasive methods of determining the presence of ACL deterioration in canines include the drawer test, the tibial thrust test, and stress radiography. To perform the drawer test, the veterinarian stabilizes the canine femur with one hand while manipulating the tibia with the other hand (Figure 4). The veterinarian subjectively assesses the extent of the forward translation to determine if the ACL is ruptured. To perform the tibial thrust test the veterinarian stabilizes the femur with his hand while flexing the canine paw with the other hand. Again, the veterinarian assesses the extent of forward tibial translation to determine if the ACL is ruptured. Often it is necessary to sedate the canine for both tests because tension in the canine leg muscles can prevent tibial translation and thus obscure the result of the test (www.dogkneeinjury.com). Diagnosis of partial ACL deterioration is difficult using these tests due to their subjective assessment of tibial translation (DeRooster 573).

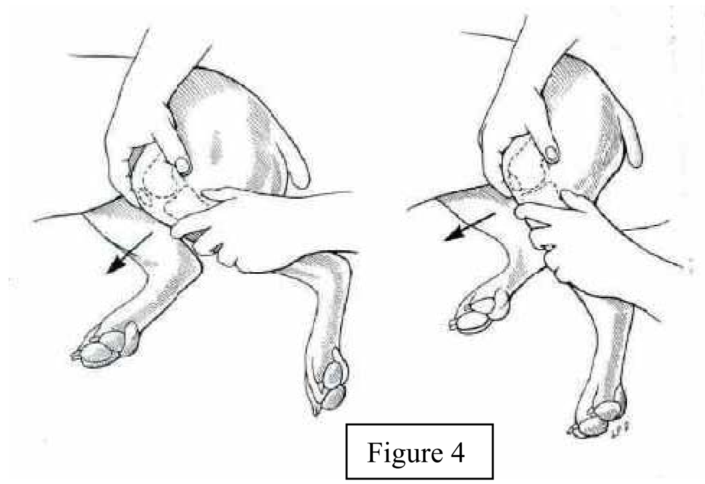


Figure 4

Stress radiography may be used to assess ACL rupture. To perform a stress radiography exam, the canine femur and tibia are positioned at a 90 degree angle and a preliminary radiograph is taken. A second radiograph is taken while the examiner stabilizes the femur with his hand, pressing up on the paw to apply a maximum stress to the knee joint (DeRooster 573). The ACL will not be visible on either radiograph, but a comparison of the tibia position relative to the femur can be used to assess ACL deterioration. This method of diagnosis is less favorable due to the cost of the radiographs.

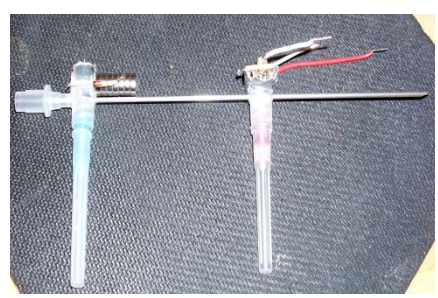
Arthroscopy can also be used to assess ACL deterioration. To do this an incision is made near the knee joint and an arthroscope is inserted through the incision. The arthroscope is connected to a video screen and displays a video feed of the canine knee. Manipulation of the arthroscope allows for direct visual assessment of the extent of ACL deterioration. Drawbacks to this technique include the necessity of healing time for the canine, and the cost of the procedure is $1700 on average (www.vetsportsmedicine.com).

Design Constraints:

1. The device must be able to secure to the anatomical landmarks of a canine's leg and measure the amount of displacement in the tibia effectively.
2. The Hall Effect sensor and magnet system must stay in the same plane during the measurement.
3. The range of displacement measured must be within 1mm to 10mm.
4. The device should not cause any serious harm to a canine's leg.
5. The device must be as inexpensive as possible.
6. Data should be collected that is repeatable and accurate.
7. The device must have an internalized system to increase accuracy and cleanliness.

Current Device:

Figure 5



The current component of the device being used to measure forward displacement of the tibia consists of two hypodermic needles attached to a metal rod (Figure 5). One needle is fixed in place while the other is free to slide along the metal rod. The needles are placed in specific anatomical markers in the canine knee (Figure 3). One needle is placed between the fabella and femur (#1) while the other needle is placed between the tibia and femur (#2). These anatomical markers are easily recognizable by a veterinarian so placement of needles is highly repeatable. A powerful magnet is mounted on the fixed needle while the Hall Effect sensor is mounted on the mobile needle. As the tibia displaces forward, the needles move closer together, moving the Hall Effect sensor closer to the magnet. This causes a measurable change in voltage output of the Hall Effect sensor which can be related to the displacement of the needles.

The component of the device being used to measure the force applied to the canine paw consists of two plastic plates with a Velcro strap (Figure 9). A load cell will be embedded between the two plastic plates. This component is strapped to the canine paw when the veterinarian applies a force while performing the tibial thrust test. The load cell will measure the force being applied to the canine paw.

Hall Effect:

The device we have chosen for measuring the distance of the tibial translation is a Hall Effect sensor. The circuit only consists of a 1kΩ resistor, the Hall Effect sensor and a 6V zener diode. The resistor in the circuit provides current protection and the zener diode provides voltage protection across the sensor. All of the testing was done at an input voltage of 15V. As the magnetic field passes through the Hall Effect sensor, the output voltage is adjusted to the field intensity. The correlation of magnetic field and

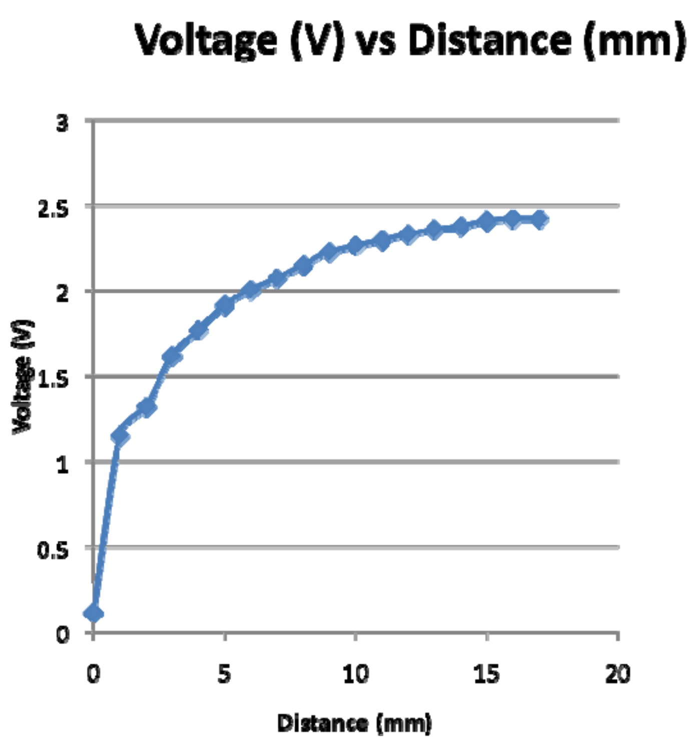


Figure 6

voltage can be seen in Figure 6. This data is expected because magnetic field intensity decreases as a square of the distance. Our data points have a line of good fit between 1mm and 10mm, demonstrating that the Hall Effect sensor is consistent with our design constraints.

Load Cell:

The load cell is a device used to measure the amount of force applied on a force plate. For our purposes, we will use the load cell to collect data on the amount of force applied to a canine's leg. During the ACL rupture examination, the canine's leg will be anchored at the femur and force will be applied at the paw and measured by the amount of torque the force plate creates on the body of the load cell (Figure 7). The load cell gives a certain output voltage for a certain weight of a load upon it. We have collected consistent data ($R^2 \approx 1.00$) up to a load of 10 kg, which will be all that is needed for a canine ACL rupture test (Figure 8). The load cell will be attached to a device with a Velcro strap during the actual clinical trial (Figure 9).

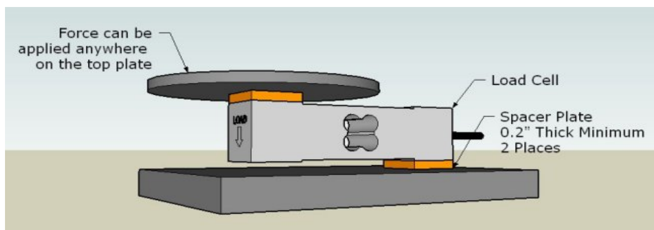


Figure 7

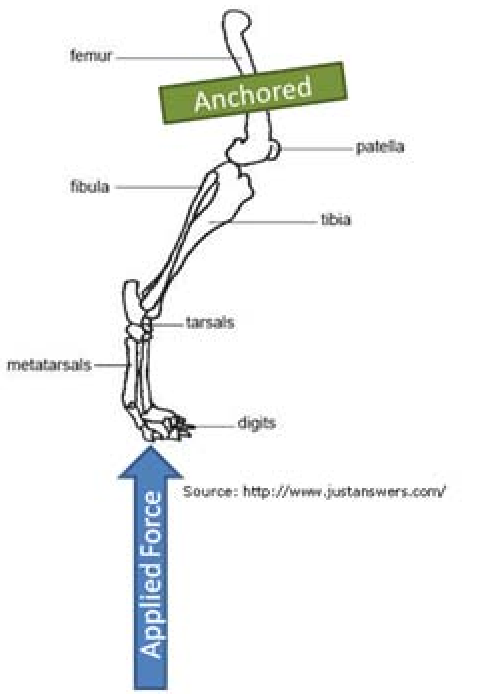


Figure 8

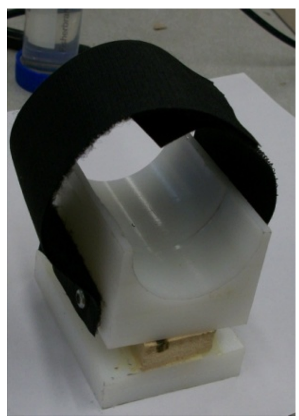
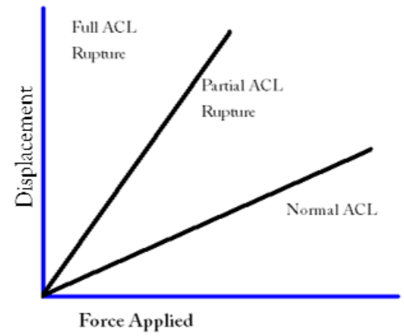


Figure 9

Future Work:

The next step is to test the device on cadavers. The data we collect performing the test on the cadavers must be consistent with the data we have collected with the Hall Effect sensor and load cell testing. A trained veterinarian will help us locate the anatomical markers during testing to mimic the actual process. We will determine what the ranges are for a partial ACL Rupture, full ACL rupture, and a healthy ACL from this testing (figure 10).

Figure 10



After this phase of testing is completed, we will build a final prototype that is internalized and meets all of the design requirements. We will test this final prototype in the same fashion as before, and if all data is consistent then it will be ready to be used in clinical trials.

If the final prototype used in clinical trials is successful, we will modify the device so that it can be applied to humans. It will provide a more quantitative and inexpensive way to diagnose ACL rupture and can be very useful for Sports Medicine and other various fields where proper diagnosis is of the utmost importance.

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Product Design Specifications for BME 301 Group 8: Measurement of tibial translation in dogs with anterior cruciate ligament rupture (tibial_measurement)

Group Members: Alex Bloomquist, Graham Bousley, James Madsen, Mike Nonte

Problem Statement:
Arthritis in canines often leads to joint degeneration and rupture of the Anterior Cruciate Ligament (ACL). Diagnosis of this condition is often difficult because the current methods used are non-quantitative. The aim of this project is to quantify the amount of tibial translation in a canine's leg caused by a known applied force in order to determine the severity of an ACL rupture. Preliminary parts for a device that can accomplish this have been developed and it is the goal of this team to create and test a working model.

1. **Design Requirements**: The device must meet all of the client requirements

a. Performance Requirements: The device must be able to secure to the anatomical landmarks of a canine's leg and measure the amount of displacement in the tibia effectively. The Hall Effect sensor and magnet system must stay in the same plane during the measurement.
b. Safety: The device should not cause any serious harm to a canine's leg.
c. Accuracy and Reliability: Data obtained from testing should be repeatable so that the device may be accurate when used in clinical testing. Hall Effect sensor should be accurate at 15V of input voltage.
d. Life in Service: The device should last for 10 years.
e. Shelf life: The device should have a shelf life of 5 years.
f. Operating environment: The device should withstand room temperature and be easily cleanable so that it can be as sterile as possible.
g. Ergonomics: A trained veterinarian should operate the device.
h. Size: The device should not be big so that it will not cause injury to the canine.
i. Weight: The device must not weigh more than 15 grams.
j. Materials: The device must be made of sterile and lightweight materials so that the canine will not be injured when the ACL rupture test is performed with the device.
k. Aesthetics, Appearance, Finish: The device must have an internalized system to increase accuracy.
2. Production Characteristics:
a. Quantity: One working unit is necessary to quantify tibial translation.
b. Target Product Cost: As cheap as possible for mass-production.
3. Miscellaneous:
a. Standards and Specifications: Approval from a medical organization.
b. Customer: Veterinarians should be able to use this easily.
c. Patient-Related Concerns: The device should be sterile and the system must be properly internalized so the canine is not caused any harm.
d. Competition: The model is similar to an arthrometer for humans. X-ray is a good qualitative method but it is expensive and non-quantitative.