A Biomechanical Cadaver Study to Determine the Effectiveness of the Lateral Graft Technique and Isometric Suture Placement for Extracapsular Stabilization of the Cranial Cruciate Ligament Deficient Stifle in the Dog

by

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Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Veterinary Medical Science

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March 18th, 2003

Blacksburg, Virginia

Keywords: canine, stifle, cruciate, graft, biomechanical

A BIOMECHANICAL CADAVER STUDY TO DETERMINE THE
EFFECTIVENESS OF THE LATERAL GRAFT TECHNIQUE AND ISOMETRIC
SUTURE PLACEMENT FOR EXTRACAPSULAR STABILIZATION OF THE
CRANIAL CRUCIATE LIGAMENT DEFICIENT STIFLE IN THE DOG

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(ABSTRACT)

Objective – 1) To determine whether a graft of fascia lata and part of the patellar ligament, used in an extracapsular fashion from the tibial crest to the femorofabellar ligament, would eliminate abnormal cranial drawer motion in the cranial cruciate ligament (CrCL) deficient stifle 2) To determine if two new tibial suture anchor points would enhance biomechanical function of the lateral fabellar-tibial suture (FTS).

Study Design – Experimental.

Animals – 28 canine cadaver hind limbs.

Methods – Stifles were mounted in a jig that allowed tibial rotation during loading and were tested between loads of – 65 to 80 N in caudal and cranial drawer respectively. Stifles were tested with the CrCL intact followed by one of four stabilization techniques after CrCL transection: lateral graft technique (LGT) and three FTS with different tibial anchor points.

Results – Differences in cranial drawer motion (displacement) and stiffness between the LGT and standard FTS were not significant in two data sets, when compared to the intact

CrCL. The FTS with the anchor point in the tibial crest showed the least displacement of all stabilization methods. Differences in stiffness were not significant between the stabilization techniques.

Conclusions – Stability provided by the LGT is comparable to that of the standard FTS for the CrCL-deficient stifle in the cadaver. Altering the tibial anchor points for the FTS did not improve stiffness or result in a further decrease in cranial drawer motion.

Clinical Relevance – The LGT could be used for the treatment of acute and chronic CrCL ruptures in the dog. A clinical study is recommended.

Dedication

To my parents Mary and Winston, who always encouraged me to reach for the stars and to my family and friends for their love and support.

Special thanks to Dr. Simon Roe for his assistance during the design and development of the experimental design and guidance during writing of the thesis.

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Purpose

    CrCL rupture is a common cause of hind limb lameness in the dog. Surgical stabilization of the CrCL-deficient stifle is usually performed in dogs weighing greater than 15-20 kg. Many general practice veterinarians will perform surgical stabilization of the CrCL-deficient stifle using a variety of techniques. This study was designed to investigate biomechanically the effectiveness of an alternative technique for stabilization of the CrCL-deficient stifle in dogs. An extracapsular technique using autogenous tissue that does not require specialized instrumentation, is relatively easy to perform and that can be used for both acute and chronic CrCL ruptures on all sizes of dogs would be the ideal technique.

    The FTS is a popular technique used for stabilization of the CrCL-deficient stifle. This study also investigated biomechanically possible methods for enhancing the effectiveness of this surgical technique.

Introduction

Anatomy and histology

The CrCL is one of the four femorotibial ligaments necessary for stability and function of the stifle joint.[1]   The CrCL originates from the caudomedial part of the lateral femoral condyle. It runs cranially, medially, and distally as it crosses the intercondyloid fossa, and inserts on the cranial intercondyloid area of the tibia.[2,3] The CrCL crosses the caudal cruciate ligament which lies medial to it.[2] Some of the fibers of the cranial dorsal portion of the ligament attach to the posterior lateral aspect of the intercondylar area. Some of the fibers also attach to the cranial lateral aspect of the medial intercondylar tubercle.[3] The CrCL is divided into two bands, a craniomedial band and a larger caudolateral band.[4] The orientation of the fibers on the femoral and tibial attachments results in the ligament having a proximo distal outward lateral spiral of approximately 90 degrees and as the stifle is flexed, the CrCL winds and twists on itself.[3] The CrCL is covered with synovium and is considered to be extrasynovial and intra-articular.[3]   Histologically, the central region of a normal canine CrCL is formed of highly ordered, parallel arrays of collagen fibers. The most frequent degenerative changes occur in the central core region of the CrCL.[5] The blood supply to the cruciate ligaments arises from branches of the genicular arteries on the lateral and medial aspect of the stifle joint. These branches form a system of vessels that penetrate the ligament transversely and freely form anastomoses with longitudinal endoligamentous vessels. The central core regions of the cruciate ligaments are not as well vascularized as the proximal and distal portions.[3]

Functions of the stifle joint

Stifle joint motion is very complex. Movement about the stifle can be described using three orthogonal axes, x, y and z. The x axis is parallel to the joint in a medial to lateral direction through the femoral condyles. Flexion and extension of the joint occurs

about this axis. The y axis is parallel to the shaft of the tibia and axial rotation of the tibia on the femur occurs about this axis. The z axis passes through the center of the joint space in a cranial to caudal direction. Rotation about this axis results in varus or valgus angulation of the stifle. The various movements about these axes are limited by the stabilizers of the stifle joint i.e. the cruciate ligaments, collateral ligaments and the menisci. Combined motion of the stifle joint however occurs in two planes, flexion and extension about the x axis and rotation of the tibia on the femur about the y axis. The amount of internal rotation of the tibia on the femur is limited by the twisting of the cruciate ligaments on one another as the stifle is flexed. During stifle flexion and extension, the menisci slide caudally and cranially respectively, resulting in a rolling and sliding motion of the femoral condyles on the tibial plateau during movement. The x axis (axis of flexion) is not static and changes its position during flexion and extension of the stifle because of the complex motion of the stifle joint. There is a point on the femur however that does not change position during stifle motion. This has been referred to as the instant center of motion. If this point lies on the articular surfaces, there is rolling of the joint and the least damage to the articular surfaces. The location of this point will change in the CrCL-deficient stifle resulting in abnormal movement between the articular surfaces and thus damage to the articular cartilage.[3,6] The functions of the CrCL are to limit internal rotation of the tibia relative to the femur in both flexion and extension, prevent cranial displacement of the tibia on the femur (cranial drawer motion) and to act as the primary check against hyperextension of the stifle joint.[3,7,8]

CrCL rupture and surgical techniques

　　CrCL rupture is one of the most common orthopedic conditions seen in dogs and people. In the dog it is one of the most common causes of hind limb lameness,[4,8,9] leading to stifle instability, pain and chronic lameness.[10,11] Degenerative joint disease (DJD) is the usual result which is characterized by osteophytosis and articular

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erosions.[8,11]   Meniscal damage is a common secondary finding.[11-13] Rupture of the CrCL may be complete or partial. The cause of CrCL rupture is not known however many theories have been postulated including decreased blood supply to the mid-portion of the ligament,[5] abnormal conformation e.g. tibial plateau slope, congenital narrowing or malformation of the intercondyloid fossa,[9] immune-mediated disease and obesity.

Numerous surgical techniques have been described to stabilize the CrCL-deficient stifle.[4,10,14,15] They can be divided into intracapsular and extracapsular techniques. Factors that are reported to contribute to the success of a CrCL repair include body size and patient activity, technical difficulty of the procedure, postoperative complications, biocompatibility of implants, concurrent DJD and meniscal damage.[16] No surgical technique has been shown to consistently arrest the development or the progression of DJD. Objectives of surgery are to provide normal joint mechanics and stability, relief of pain, prevent the development of further DJD, and hasten the return of normal limb function.[17-20]

Conventional surgical methods used for restoring stability in a joint with cranial cruciate ligament rupture include - (1) Primary repair of the damaged ligament - only feasible in avulsion injuries in which the avulsed bone segment can be stabilized adequately (2) Reconstruction or substitution of the ligament using various materials (intra-capsular) (3) Stabilization of the joint by transposition of periarticular structures or placement of suture materials outside of the joint (extra-capsular). In one study limb function improved in over 85% of cases following stabilization of the stifle, however less than 50% of the cases regained complete function regardless of the technique used.[21]

The most frequently used materials for intracapsular repairs are autografts consisting of the patellar ligament, fascia lata, or a combination of the two. Advantages of using autogenous tissues are the convenience of collecting the graft directly from the patient and lack of an immune response.[4] Disadvantages of using autogenous grafts include lack of blood supply and early necrosis of the ligament and mechanical failure at the bone-

ligament interphase.[22] Studies have shown however that good vascular responses can be seen in intracapsular ligament substitutes as early as four weeks following surgery.[22] The Under-and-Over Fascial Replacement Technique[23] uses a combined fascia lata and patellar ligament graft for stabilization of the CrCL-deficient stifle. Complications specific to intracapsular techniques include iatrogenic damage to the articular cartilage, injury to the caudal cruciate ligament, and possible fraying of a graft at its bony edge interface in repairs using a bony tunnel.[11] Narrowed intercondylar notch widths seen in dogs with CrCL injuries may also predispose intracapsular repairs to damage by impingement of the graft by the intercondylar notch.[9] Intracapsular grafts are also contraindicated in joints in which there is marked DJD as damage to the graft occurs during movement of the stifle by impingement of osteophytes and irregular articular surfaces on the graft.[24]

Extracapsular repairs involve placement of the stabilization material outside of the joint (extracapsularly). When CrCL injury is chronic with moderate to severe DJD present, intracapsular techniques may be contraindicated because of an inhospitable local environment, leaving an extracapsular technique as a better choice of procedure.[11] Extracapsular techniques aim to eliminate abnormal cranial drawer motion associated with CrCL rupture as well as minimize abnormal internal tibial rotation. They also avoid placement of material (foreign or autogenous) within the joint. Extracapsular techniques that have been described use either autogenous tissues or prostheses. Extracapsular methods for stabilization of the CrCL-deficient stifle include:

1. Fibular head transposition – the fibular head is surgically moved into a cranial position resulting in cranial transposition of the lateral collateral ligament. The new cranial location of the lateral collateral ligament restricts cranial drawer motion and limits internal rotation of the tibia on the femur.[10] Complications associated with the procedure include fracture of the fibular

head or neck, transection or avulsion of the lateral collateral ligament, injury

to the peroneal nerve and damage to the long digital extensor tendon.[10]

2.   Modified lateral retinacular imbrication technique – three extracapsular

mattress sutures are placed; one is passed from the lateral fabella to the tibial

crest, one from the medial fabella to the tibial crest and another lateral fabellar

suture is attached to the patellar region as an imbrication suture.[14]

3.   Lateral suture technique – three extracapsular mattress-like sutures are placed;

one around the lateral fabella and through the patellar ligament, one around

the lateral collateral ligament below the level of the fabella and back through

the patellar ligament and a third suture around the lateral collateral ligament

above the attachment to the head of the fibula and then through the patellar

ligament.[25]

4.   Three-in-one technique – this has been described as a modification of the

modified retinacular imbrication technique in which the caudal sartorius

muscle is advanced medially and the biceps femoris is advanced laterally to

add additional support to the repair.

The fibular head transposition and the modified retinacular imbrication technique are two

of the more common surgical techniques used and investigated experimentally.[10,18,26-28]

Other techniques that have been described using autogenous tissues include the

popliteal tendon transposition technique.[20] It was not however a very effective repair

method. The FTS is a commonly used extracapsular repair technique, particularly in

general practice. Materials that have been used include orthopedic wire, polyester,

polybutester, polypropylene, nylon and monofilament nylon leader material. [29-34]

Other extracapsular techniques have been described which are directed at eliminating

cranial tibial thrust associated with CrCL rupture by altering the angle of the tibial

plateau. The tibial wedge osteotomy[35] and the tibial plateau leveling osteotomy[36] are two

such surgical procedures. They are not designed to eliminate cranial drawer motion.

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Kinematic studies have been performed in human orthopedics to determine the optimal femoral and tibial anchor points for extracapsular stabilization techniques. The best femoral attachment site was found to be just proximal to the lateral collateral ligament and the best tibial attachment site is on the anteriolateral aspect, just at or in front of the tubercle of Gerdy.[37] Selecting an isometric origin and insertion point both proximal and distal to the canine stifle joint should optimize the function of an extracapsular suture.[28] Radiographic analysis of these points using cadaver stifles has been reported. Change in length of sutures originating from the fabella and inserting at various sites on the tibia was determined. The most isometric points were those most closely aligned with the line of the CrCL.[28] This has not however been tested biomechanically. By placing the insertion hole of an extracapsular suture through the prominences on either the cranial or caudal aspect of the extensor groove (EG), stabilization of the CrCL-deficient stifle should result without limiting range of motion of the stifle joint. A 1994 survey showed that the majority of veterinary surgeons preferred extracapsular techniques for the repair of CrCL ruptures in the dog.[38] A technique for medium to large breed dogs that requires minimal implants or uses absorbable implants, is easy to perform, has a low complication rate, and stabilizes the stifle joint while maintaining a complete range of motion, and repeatedly results in a successful outcome would be the ideal technique, particularly in general practice.

Different autogenous tissues have been described for CrCL replacement in the dog including whole thickness skin grafts[39] and transplantation of the long digital extensor tendon.[40] Patellar ligament has been used either alone or combined with other autogenous tissues for stabilization of the CrCL-deficient stifle.[41] Autogenous grafts in which the fascia lata and the lateral one-third of the patellar ligament have been used for stabilization of the CrCL-deficient stifle have been described.[22,42] The LGT, modified from the original MacIntosh procedure[24] used in human orthopedics for anterior cruciate

ligament repair involves the use of a combined patellar ligament and fascia lata graft. It meets the criteria for an ideal material and could possibly be used for both acute and chronic CrCL ruptures. An extracapsular fascial strip technique in which the fascial strip is sutured to itself, the patellar ligament, the femorofabellar ligament, the lateral collateral ligament and combined with a medial buttress suture has been successfully used in clinical patients.[43] The biomechanical effectiveness of the graft alone has not been tested.

A goal of this study was, in part, to determine whether a pedicle graft of fascia lata and the lateral one-quarter to one-third of the patellar ligament, with its base on the proximal tibia, would eliminate abnormal cranial drawer motion in the CrCL-deficient stifle. Another goal was to compare the LGT to the standard FTS and to determine if placement of the tibial anchor point in either the cranial or caudal prominence of the EG would enhance the biomechanical function of this extracapsular suture.

Materials and methods

Twenty-eight hind limbs were harvested from skeletally mature dogs of either sex and weighing between 22 and 36 kg. The hind limbs were obtained immediately following euthanasia for reasons unrelated to this study, and skeletal maturity was determined fluoroscopically before inclusion into the study.

Harvesting specimens: Each hind limb was disarticulated at the coxofemoral joint. The specimen included the femur, tibia, and surrounding musculature. The skin was removed and the limbs were rinsed with 0.9% NaCl (saline) and then individually wrapped in saline soaked paper towels before being placed in plastic bags and frozen at -8° C until testing.

Graft Dissection: Thawing was done prior to testing by leaving the plastic bag containing the frozen specimen immersed in a container of tap water overnight in a refrigeration room. On the day of testing, the graft was harvested prior to dissection and removal of the musculature from the limb. The subcutaneous fat and superficial fascia were dissected away from the deeper fascia lata. A number 15 scalpel blade was used to make a 1-cm longitudinal stab incision in the lateral one-quarter to one-third of the mid-portion of the patellar ligament without incising the joint capsule (Figure 1). Another 1-cm incision was made in the most proximal aspect of the tensor fascia lata at a point 6 - 10 cm proximal to the patella at the cranial margin of the cranial sartorius muscle. This incision was extended distally along the lateral margin of the patella to connect with the first incision in the patellar ligament, forming the craniomedial margin of the graft.   The width of the graft distally was determined by the distance between the incision in the patellar ligament and the caudolateral aspect of the attachment of the fascia lata at the prominence on the cranial border of the EG of the tibia. Beginning at the most proximal portion of the graft and maintaining its predetermined width, the fascia lata was cut

parallel to the craniomedial margin of the graft, forming its caudolateral margin. The distal attachment of the fascia lata on the tibial plateau was preserved (Figures 2&3).

Once the graft was harvested, the musculature on the femur and tibia was removed except for a 1 cm length of the lateral head of the gastrocnemius muscle distal to the lateral fabella. The fascial graft, medial and lateral collateral ligaments of the stifle, and the cruciate ligaments and menisci were left intact (Figure 4). The stifle was wrapped in clear plastic wrapping and moistened with saline. The plastic wrapping kept the soft tissues moist during potting and testing.

Potting: After harvesting of the graft and removal of the musculature, the tibia and femur were individually potted using a polyester resin (Bondo®, Bondo Corporation, 3700 Atlanta Industrial Parkway NW, Atlanta GA 30331) prior to testing. Both were cut to 11.43 - 12 cm in length, measured from the stifle joint. The bones were each potted in a 6.35 cm deep aluminum cylinder that allowed centering of the bones in the resin. The potted construct was fixed in the testing apparatus for biomechanical testing.

Testing: The testing procedure followed the design described in two previous studies[16,44] with two major modifications: - 1. The potting cylinders holding the femur and tibia were individually mounted in a jig so that a normal stifle angle of 135° was maintained throughout testing (Figures 5&6). 2. The tibial potting cylinder was mounted on ball bearings that allowed unrestricted rotation of the tibia about its long axis during testing (Figure 7). The plate holding the tibial potting cylinder was also mounted on doubled plates with ball bearings in between the two plates. This also allowed free movement of the tibia in the plane parallel to its long axis i.e. parallel to the floor, when the construct was loaded in the jig.

The potted construct was placed in the jig with the femur in the top cylinder and the tibia in the bottom cylinder. A laser beam was mounted at the top of the jig and was used for alignment (Figure 8). The beam ensured that all specimens were similarly centered at the intercondylar space on the caudal aspect of the femur. Three screws on each cylinder

were used to lock the specimens in place after centering. Once the cylinders were secured it was noted that there were load and displacement readings for the specimen on the X-Y recorder. During loading of the specimen the crosshead was manipulated to facilitate ease of loading and this may have placed some strain on the soft tissues. The crosshead was therefore manipulated while the tibia was allowed to rotate within the tibial cylinder and the tibial plate was allowed free movement until a zero displacement was recorded. This was taken as the "zero point" for the specimen.   A permanent marker was used to make corresponding marks on the aluminum cylinders and the resin holding the specimens to ensure that the original positions of the potted specimens were maintained throughout testing. The laser beam and the marks therefore ensured that each construct was replaced in the same position after removal from the jig. The jig was fixed to an electrically driven Universal Testing Machine (Instron – model 4204, Universal Testing Machine) that applied a load to the stifle being tested. Loads of –65N (caudal drawer) to 80N (cranial drawer) were applied in cycles at a crosshead speed of 25 mm/min.   Testing was done below the crosshead.

Stifles were first tested with the CrCL intact and then with one of four stabilization techniques following CrCL transection (LGT and three FTS with different tibial anchor points). Stifles were also tested with the CrCL transected and this was included as a treatment. All six treatments were performed on each stifle – intact, transected CrCL, LGT and the three suture techniques. For each treatment, each stifle was loaded through 12 cycles between 80N and –65N. A pilot study performed prior to this study revealed that reproducible load-deformation curves were attained through 12 cycles of loading. Displacement of the femur in relation to the tibia and stiffness for the 12 cycles in each test were determined. Each stifle construct was considered a block and the order of treatments was randomized separately for each construct. The twelve sets of measurements for each treatment from each stifle were considered subsamples. Load-displacement curves were generated for each cycle. Displacement was measured as the

distance in millimeters between –25 and +25 N. Stiffness was calculated as the slope of the line between 60 and 80 N (Figures 9a & 9b).

Data were collected simultaneously during testing using a computerized data acquisition system (Labview 5.0 Graphical Programming for Instrumentation, National Instruments Version 5.0.1). Figure 10 is an example of the data sheet generated. The data collection system did not consistently record displacement at –25 and +25N. Equations were therefore generated for the line through these points using the generated values closest to the points. Three values were used for each equation with at least one point less than and one point greater than the required value (Figure 10). Once the equation was generated in the form y = mx + b, where m was the slope of the line, the y value (25 N or –25N) was substituted into the equation to determine the exact value of x (displacement in millimeters). The same method was used to determine stiffness (slope of the line between 60 and 80 N). Since the load-displacement curve was approximately linear in this region and exact values for x were not consistently recorded at 60 and 80 N, the equation for the line between 60 and 80 N was generated in the form y = mx + b with the value for b as slope of the line, which was equal to the stiffness at that point.

Stifle stabilization techniques:
Lateral graft technique (LGT)

A curved mosquito hemostat was passed in a craniocaudal direction through a small stab incision made parallel to the fibers in the middle of the lateral femorofabellar ligament. The stifle was held at 135° of flexion and the free end of the previously harvested graft was grasped in the tip of the hemostat and pulled caudal to the fabella and gastrocnemius muscle stump and through the femorofabellar ligament cranially (Figure 11). Tension was applied until cranial drawer motion was eliminated and the graft was then secured to the craniolateral aspect of the distal femur just proximal to the trochlear groove. Staples inserted with an electric stapler were used for fixation of 10 stifles and

4.5 mm screws (Synthes®) and spiked washers (Imex™) (Figure 12) were used in a further 18 stifles.

FTS with the tibial anchor point in the tibial crest (FTS:tibial crest)

A curved Securos™ J-needle loaded with a doubled strand of either Mason[♣] 50-lb. test nylon leader or 80-lb. test monofilament nylon leader[φ] was passed through the femorofabellar ligament in a proximal to distal direction, around the lateral fabella. (The same technique was used to place the nylon through the femorofabellar ligament and around the lateral fabella in all FTS specimens).

A 3/32" Steinmann pin was used to drill a hole through the tibial crest, from medial to lateral, 1 cm caudal to the insertion of the patellar ligament. The caudal end of nylon was passed through this hole in a medial to lateral direction and secured to the cranial end, forming a figure-of-eight configuration. The suture was secured using either hand ties or the Securos 80-lb. Cranial Cruciate Ligament Repair System[TM]. (The entire patellar ligament was not preserved in this study. A 1-cm portion of the ligament was preserved distally at the level of its insertion on the tibial crest (Figure 12). In a clinical setting the caudal strand of nylon would be passed under the patellar ligament before passing it through the hole in the tibial crest).

FTS with the tibial anchor point in the cranial prominence of the extensor groove (FTS:cranial EG)

A 3/32" Steinmann pin was used to drill a hole in a proximal to distal direction in the cranial prominence of the EG on the tibial plateau. The hole was made just cranial to the tibial attachment of the intermeniscal ligament at the level of the cranial edge of the fat pad. The caudal strand of nylon was passed through this hole in a proximal to distal

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[♣] Mason Original Hard Type Monofilament Nylon Leader Material, Mason, Tackle Co., Otisville, Michigan 48463
[φ] Securos, Inc., Veterinary Orthopedics, 278 Southbridge Rd., Charlton, MA 01507

direction and secured to the cranial strand, forming a figure-of-eight configuration. The suture was secured using either hand ties or the Securos 80-lb. Cranial Cruciate Ligament Repair System^{TM}.

FTS with the tibial anchor point in the caudal prominence of the extensor groove (FTS:caudal EG)

A 3/32" Steinmann pin was used to drill a hole in a proximal to distal direction in the caudal prominence of the EG. The hole was centered on this prominence with the long axis of the pin parallel to the sagittal plane of the lateral femoral condyle. The caudal strand of nylon was passed through this hole in a proximal to distal direction and secured to the cranial strand forming a figure-of-eight configuration. The suture was secured using either hand ties or the Securos 80-lb. Cranial Cruciate Ligament Repair System^{TM}. Figure 13 shows the location of the extensor groove and the points at which holes were drilled for suture placement.

Three data sets were generated during the study:

Securos® fixation data   n = 10

A screw and spiked washer were used to secure the graft in all 10 stifles in this data set.

80 lb. nylon leader and the Securos 80-lb. Cranial Cruciate Ligament Repair System™ were used for all suture stabilization techniques for these 10 stifles. The Securos™ tensioning device was advanced one click at a time until cranial drawer motion was eliminated. It was then advanced to one click past that point.

Staple fixation data   n = 10

Staples inserted with an electric stapler were used to secure the graft in all 10 stifles in this data set. 50 lb. nylon leader and hand ties were used for all suture stabilization techniques for these 10 stifles. A slipknot was used and the suture was tightened at the level of the proximal aspect of the lateral fabella until cranial drawer motion was eliminated.

Screw and washer fixation data   n = 8

A screw and spiked washer were used to secure the graft in the 8 stifles in this data set.

50 lb. nylon leader and hand ties were used for all suture stabilization techniques for these 8 stifles. A slipknot was used and the suture was tightened until cranial drawer motion was eliminated.

All assessments of cranial drawer motion were made by the primary investigator.

Statistical analysis

The means for displacement and stiffness for the twelve cycles in each test were calculated for each stifle. The MIXED procedure of the SAS System (ver. 8.2, SAS Institute Inc., Cary, NC 27513) was used to perform a two-way analysis of variance to test the hypothesis that all of the treatment means were equal. The Tukey-Kramer multiple comparison procedure was used for pairwise comparisons between treatment means in each data set. Differences between treatment means were considered significant at $P<0.05$.

<center>**Results**</center>

Securos™ fixation data

    The mean values for displacement and stiffness are shown in Table 1. Displacement was greatest for the transected (cut) CrCL (12.03 mm) and least for the intact CrCL (1.75 mm). The LGT resulted in the least displacement of all stabilization techniques, (2.69 mm) and was not significantly different from the intact CrCL (P=0.44) or the FTS:tibial crest (P= 0.91). When compared to each other there was no significant difference in displacement between the LGT, FTS: tibial crest or the FTS:cranial EG.

    Stiffness was greatest for the intact CrCL (93.1 N/mm) and was significantly different from the cut CrCL and all stabilization techniques (P<0.0001). There was no significant difference in stiffness when the suture techniques were compared to each other. There was no significant difference in stiffness between the LGT and the FTS: tibial crest (P=0.25).

Staple fixation data

    The mean values for displacement and stiffness are shown in Table 2. Displacement was greatest for the cut CrCL (12.85 mm) and least for the intact CrCL (2.03 mm). The FTS: tibial crest resulted in the least displacement of all stabilization techniques (4.38 mm), which was not significantly different from the intact CrCL (P=0.16) or the FTS:cranial EG (P= 0.99). The LGT resulted in the greatest displacement of the stabilization techniques (7.81 mm) and this was significantly different from all other stabilization techniques except the FTS:caudal EG (P=0.61). When compared to each other there was no significant difference in displacement between the FTS: tibial crest, the FTS:cranial EG or the FTS:caudal EG.

<center>16</center>

Stiffness was greatest for the intact CrCL (88.51 N/mm) and this was significantly different from the cut CrCL and all stabilization techniques ($P<0.0001$). There was no significant difference in stiffness between stabilization techniques when compared to each other.

Screw and washer fixation data

The mean values for displacement and stiffness are shown in Table 3. Displacement was greatest for the cut CrCL (11.68 mm) and least for the intact CrCL (1.93 mm). The FTS: tibial crest resulted in the least displacement of all stabilization techniques (2.92 mm), which was not significantly different from the intact CrCL ($P=0.49$) or the LGT ($P=1$). When compared to each other there was no significant difference in displacement between the LGT, FTS: tibial crest or the FTS:cranial EG. There was no significant difference in displacement between the FTS:cranial EG and the FTS:caudal EG ($P=0.49$).

Stiffness was greatest for the intact CrCL (90 N/mm) and was significantly different from the cut CrCL and all stabilization techniques ($P<0.0001$). There was no significant difference in stiffness when the suture techniques were compared to each other. There was no significant difference in stiffness between the LGT and the FTS: tibial crest ($P=0.5$).

Comparative mean displacement and stiffness for all data sets are shown in Figure 14 and Figure 15 respectively.

Displacement was significantly decreased in all stabilization techniques in each data set. Displacement for the LGT was greater in the stapler data set than in the Securos™ or screw and washer data sets. During testing there was either slippage of the graft under the staples or tearing of the graft at the points through which staples had been placed. The increase in displacement was attributed to failure of the staples to adequately secure the graft. In both the Securos™ and the screw and washer data sets, the LGT, FTS: tibial

crest and FTS:cranial EG resulted in significantly less displacement than the FTS:caudal EG. In these two data sets there was no significant difference in displacement between the LGT and the FTS:tibial crest and the intact CrCL.

Stiffness was greatest for the intact CrCL in all data sets. Stiffness was significantly decreased for all stabilization techniques in each data set when compared to the intact CrCL. Stiffness was similar for all suture techniques in each data set. There was no significant difference in stiffness between the LGT and the FTS:tibial crest in any of the data sets.

In every test, the FTS:caudal EG resulted in extreme flexion of the stifle joints, restricting stifle extension.

Tibial rotation was evident during testing and varied between 0 and 17º for the various tests.

Discussion

The cruciate ligaments twist around each other to limit internal rotation of the tibia in the normal canine stifle as well as to constrain hyperextension and tibial translation. Previous biomechanical studies comparing surgical techniques or suture materials for stabilization of the CrCL-deficient stifle have restricted tibial rotation about its long axis, and other investigators have reported difficulty in determining the center of axial rotation of the tibia.[16,44] The jig used in this study was fabricated to allow for testing of the stifle joint at an angle of 135° with the least possible constraints to tibial movement, primarily rotation. The tibial potting cylinder and tibial plates were mounted on bearings. This allowed unrestricted movement of the tibia about its long axis (rotation) as well as in the plane parallel to it long axis. Once the constructs were mounted in the jig, the tibia was allowed to rotate and move about the plane parallel to its long axis. Lack of movement (displacement) of the tibia with no load imposed on the stifle was taken as the "zero" point of the joint. This initial position of the tibia was maintained throughout testing. Gross evidence of tibial rotation during testing, with return to the original "zero" position in the absence of load on the joint, suggests that the jig modifications allowed normal canine stifle rotation during flexion and extension. Tibial rotation was evident during loading of the stifle in cranial and caudal drawer. The amount of rotation however varied between and within the different stabilization techniques and was not consistently measured for all repair methods therefore the data was not analyzed, however, the ability to maintain and not restrict tibial rotation during testing was considered to be an advantage in this study.

It has often been reported that extra-articular techniques eliminate, rather than limit, internal tibial rotation during stifle flexion resulting in alteration of the normal kinematics of the stifle by increasing compression of the joint surfaces, which in turn may promote

cartilage and meniscal injury.[4] Preservation of internal rotation of the stifle joint during flexion is an important consideration for techniques for stifle stabilization. Estimations of rotation and direction of rotation during this study showed that the LGT resulted in varying degrees of external rotation of the tibia. It however allowed for some internal rotation in some stifles. Although the graft may limit internal rotation initially, it would be expected to stretch and remodel and allow for some internal rotation. Assessment of cranial drawer motion has done seen in long term studies on dogs that have had surgical stabilization of the CrCL-deficient stifle with a variety of repair techniques. Most studies have shown that there is return of cranial drawer motion in the stifles of these dogs.[21,26,45] The significance of the amount of drawer present has not yet been determined and it does not seem to correlate with clinical improvement.[26] We therefore do not anticipate that minimal amounts of drawer motion that may return in dogs in which this procedure is used to have a significant clinical effect. Studies so far have shown that regardless of the surgical technique, approximately 85 to 91% of dogs will show clinical improvement after surgical stabilization of the CrCL-deficient stifle.[21]

Loads of -65N in caudal drawer and 80N in cranial drawer were used in a previous study as they permitted evaluation of the biomechanical characteristics of the stifle joint without creating permanent (plastic) deformation.[16] These same loads were used in this study and allowed evaluation of displacement and stiffness without permanent deformation of the cruciate ligaments. Testing for load at failure was not performed as we were investigating stifle biomechanics under physiologic loads.   Stiffness was measured as the slope of the line between 60 and 80N since stiffness was approximately linear in this region of the curve. Displacement was measured between –25 and +25 N as this represented the horizontal part of the curve in which there was no load on either of the cruciate ligaments.

Some amount of creep and plastic deformation are expected when working with ligamentous tissues. This is seen as a gradual shift of the load-deformation curve to the

right with repeated cycling of the specimen being tested. In some studies on ligamentous tissues conditioning of the specimen is done prior to testing. The specimen is considered conditioned when a reproducible load-deformation curve is obtained. In a pilot study done prior to this study, re-tracing of the curve occurred within 3 to four cycles of loading for most specimens. 12 cycles were used in this study as it was also used in a previous study.[16] Testing in this study however was performed at physiologic loads and the precise retracing of the load-deformation curves was an indication that plastic deformation was not occurring at the loads used for testing. In the present study there were specimens in which there was a shift in the load-deformation curve to the right during testing, however this was attributed primarily to the method of fixation of the graft. There were differences in displacement between groups even though all stabilization methods were tensioned to eliminate cranial drawer motion. This was attributed to differences in the amount of tension applied to the either the suture techniques or the LGT as well as differences in the amount of yield of the soft tissues (femorofabellar ligament). The amount of tension required to eliminate drawer motion can vary from stifle to stifle and would also depend on the conformation of the limb as well as subtle discrepancies in placement of either the holes for the tibial suture anchor point or for the distal femoral graft anchor point. This probably accounts for differences between the suture stabilization techniques as well as the FTS:cranial EG and the intact CrCL.

The use of autogenous tissues for cruciate repair in veterinary medicine is not new however most of the described techniques involve intracapsular repairs.[22,23,46,47] Extracapsular techniques are advantageous in situations in which intracapsular repairs cannot be used, e.g. failure of an intracapsular technique, after infection of the joint, or in cases of severe osteoarthritis within the joint.[24] Ideal tissue for stabilization of the CrCL-deficient stifle would be histocompatible and have rheologic properties similar to that of the CrCL.[16,22] The combination of fascia lata and the lateral one-third of the patella

ligament has been used for intracapsular stabilization of the CrCL-deficient stifle and has been shown to take on the gross and histologic appearance of ligamentous tissue.[22,48] Because of this it is thought to contribute significantly to joint stability when used for stabilization.[22] The FTS:tibial crest is currently considered to be the standard for extracapsular suture stabilization. The displacement and stiffness of the LGT in this study was comparable to that of the FTS:tibial crest. In two of the data sets there was no significant difference in displacement between the LGT and the intact CrCL. This suggests that the LGT can provide effective stabilization, through a decrease in cranial drawer motion, of the CrCL-deficient stifle in the cadaver model. Bone-ligament-bone preparations are inherently stronger than ligaments fixed to soft tissues. Fixation of a graft, which will assume the function of a ligament, to bone should prevent loosening of the graft.[49] It is expected that collagenous adhesions will form at the ligament-bone interface at the point at which the graft is secured. This may be evident as early as four weeks following surgery.[50] Authors of previous studies believe that lack of bone-ligament-bone substitutes for stabilization of the stifle may contribute to joint laxity and this was reported to contribute to technique failure in one study.[22] The use of a screw and spiked washer has been described as an effective method for fixation of the graft to the distal femur.[46] Using staples was an attempt at a simple method of fixation of the proximal end of the graft to the distal femur. Failure at the point(s) of fixation with this method was evident and the significant displacement seen with the LGT in the staple fixation data was attributed to slippage of the graft. In a study comparing the biomechanical stability of four CrCL repair techniques in the dog, failure of all of the intracapsular grafts occurred at the point of graft fixation.[16]   The staples were replaced by a screw and spiked washer for fixation of the graft to the distal femur in this study. Displacement for the LGT was less in the two data sets in which the screw and washer were used than in the data set in which the staples were used.

The amount of tension in the grafts was not determined during this study. The effectiveness of the LGT in restricting cranial drawer motion would depend on how tightly the graft is pulled. Estimating the amount of tension in the grafts would be an objective way to standardize the amount of tension applied during stabilization of the stifles experimentally, however both the sutures and the grafts were "tightened" until cranial drawer motion was eliminated. Clinically, the graft or lateral fabellar suture are tightened until cranial drawer motion has been subjectively determined to be absent. The amount of tension required to eliminate cranial drawer motion would vary in the clinical setting and would depend on a number of variables including position of the limb during tightening of the graft, point at which the graft is secured on the distal femur, width of the graft and handling of the graft.   Patellar ligament grafts that are used as CrCL substitutes are avascular and have been shown to undergo a 20-week period of revascularization.[51] Therefore maintaining the distal attachment of the lateral graft is advantageous as some of the blood supply to both the portion of the patella ligament and the fascia is preserved, therefore minimizing or eliminating the ischemic necrosis phase.[42] An additional advantage of leaving graft tissue attached to its anatomical origin e.g. patellar ligament anchored to the tibial tuberosity, is that the attachment site is secure, with the additional advantage of gradual stress transfer from graft to bone.[4]

Stiffness for the cut CrCL was significantly different from all other tests in each data set. Figure 16 is an example of a typical curve generated during testing of the cut CrCL. The horizontal part of the curve represented absence of deformation of the periarticular soft tissues. As the stifle was loaded to 80N in cranial drawer there was an exponential increase in deformation. As the stifle was loaded to –65N in caudal drawer there was also an exponential increase in deformation. The CrCL had already been transected and the deformation represented is most likely from the other stifle restraints that were present i.e. the medial and lateral collateral ligaments, the medial meniscus and the lateral meniscofemoral ligament, as well as a significant contribution from the caudal cruciate

ligament in caudal drawer. The stiffness measurement for the cut CrCL is therefore not comparable to the other stiffness measurements.

The FTS:tibial crest is reportedly one of the most common extracapsular methods used to stabilize the CrCL-deficient stifle in dogs.[52] It is based on Flo's modification of the retinacular imbrication technique[14]. Usually a single lateral (and occasionally a medial) fabellar-tibial suture is used. Isometric origin and insertion points may enhance function of the FTS:tibial crest.[28] In human orthopedics the tubercle of Gerdy (which anatomically corresponds to the cranial and caudal prominences of the EG in the dog) is the distal site of fixation for stabilization procedures of the knee.[37] In veterinary medicine, stabilization procedures involving the use of a fascial strip or graft maintain the distal attachment which includes the cranial prominence of the EG.[46] The FTS:caudal EG in this study resulted in extreme flexion of the joint, restricting stifle extension in every test. This was therefore not considered to be a functional suture placement position. There was no significant difference in displacement or stiffness between the FTS:cranial EG and the FTS: tibial crest in any of the experiments in this study. However, only the function of the FTS: tibial crest was comparable to that of the intact CrCL.

Conclusion

The results of this study indicate that placement of the tibial suture anchor point in the prominence at either the cranial or caudal aspect of the EG did not improve resistance to displacement when compared to the FTS: tibial crest. It therefore did not enhance the biomechanical function of the FTS. We also found that neither the LGT nor the FTS: tibial crest resulted in equal or greater stiffness than the intact CrCL and that biomechanically, although the LGT does not completely eliminate cranial drawer motion, it was similar to the FTS in its ability to provide adequate stabilization of the CrCL-deficient stifle in the cadaver model.

The jig design allowed tibial rotation to be measured and although it was not one of the aims of this study, another study specifically designed to assess the effect of the LGT on range of motion and flexion would be of benefit.

In our hands we believe that the LGT is a simple and effective technique for stabilization of the cranial cruciate ligament deficient stifle. The LGT possesses the properties of an ideal material for stabilization of the canine cadaver stifle therefore a clinical study to determine the effectiveness of the graft in dogs is recommended.

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APPENDIX A

Table 1 Mean displacement and stiffness for the Securos™ fixation data set.

Stabilization Technique	Displacement * (mm)	Stiffness** (N/mm)
Intact cruciate	1.75^a ♦	93.1
Cut cruciate	12.03	62.62
LGT	2.69^{ab}	38.13^a
FTS: tibial crest	3.21^{ab}	43.89^{ab}
FTS:cranial EG	4.12^b	46.28^b
FTS:caudal EG	5.96	48.66^b

*Standard error for all treatments = 0.37

**Standard error for all treatments = 1.89

♦ Superscripts after treatment means denote results of pairwise comparisons. There was no significant difference between treatments with similar superscripts e.g. in the stapler data set there was no significant difference in displacement between the intact CrCL and the FTS-TC as they both have ^{a} as a superscript. There was a significant difference in displacement between the intact and cut CrCL for all three data sets as the intact CrCL has a superscript of ^{a} and there is no superscript for the cut CrCL.

Table 2. Mean displacement and stiffness for the staple fixation data set.

Stabilization Technique	Displacement * (mm)	Stiffness** (N/mm)
Intact cruciate	2.03^a	88.51
Cut cruciate	12.85	61.18
LGT	7.81^b	47.35^a
FTS: tibial crest	4.38^{ac}	40.2^a
FTS:cranial EG	4.79^{ac}	42.19^a
FTS:caudal EG	6.19^{bc}	48.37^a

*Standard error for all treatments ~ 0.7

**Standard error for all treatments = 2.6

Table 3. Mean displacement and stiffness for the screw and washer fixation data set.

Stabilization Technique	Displacement * (mm)	Stiffness** (N/mm)
Intact cruciate	1.93^a	90
Cut cruciate	11.68	65.37
LGT	3.03^{ab}	38.19^a
FTS: tibial crest	2.92^{ab}	43.03^{ab}
FTS:cranial EG	4.26^{bc}	46.65^b
FTS:caudal EG	5.36^c	50.34^b

*Standard error for all treatments = 0.46

**Standard error for all treatments = 2.2
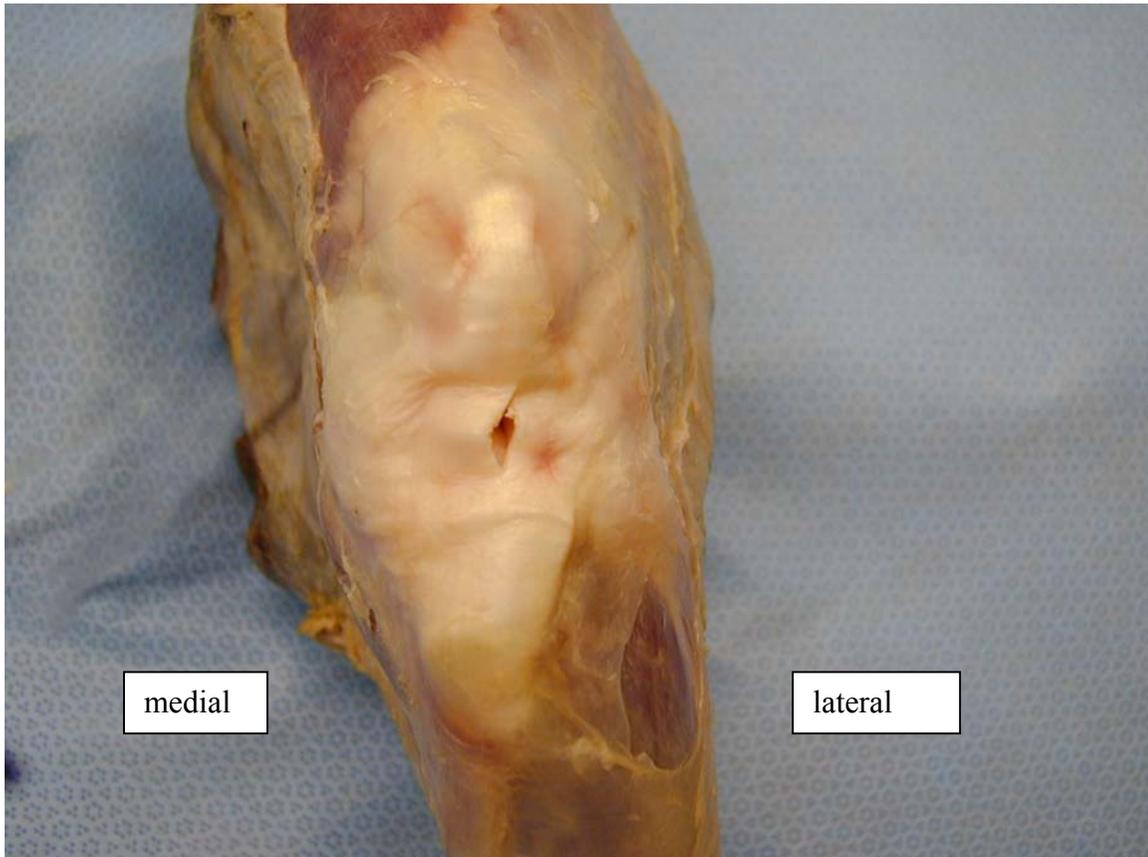
Figure 1 1-cm stab incision in the lateral one-quarter to one-third of the patellar ligament.
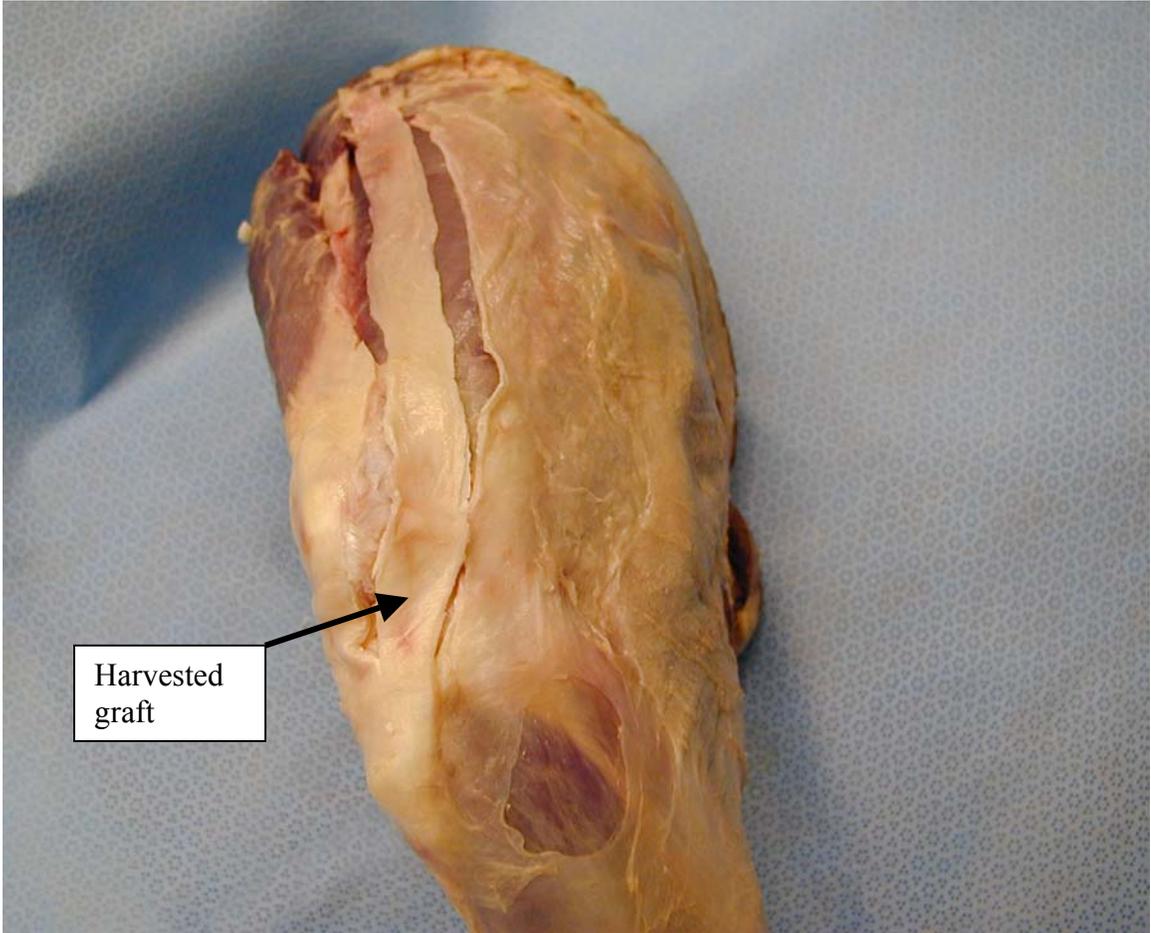
Figure 2 Harvested graft in situ.
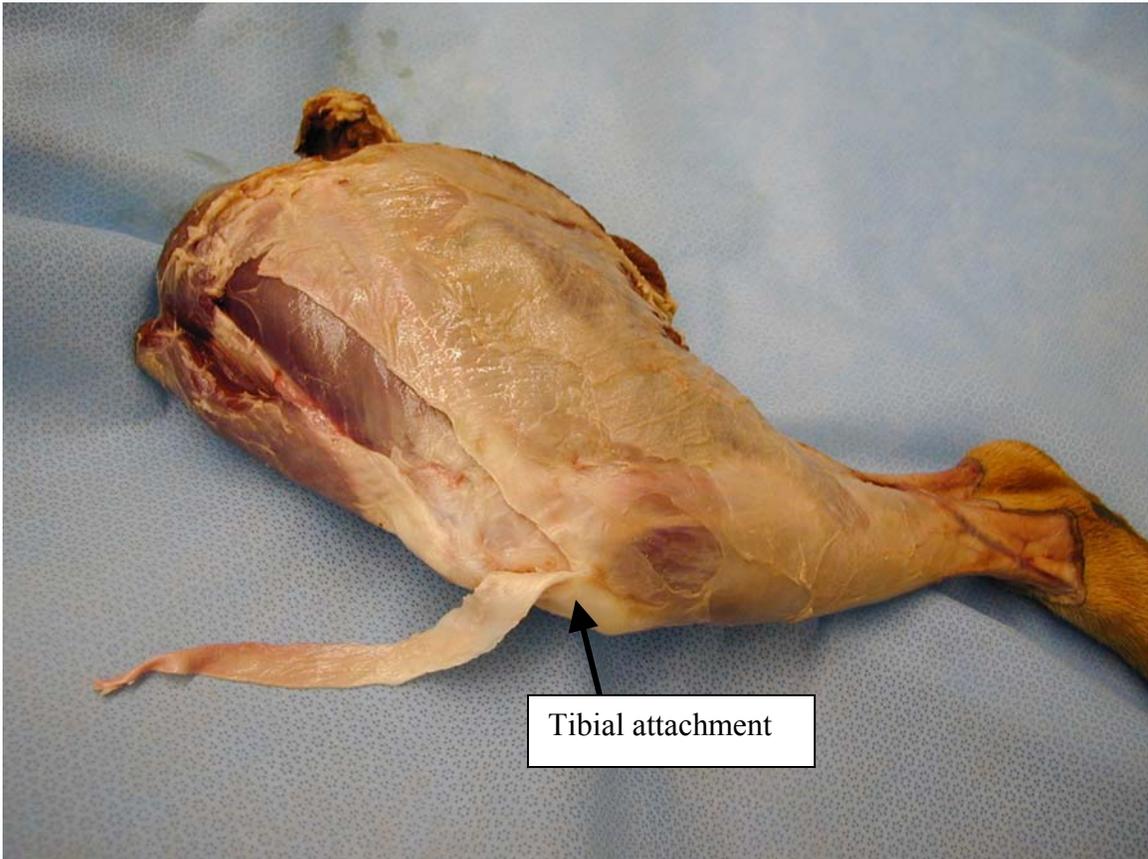
Figure 3 Harvested graft lifted off of the underlying musculature showing the preserved tibial attachment.

Figure 4 Stifle with musculature removed. The fascial graft, medial and lateral collateral ligaments, cruciate ligaments, menisci and a portion of the lateral head of the gastrocnemius muscle have been preserved.
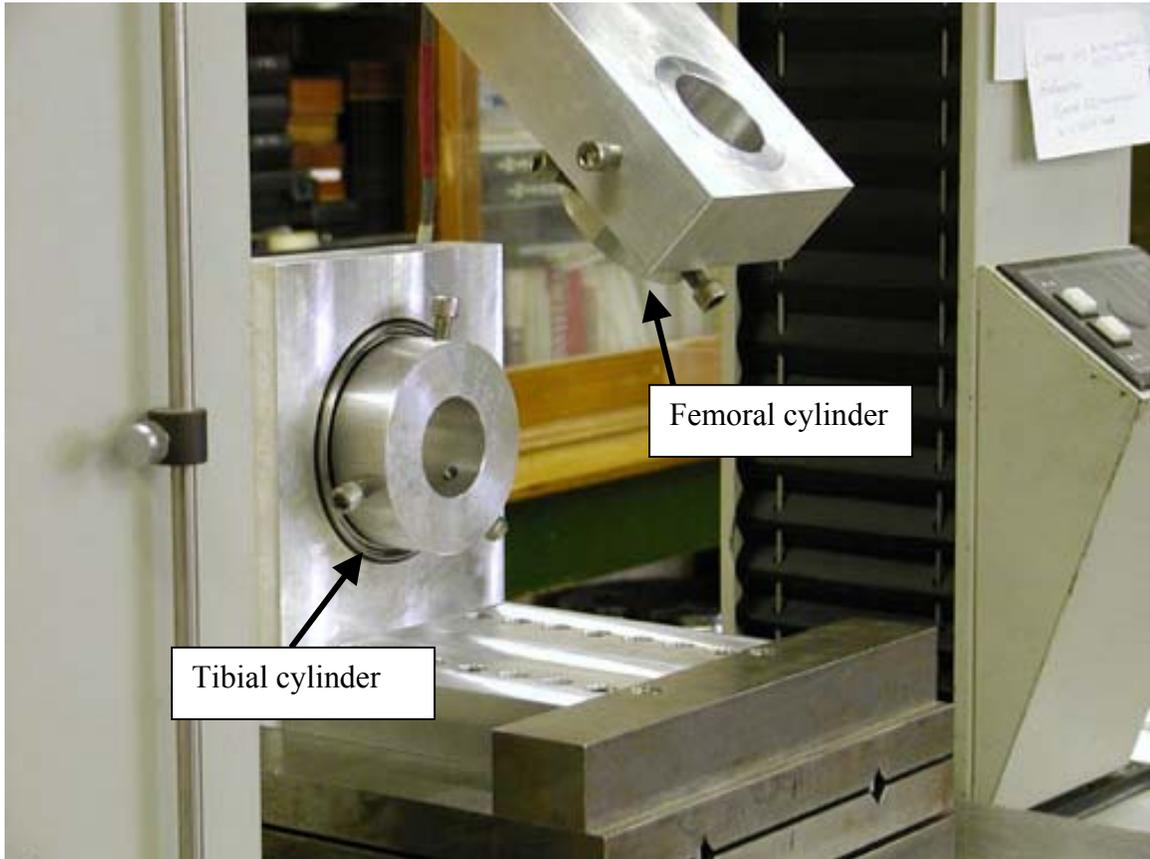
Figure 5 Testing jig loaded in the Instron Universal Testing Machine.

Figure 6 Loaded construct ready for testing. The construct is wrapped in plastic to keep the soft tissues moist.

Resin with
potted tibia

Figure 7 Back of the tibial potting cylinder showing double cylinders (ball bearings are
located between the two cylinders) with 5-degree marks for estimating rotation.
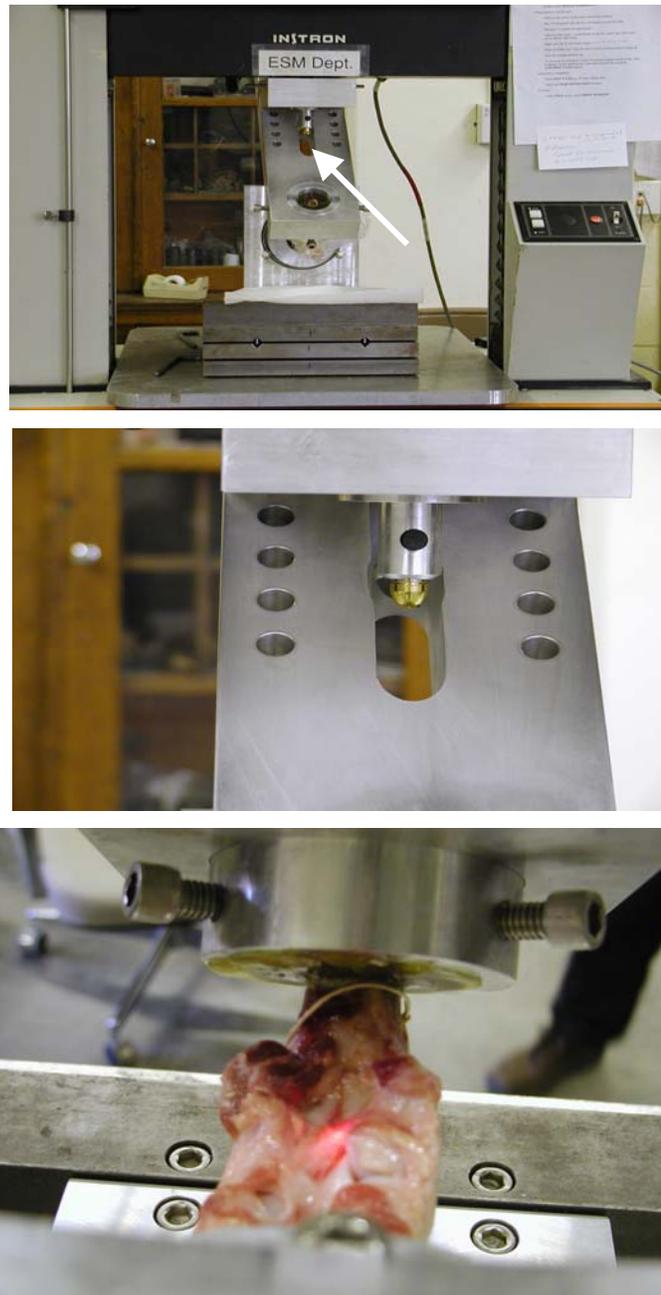
Figure 8 Laser beam mounted on the jig centered on the caudal intercondylar space.
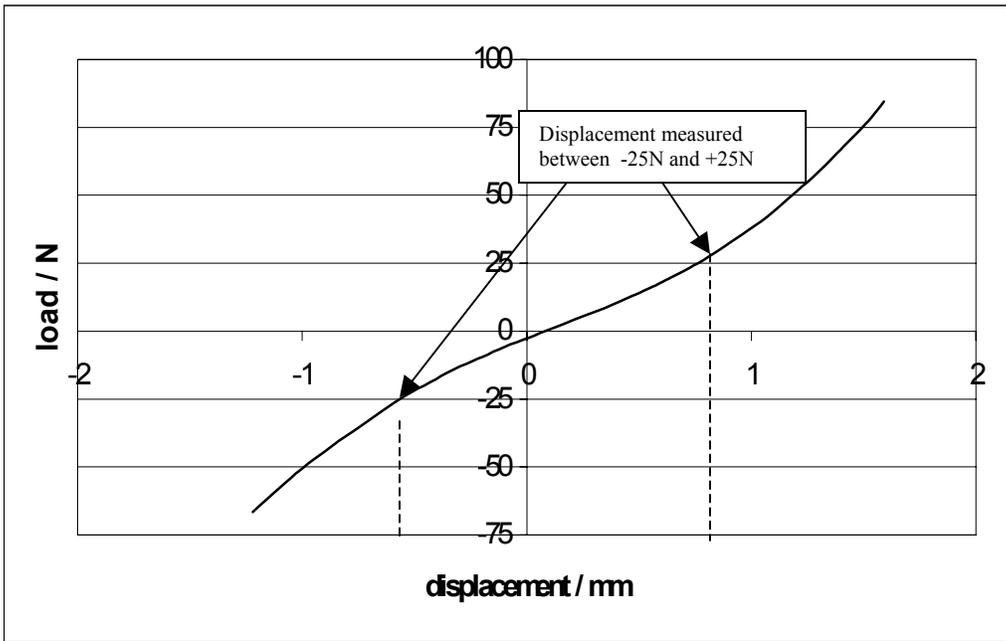
Figure 9a Load-displacment curve showing points (-25N and 25N) between which displacement was measured.
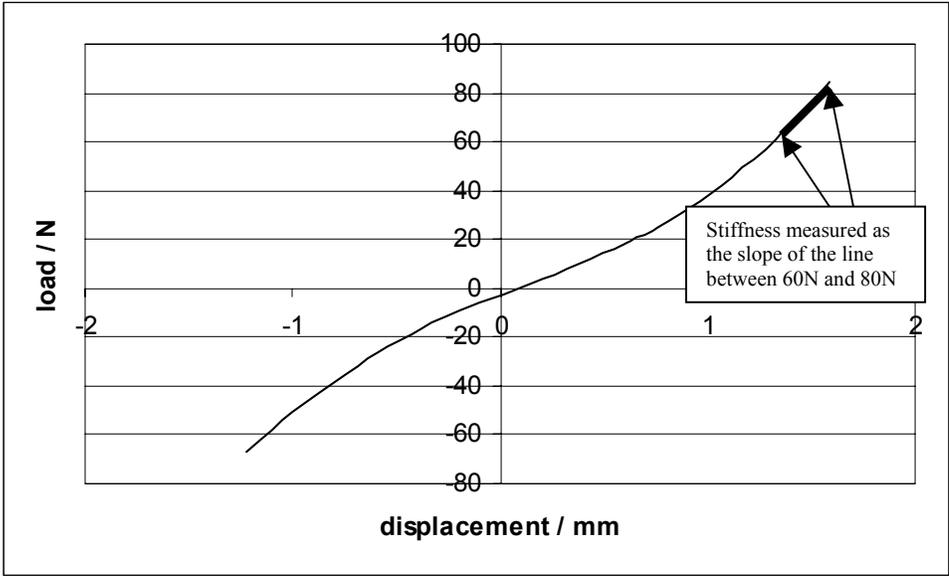
Figure 9b Load-displacement curve showing points (60N to 80N) at which stiffness was measured.

Time, min	Load, Newtons	X-Head Disp., mm	Load, Newtons
0.1999	42.52	2.67	42.52
0.2041	39.95	2.57	39.95
0.2083	37.45	2.46	37.45
0.2124	35.17	2.36	35.17
0.2166	32.97	2.26	32.97
0.2208	30.85	2.15	30.85
0.225	28.86	2.05	28.86
0.2292	26.98	1.94	26.98
0.2333	25.18	1.84	25.18
0.2375	23.46	1.74	23.46
0.2417	22.15	1.63	22.15
0.2459	20.56	1.55	20.56
0.2501	18.71	1.42	18.71
0.2543	17.26	1.32	17.26

Points used to plot trendline. Equation generated was used to detemine the value of x in millimeters when y = 25 N

$y = 14.387x - 1.3882$
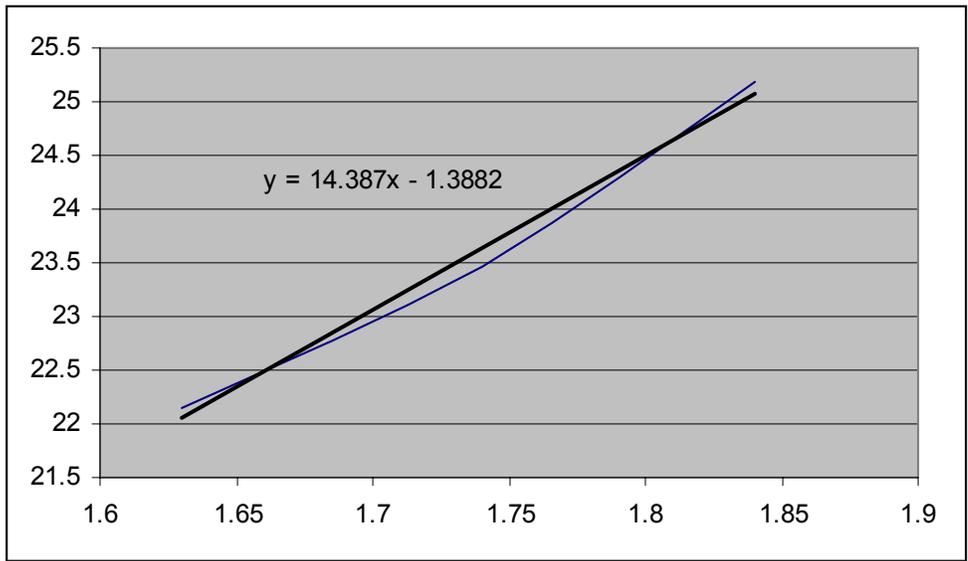
Figure 10 An example of data points generated and determination of the equation of the line through a particular point.

Figure 11 Illustration showing the lateral graft being pulled caudal to the lateral fabella and through the femorofabellar ligament using a curved hemostat.
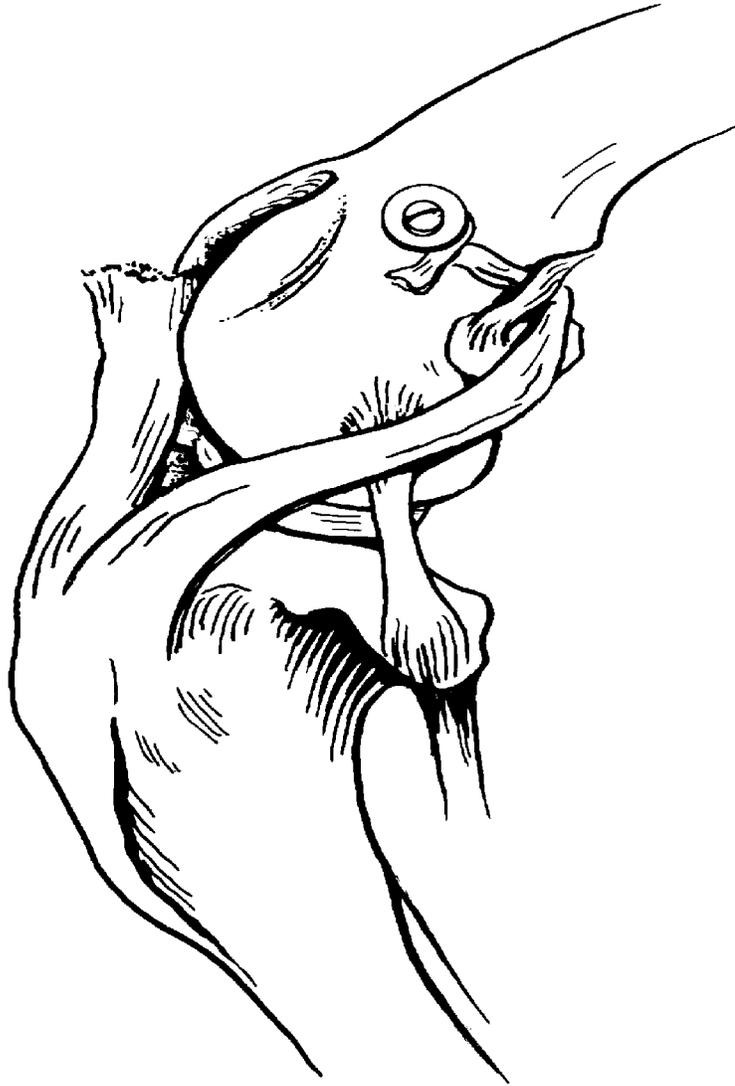
Figure 12 Illustration showing the graft secured to the distal femur with a screw and
washer.
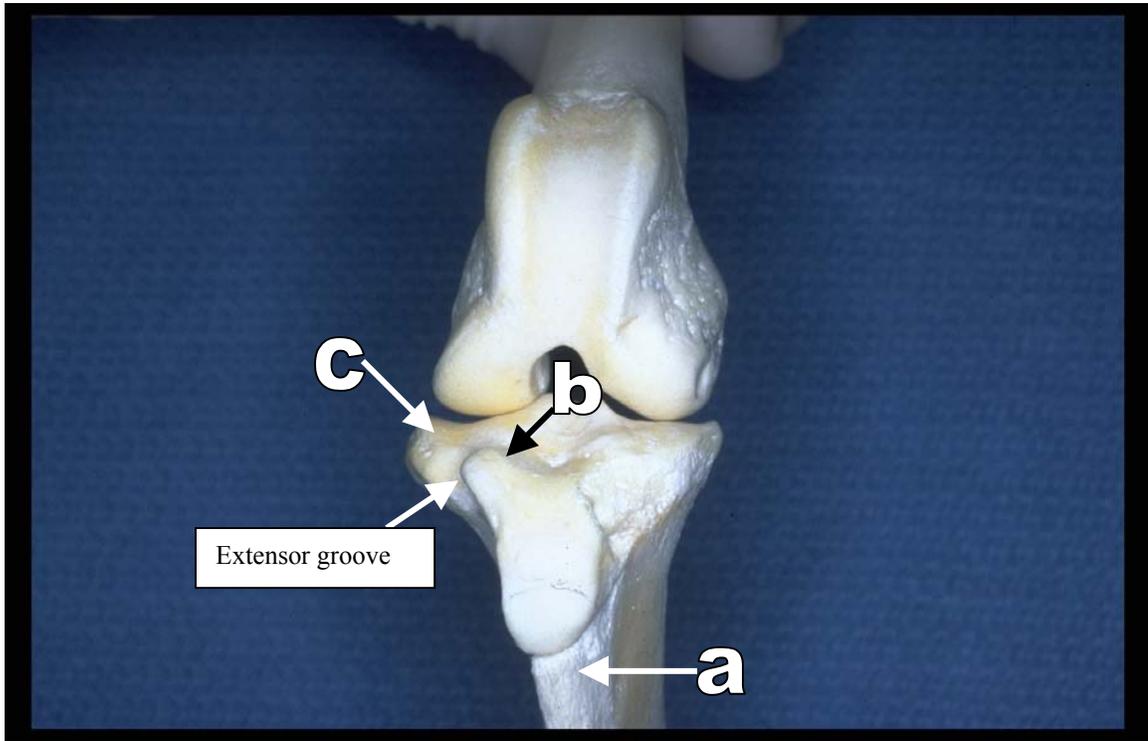
Figure 13 Location of the extensor groove and points at which holes were drilled for suture placement (a = tibial crest; b = cranial prominence of the extensor groove; c = caudal prominence of the extensor groove)
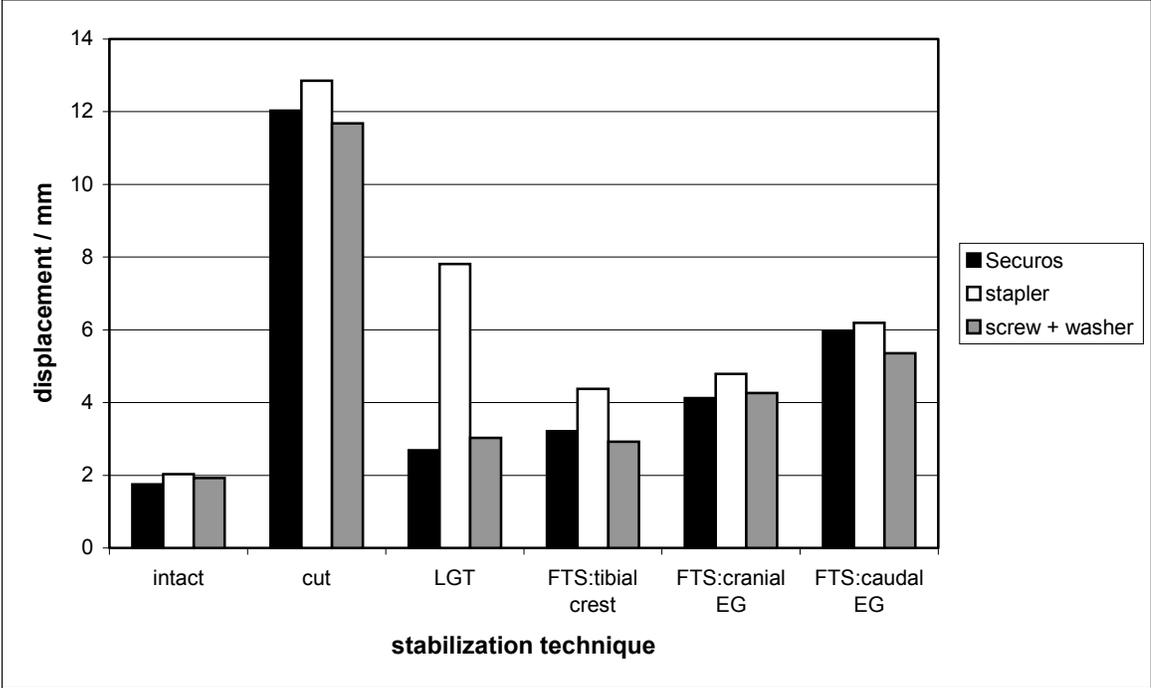
**Figure 14** Comparative mean displacements for the three data sets.
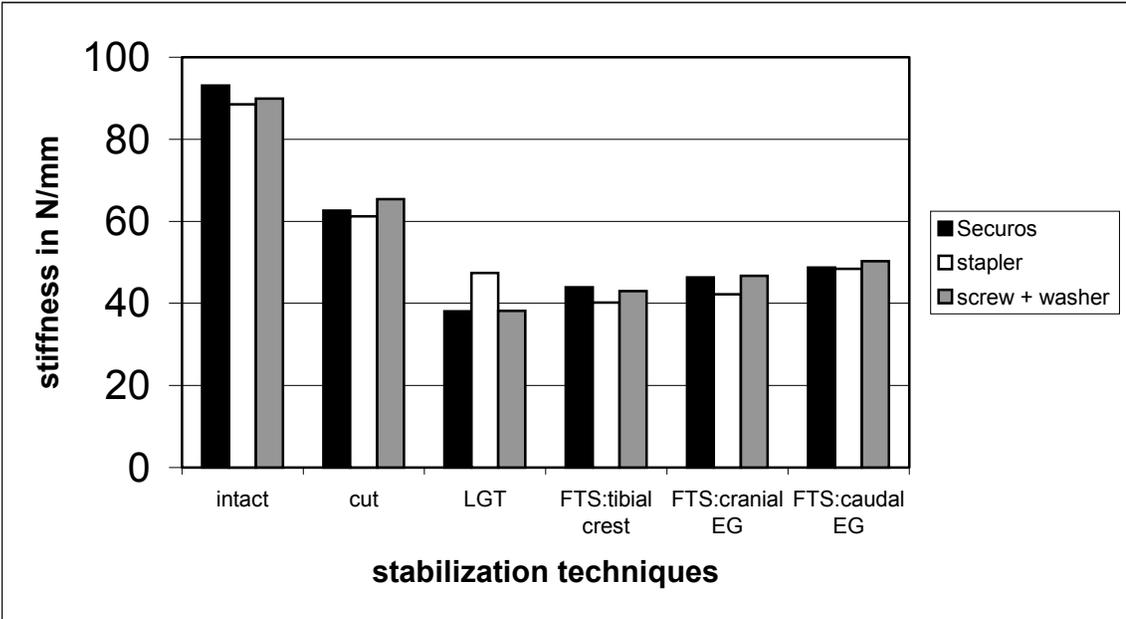
**Figure 15** Comparative mean stiffness for the three data sets
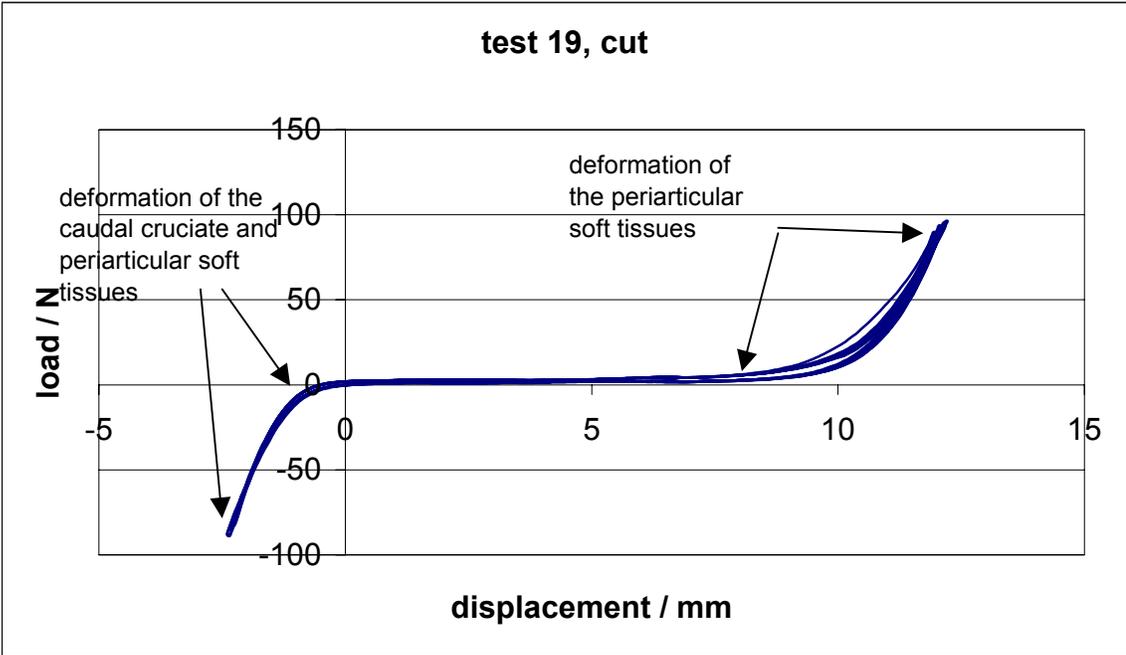
Figure 16 Typical load-displacement curve generated for the cut cruciate ligament.

APPENDIX C

ABBREVIATIONS

CrCL - cranial cruciate ligament

DJD - degenerative joint disease

EG - extensor groove

FTS - fabellar –tibial suture

LGT - lateral graft technique

Vita

Tisha Adele Maria Harper was born in St. Anns, Trinidad West Indies on January 8th, 1972. She attended the Mt. Lambert RC School where she did her primary education and then did her secondary education at the St. Augustine Girls' High School. She followed in her fathers' footsteps and pursued a career in veterinary medicine. She received her Doctor of Veterinary Medicine degree in 1995 from the School of Veterinary Medicine, Faculty of Medical Sciences, University of the West Indies (UWI), Trinidad West Indies. She worked as a clinician in private practice and at the Veterinary Teaching Hospital and was appointed as a faculty member in the Department of Small Animal Clinical Sciences (UWI) in 1999. She was accepted as a resident / graduate student at the Virginia-Maryland Regional College of Veterinary Medicine, Blacksburg VA and began her program in July 2000. She will be completing her program in July 2003.