

BIOMECHANICAL ANALYSIS OF SUTURE  
ANCHORS AND SUTURE MATERIALS  
IN A CANINE FEMUR MODEL

By

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## CHAPTER I

### INTRODUCTION

Suture anchors are metallic or absorbable orthopedic devices that facilitate the attachment of suture or a suture-soft tissue union to bone. Suture anchors are designed to provide temporary fixation of soft-tissue to bone or fixation of a prosthetic material until functional healing or peri-articular fibrosis and stabilization occur.<sup>1-2</sup> Suture anchors are an effective alternative to the use of staples, transosseous tunnels and screw-washer combinations for anchorage of suture-soft tissue to bone.<sup>2,3,5</sup> The use of suture anchors in human and veterinary surgery has been described.<sup>1-9</sup> Suture anchors have been used extensively in human surgery through arthroscopic and open techniques for ligament, joint capsule and tendon reattachment or prosthesis placement, head and neck soft-tissue reconstruction, urologic and gynecologic applications.<sup>3,5,10-18</sup> Described veterinary applications include tarsal and phalangeal ligament deficiencies, coxofemoral luxation, shoulder luxation, elbow luxation, extracapsular stifle stabilization for cranial cruciate and/or collateral ligament deficiency, common calcaneal tendon avulsion, triceps avulsion, carpal extensor avulsion, gastrocnemius avulsion and acetabular fracture.<sup>6-9,19</sup>

Defining features of suture anchors include their location within the bone, thread design, eyelet design, deployability and composition (metallic vs. absorbable). Suture anchors

may have transcortical or subcortical location.<sup>2</sup> Transcortical anchors are a screw-type design with a suture eyelet and engage the *cis*-cortex. Subcortical anchors may be screw-type or have prongs/flanges that resist pullout. While absorbable anchors are extensively used in human surgery, their use is not reported in the veterinary literature. Decreased mechanical strength currently makes absorbable suture anchors less useful in veterinary patients.<sup>20</sup> Eyelet design has a significant impact on suture abrasion and excess friction lowers load to failure and cycles to failure.<sup>20,21</sup> Eyelets of human metallic suture anchors are generally round or streamlined with one or more suture protection channels.<sup>20</sup> Features of eyelets that contribute to friction placed on the suture include the smoothness of the surface, the shape and design of the eyelet, and the radius of curvature of the eyelet. A larger radius will permit a smoother arc and limit abrasion. If the angle of suture pull is out of a suture-protecting channel, the suture may be abraded on a relatively sharp surface.<sup>20,21,22</sup>

The anchor location within a bone will vary with anchor type and clinical application. Loads to failure vary with anchors placed in different bones and within regions of the same bone.<sup>23-25</sup> Biomechanical studies have been performed with veterinary suture anchors in the proximal and distal tibial metaphyses, proximal humeral metaphysis, acetabular wall, dorsal acetabular rim and femoral condyles.<sup>2,4,8,9</sup> The studies involving the acetabulum and femoral condyles utilized Bone Biter™ suture anchors (Innovative Animal Products LLC™, Rochester, MN), which are subcortical flange-type anchors that may have different failure loads than transcortical screw-type anchors.<sup>8,9</sup> Applications for suture anchor placement in the femoral condyle include the lateral suture technique



for cranial cruciate ligament rupture, collateral ligament repair and reattachment of the long digital extensor tendon. To the authors' knowledge, this is the only veterinary study that evaluates transcortical suture anchor placement in the femoral condyle of a dog.

### ***Modes of Failure***

The angle of suture pull is a feature that may significantly effect suture abrasion and failure.<sup>21,22,26,27</sup> Many human suture anchors are designed such that a suture pull of 0° (along the axis of insertion) results in the least suture abrasion. However, clinical application may dictate that the suture pull angle is 45° or 90° to the angle of insertion. In human rotator cuff repair, Burkhart concluded the optimal anchor to suture angle to create an equilibrium between the anchor and the rotator cuff is 45°.<sup>28</sup> The suture pull angle is typically 90° in collateral or cranial cruciate ligament stabilizations in dogs. Studies have demonstrated that with rigid eyelets, many anchor-suture combinations experience reduced cycles and loads to failure at 45° and 90° suture pull angles when compared to 0°.<sup>21,22,26</sup> Interestingly, an absorbable suture anchor with a flexible polyaxial suture serving as an eyelet demonstrated no statistical difference between different suture pull directions.<sup>26</sup> Another consideration for eyelet orientation is the alignment of the in-plane axis of the eyelet with the direction of suture pull. Some metallic anchors/suture combinations demonstrate reduced cycles and loads to failure with the eyelet in a coronal orientation (out-of-plane) compared to a sagittal (in-plane) orientation with a 45° angle of suture pull.<sup>22,26</sup>

Suture anchor constructs are susceptible to failure at the bone-anchor interface, anchor-suture interface, suture-tissue interface or other abrasive areas on the suture, such as a bone edge, knot or crimp-clamp.<sup>1,20,22</sup> In suture anchor constructs in which the suture engages soft tissue, the suture-tissue interface is typically the weakest link.<sup>28-30</sup> Typically, the suture anchor and the anchor/bone interface have a higher load to failure than the suture it accommodates.<sup>30-32</sup>

Suture anchor constructs may be tested in acute load to failure (ALF) or cyclic testing. Acute load to failure is useful for direct comparison between anchors' holding ability during a single, supra-physiologic load. However, cyclic testing is a clinically more useful model to accurately assess stress on the suture anchor construct during weight bearing, range of motion, and activity.<sup>1,28</sup>

### ***Suture Materials***

Monofilament nylon leader line (NLL) secured with a crimp-clamp system is commonly utilized for lateral fabella-tibial suture techniques in the canine cranial cruciate ligament deficient stifles.<sup>33-37</sup> Nylon leader line has also been recommended for use with a veterinary suture anchor.<sup>4</sup> It has been reported that monofilament nylon is more resistant to cyclic loading than braided suture because individual strands cannot be serially abraded,<sup>4</sup> however, to the author's knowledge, this claim is not supported in the literature. Many human suture anchors are pre-loaded with a non-absorbable, multifilament, polyester suture, Ethibond Excel™ (Ethicon Inc, Somerville, NJ). Recently, a polyethylene-based multifilament suture, Fiberwire™ (Arthrex Inc., Naples,

FL) has been released and is used frequently with suture anchors. Mechanical testing indicates that 2 USP Fiberwire is significantly stronger, stiffer and more abrasion resistant than 2 USP Ethibond.<sup>26,27,38,39,40</sup>

### ***Objectives***

The first objective of this study was to evaluate the ALF at 0° to the angle of insertion in cadaveric canine femoral condyles with the Securos® 3.5mm (Securos Inc., Charleston, MA), FlexiTwist™ 3.5mm (Innovative Animal Products LLC™, Rochester, MN), IMEX™ 4.0mm x 10mm (IMEX™ Veterinary Inc., Longview, TX) and Mitek Fastin™ 4.0mm (DePuy-Mitek Inc., Raynham, MA). The first three are products designed for use in veterinary medicine and the 4.0mm Fastin is designed for use in human medicine. The null hypothesis was that all suture anchors tested would have the same load to failure.

The second objective of this study was to evaluate the cycles to failure of the above suture anchors with 5 USP Fiberwire and 27kgt NLL (Securos Inc., Charleston, MA) secured with two crimp-clamps and cycled at 90° to the angle of anchor insertion. Those constructs that completed 10,000 cycles were subjected to ALF at 90° to the angle of insertion. The null hypothesis was that all suture anchor constructs would have the same cycles to failure and the same ALF.

## CHAPTER II

### MATERIALS AND METHODS

#### **Objective 1- Acute Load to Failure**

**Implants- anchors:** The following four anchors were examined in this experiment: Securos 3.5mm x 19mm, FlexiTwist 3.5mm x 20mm, IMEX 4.0mm x 10mm, Fastin 4.0mm x 9.7mm (Figure 1).



**Fig 1. Photograph of the suture anchors tested from left to right: Securos 3.5mm, FlexiTwist 3.5mm, IMEX 4.0mm, Fastin 4.0mm.**

**Specimens:** Femurs were harvested from 20-30kg, skeletally mature dogs immediately following euthanasia for an unrelated project. The femurs were denuded of soft tissue, wrapped in saline-soaked (.9%NaCl) gauze, placed in plastic bags and stored in a freezer at  $-86^{\circ}\text{C}$  until mechanical testing. Prior to testing, the bones were thawed to room temperature. Throughout all stages, the bones were maintained in a moistened state with saline-soaked gauze.

**Construct Design:** Prior to testing, the proximal one-third was removed from each femur. The bone was inserted into a 14 gauge perforated-steel tube and secured with three u-bolts. Two 2.4mm Steinman pins were placed through the tube and bone at orthogonal angles to prevent rotation. Four anchors were placed in each femur; two in each condyle separated by a minimum of 1cm between the caudal and central anchor to prevent crack propagation, as previously recommended.<sup>1</sup> Each brand of anchor was rotated between cranial-caudal and medial-lateral positions to monitor for variation in failure loads with respect to anchor position. The anchors were inserted perpendicular to the femoral condyles according to the following manufacturers' recommendations:

1. Securos 3.5mm anchor: A 3.2mm pilot hole was drilled by use of a power drill. The spindle of the anchor was placed into a Jacobs chuck and inserted into the femoral condyle and the chuck levered to break the insertion shaft free from the anchor.
2. FlexiTwist 3.5mm anchor: A 2.7mm pilot hole was drilled by use of a power drill. The anchor was placed into the custom anchor driver and inserted into the femoral condyle.

3. IMEX 4.0mm x 10mm anchor: A 2.7mm pilot hole was drilled by use of a power drill. The anchor was placed into the custom anchor driver and inserted into the femoral condyle.

4. Fastin 4.0mm: A 3.5mm pilot hole was drilled by use of a power drill. The anchor was removed from the custom insertion spindle and the pre-loaded suture (2 USP Ethibond) was removed. Five USP Fiberwire was placed through the anchor eyelet and the anchor replaced in the insertion spindle. The spindle was placed in a power drill and inserted at a low speed until the spindle detached from the anchor.

Each anchor was loaded with an appropriate wire or suture based upon eyelet size, with the intent to eliminate suture breakage as a mode of failure. Since the various brands had different eyelet sizes, a single material could not be used in all anchors. The following anchor and wire or suture combinations were used: 3.5mm Securos and FlexiTwist with 1.2mm Kirschner wire, IMEX 4.0mm with 18 gauge (1.0mm) orthopedic wire and Fastin 4.0mm and 5 USP Fiberwire. Preliminary tests demonstrated that 18 gauge orthopedic wire failed before pullout of the Securos and FlexiTwist anchors occurred. The largest wire accommodated by the Fastin 4.0mm anchor is 22 gauge (.6mm), however, it failed during preliminary tests. Number 5 USP Fiberwire consistently achieved anchor pullout without suture failure. All specimens were prepared by one author (JTG).

**Mechanical Testing:** All testing was performed with a servohydraulic uniaxial testing machine equipped with a 5kN load cell (MTS Systems Corporation, Eden Prairie, TX) and Fastrack 8800D controller (Instron Corporation, Norwood, MA). Each femur was

placed in the bone-holder and secured in a vise, which was attached to the lower movable jaw of the uniaxial test machine. The specimen was adjusted so the anchor was at the center of the load cell allowing the applied load to be at 0° to the angle of insertion. The appropriate coupler wire or suture was placed through the anchor eyelet and clamped to a bolt connected to the load cell. Acute load to failure tests were performed in displacement-control with an initial pre-load of 10N. The load was applied at 1mm/s and data collected at 100 Samples/s. The load at failure was recorded as well as the mode of failure. Figure 2 depicts a typical construct for the acute load to failure testing.



**Fig 2. Photograph of the construct using a Securos suture anchor immediately following an acute load to failure test.**

## **Objective 2- Cyclic Testing**

**Implants- anchors and sutures:** The same four anchor types were tested with two different suture materials: 5 USP Fiberwire tied in a knot and 27kgt NLL secured with two 36kg stainless steel crimp-clamps (Securos Inc., Charleston, MA). The 27kgt NLL was selected because it was the largest size that would fit all the veterinary anchors. Thirty-six kgt fits through the 3.5mm Securos and FlexiTwist anchors, but not the IMEX 4.0mm anchor. Due to the small eyelet size of the Fastin 4.0mm anchor, it was only tested with 5 USP Fiberwire.

**Specimens:** The specimens were harvested and handled in an identical fashion to objective 1.

**Construct Design:** Prior to testing, the proximal one-third was removed from each femur. The femur was seated in a 14 gauge perforated-steel tube and two 2.4mm Steinman pins inserted at orthogonal angles. The femur was potted within the tube with Master® Dyna-Cast® (Kindt-Collins Company, LLC, Cleveland, Ohio). Anchors were inserted into the caudal aspect of the femoral condyle according to previously described manufacturers' recommendations. The anchors were randomly assigned to different femurs and medial or lateral condyle so they were distributed evenly. The anchors were placed so the in-plane axis of the eyelet was in the same plane as the suture direction. To achieve a uniform loop circumference, five USP Fiberwire was placed through the anchor eyelet and tied around a 28cm circumference section of polyvinylchloride pipe by use of a surgeon's knot followed by four single overhand throws.<sup>40</sup> The 27 kgt NLL was

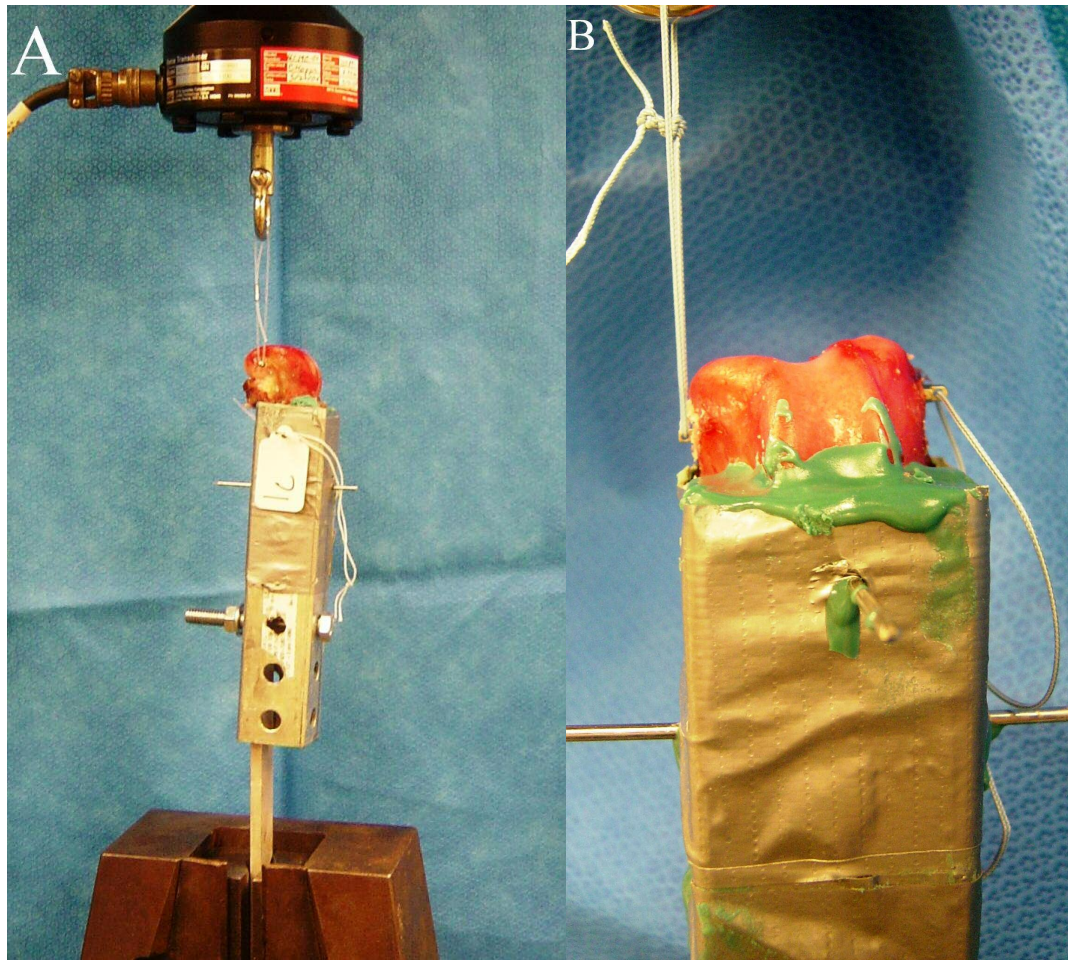


inserted through the eyelets of the veterinary anchors and both ends passed through two 36kg crimp-clamps. The 27 kgt NLL was placed around the 28cm polyvinylchloride pipe and the two crimp-clamps placed over a 3 cm rectangular notch in the pipe. Each of the crimp-clamps was crimped in three places with a Securos crimping device according to manufacturer recommendation. After creation of the loop, the polyvinylchloride pipe was removed and a steel bar was secured within the specimen tube and placed in a 50K lb gripper (MTS Systems Corporation, Eden Prairie, TX). The suture was placed through a stainless steel chain anchor which was attached to the 5kN load cell. The construct was adjusted so the angle of suture load was 90° to the angle of anchor insertion and in-plane with the eyelet rotation angle. The rotation angle of the Fastin anchor could not be controlled because the insertion spindle automatically detaches when the anchor is inserted to the appropriate depth. Since this is how the Fastin anchor is employed clinically and adjustments may damage the suture, no attempt was made to adjust the rotation angle. The specimens were prepared by one author (JTG).

**Mechanical Testing:** All testing was performed with a uniaxial testing machine equipped with a 5kN load cell (MTS Systems Corporation, Eden Prairie, TX) and Fastrack 8800D controller (Instron Corporation, Norwood, MA). An initial pre-load of 10N was applied. Cyclic tests were performed under load control with a load range of 280-332N at 5 hertz. The maximum load of 332N (80% of the ultimate failure load) was selected based upon an ultimate failure of 27 kgt NLL with a crimp-clamp of 416N as reported by Banwell, et al.<sup>35</sup> Preliminary tests yielded similar results and demonstrated 5 USP Fiberwire™ was stronger than the 27 kgt NLL. The use of a maximum load of 80%

of the ultimate failure load theoretically will allow failure of some of the constructs and give a basis for comparison. The load was increased from 10N to 280N over 15 seconds. The data collection rate was 20 Samples/s. Each sample was cycled for 10,000 cycles or until the suture-anchor construct failed. The number of cycles at failure and mode of failure were recorded. Constructs that achieved 10,000 cycles were subject to an ALF in the same configuration, with the suture load at 90° to the anchor insertion. Acute load to failure tests were performed in displacement-control with an initial pre-load of 10N. The load was applied at 1mm/s and data collected at 100 Samples/s. The load at failure and mode of failure were recorded. Figure 3 depicts a typical construct for the cyclic testing.

**Statistical Analysis:** All data were analyzed using PC SAS Version 9.1 (SAS Institute, Cary, NC). Analysis of variance techniques were employed using SAS PROC MIXED. A completely randomized two factor arrangement was used as the model in the ANOVA with brand and location as the factors of interest for ALF (Objective 1) and brand and suture as the factors of interest for cyclic testing (Objective 2). The response variables for the ANOVA were pullout force for Objective 1 and cycles to failure for Objective 2. Simple effects of brand for each location (or suture type) were assessed using a SLICE option in an LSMEANS statement, and pair-wise t-tests performed if the overall simple effects were significant.



**Fig 3. Photographs of the construct utilized for cyclic testing. (A) Lateral view of a FlexiTwist/NLL construct. Note: this was a preliminary test in which only a single crimp-clamp was used to secure the NLL rather than two crimp-clamps used in the actual experiments. (B) Cranial-caudal view of an IMEX/Fiberwire construct.**

## CHAPTER III

### RESULTS

#### **Objective 1- Acute Load to Failure**

There was no statistical difference ( $p=.131$ ) in acute load to failure among the four anchors in the cranial aspect of the condyle (table 1). The veterinary anchors all had significantly higher failure loads ( $p<.0001$ ) in the caudal aspect of the femoral condyle compared to the cranial aspect. There was no statistical difference in load to failure between the caudal and cranial positions with the Fastin anchor (table 2). There was no significant difference between the medial and lateral femoral condyle. Two of 10 of the Flexitwist suture anchors failed by fracture of the eyelet. All of the other suture anchors failed by pullout of the anchor from the bone. Figure 4 demonstrates a typical load-displacement curve for an acute load to failure test.

**Table 1: Mean acute load to failure in newtons (N) and standard error of the mean (SEM) for suture anchors in the cranial aspect of femoral condyle.**

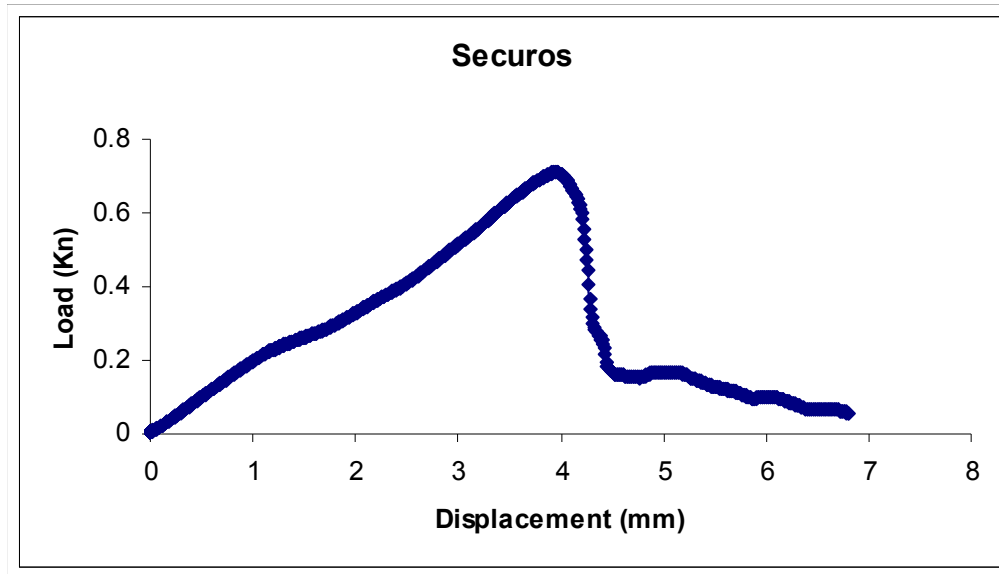
<b>Anchor</b>	<b>n</b>	<b>Mean Failure (N)</b>	<b>SEM</b>
Securos	5	611.70 a	55.68
FlexiTwist	6	582.58 a	80.29
IMEX	4	498.62 a	112.75
Fastin	4	359.86 a	68.55

**Means with the same letter are not significantly different using a .05 significance level.**

**Table 2: Mean acute load to failure in newtons (N) and standard error of the mean (SEM) for anchors in caudal aspect of femoral condyle.**

<b>Anchor</b>	<b>n</b>	<b>Mean Failure (N)</b>	<b>SEM</b>
Securos	5	1192.74 a	105.7
FlexiTwist	5	1156.77 a	45.097
IMEX	5	736.79 b	86.645
Fastin	5	277.96 c	39.739

**Means with the same letter are not significantly different using a .05 significance level.**



**Figure 4: Load-displacement curve for acute load to failure test**

### **Objective 2- Cyclic Testing and Post-Cycling Acute Load to Failure**

All cyclic tests that failed did so by suture breakage at the eyelet. Constructs that completed 10,000 cycles were subjected to an acute load to failure at 90° to the insertion angle and all failed by suture breakage at the eyelet. The results of the cyclic tests and acute load to failure for those that completed 10,000 cycles are summarized in table 3. The p-value for mean cycles to failure was .0093. The Fiberwire (n=3) was statistically stronger (p=.024) than NLL (n=6) in post-cycling ALF. Fiberwire only completed 10,000 cycles with the Securos anchor, while NLL completed the cycles with Securos (n=3), FlexiTwist (n=2) and IMEX (n=1). Two of the Fastin anchors failed while being

ramped to 280N and completed no cycles. All of the Fastin anchors shifted in the direction of the suture pull when the load was applied.

**Table 3: Mean ( $\pm$  SEM) of cycles to failure for anchor/suture combination, number completed 10K cycles and mean post-cycling acute failure load (N) ( $\pm$  SEM).**

Anchor	Suture	n	Mean Cycles	SEM	# Completed 10K cycles	Mean Failure (N)	SEM
FlexiTwist	NLL	5	7280.8 a	1727.56	3/5	440.411 b	3.277
Securos	Fiberwire	5	6733.0 ab	2009.29	3/5	573.122 a	37.31
Securos	NLL	5	6123.2 ab	2119.92	2/5	422.184 b	12.474
IMEX	Fiberwire	5	2701.6 bc	774.64	0/5	NA	
IMEX	NLL	5	2559.6 bc	1874.22	1/5	416.610 b	
FlexiTwist	Fiberwire	5	1258.6 c	324.19	0/5	NA	
Fastin	Fiberwire	5	196.0 c	82.86	0/5	NA	

**Means with the same letter are not significantly different using a .05 significance level.**

## CHAPTER IV

### DISCUSSION

#### *Acute Load to Failure*

The objectives of this study were to compare failure loads with veterinary suture anchors and a currently available human anchor in a canine femoral condyle model and evaluate the anchors loaded two different suture materials in a cyclic model. Suture anchors may be placed in the femoral condyle for repair of the cranial cruciate or collateral ligaments or the long digital extensor tendon. To the authors' knowledge, Singer et al performed the only study evaluating a veterinary suture anchor (Bone Biter) in a canine femoral condyle.<sup>8</sup> Unlike the current study, their study demonstrated no statistical difference between the cranial and caudal position of the femoral condyle. The Bone Biter suture anchor is a flange-type, sub-cortical anchor that does not have thread-interface with the cortex. Cortical thickness may have less of an impact on anchor pullout strength with the subcortical Bone Biter than a screw-type anchor. All three veterinary anchors in the current study were significantly stronger in the caudal aspect of the femoral condyle, while the Fastin showed no statistical difference. Plausible explanations include possible differences in cancellous and cortical bone mineral density in the caudal and central aspects, engagement of the *cis* and *trans*-cortex by the veterinary anchors, or both. Several studies demonstrated differences in anchor loads and



cycles to failure within different regions of the human proximal humerus which corresponded to variations in bone mineral density.<sup>23-25, 41</sup> While it is beyond the scope of this study, a relationship of suture anchor failure loads and bone mineral density in different locations within the femoral condyle may be investigated by the use of peripheral quantitative computed tomography.<sup>24</sup> The length of the veterinary suture anchors allowed them to partially or fully engage the *trans*-cortex in caudal aspect of the femoral condyle in many of the specimens. The Fastin suture anchor was not long enough to engage the *trans*-cortex, which may partially explain the lack of difference in failure loads between positions with this anchor. While engaging both cortices of the femoral condyle increases the failure loads, caution should be used in selecting anchor length and pre-drilling to avoid damage to the caudal and cranial (if present) cruciate ligaments. The Fastin is inserted to a depth that places the eyelet below the level of the cortex, which reduces soft-tissue irritation. However, that feature minimizes the threads that engage the cortex and may lower failure loads. Mahar et al reported that anchors inserted deeper in the human proximal humerus had more migration and no improved strength over anchors at standard depth.<sup>42</sup> The anchors were placed in the cranial and caudal aspect of the femoral condyle in the ALF portion of this study to maximize the use cadaveric limbs. However, in clinical application for CCL deficiency, anchor placement should be in the caudal aspect of the femoral condyle.

In the current study, the mean ALF for the Securos 3.5mm suture anchor were 611.70 ±55.68N and 1192.74 ±105.7N in the cranial and caudal aspect of the femoral condyles, respectively. These values are statistically different. Balara et al reported a failure load

of  $385 \pm 30\text{N}$  in the proximal canine humerus.<sup>4</sup> Since the time of their study, Securos has modified the 3.5mm anchor by increasing the length from 16mm to 19mm, which should increase failure loads, as well as modifying the eyelet. The current study yielded statistically different failure loads for the IMEX 4.0mm anchor of  $498.62 \pm 112.75\text{N}$  and  $736.79 \pm 86.65\text{N}$  in the cranial and caudal aspects of the condyle, respectively. Robb et al reported a combined load to failure of IMEX 4.0mm anchor in the proximal and distal tibial metaphyses of  $661 \pm 163\text{N}$ .<sup>2</sup> The current study demonstrated statistically different failure loads for the FlexiTwist 3.5mm anchor of  $582.58 \pm 80.29\text{N}$  and  $1156.77 \pm 45.1\text{N}$  cranial and caudal aspects of the femoral condyle, respectively. To the authors' knowledge, there are no published studies reporting the failure loads of the FlexiTwist suture anchor. This study demonstrated statistically similar failure loads for the Fastin 4.0mm of  $359.86 \pm 68.55\text{N}$  and  $277.96 \pm 39.74\text{N}$  in the cranial and caudal aspect of the condyles, respectively. Barber et al reported acute loads to failure of 431-449N in fresh porcine femurs.<sup>43</sup>

### ***Suture Materials***

The suture is a component in a suture anchor construct that may fail. An objective of this study was to compare 27kgt NLL secured with two steel crimp-clamps and 5 USP Fiberwire secured with a knot. It has been recommended that a total of seven throws (1 surgeon's knot followed by 4 overhand throws) be utilized to achieved maximum knot security with 2 USP Fiberwire.<sup>40</sup> To the author's knowledge, the ideal number of throws for 5 USP Fiberwire has not been published. Differences in suture anchor eyelet size present a challenge in selecting suture size. The 3.5mm FlexiTwist and Securos anchors

will accommodate 36kgt NLL, while the IMEX 4.0mm anchor will not. The human anchor selected, Fastin 4.0mm, has a small eyelet that will not accommodate 27kgt NLL. While it did accommodate 5 USP Fiberwire, it is designed for a 2 USP suture. Friction while placing the Fiberwire may have created defects that lowered the cycles to failure. Securos does not recommend using 27kgt NLL with 36kg crimp-clamps. However, this and previous studies demonstrate successful employment of this combination.<sup>35,37,44</sup> Preliminary tests with a single crimp-clamp all failed by the NLL pulling through the crimp. Following application of a second crimp-clamp, all NLL failed at the eyelet with no slippage through the crimp. Two studies report successful use of 27kgt NLL with a single crimp-clamp.<sup>35,44</sup> Differences in the current study include the use of Securos NLL rather than Mason Hard Type Leader Material (Mason Tackle Company, Otisville, MI) and manufacturer changes in the crimper device, which limit the maximum pressure applied to the crimp-clamp. With the current materials, use of two crimp-clamps is advised.

### ***Cyclic Testing***

The exact strength needed to stabilize the canine CCL deficient stifle is unknown. Ultimate forces of approximately 700N and 1300N have been reported in intact CCLs of Labrador Retrievers and mixed-breed dogs, respectively.<sup>45,46</sup> Caporn and Roe estimated that the canine CCL can be estimated to resist loads of 50N at a walk and maximum loads of 400-600N during vigorous activity.<sup>34</sup> The load applied in cyclic testing in this study ranged from 280-332N, which approaches the maximal loads that the canine CCL may

experience during vigorous activity. A higher load was selected to achieve failure in the majority of the constructs and provide a basis for comparison in performance. However, the load selected is higher than might be expected for typical activity in the post-operative patient.

In the cyclic testing, four statistical categories were identified, which are summarized in Table 3. The constructs in order of most statistically significant number of cycles completed to least are as follows: FlexiTwist/NLL ( $7280.8 \pm 1727.56$ ) > Securos/Fiberwire ( $6733 \pm 2009.29$ ) and Securos/NLL ( $6123 \pm 2119.92$ ) > IMEX/Fiberwire ( $2701.6 \pm 774.64$ ) and IMEX/NLL ( $2559.6 \pm 1874.22$ ) > FlexiTwist/Fiberwire ( $1258.6 \pm 324.19$ ) and Fastin/Fiberwire ( $196 \pm 82.86$ ). Interestingly, the FlexiTwist anchor achieved the most cycles of all constructs with NLL and the least of the veterinary constructs with Fiberwire. The Securos and IMEX anchors each had statistically similar performance with NLL and Fiberwire (although Securos had significantly more cycles than IMEX). While FlexiTwist/NLL achieved the most cycles, all of the veterinary constructs exceeded 1200 cycles at a load of 280-332N and should be adequate for a properly confined post-operative patient. The reduced cycles to failure of the Fiberwire compared to NLL with the FlexiTwist anchor is interesting. The FlexiTwist has a narrower eyelet than the Securos, which may create more abrasion that identifies an enhanced abrasion resistance of the NLL. However, the IMEX anchor also has a narrower eyelet than the Securos and there was no statistical difference in cycles to failure between the Fiberwire and NLL with the IMEX. Additional studies to compare abrasion resistance between Fiberwire and NLL would be useful. Given the superior

performance of NLL with the FlexiTwist anchor, Fiberwire can not be recommended with this particular suture anchor. Since Fiberwire and NLL had similar results with the Securos and IMEX anchors, either suture is acceptable. The loads applied in this study exceeded the maximum recommended loads for the Fastin anchor. Additionally, this anchor may be implanted with or without pre-drilling. The Fastin anchor may experience different failure loads without pre-drilling or smaller diameter pre-drilling than the loads achieved in this study. For the constructs that completed the cyclic testing, Fiberwire had a statistically significant higher ALF (573N) when compared to NLL (416-440N). The Fiberwire completed 10,000 cycles with the Securos anchor only (3/5), while NLL completed the cycles with FlexiTwist (3/5), Securos (2/5) and IMEX (1/5).

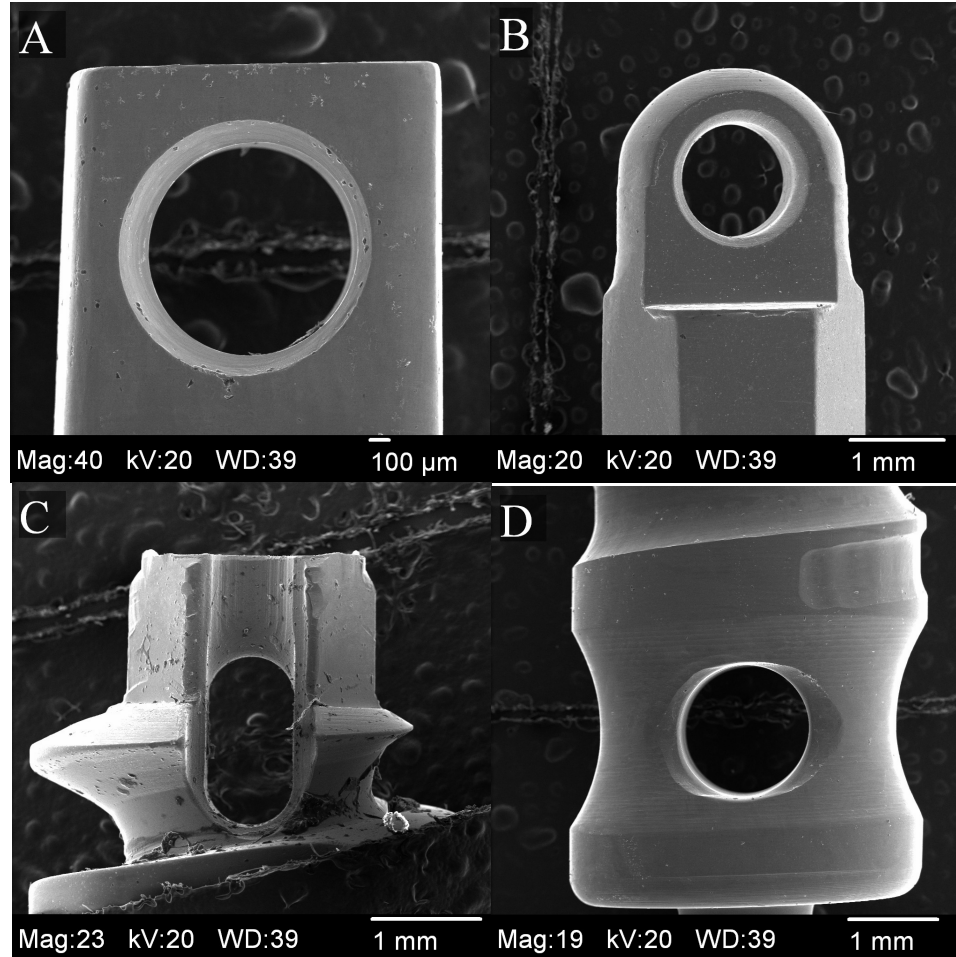
### ***Limitations***

Limitations in this study include low numbers of tested specimens, use of dry and unsterilized suture material and large standard error in cycles to failure. The number of samples tested in both objectives was limited by the requirement for a large number of cadaveric femurs. Cyclic testing of the constructs in a fluid environment will reduce friction, increase heat dissipation and should increase the cycles to failure.<sup>27</sup> The tested materials in a moist, in vivo environment should have better performance than in the current study. As reported by Banwell et al, conflicting data exist regarding the effect of various sterilization methods on NLL.<sup>35</sup> Therefore, we opted to utilize non-sterilized suture specimens. Despite large standard error in the cyclic testing treatment groups, statistical significance was achieved. The Fiberwire was all from the same lot and NLL

was from a single spool. The sutures and suture anchors were handled with great care, but damage may still have occurred during implantation. Small defects on the suture anchor eyelets from manufacturing or handling may create friction leading to early suture failure. Scanning electron microscopy (SEM) images of the eyelets of tested anchors demonstrate small defects on the eyelets' surface that may create suture abrasion (Fig 5). Microscopic imaging of the eyelets before and after testing may have allowed conclusions regarding eyelet defects and cycles to failure.

### ***Conclusions***

In ALF testing, the veterinary anchors tested all exceeded the human anchor in the caudal aspect of the femoral condyle. While there was no statistical difference detected in any of the anchors in the cranial aspect of the condyle, the caudal aspect is the appropriate insertion point for collateral or cruciate ligament deficiencies. In cyclic testing, all veterinary suture/anchor combinations exceeded the human suture anchor construct of Fastin/Fiberwire, with the exception of FlexiTwist/Fiberwire, which was statistically similar. Fiberwire and NLL had statistically similar cycles to failure with Securos and IMEX, but NLL achieved more cycles than Fiberwire with the FlexiTwist anchor. For constructs that completed the cycles, Fiberwire was statistically stronger in ALF than NLL. Both 27kgt NLL secured with two crimp-clamps and 5 USP Fiberwire secured with a knot are suitable for use with the 3.5mm Securos anchor and 4.0mm IMEX anchor in the femoral condyle. The 27kgt NLL appears to be a more suitable material than 5 USP Fiberwire for the 3.5mm FlexiTwist anchor.



**Fig 5. SEM images of the tested suture anchor eyelets: (A) IMEX, (B) FlexiTwist, (C) Fastin, (D) Securos. Note: the Fastin anchor was explanted and has defects from the explantation procedure.**

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VITA

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Scope and Method of Study: Biomechanical analysis of acute load to failure (ALF) of three veterinary and one human suture anchor and cyclic load to failure with two suture-material/suture anchor constructs in cadaveric canine femoral condyles. Three veterinary and one human suture anchor were placed in the cranial and caudal aspects of the femoral condyle and subjected to a 0° ALF. The anchors were loaded with 5 USP Fiberwire or 27 kilogram test nylon leader line and subjected to 90° cyclic testing for 10,000 cycles followed by an ALF.

Findings and Conclusions: The veterinary anchors had higher ALF in the caudal aspect of the condyle, while position had no effect on the human anchor. In the caudal aspect of the condyle, all veterinary anchors had higher ALF than the human anchor. Differences were detected between anchor and suture brands in cycles to failure and in post-cycling ALF.

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