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Biomechanical evaluation of medial and lateral approaches for experimentally created medial condylar fractures of the equine third metacarpal bone

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BIOMECHANICAL EVALUATION OF MEDIAL AND LATERAL APPROACHES FOR EXPERIMENTALLY CREATED MEDIAL CONDYLAR FRACTURES OF THE EQUINE THIRD METACARPAL BONE

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DEDICATION

I would like to dedicate this work to:

Dr. Gary A. Sod, and Dr. Laura M. Riggs for their encouragement, support, and belief in me throughout the years and this program.

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The author would like to thank her major professor, mentor, and friend, Dr. Gary A. Sod for his continued patience and guidance throughout her graduate program. Without his constant encouragement, confidence, hours spent in necropsy helping prepare samples and support throughout this program the author could not have made it through this program.

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ABSTRACT

Objective -To compare the compression produced in reduction of experimentally created medial condylar fractures using lag screw fixation with medial vs. lateral approach, and to determine the maximum torque at screw failure.

Materials and Methods- Twelve (12) pairs (left and right) 3rd metacarpal bones (MC3) were collected from adult (2-7 years) Thoroughbreds euthanized for reasons unrelated to orthopedic disease. Complete parasagittal medial condylar osteotomies were created at a measurement of 9, 13, and 21 mm axial to the epicondylar fossa on four pairs each of cadaveric MC3 bones resulting in fracture fragments measuring 8, 12, and 20 mm in thickness. For each pair of cadaveric MC3, a lateral or medial approach was randomly selected to repair the condylar fracture using a single 4.5 mm AO cortical screw. Each repair was tested for fracture plane compression and screw torque to failure.

Results-There was no significant difference in compression between the medial and lateral approaches for the 8 or 12-mm fragment groups. There was significantly more compression generated in the lateral approach when compared to the medial approach for the 20-mm fragment group. Failure occurred at significantly lower torque in the 8-mm group. There was no significant difference between medial and lateral approach in torque to failure for the 12 and 20-mm groups.

Conclusion-Based on this data we have concluded that there was no significant difference in torque to failure between a medial vs. lateral approach for the 12 mm fragments but there was a

significant difference for the 8 mm fragments and that a lateral approach may be acceptable for the repair of medial condylar fractures in 12-mm or thicker fragments. The compression achieved by a medial approach was not significantly greater for the 8, 12 or 20-mm groups.

Clinical Relevance- Based on our results the 20 mm size fragments reaches a higher compression at a faster rate when compared to the 8 and 12 mm size fragments. We recommend using caution when repairing medial condylar fractures with a lateral approach for fragment sizes measuring 8-mm thick. The smaller fragment torque to failure was low and not much higher than the insertional torque. Failure resulted from the screws stripping in the bone fragment. The screws in the thicker fragments (12 and 20 mm) engage more bone and have a higher torque to failure as a result.

CHAPTER 1

GENERAL INTRODUCTION

1.1 The Metacarpo(-tarso)phalangeal Joint

The equine metacarpophalangeal and metatarsophalangeal joints (fetlock joints) are made up of the third metacarpal bone, both proximal sesamoid bones, and the first phalanx. It is classified as a ginglymus (hinged) joint, thus it has only one axis of movement in the sagittal plane through flexion and extension. This limitation is due to the presence of the prominent medial and lateral collateral ligaments of the fetlock. It is the one joint in the horse with the highest range of motion ranging from 120° of extension to 120° of flexion. This is best appreciated during athletic activity such as racing or jumping (Bertone, 2004). In the standing horse, the fetlock is supported by the suspensory ligament, intersesamoidean ligament, distal sesamoidean ligaments, deep and superficial flexor tendons, the common digital and lateral digital extensor tendons, and the medial and lateral collateral ligaments.

The locomotor functions of the digit and fetlock include the flexion essential to movement, extension when the foot is off the ground, the diminution of concussion when the hoof contacts the ground, and the recovery from extension (Kainer, 2002). The normal movemements of the digit were elaborated by Rooney (1974). When the body weight of the horse is applied to the leg, the fetlock joint extends and translates downward as a result of distal interphalangeal joint motion. With extension, the cannon bone and the first phalanx (P1) tend to rotate about their long axes in a medial to lateral direction. As the limb is unloaded the fetlock joint begins to flex, allowing the dorsal angle of the fetlock to open, and the pastern elevates because of the distal interphalangeal joint motion in the opposite direction. During this opening and elevating movement, the cannon bone and the first phalanx again rotate, however this time about their long axes in a lateral to medial direction. This movement necessitates that the two bones must move in synchrony.

1.2 The Equine Third Metacarpal Bone

The MC3 is a substantial bone, measuring approximately 26 cm in length from the midsagittal ridge to the carpometacarpal joint. At the distal metaphysis, it is approximately 50 wide from the lateral to medial supracondylar fossae. Cortical and trabecular densities for equine bone have been previously measured and determined to be 1035.25 mg hydroxyapatite/ml and 1048.55 mg hydroxyapatite/ml, respectively (Furst et al, 2008). Mean tensile strengths and modulus elasticity have been reported to be 2137.9 to 2295.7 MPa (El Shorafa et al, 1979) and 16.3 GPa (Batson et al, 2000), respectively.

1.3 Pathophysiology of Condylar Fractures

It has been theorized that condylar fractures result due to asynchronous movement between the cannon bone and the proximal phalanx. The asynchronous movement leading to lateral condylar fractures was described (Alexander and Rooney 1972, Rooney 1974) as the proximal phalanx remains stationary with the fetlock in a fully dorsiflexed position while the cannon bone rotates in a lateral to medial direction, owing to fracture of the lateral condyle as it strikes the stationary lateral aspect of proximal P1. This asynchrony would be expected near the end of the support phase of the stride when the fetlock joint dorsal angle is opening (Rooney

1974). No work has been performed to support this theory, however more recent efforts have been made to determine predisposing factors associated with condylar fracture formation.

Recent work evaluating the pathophysiology of the development of condylar fractures suggests that they originate from microfractures in the subchondral bone that develop secondary to repetitive loading from exercise related stress remodeling (Fig. 1.1A and 1.1B), and is associated with significant cyclic shear loading of the condyle in dorsopalmar (-plantar) bending which then leads to propogation of a dominant crack proximally (Radtke et al. 2002). Ultrastructural work further revealed that these microfractures develop into clusters and most notably in the palmar aspect of the condyle; these macrofractures propogate along cement lines and interfaces between bone lamellae (Fig. 1.2A and 1.2B) (Stepnik et al. 2004).

Condylar fractures involving the third metacarpal and metatarsal bones have long been recognized as a significant problem among racehorses, and in severe cases can require euthanasia (Rooney 1974, Pool 1990, Wilson et al 1993, Stover 1994, Kane et al 1996, Kane et al 1998). Severe condylar fractures account for 20% (Johnson et al, 1994) to 25% (McKee, 1995) of catastrophic injuries in Thoroughbred racehorses in California and the United Kingdom, respectively. Condylar fractures of the left third metacarpal bone are the most commonly noted site in Thoroughbred racehorses, accounting for 39% to 57.1% of all condylar fractures (Rick et al. 1983, Ellis et al. 1994); whereas there appears to be a more even distribution with regards to left vs. right in Standardbred racehorses. This increased prevalence for occurrence in the left forelimb among Thoroughbred racehorses has been theorized to be due to the direction in which

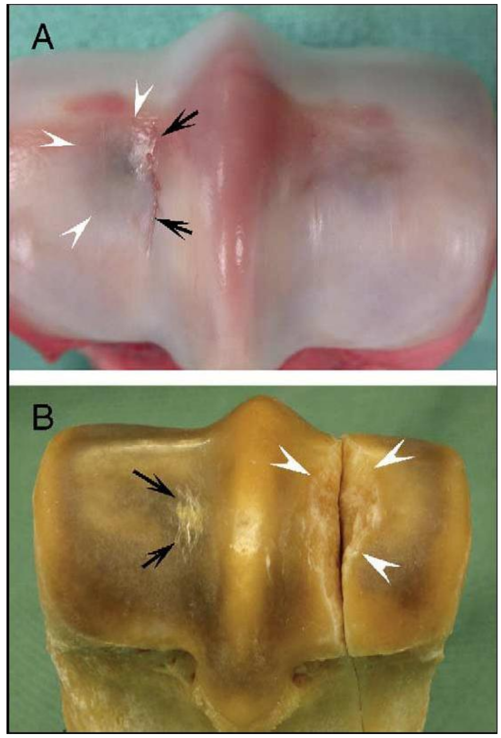

Figure 1.1. Photographic view of the palmar distal region of the distal joint surfaces of the MC3 bones from a 3-year-old male Thoroughbred. (A) In the right MC3 bone, a parasagittal defect can be seen in the articular cartilage of the lateral condylar groove (black arrows). Adjacent to this lesion is circular area of cartilage degeneration in the lateral condylar (white arrow heads). A similar lesion is also present to a lesser extent in the medial condyle. Parasagittal linear wear lines in the articular cartilage are also visible. (B) In the left MC3 bone, a parasagittal condylar fracture is present in the lateral condylar groove (white arrowheads). In the medial condylar groove, a branching array of subchondral cracks can be seen (black arrows). In the lateral condylar groove, comminution of this subchondral bone developed during propagation of the fracture. The articular cartilage was removed by treatment with 0.1 M NaOH to permit the articular surface of the subchondral bone to be examined. (Pictures taken from Radtke et al. 2002)

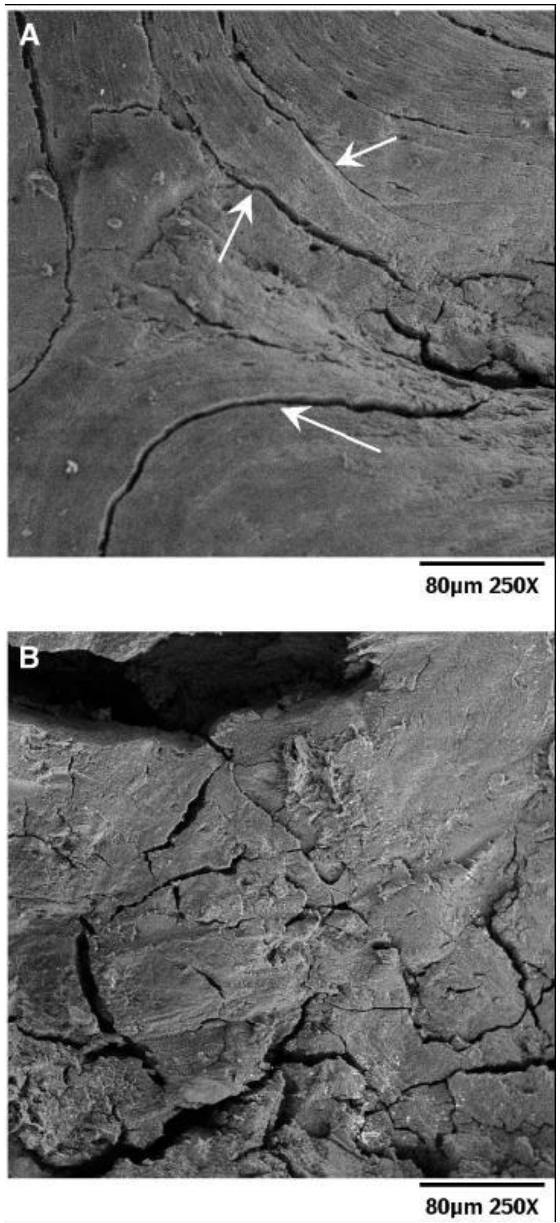

Figure 1.2. Scanning electron microscopic views of the failure surface from a 5-year-old racing Thoroughbred with a catastrophic MC3 lateral condylar fracture. (A) In adapted palmar subchondral bone from the distal end of the MC3 bone, microcracks were often seen propagating along cement lines and the interfaces between bone lamellae. (B) In adapted dorsal subchondral bone from the distal end of the MC3 bone, arrays of branching microcracks were also seen, which were similar to the palmar/plantar region of the condyle. (Pictures taken from Stepnik et al. 2004)

racehorses are run, which places the left limb on the inside, thus increasing the load placed on this limb, when compared to the right limb. This same observation has been made in England, however one study reported that the majority of condylar fractures were incurred during training, which involves galloping mainly straight distances (Ellis et al. 1994).

Condylar fractures can occur in either the lateral or medial condyle; however, fractures of the lateral condyle are the most commonly occurring type (Alexander et al 1972, Meagher 1976, Rick et al 1983, Ellis 1994, Johnson et al 1994, Bassage et al 1998, Zekas 1999, LeJeune 2003), reported as being approximately 85% in various racehorse populations (Zekas et al 1999; Bassage et al 1998). Condylar fractures are typically described as being one of four types: 1) incomplete – no evidence of joint malalignment or complete extension of the fracture through the proximal cortex; 2) complete-nondisplaced fractures – neither a step at the joint surface nor evidence of separation of the fragment proximally – although the fracture line penetrates through the cortex; 3) complete-displaced fractures – malalignment at the joint surface and abaxial displacement at the proximal cortical surface; 4) special longitudinal diaphyseal fractures – either complete or incomplete – involving the medial condyle and extending various distances up the diaphysis (Figure 1.3) (Rick et al. 1983).

Historically, an onset of severe lameness following intense exercise occurs typically either immediately following injury or within a few hours of exercise. Typical physical examination findings reveal a variable lameness which does not correlate well with severity of the fracture, as severe non-weightbearing lameness is commonly seen with incomplete, nondisplaced fractures, yet a milder weightbearing lameness is

Figure 1.3. Standard dorso-palmar radiographic images of a Type 1 (A), Type 2 (B), Type 3 (C), and Type 4 (D) condylar fractures.

typically appreciated with displaced condylar fractures (Richardson, 2006). Additional findings include variable effusion of the metacarpo- or metatarso-phalangeal joint of the affected limb, elicitation of pain on flexion of the joint, and either the presence or absence including the lateromedial and dorsopalmar (-plantar) are diagnostic, however it is strongly recommended that a horizontal dorsopalmar projection with the fetlock placed in slight flexion be performed highlighting the palmar aspect of MC3/MT3 to rule out the presence of palmar comminution, a common finding associated with condylar fractures (Richardson, 2006).

Treatment goals for type 1, 2, and 3 condylar fractures are aimed at either conservative management consisting of prolonged periods of stall confinement, immobilization via external coaptation by heavy bandaging or distal limb casting (Meagher, 1976, Rick, et al. 1983), or surgical reduction; however, surgical reduction is typically recommended for the best possible prognosis. Surgical repair is most commonly performed through fracture fragment fixation via placement of either 4.5-mm or 5.5-mm AO cortical bone screws (Synthes, Paoli, PA) using the lag screw principle to allow for adequate compression and allows for fracture healing as well as to align the articular surfaces of the fracture to minimize the chances for development of degenerative joint disease (Richardson. 2006).

1.4 The AO/ASIF

The Arbeitsgemeinschaft für Osteosynthesefragen (Association for the Study of Internal Fixation) was formed in 1958 to further research into the concepts of immediate functional rehabilitation after rigid internal fixation. They have done this through research into osteosynthesis, and the development of instruments and implants that of crepitation on palpation of the limb. Radiographic evaluation of the fetlock joint typically confirms the presence of condylar fracture. Traditional radiographic projections promote rigid internal fixation. This has evolved into a worldwide organization evaluating not only the development of implants in human orthopedics, but as well in veterinary orthopedics (Colton. 1981).

1.4.1 The 4.5-mm AO Cortical Screw

The 4.5-mm AO cortical screw is made of implant quality 316L stainless steel, which contains roughly 62.5% iron, 17.6% chromium, 14.5% nickel, 2.8% molybdenum, and minor alloy additions. It is meant to be resistant to corrosion due to its low carbon content (Texhammar. 1981). This screw was designed for use in the lag principle or for plate fixation. It is a fully threaded non-self-tapping screw. In cortical bone, the screw has a holding strength of approximately 2500 N.

The dimensions of the screw are as follows:

Head diameter: 8.0-mm

Hexagonal socket width: 3.5-mm

Core diameter: 3.0-mm

Thread diameter: 4.5-mm

Pitch: 1.75-mm

Glide hole diameter: 4.5-mm

Thread hole diameter: 3.2-mm

Tap diameter: 4.5-mm

The 4.5-mm cortical screw also has characteristics similar to that of the other large AO/ASIF screws including first a spherical screw head which ensures optimal screw to plate contact even if a screw is placed at an angle. Second, the AO/ASIF screw thread which is characterized as a buttress thread profile which allows excellent holding in cortical bone due to the shallow thread and fine pitch leading to a large screw-to-bone contact area. The third common characteristic is the core diameter which is the solid stem of the screw from which the threads protrude.

1.4.2 The Lag Screw Principle

The lag screw was defined by Perren and Buchanan (1981) as *the production of interfragmental compression by compressing the bone under the screw head against the fragment in which the screw threads are anchored.* The steps for proper lag screw principle for a 4.5-mm cortical screw are as follows:

1. The fracture is reduced and held with reduction forceps.

2. The glide hole is drilled through the near cortex or fragment with a 4.5-mm drill bit protected by the drill sleeve.

3. The 3.2-mm drill sleeve is then inserted into the glide hole until it comes into contact with the far cortex or the parent bone.

4. The thread hole is then drilled in a coaxial direction in the trans-cortex or parent bone with a 3.2-mm drill bit.

5. The cis-cortex is countersunk with the large countersink.

6. Screw length is then measured with the large depth gauge

7. The thread hole is then tapped with a 4.5-mm bone tap. By turning two turns clockwise and one-half turn counterclockwise, the cut bone is directed into the channels of the cutting flutes to be removed.

8. A 4.5-mm cortical screw is inserted with the large hexagonal screwdriver, ensuring engagement of the trans cortex.

1.5 Repair of Medial Condylar Fractures

Medial condylar fractures typically differ from lateral condylar fractures by having a longitudinally originating configuration that typically does not toward the ipsilateral cortex. Medial condylar fractures tend to be more complex as they classically spiral as it propagates from the articular surface. These fractures typically have a configuration where the dorsal cortical fracture line propagates medially and the palmar/plantar cortical fracture line propagates laterally. Thus the fracture plane propagates counterclockwise when views from the distal aspect of the left limb (Turner 1977; Barr 1989; Ellis 1994). Traditionally these fractures have been repaired with the screws being placed medially. The two fragments in a spiraling medial condylar fracture are approximately the same size, thus a medial approach offers no biomechanical advantage over a lateral approach. It is technically easier to perform surgery with the affected limb uppermost (Auer 2006) but this requires a lateral approach. Repair of a dorsomedial-palmaro/plantarolateral spiral configuration fracture from the medial aspect with multiple screws in lag fashion risks screw interference with the soft tissue structures on the palmar/plantar aspect of MC3/MT3 and the second metacarpal/metatarsal bone may prevent insertion perpendicular to the fracture plane (Richardson 1990). By inserting screws from the lateral aspect, the contour of the fracture will necessitate that the holes are drilled from a more dorsal direction, naturally taking the screw heads away from the palmar/plantar structures of the leg. The advantage of direct fracture observation is the ability to insert screws perpendicularly to the fracture plane, in a biomechanically optimal position, along the entire length of the fracture (Rick, O'Brien et al. 1983; Smith, Greet et al. 2009; Wright and Smith 2009). In two case series involving Thoroughbred racehorses with medial condylar fractures, it was concluded the repair of propagating sagittal and spiral fractures of the medial condyle of MC3/MT3 with diaphyseal involvement through a lateral approach with periosteal reflection permitted stable fixation with minimal complications (Smith 2009, Wright 2009).

CHAPTER 2

COMPARISON OF COMPRESSION OF VARYING FRAGMENT THICKNESSES OF EXPERIMENTALLY CREATED MEDIAL CONDYLAR FRACTURES OF THE EQUINE THIRD METACARPAL BONE WITH A 4.5-MM AO CORTICAL BONE SCREW USING A MEDIAL VS. LATERAL APPROACH

2.1 Introduction

Fractures of the condyles of the third metacarpal (MC3) or metatarsal (MT3) bones are relatively common injuries in Thoroughbred racehorses and are the most common long bone fracture of horses in training (Ellis 1994; Wright and Smith 2009). These fractures occur more frequently in the lateral condyle while medial condylar fractures typically originate closer to the sagittal ridge and differ from lateral condylar fractures by having longitudinally originated configuration that typically does not extend towards the ipsilateral cortex and classically spirals as it propagates from the articular surface (Rick, O'Brien et al. 1983; Bassage and Richardson 1998; Smith, Greet et al. 2009). Medial condylar fractures are traditionally repaired through a medial approach; however recent publications suggest a lateral approach is acceptable clinically and is technically easier due to patient positioning(Wright and Smith 2009).

Recently, two case series have been published which describe lateral approach for repair of medial condylar fractures. These investigations had positive results and stated that fractures of medial MC3 or MT3 can be repaired by a lateral approach without greater complication rates or negative effect on outcome associated with the side of approach. However to our knowledge no controlled studies have been published comparing the biomechanical differences between lateral and medial approaches for repair of medial condylar fractures. Our study will compare the compression values of a single AO cortical screw placed in lag fashion using a medial vs. lateral approach.

2.2 Hypothesis and Objectives

We hypothesized that there will not be any significant difference in compression values when repairing an experimentally created medial condylar fracture of equine third metacarpi with lag screw fixation from a lateral approach versus a medial approach.

2.3 Materials and Methods

Twelve (12) pairs (left and right) of MC3 bones were collected from adult (2-7 years) Thoroughbreds euthanized for reasons unrelated to orthopedic disease. Each MC3 was wrapped in saline (0.9% NaCl) soaked towels with each pair identified and stored in a freezer at -20 C. The MC3 were thawed at room temperature for 24 hours prior to testing. For the preparation of the fracture, the cadaveric metacarpal bone was secured in a positioning jig and a lapidary table saw (Covington Slab Saw) with a blade thickness of 0.8 mm was used to create a medial fracture on the condyle at the level of the epicondylar fossa. The limbs were randomly divided into three groups (four pairs each). Complete parasagittal condylar osteotomies were created at 9, 13, or 21 mm axial to the medial epicondylar fossa resulting in fracture fragments measuring 8 (group 1), 12 (group 2), and 20 mm (group 3). A transverse cut was made proximal to the condyle to make a complete fracture model. In each group, a lateral or medial approach was randomly selected for each limb in the pairs, to repair the medial condylar fracture.

A Tekscan k-scan 6220 sensor with a 2 mm stay pin hole and a center hole to accommodate screws was placed in the osteotomy plane between the fracture fragments and connected to a computer. The MC3 was secured in the vice press and a 4.5 mm AO (Synthes, Paoli, PA) screw was placed in routine lag fashion through the epicondylar fossa of each bone. The screw measured 60 mm in length was positioned and tightened with a digital torque wrench to an insertional torque of 5.4 N m. The compression pressure and force was acquired at a rate of 100 frames per second via the I-Scan System during tightening and was recorded for data analysis (Figure 2.1). Results were compared with a student t-test for paired samples and analyzed using Prism software. P-value was set at <0.05.

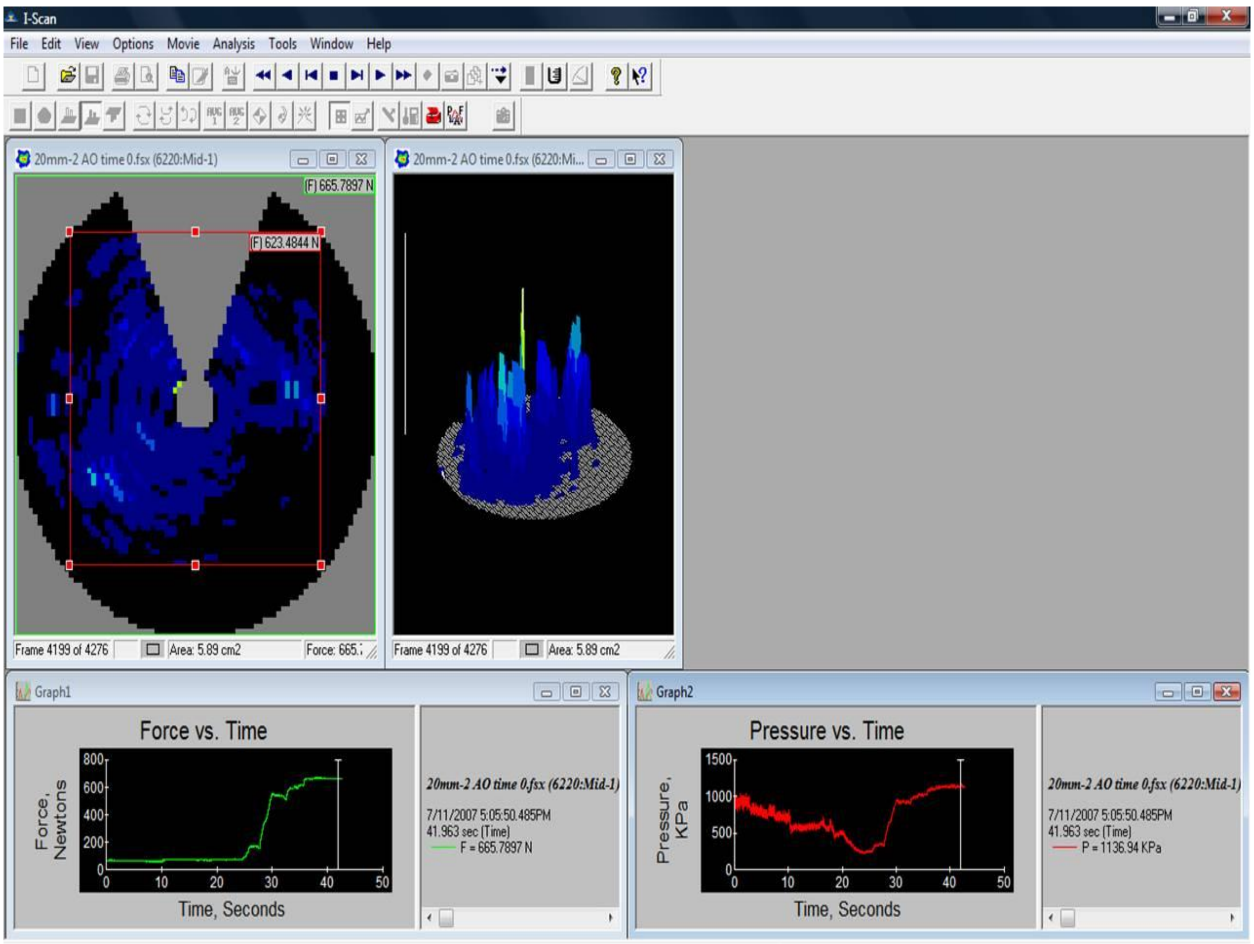

Figure 2.1 Example of a graph generated by the I-scan system recording software during the tightening of an AO screw to repair an experimentally created medial condylar fracture in an equine MC3 bone. Data was collected at a rate of 100 frames per second.

2.4 Results

There were no significant differences in compression (kPa) between medial and lateral approach for the 8 mm ($p=0.42$) or 12 mm thick fragments ($p=0.65$) (Tables 2.1 & 2.2; Figures 2.3 & 2.4). For the 20 mm fragment group, the lateral approach resulted in significantly greater compression when compared to the medial approach ($p=0.023$) (Table 2.3; Figures 2.3 & 2.4).

Table 2.1 Compression values during tightening of a 4.5 mm AO screw placed in lag fashion for reduction of an 8 mm thick experimentally created medial condylar fracture in equine MC3 bones.

Approach	Leg	Area (mm)	Force (N)	Pressure (kPa)
Medial				
	R	452	734.8	1625.6
	L	387	1242.7	3211.0
	R	495	1402.9	2834.1
	R	531	1979.2	3727.3
Standard Deviation		466.3 ± 61.9	1339.2 ± 512.6	2849.5 ± 894.3
Lateral				
	L	444	855.2	1926.2
	R	364	471.1	1294.1
	L	321	343.7	1070.7
	L	419	572.4	1366.0
Standard Deviation		387 ± 55.3	560.6 ± 217.6	1414.3 ± 363.7

R=right, L=left

Table 2.2 Compression values during tightening of a 4.5 mm AO screw placed in lag fashion for reduction of a 12 mm thick experimentally created medial condylar fracture in equine MC3 bones.

Approach	**Leg**	**Area (mm)**	**Force (N)**	**Pressure (kPa)**
Medial				
	R	485	1373.1	2831.1
	L	511	1896.9	3712.1
	L	393	783.3	1993.0
	R	447	1174.7	2627.9
Standard Deviation		459.0 $\pm$ 51.3	1307.0 $\pm$ 463.4	2791.1 $\pm$ 710.3
Lateral				
	L	526	1398.1	2658.1
	R	469	1534.9	3272.7
	R	378	675.2	1786.2
	L	412	1047.7	2543.0
Standard Deviation		446.3 $\pm$ 65.1	1164.0 $\pm$ 385.1	2564.5 $\pm$ 610.7

R=right, L=left

Table 2.3 Compression values during tightening of a 4.5 mm AO screw placed in lag fashion for reduction of a 20 mm thick experimentally created medial condylar fracture in equine MC3 bones.

Approach	**Leg**	**Area (mm)**	**Force (N)**	**Pressure (kPa)**
Medial				
	R	509	617.9	1213.9
	L	473	404.1	1854.4
	R	406	255.4	629.1
	R	452	477.9	1057.4
Standard Deviation		460.0 $\pm$ 43.0	438.8 $\pm$ 151.0	938.7 $\pm$ 253.5
Lateral				
	L	556	1091.8	1963.7
	R	504	781.1	1727.1
	L	472	547.5	1297.3
	L	517	974.4	2086.4

Standard Deviation		512.3 ± 34.8	848.7 ± 238.2	1639.5 ± 366.7

R=right, L=left

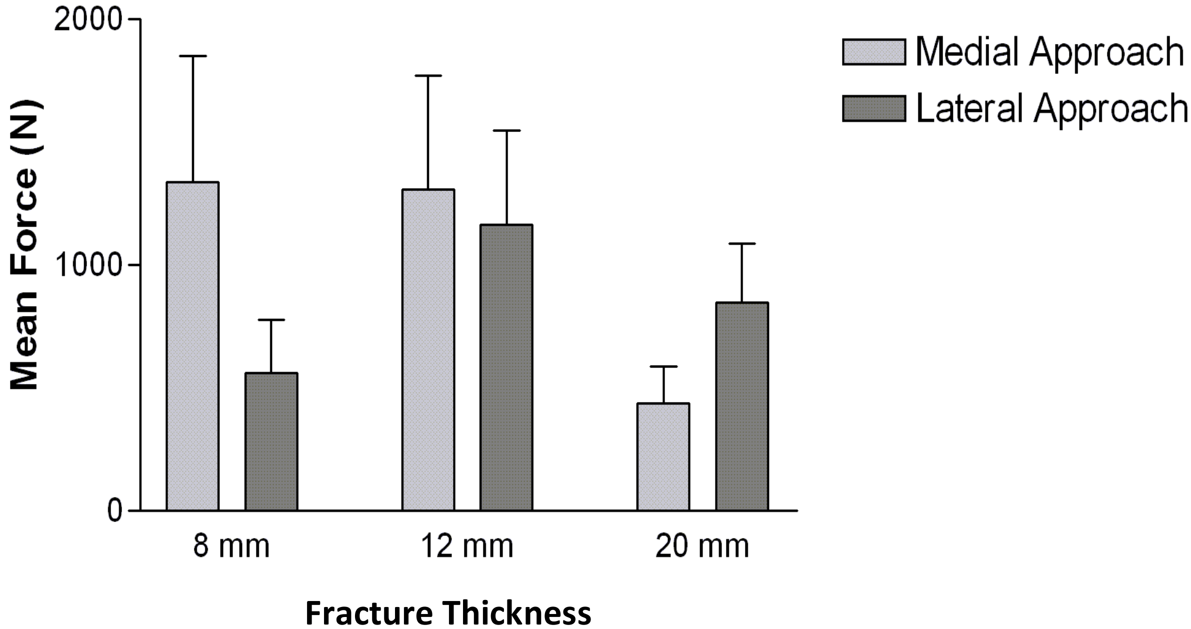

Figure 2.2 Mean fracture plane force values obtained during tightening to 4.5 N-m of a 4.5 mm AO screw placed in lag fashion for reduction of experimentally created medial condylar fractures of equine third metacarpi.

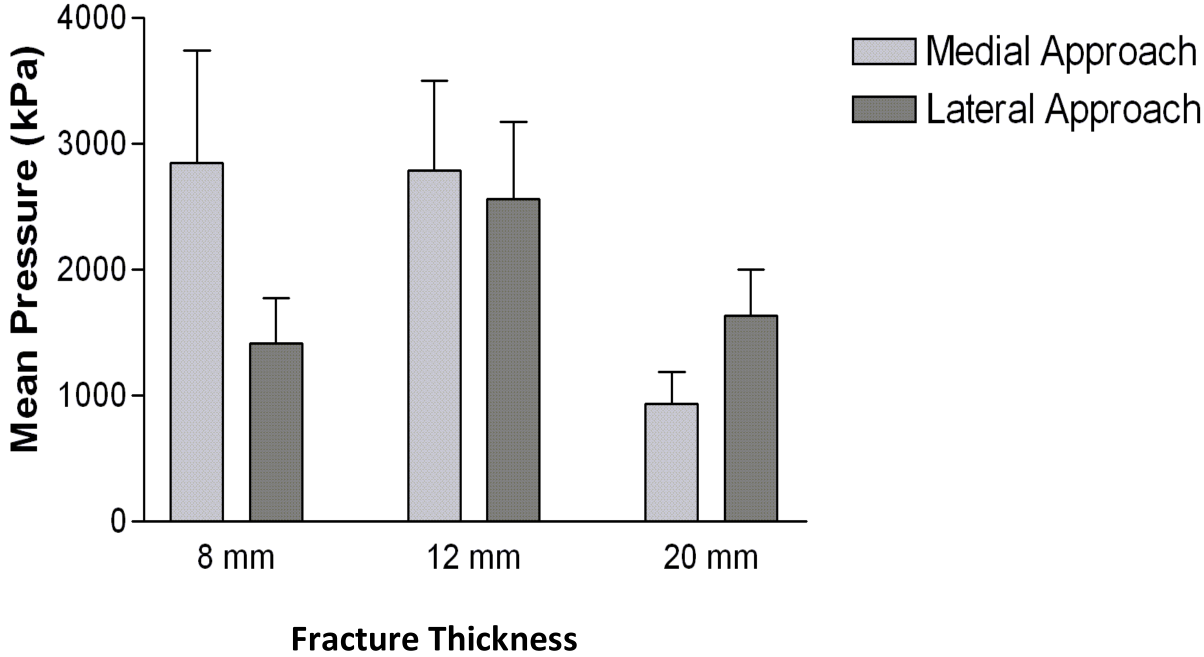

Figure 2.3 Mean fracture plane pressure values obtained during tightening to 5.4 N-m of a 4.5 mm AO screw placed in lag fashion for reduction of experimentally created medial condylar fractures of equine third metacarpi.

2.5 Discussion

Adequate fracture compression using lag screw technique for the repair of condylar fractures requires substantial engagement of the bone by the screw in the thread hole. The compression achieved is related to the number of threads engaging the bone although a minimum number of threads and thus minimum value for "adequate" compression is not defined for this fracture configuration. The 4.5 mm cortical screw used here has a thread pitch, the distance from one thread to the next, of 1.75 mm. Given this value, a thread hole created in 8, 12 and 20 mm fragments will engage 4.6, 6.9 and 11.4 threads, respectively, a step-wise increase of 50% and 67%.

The results of this study indicate that there is no significant difference in compression values between a medial and lateral approach for a medial condylar fracture with an 8 or 12 mm fragment. This result is in agreement with our hypothesis and appears to indicate that even small fracture fragments (8-12 mm) will engage enough of the screw to produce compression at an insertional torque of 5.4 N-m. This may allow for adequate compression and thus fracture healing without a gap at the articular surface.

The 20 mm fracture fragment also demonstrated adequate compression from both the medial and lateral approach. Interestingly the medial force and pressure were actually much lower, by approximately half, than the lateral approach and these results were statistically significant. Greater compression was expected with the medial approach due to the number of screw threads the bone would engage. However, that was not the case and cannot be easily explained. One possibility is that there is a threshold amount of screw engagement, to the point that compression can no longer increase. These findings in the larger fracture fragment bring up new questions to be answered. While it doesn't appear to be clinically relevant because of the substantial values obtained, it is an interesting phenomenon. Potentially, there is a point in the ratio of fracture fragments at which the bone and screw interface have a physical property change and different biomechanical principles are in effect. This theory remains to be proven.

It appears that the use of a lateral approach for the repair of medial condylar fractures is acceptable with regards to the compressive forces applied at the distal screw. This is an important point of repair for this fracture configuration and is vital for the congruency at the articular surface. Lateral repair of medial condylar fractures are technically easier to perform and allow for more direct approach to the fracture without interference by other structures. With increased use in clinical cases, we may find that this approach improves prognosis.

CHAPTER 3

COMPARISON OF TORQUE TO FAILURE FOR VARYING FRAGMENT THICKNESSES OF EXPERIMENTALLY CREATED MEDIAL CONDYLAR FRACTURES OF THE EQUINE THIRD METACARPAL BONE WITH A 4.5-MM AO CORTICAL BONE SCREW USING A MEDIAL VS LATERAL APPROACH

3.1 Introduction

Fractures of condyles of the third metacarpal (MC3) or Metatarsal (MT3) bone are relatively common injuries in Thoroughbred racehorses. They are amongst the most common long bone fractures of horses in training (Ellis 1994; Wright and Smith 2009). These fractures occur more frequently in the lateral condyle. Medial condylar fractures originate closer to the sagittal ridge and differ from lateral condylar fractures by having longitudinally originated configuration that typically does not extend towards the ipsilateral cortex and classically spirals as it propagates from the articular surface (Smith, Greet et al. 2009) (Rick, O'Brien et al. 1983; Bassage and Richardson 1998) Typically when screws are inserted in lag fashion the smaller bone fragment contains the glide hole and is compressed to the larger bone fragment. Stability is achieved by compression with a screw that is oriented perpendicular to the fracture(Smith, Greet et al. 2009). The compression that can be achieved is related to the strength of the screw-bone construct.

Recently, case series have been published which describe lateral approach for repair of medial condylar fractures. These reports presented positive results and stated that fractures of medial MC3/MT3 can be repaired by a lateral approach without greater complication rates or negative effect on outcome associated with the side of approach. However to our knowledge no controlled studies have been published comparing lateral vs. medial approaches for repair of medial condylar fractures. Thus this study will compare the torque to failure of 4.5 mm AO cortical screws placed in lag fashion for repair of experimentally created medial condylar fractures of various thicknesses in equine MC3 bones using a medial vs. a lateral approach.

3.2 Hypothesis and Objectives

We hypothesized that there will be significant difference in measurements of torque to failure of 4.5 mm cortical screws with a medial versus lateral approach.

3.3 Materials and Methods

Twelve pairs (left and right) of MC3 bones were collected from adult (2-7 years) Thoroughbred race horses euthanized for reasons unrelated to orthopedic disease. Each MC3 was wrapped in saline (0.9% NaCl) soaked towels with each pair identified and stored in a freezer at -20 C. The MC3 were thawed for 24 hours at room temperature prior to testing. For the preparation of the fracture the cadaveric metacarpal bone was secured in a positioning jig, and a lapidary table saw (Covington Slab Saw) with a blade thickness of 0.8 mm was used to create a medial fracture of the condyle at the level of the epicondylar fossa. The limbs were randomly divided into 3 groups (four pairs each). Complete parasagittal condylar osteotomies were created at 9, 13, or 21 mm axial to the medial epicondylar fossa resulting in fracture fragments measuring 8 (group 1), 12 (group 2), or 20 mm (group 3). A transverse cut was made proximal to the condyle to make a complete fracture model (Figure 2.5). In each group, a lateral or medial approach was randomly selected for each limb in the pairs to repair the medial condylar fracture. A Tekscan k-scan 6220 sensor with a 2 mm stay pin hole and a center hole to accommodate screws was placed in the osteotomy plane between the fracture fragments and connected to a computer (Figure 2.1). The MC3 was secured in the vice press and a 4.5 mm x 60 mm length AO screw was placed in routine lag fashion through the epicondylar fossa of each bone. The screws were tightened with a torque wrench with a digital display.

After the initial torque measurements were obtained the screws were tightened to the point of failure with the digital torque wrench and that measurement was recorded and compared between fragment thicknesses (Figure 3.1). In the figure 3.1 fragment thicknesses of 12 mm and 20 mm were used with the lateral and medial approach both showing screw failure with lag screw fixation. Medial and lateral approaches were compared with a student t-test for paired samples using Prism software. The p-value was set at <0.05. The mode failure was recorded for each limb.

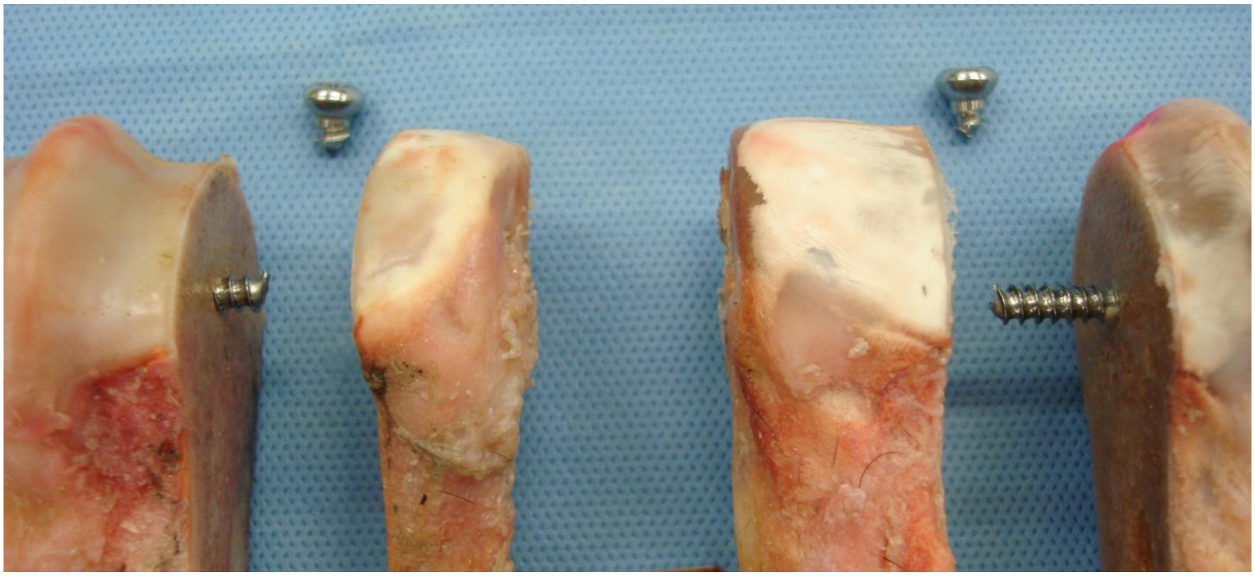

Figure 3.1 Equine cadaveric third metacarpal bones that were tested for torque to failure of experimentally created medial condylar fractures of various thicknesses repaired with a 4.5 mm AO screw placed in lag fashion. Types of failure that can occur with repair of condylar fractures include bone failure with the threads stripping or screw failure with the screw breaking at the screw head junction.

Figure 3.2 Image of the condylar region of an equine third metacarpal bone showing where a cortical screw engaged the bone with lag screw fixation of a fracture.

3.4 Results

The mean value for the torque to failure of 8 mm, 12 mm, and 20 mm fragments for the medial approach were 9.76 $\pm$ 0.33 N-m , 9.45 $\pm$ 0.73 N-m, and 10.15 $\pm$ 0.38 N-m, respectively. For the lateral approach with fragment sizes of 8 mm, 12 mm, and 20 mm the torque to failure measurements were 5.88 $\pm$ 0.19 N-m, 10.0 $\pm$ 0.30 N-m, and 10.07 $\pm$ 0.41 N-m, respectively. For the 8 mm fragment group there was a significant increase in maximum torque at failure for the medial approach when compared to the lateral approach ($p<0.000008$) while there was no significant difference between medial and lateral approach for the 12 and 20 mm fragments, $p=0.22$ and $p=0.78$, respectively.

The mode of failure was dependent on fragment thickness and approach. For the 8 mm fragment, all screws introduced through a medial approach failed by screw breakage while all screws introduced through a lateral approach failed by stripping of the screw threads (Table 3.1). For the 12 mm fragment the results were mixed (Table 3.2) and for the 20 mm fragments all screws failed by screw breakage (Table 3.3).

Table 3.1 Torque to failure values and failure modes of 4.5 mm AO screws placed in lag fashion used for repair of experimentally created 8 mm thick medial condylar fractures in equine MC3 bones.

Approach	**Leg**	**Failure Torque (N-m)**	**Failure Mode**
Medial			
	R	9.47	Broken Screw
	L	9.83	Broken Screw
	R	9.55	Broken Screw
	R	10.21	Broken Screw
Standard Deviation		9.76 $\pm$ 0.33	
Lateral			
	L	6.11	Threads Stripped
	R	5.96	Threads Stripped
	L	5.67	Threads Stripped
	L	5.79	Threads Stripped
Standard Deviation		5.88 $\pm$ 0.19	

R=right, L=left

Table 3.2 Torque to failure values and failure modes of 4.5 mm AO screws placed in lag fashion used for repair of experimentally created 12 mm thick medial condylar fractures in equine MC3 bones.

Approach	**Leg**	**Failure Torque (N-m)**	**Failure Mode**
Medial			
	R	10.33	Broken Screw
	L	9.61	Broken Screw
	L	9.29	Broken Screw
	R	8.56	Broken Screw
Standard Deviation		9.45 $\pm$ 0.73	
Lateral			
	L	9.68	Broken Screw
	R	10.37	Threads Stripped
	R	9.89	Broken Screw
	L	10.14	Threads Stripped
Standard Deviation		10.0 $\pm$ 0.30	

R=right, L=left

Table 3.3 Torque to failure values and failure modes of 4.5 mm AO screws placed in lag fashion used for repair of experimentally created 20 mm thick medial condylar fractures in equine MC3 bones.

Approach	**Leg**	**Failure Torque (N-m)**	**Failure Mode**
Medial			
	R	10.54	Broken Screw
	L	10.39	Broken Screw
	R	9.72	Broken Screw
	R	9.96	Broken Screw
Standard Deviation		10.15 ± 0.38	
Lateral			
	L	9.93	Broken Screw
	R	9.87	Broken Screw
	L	10.67	Broken Screw
	L	9.80	Broken Screw
Standard Deviation		10.07 ± 0.41	

R=right, L=left

3.5 Discussion

The results of torque to failure testing indicate a distinct difference in failure for both the three fragment thicknesses and approach used. The differences are likely due to the amount of bone engaged by the screw with varying fragment thicknesses and surgical approach. These differences could impact the success of a clinical case.

We have concluded that there is a significant difference in the maximum torque to failure between a medial and lateral approach in the 8 mm fragment group. Failure torque values for the 8 mm fragment (Table 3.1) using the medial approach were significantly greater, almost twice that of the lateral approach. While the mean torque to failure was 9.76 N-m for the medial approach, it was only 5.88 N-m for the lateral approach.

It is concerning that the mean torque to failure for the lateral group was only slightly higher than the insertional torque of 5.4N-m.. Because insertional torque routinely exceed 5.4 N-m this minimal difference highlights a substantial risk of screw stripping when a screw is tightened under common clinical conditions.. This is supported by the failure mode for the 8 mm fragments. While each 8 mm fragment compressed from a traditional medial approach failed by screw breakage, the screw stripped in each of the lateral approach specimens indicating a lack of adequate purchase in the bone. The 4.5 mm cortical screw used here has a thread pitch, the distance from one thread to the next, of 1.75 mm. Given this value, a thread hole created in 8, 12 and 20 mm fragments will engage 4.6, 6.9 and 11.4 threads, respectively, a step-wise increase of 50% and 67%. These values indicate a minimum acceptable number of threads engaged to decrease the risk of screw breakage.

For the 12 mm fragments there was no significant difference in the failure torque between the medial and lateral approach. Also the failure mode revealed both screw breakage and stripping for both medial and lateral approaches.

For the 20 mm fragments there was no significant difference in the failure torque between the medial and lateral approach. The failure mode (Table 3.3) for all specimens in this group was screw breakage. Therefore the screws were engaged in enough bone that the screw failed instead of stripping when maximally tightened.

The results of this study do not support a definitive acceptable minimum for fragment size in the case of a lateral approach for a medial condylar fracture. They do, however, support the conclusion that the risk of stripping a screw at insertion is great when the fragment containing the thread hole engages few screw threads as is the case in these 8 mm fragments. Clinically, the medial condylar fracture is more likely to propagate from an axial location on the articular surface and therefore, be a thicker fragment in the 12-20mm range. This lessens but does not completely mitigate the risk of failure by the screw at insertion under normal conditions and torque.

The use of the lateral approach for medial condylar fractures has been used successfully and in the majority of clinical situations use of the approach is supported by the data presented here. It remains to be determined if the risks associated with the approach outweigh the benefits.

CHAPTER 4

FINAL DISCUSSION AND CONCLUSION

4.1 Summary

In summary, we have compared a medial vs. lateral approach of the repair of medial condylar fractures by measuring the interfragmentary compression and torque to failure for 3 different simulated fracture fragment thicknesses in adult equine third metacarpal bones. We have concluded that there is no significant difference in compression between a medial and lateral approach for a medial condylar fracture with an 8 or 12 mm thick fragment. A possible explanation is that the screws were not tightened to a maximal torque. This maximal torque would have most likely been different for medial and lateral approaches due to the differences in the number of threads engaged in the bone. This in turn would have most likely resulted in differences in interfragmentary compression between the medial and lateral approaches.

There is a significant difference in the torque to failure between a medial and lateral approach for a medial condylar fracture. A possible explanation for this is due to the amount of screw that is engaged into the bone with the varying fragment thicknesses. The larger the fragment the more surface area of bone that is in contact with the screw causes more friction thus causing the screw to fail due to threads stripping before reaching the maximal torque because the amount of the screw that is engaged with the bone. The failure torque for the 8 mm fragments is not much greater than the insertional torque of 5.4 Nm. The insertional torque of 5.4 N m is not an adequate amount of torque used to tighten screws in a repair of a condylar fracture. Screws are typically tightened farther than 5.4 N m of torque and tightened closer to the maximal torque around 9 N m. Thus in conclusion, the lateral approach may be an acceptable alternative for repair of the medial condylar fracture of at least 12mm in thickness.

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VITA

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