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BIOMECHANICAL COMPARISON OF THREE METHODS FOR INTERNAL FIXATION OF FEMORAL NECK FRACTURES IN DOGS

By

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BIOMECHANICAL COMPARISON OF THREE METHODS FOR INTERNAL FIXATION OF FEMORAL NECK FRACTURES IN DOGS

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Research evaluating the surgical repair of femoral neck fractures in dogs is limited. This study evaluated the *in vitro* mechanical properties of canine femoral neck fractures stabilized with two medium Orthofix® Partially-threaded Kirschner Wires (Orthofix pins), a 2.7 mm cortical bone screw placed in lag fashion with anti-rotational Kirschner wire (K-wire), and three 1.1 mm divergent K-wires. This study compared the mean compressive pressure, compressive force and area of compression created by the insertion the Orthofix pins and a 2.7 mm cortical bone screw placed in lag fashion. Monotonic testing was used to quantify mechanical strength and pressure sensitive film was used to quantify compression. There was no significant difference in the stiffness or load to failure for the three repair methods evaluated. There was no significant difference in the compressive pressure, compressive force or area of compression in osteotomies stabilized with Orthofix pins and 2.7 mm bone screws.

DEDICATION

I would like to dedicate this research to my parents Larry and Sue Fisher, for all the love and support they have given me throughout my lifetime. I would also like to dedicate this research to my wonderful wife Juli Gunter Fisher and my two beautiful children Rylee Elizabeth Fisher and Ethan Gunter Fisher, for all the time, love and support they have given me during my residency and master's degree.

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CHAPTER I

INTRODUCTION

Background

Canine femoral neck fractures may be intracapsular (subcapital or transcervical) or extracapsular (basilar). The majority of fractures are simple basilar fractures; however, comminuted fractures can occur (1). Canine femoral neck fractures typically occur in dogs less than one year of age and are usually associated with trauma (2). In the immature animal, physeal fractures of the femoral head are encountered most commonly and occur through the weak area at the zone of hypertrophy (3). Non-surgical therapy for canine femoral neck fractures consists of analgesia and cage rest, typically resulting in the development of a hypertrophic pseudarthrosis and persistent pelvic limb lameness and pain (1,2,4,5). Surgical correction of the fracture is recommended to restore function (1,2). Comminuted femoral neck fractures are typically managed with femoral head and neck ostectomy or total hip replacement. Simple fractures of the femoral neck are typically managed with femoral head and neck ostectomy or internal fixation (1,2,4,5). Achieving adequate internal fixation of canine femoral neck fractures can be difficult due to the small size of the bone segments, the degree of motion at the site, and the large shear forces acting on the fracture site (1,2). Techniques reported for internal fixation of femoral neck fractures include normograde placement of a cortical bone screw in lag fashion (with an anti-rotational Kirschner wire) and normograde insertion of three divergent Kirschner wires (K-wires) (1,2,6). Lag screw placement creates interfragmentary compression and is thought to provide the best stability and success rate for repair of femoral neck fractures, but is technically more challenging (1,2,4,7,8). Insertion of divergent K-wires is more easily achieved, but does not create interfragmentary compression and therefore results in a decrease in fixation strength compared to lag screws (1,2,4,7).

Orthofix® Partially-threaded Kirschner Wires (Orthofix pins), when properly applied, create interfragmentary compression and are technically easier to insert than bone screws placed in lag fashion (9-11). No glide hole is needed, and the pins can be inserted as easily as traditional K-wires (12). Orthofix pins are used in human orthopedic surgery to stabilize many fractures, including fractures of the phalanges, distal radius, humeral epicondyle, radial head, olecranon, proximal humerus, greater trochanter, patella, proximal and distal tibia, and metatarsal bones. (12). The most common use of Orthofix pins in veterinary medicine has been for repair of humeral condylar fractures (9-11,13). Long term clinical and radiographic outcome was reportedly good (10) and Orthofix pins were found to provide adequate strength when physiological shear loads were applied (11).

Canine Proximal Femur Anatomy

The coxofemoral joint is a synovial or diarthrodial joint with a “ball-and-socket” configuration. The joint consists of a joint cavity, joint capsule, synovial fluid, articular cartilage, and underlying bone. The femoral head is anchored to the acetabulum by the round ligament (ligament of the head of the femur), surrounding joint capsule, and transacetabular ligament (14,15).

The femur is a typical long bone with a cylindrical body and two expanded metaphyses. The proximal femur presents on its medial aspect a smooth, nearly hemispherical head, most of which is articular except for the fovea capitis femoris, to which the ligament of the head of the femur is attached. The head is attached to the femur by the neck of the femur. The neck is distinct but short and provides attachment for the joint capsule. The greater trochanter is the largest eminence of the proximal femur and is located directly lateral to the head of the femur. The greater trochanter also serves as the attachment site for the middle and deep gluteal muscles. The trochanteric fossa is a deep cavity located medial to the greater trochanter. It serves as the insertion point for the muscles of the gemilli and internal obturator. The lesser trochanter is a pyramidal projection on the medial aspect of the femur distal to the femoral head and serves as the insertion point of the iliopsoas muscle. A ridge of bone extends from the summit of the greater trochanter to the lesser trochanter. This ridge represents the caudolateral boundary of the trochanteric fossa. The quadratus femoris muscle inserts on its crest at the level of the lesser trochanter. The third trochanter is poorly developed. It appears at the base of the greater trochanter as a small, rough area on which the superficial gluteal muscle inserts. The third and lesser trochanters are located in about the same transverse plane (14).

Blood Supply to the Coxofemoral Joint and Proximal Femur

The arterial supply to the coxofemoral joint and the proximal femur has been studied extensively because of the high frequency of traumatic and degenerative diseases affecting the canine coxofemoral joint.

The medial and lateral circumflex femoral arteries (branches of the external iliac arteries) provide about 70% of the extraosseous blood supply to the proximal femur and the coxofemoral joint. The caudal gluteal, cranial gluteal, and iliolumbar arteries (branches of internal iliac arteries) also contribute to the proximal femoral blood supply (14-22).

The intracapsular blood supply is a continuation of extraosseous vessels within the coxofemoral joint capsule. The intracapsular vessels form a retinaculum at the base of the femoral neck (14-16,18). The dorsal retinacular artery supplies a majority of the proximal femoral epiphysis as a single vessel or as a part of a vascular arcade with the ventral retinacular artery (14,15). Retinacular vessels course along the femoral neck in an intracapsular, extraosseous position as they cross the physis and penetrate the femoral epiphysis (14,15).

The intraosseous blood supply of the proximal femur is composed of terminal branches of metaphyseal and epiphyseal arteries supplying the endosteum of cancellous and cortical bone in mature canines (15,19). Retinacular vessels pass through the epiphyseal cartilage and become epiphyseal vessels that anastomose and arborize. This provides blood to the entire epiphysis (15,17). Intraosseous arteries of the epiphysis and metaphysis are separated by the physis in immature canines. Normally the physeal barrier is not invaded until after maturity, when anastomosis of the epiphyseal and metaphyseal vessels can occur (15,17,20,21). Trauma such as physeal fractures compromises the physeal barrier and metaphyseal vessels then cross and revascularize the epiphysis (15,23,24).

The round ligament, which originates in the ventral acetabulum and inserts on the medial aspect of the femoral epiphysis, contributes to coxofemoral joint stability but does not contribute to the blood supply of the proximal femur (14). Vessels in association with this ligament also do not contribute to revascularization of the proximal femoral epiphysis after experimental fracture repair (15,23,24).

Retinacular vessels supplying the femoral epiphysis are located along the neck of the femur, predisposing them to obstruction and compression from increased intra-articular pressure. Increased intra-articular pressure from joint effusion or trauma has been hypothesized to cause vascular tamponade, which can result in pathologic damage to the femoral head and neck (15,17,23,25). Accumulation measurements of radio-labeled phosphorus (P^{32}) during experimental studies on the proximal femoral circulation found that puppies had decreased uptake as intra-articular pressures increased, proving decreased vascular flow with increased joint pressure (15,17). Traumatic injuries of the femoral head and neck stabilized with rigid internal fixation result in revascularization from metaphyseal vessels crossing the fractured physis. This suggests that revascularization of the femoral head cannot occur without partial or complete physeal closure (15,23,24).

Diagnosis and Treatment of Femoral Neck Fractures

Traumatic fracture of the femoral neck can occur in any age, breed, or sex of dogs but occurs most commonly in dogs less than one year of age (1,2). A thorough evaluation of the patient is required, including abdominal radiographs, thoracic radiographs and electrocardiography, to rule-out potential life threatening abnormalities associated with trauma (15,26). Dogs suffering traumatic fracture of the femoral neck typically present for a non-weight bearing pelvic limb lameness and reluctance or inability to stand or move and may have a history of trauma (2,15). Orthopedic examination findings commonly include pain and crepitation on flexion, extension, abduction, and adduction of the coxofemoral joint and swelling over the coxofemoral region. (2).

Femoral neck fractures are usually diagnosed clinically by standard craniocaudal and lateral radiographic views of the coxofemoral joint. A ventrodorsal frog-legged view may also be performed to distract the fracture and facilitate diagnosis.(1,2,15).

Conservative treatment of femoral neck fractures commonly results in hypertrophic pseudarthrosis and persistent lameness and pain. Surgical intervention is the treatment of choice for femoral neck fractures (2).

The first report of the use of rigid internal fixation for repair of a femoral neck fracture was by Nilsson in 1941. A single bone screw was placed across the fracture line, but the application of interfragmentary compression was not mentioned (27). In 1966, Brinker reported good surgical outcomes with rigid fixation of femoral neck fractures using threaded pins to create compression of the fracture site. It was his hypothesis that threaded pins provided more rigid stabilization than smooth pins (8). Another report in 1966 (28) documented the use of threaded pins for stabilization of femoral neck fractures in 20 dogs. The fracture lines were united at the fourth week postoperatively; however, avascular necrosis was observed on all radiographs. Hulse et al. in 1974 described the use of a bone screw placed across the fracture line to create interfragmentary compression of femoral neck fractures in 11 dogs and 1 cat. Avascular necrosis of the femoral neck was evident in almost every case. However, 12 months post-operatively, radiographs revealed no evidence of avascular necrosis and completed fracture healing. Thickening of the femoral neck was observed in all cases at the time of fracture union. In 1983, Brinker et al. (6) described the repair of femoral neck fractures using multiple Kirschner wires (K-wires). Lambrechts et al. in 1993 published the results of a cadaveric study using monotonic testing to failure to evaluate and compare four methods of fixation of femoral neck fractures: cortical screw placed in lag fashion with an anti-rotational K-wire, 2 parallel K-wires, 2 divergent K-wires, and 3 parallel K-wire configurations. This study showed that only constructs stabilized with a cortical screw placed in lag fashion with an anti-rotational K-wire and 3 parallel K-wires were sufficiently strong to resist force three times the animal's body weight (29). The results of these studies indicate that surgical stabilization of canine femoral neck fractures is best achieved with a bone screw placed in lag fashion with an anti-rotational K-wire or the insertion of 3 K-wires in divergent or parallel fashion.

Surgical Technique

The animal is placed in lateral recumbency with the affected leg up. The surgical site is clipped, scrubbed and sterilely draped. A skin incision is centered at the level of the greater trochanter and lies over the cranial border of the shaft of the femur. The skin margins are undermined and retracted. An incision is made through the superficial leaf of the fascia lata, along the cranial border of the biceps femoris muscle. The biceps femoris muscle is retracted caudally to allow incision in the deep leaf of the fasciae latae muscle. The incision continues proximally through intermuscular septum between the cranial border of the superficial gluteal muscle and the tensor fasciae latae muscle. The fascia lata and the attached tensor fasciae latae muscle are retracted cranially and the biceps femoris is retracted caudally. Blunt dissection and separation along the neck of the femur with a blunt instrument or finger allows visualization of a triangle bound dorsally by the middle and deep gluteal muscles, laterally by the vastus lateralis muscle, and medially by the rectus femoris muscle. The joint capsule is covered by areolar tissue which must be cleared away by blunt dissection. An incision is then made in the joint capsule and continued laterally along the femoral neck through the origin of the vastus lateralis muscle on the neck and lesser trochanter. Exposure can be improved by tenotomy of the deep gluteal tendon close to the trochanter. The origin of the vastus lateralis muscle is elevated from the femoral neck and reflected distally. Hohman retractors are placed intra-capsularly ventrally and caudally to the femoral neck to allow visualization of the femoral head and the fracture site (30).

Reduction of the fracture can be attempted manually or with assistance of reduction forceps. The fracture, once reduced, is maintained in reduction with the use of pointed reduction forceps. Implants are inserted to stabilize the fracture as described below. Closure of the surgical site is started with one or two mattress sutures placed in the deep gluteal tendon incision, and the origin of the vastus lateralis muscle is sutured to the cranial edge of the deep gluteal muscle. Continuous sutures are placed in the insertion of the tensor fasciae latae muscle distally and continued proximally along the cranial border of the superficial gluteal muscle. The superficial gluteal leaf of the fascia lata distally and the gluteal fascia proximally are sutured to the cranial border of the biceps femoris with a continuous pattern. The subcutaneous layer is sutured with a continuous pattern. The skin is apposed routinely (30).

Cortical Screw Placed in Lag Fashion with an Anti-rotational K-wire

A glide hole is drilled through the near fragment starting at the distal end of third trochanter and exiting at the fracture site. With the fracture segments reduced and compressed, a K-wire is inserted through the trochanter, femoral neck and head. The K-wire is placed proximally so that it does not interfere with insertion of the bone screw. An appropriate-size drill sleeve is inserted into the glide hole to serve as a guide for centering and drilling the appropriate-size tap hole in the femoral head. A thread hole is drilled in the far fragment to exit the femoral head near the round ligament. The depth of the hole is measured, tapped, and the appropriate-size cortical screw is inserted. Interfragmentary compression should be confirmed visually during tightening of the screw. The joint is moved through a normal range of motion to ensure that an implant has not penetrated the articular surface (6,31).

Kirschner Wire (K-wire) Fixation.

The fracture is reduced and temporarily stabilized with a bone forceps. Three K-wires are inserted from the base of the greater trochanter, across the fracture site, and into the femoral head. The outer wires are placed as proximally and distally in the neck as possible. Care is taken to avoid penetration of the articular cartilage during pin insertion (6,31).

Outcome and Complications

Postoperative radiographs are performed to evaluate fracture reduction and implant location. Strict cage confinement is recommended until the fracture is deemed healed (6-12 weeks). Passive range of motion exercises should be performed to encourage optimal limb function after healing has occurred. Radiographs are performed at 4-6 week intervals to assess fracture healing until the fracture is completely healed (2).

The most common complications reported after internal fixation of femoral neck fractures are implant failure, avascular necrosis, damage to the articular cartilage, and infection. Implant failure is typically associated with inadequate fracture reduction or the use of inappropriately sized implants. With poor reduction or insufficiently sized implants, bending and shear forces at the fracture site can lead to implant failure. Micromotion at the pin-bone interface can also arise from high physiologic stress and may cause the implant to prematurely loosen. Meticulous care during fracture reduction and implant placement may help reduce the chance of avascular necrosis. Damage to the articular cartilage can be prevented by precise pre-operative measurements as well as awareness of length of instruments used for fracture reduction and stabilization. Aseptic technique should be strictly followed to decrease the chance of infection (2).

Orthofix® Partially-threaded Kirschner Wires

Orthofix® Partially-threaded Kirschner Wires (Orthofix pins) are end-threaded, trocar-tipped, surgical grade stainless steel pins that have a chamfer adjacent to a larger diameter, threadless portion of the shaft. On insertion, the chamfer contacts the *cis*-cortex allowing the wider portion of the shaft to press against the near cortex. The threads then engage the *trans*-cortex as pin rotation strips the bone in the *cis*-fragment making a glide hole. This action by engagement of the *trans* cortex and rotation in the *cis* cortex produces interfragmentary compression across the fracture site (10-12). The Orthofix pins allow interfragmentary compression in a single step without pre-drilling both glide and thread holes. Orthofix pins are available in 3 sizes: small (thread diameter of 1.2 mm/ shaft diameter of 1.5 mm), medium (thread diameter of 1.6 mm/ shaft diameter of 2.0 mm) and large (thread diameter of 2.2 mm/ shaft diameter of 3.0mm). All pins come in one length (120mm) and are available in different thread lengths. Washers can be added to the construct for both the medium and larger diameter Orthofix pins to distribute compressive forces at the pin's chamfer (10-12).

Lanz et al. reported use of an Orthofix pin to stabilize a physeal fracture of the humeral condyle of a miniature pinscher in 1999. Three weeks after surgery the dog was fully weight bearing with return of full range of motion. Eight week post-operative radiographs revealed complete fracture healing with mild soft tissue swelling over the surgical site. Radiographs six months after surgery revealed the fracture to be healed with no evidence of degenerative joint disease (9). Guille et al. reported short- and long-term clinical and radiographic outcomes in 23 dogs with humeral condylar fractures repaired using Orthofix pins. All fractures with adequate follow up achieved radiographic union. All dogs available for long term follow up were sound or had subtle weight bearing lameness. Long-term radiographic follow-up revealed that 57% of the treated joints had no radiographic evidence of osteoarthritis. All dogs had good or excellent limb function (10). Vida et al. compared shear stability in simulated humeral lateral condylar fractures reduced with either an Orthofix pin or a cortical bone screw. Both constructs reportedly provided adequate strength in applied shear to sustain physiologic loads throughout fracture healing (11). Daubs et al. evaluated the compression generated by Orthofix pins and lag screws in simulated lateral humeral condylar fracture. This study revealed the mean compression, area of compression, and mean compressive forces generated by insertion of a lag screw were significantly greater than those generated by insertion of a similar size Orthofix pin; however, the authors suggested that repair of lateral humeral condylar fractures with Orthofix pins would be an acceptable technique (13).

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CHAPTER II

BIOMECHANICAL COMPARISON OF THREE METHODS FOR INTERNAL FIXATION OF FEMORAL NECK FRACTURES IN DOGS

Objectives

The objective of this study was to compare the *in vitro* mechanical properties of canine femoral neck fractures stabilized with two medium Orthofix pins, a 2.7 mm cortical bone screws placed in lag fashion with anti-rotational K-wire, and three 1.1 mm divergent K-wires. This study also compared the mean compressive pressure, compressive force and area of compression created by the insertion of two medium Orthofix pins and a 2.7 mm cortical bone screw place in lag fashion when applied to a femoral neck fracture model. Our hypothesis were (1) the mechanical properties of constructs stabilized with a lag screw and with Orthofix pins will be similar, and will be greater than constructs stabilized with divergent K-wires; and (2) the compression generated at the fracture site will be similar in constructs stabilized with a bone screw in lag fashion and Orthofix pins.

Materials and Methods

Specimen Preparation

Fifty femora were collected from 2-4 year old beagle dogs with body weights ranging from 9-15 kg. The dogs were euthanized for reasons unrelated to this study and the femora were collected by disarticulation of the coxofemoral joint and the stifle joint. All soft tissue was removed and each femur was wrapped in 0.9% saline-soaked laparotomy sponges and frozen at -29°C. Prior to testing, each femur was thawed to room temperature over a 24 hour period. The diameter of each neck was measured with a digital caliper.[a] The measurements were obtained in a dorsoventral direction by placing one arm of the caliper just medial to the greater trochanter and the other just proximal to the third trochanter. The distal end of each femur was then resected 70 mm distal to the trochanteric fossa using a Stryker bone saw[b] to ensure all femurs were the same length. The distal end of each femur was potted with polymethyl methacrylate (PMMA)[c] to facilitate mechanical testing.

Ten femora were randomly assigned to each of four groups:

- Group C: Control group (intact femoral neck- no osteotomy).
- Group D: Osteotomy stabilized with three 1.1 mm divergent K-wires.
- Group L: Osteotomy stabilized with a 2.7 mm cortical bone screw place in lag fashion and a 1.1 mm anti-rotational K-wire.
- Group M: Osteotomy stabilized with two Medium Orthofix® Partially-Threaded pins (shaft diameter = 2.0 mm, thread diameter = 1.6 mm) with washers.

No osteotomy was performed on femurs in Group C. Femurs in Groups D, L and M were prepared by performing a sagital osteotomy perpendicular to the femoral neck axis at the base of the femoral neck with a Stryker bone saw. The proximal aspect of the saw blade was positioned just medial to the greater trochanter and the blade was orientated the same for all osteotomies to ensure consistency. Osteotomies were held in anatomic reduction with point-to-point bone forceps[d] while fixation was applied. Anatomic reduction was confirmed visually in each construct.

Osteotomized femurs in Group D were stabilized by inserting three K-wires[e] (1.1 mm diameter) across the osteotomy site in a divergent fashion. The first K-wire was inserted perpendicular to the osteotomy starting at the third trochanter and exiting the femoral head near the round ligament. The second K-wire was inserted proximal to the first wire and angled toward the cranio-proximal aspect of the femoral head. The third K-wire was inserted ventral to the first wire and angled toward the distal-ventral aspect of the femoral head. All implants were allowed to penetrate the articular surface of the femoral head to ensure maximum bone purchase and then cut flush with the femoral head.

Osteotomized femurs in Group L were stabilized by inserting a 2.7 mm diameter cortical bone screw[f] in lag fashion. A 2.7 mm glide hole was drilled perpendicular to the osteotomy starting at the third trochanter and exiting at the osteotomy site. A drill sleeve with a 2.7 mm outer diameter was inserted into the glide hole. A 2.0 mm drill bit was used to drill the thread hole (core diameter of the screw), which exited the femoral head near the round ligament. The thread hole was tapped with a 2.7 mm tap. A 2.7 mm cortical bone screw was inserted. All screws were tightened by one surgeon, mimicking the force used clinically. Screws of sufficient length to penetrate the articular surface of the femoral head were inserted to ensure maximum bone purchase and then cut flush with the femoral head. After placement of the bone screw, a 1.1 mm diameter K-wire[e] was inserted proximal and parallel to the screw. It also penetrated the articular surface of the femoral head and was cut flush.

Osteotomized femurs in Group M were stabilized by inserting two Medium Orthofix pins[g] (with washers) across the osteotomy site. The diameter of the smooth portion of a Medium Orthofix pin was 2.0 mm; the diameter of the threaded portion was 1.6 mm. A washer was placed over the threaded portion of the pin and rested against the smooth portion of the pin shaft (chamfer). A drill[h] was used to insert the first pin perpendicular to the osteotomy starting proximal to the third trochanter and exiting near the round ligament. The second pin was inserted distal and parallel to the first pin. Both pins exited the articular surface of the femoral head. All pins were inserted by one surgeon. The smooth shaft was cut 2-3 mm from the lesser trochanter. The threaded shaft was cut flush with the articular surface of the femoral head.

Mechanical Testing

Each construct was individually mounted in a Bionix 858 Test System materials testing machine[i]. (Figure 1) The potted portion of the distal femur was placed into a custom container. The container was filled with PMMA[d] to secure each construct and the PMMA was allowed to fully harden prior to testing. The custom container was then secured to the base of the testing machine with four threaded bolts. Load was applied to the proximal aspect of the femoral head and aligned with the axis of the femoral shaft using a dowel pin (2.54 cm long, 1.3 cm in diameter). The top arm of the testing machine[i] rested on the aluminum dowel pin with no preload applied to the construct. Load was then applied at 50 mm/sec until construct failure occurred. Failure was defined as implants shearing through the bone, bending of the implants greater than 2.5 mm, or complete fracture of the femoral neck. Construct stiffness and load to failure were measured and recorded

Compression Testing

The remaining 10 femurs were used to measure compression created at the osteotomy site during stabilization with a lag screw and anti-rotational K-wire (n=5) or Orthofix pin insertion (n=5). Osteotomies of the femoral neck were performed as described. However, prior to insertion of the implants, a 2.5 cm by 2.5 cm piece of Pressurex Sensitive Film[j] was placed in the osteotomy site. The film was covered with plastic to protect the film from oils within the bone. Point-to-point reduction forceps[d] were gently placed to maintain reduction while ensuring the osteotomy was not compressed. Implants were inserted as previously described and left in place for two minutes. The implants were then removed and the Pressurex film was collected. Humidity and temperature remained constant during testing. The Pressurex film samples were digitally analyzed by Sensor Products, Inc[k] using Topaq software[l] to determine compressive pressure (PSI), compressive force (lbf), and area of compression (in^2) across the osteotomy site. (Figs. 2 and 3).

Statistical Analysis

An analysis of variance was conducted for each of the outcomes of the monotonic and compression testing using the ANOVA procedure in SAS for Windows v9.2[m]. If the treatment effect was found to be significant ($p < 0.05$), Tukey's multiple comparison tests of the means were conducted when appropriate.

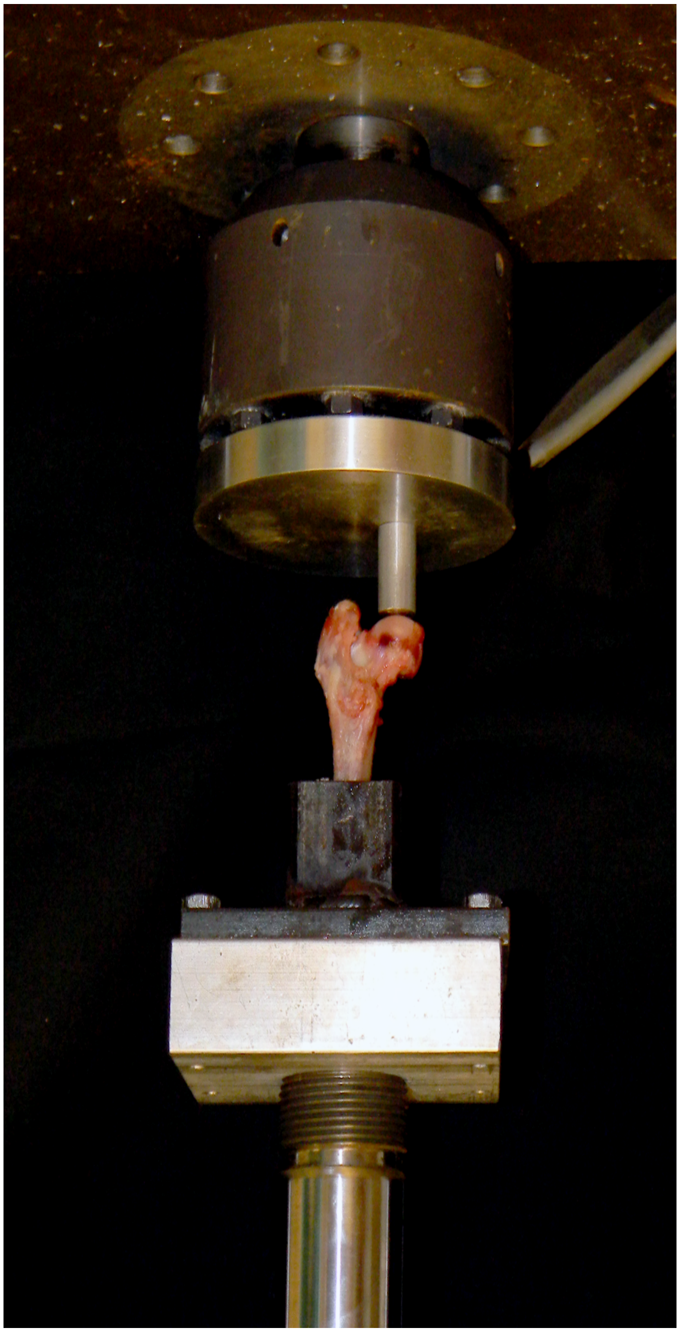

Figure 1

Photograph of an intact femur (control) mounted for mechanical testing

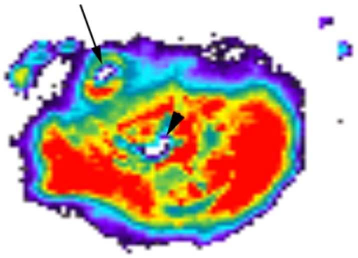

Figure 2

Digital image of compression film analysis from femoral construct stabilized with a 2.7 mm lag screw and a 1.1 mm anti-rotational K-wire

Note: The arrowhead indicates the hole created by insertion of a 2.7 mm cortical screw place in lag fashion through the Pressurex film and across the osteotomy site. The small arrow indicates the hole created by insertion of a 1.1 mm K-wire. The color purple indicates areas of least compression (1305 PSI): the color red indicates areas of highest compression (7977 PSI).

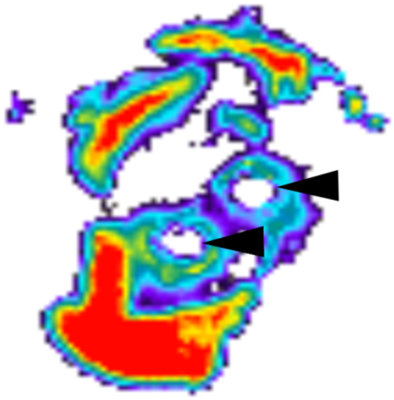

Figure 3

Digital image of compression film analysis from femoral construct stabilized with two medium Orthofix pins

Note: The arrowheads indicate the holes created by insertion of the two Orthofix pins through the Pressurex film and across the osteotomy site. The color purple indicates areas of least compression (1305 PSI): the color red indicates areas of highest compression (7977 PSI).

Results

The mean femoral neck diameter was 13.46 +/- 0.71 mm, 13.31 +/- 0.67 mm, 13.43 +/- 0.53 mm, and 13.42 +/- 0.53 mm for Groups C, D, L, and M, respectively. There was no significant difference in femoral neck diameter among the groups. (P = 0.95). (Table 1)

The mean stiffness of the constructs was 1406.5+/- 336.7 N/mm, 698.23 +/- 225 N/mm, 802.12 +/- 164 N/mm, and 688.82 +/- 293 N/mm for Groups C, D, L, and M, respectively. Constructs in the control groups were significantly stiffer than those stabilized surgically (P = <0.0001). There was no significant difference in stiffness among Groups D, L, and M (P = 0.49).

Load to failure was 2158.6 +/- 331 N, 785.12 +/- 413 N, 797.4 +/- 184 N, and 630.87 +/- 159 for Groups C, D, L, and M, respectively. Constructs in the control group failed at a significantly higher load than those stabilized surgically (p =<0.0001). There was no significant difference in load to failure among Groups D, L, and M. (P = 0.34).

The mean compression generated at the osteotomy in constructs stabilized with a 2.7 mm lag screw was 4113.27 +/- 387.25 PSI. The mean compression generated at the osteotomy in constructs stabilized with two Medium Orthofix pins was 3550.52 +/- 395.95 PSI. There was no significant difference in the compression generated by the two repair methods (P =0.05).

The mean area compressed at the osteotomy in constructs stabilized with a 2.7 mm lag screw was 0.11 +/- 0.48 in^2. The mean area compressed at the osteotomy in constructs stabilized with two Orthofix pins was 0.09 +/-0.03 in^2. There was no significant difference in the mean area compressed by the two repair methods. (P = 0.53).

The mean compressive force (compression x area compressed) generated at the osteotomy in constructs stabilized with a 2.7 mm lag screw was 449.62+/- 177.60 lbf. The mean compressive force generated at the osteotomy in constructs stabilized with two Orthofix pins was 330.47 +/- 121.40 lbf. There was no significant difference in the mean compressive force created by the two repair methods. (P = 0.26).

The number of points that exceeded the mean compression generated at the osteotomy site with pressures of 4000 PSI, 5000 PSI, 6000 PSI and 7000 PSI for both the lag screw and Orthofix pins were recorded. The mean values that exceeded 4000 PSI, 5000 PSI, 6000 PSI and 7000 PSI for lag screws and Orthofix pins were as follows: 18.8 vs. 17.8, 16.0 vs. 14.4, 12.2 vs. 11.4 and 12.2 vs. 9.4 respectfully. No significant differences were found among any of the points between the two constructs.

Table 1

Biomechanical Testing and Compression Analysis Results

Construct (Group)	Diameter (mm)	Load to Failure (N)	Stiffness (N/mm)	Compression (PSI)	Compressive Force (lbf)	Area of Compression (in2)
Control/Intact (C)	13.46 ± 0.71	*2158.60 ± 331.5**	*1406.50 ± 336.7**	N/A	N/A	N/A
Lag Screw (L)	13.43 ± 0.53	797.40 ± 183.99	802.12 ± 164.45	4113.27 ± 387.25	449.62 ± 177.60	0.11 +/- 0.48
K-wires (D)	13.31 ± 0.67	785.12 ± 412.52	698.23 ± 225.20	N/A	N/A	N/A
Orthofix Pins (M)	13.42 ± 0.53	630.87 ± 158.85	688.82 ± 293.71	3550.52 ± 395.95	330.47 ± 121.40	0.09 +/-0.03

Table 1: Results of mechanical and compression testing data (mean +/- S.D.) collected from canine femoral neck fractures stabilized with a 2.7 mm cortical screw placed in lag fashion (with an anti-rotational K-wire), two medium Orthofix Pins, and three 1.1 mm divergent K-wires, * = significantly different ($p < 0.05$).

Discussion

Internal fixation is often used to stabilize canine femoral neck fractures. Insertion of a cortical screw placed in lag fashion (with an anti-rotational K-wire) is considered to be the gold standard for repairing femoral neck fractures due to the creation of interfragmentary compression across the fracture line (1). The insertion of divergent K-wires is also reported as an acceptable method of fixation of femoral neck fractures, though interfragmentary compression in not achieved (2-6). Orthofix® Partially-threaded Pins create interfragmentary compression when inserted, are technically easier to place than bone screws placed in lag fashion, and have been evaluated for use in the stabilization of humeral condylar fractures in dogs (7-9). However, there are no reports in the veterinary literature comparing the mechanical properties or clinical use of these three repair methods for use in canine femoral neck fractures.

This study evaluated the *in vitro* mechanical stability of canine femoral neck fractures stabilized with a 2.7 mm lag screw (with a 1.1 mm anti-rotational K-wire), two medium Orthofix pins, and three divergent K-wires (1.1mm). We hypothesized that constructs stabilized with a lag screw or two Orthofix pins (because they create compression) would be stiffer and have higher loads to failure than constructs stabilized with three divergent K-wires. Also, the area moments of inertia for three 1.1 mm K-wires, a 2.7 mm bone screw and one K-wire, and 2 medium Orthofix pins are 0.22 mm^4, 0.71 mm^4, and 0.38 mm^4, respectively; suggesting that constructs stabilized with a lag screw and anti-rotational K-wire would be stiffer (10). However, our results indicated that stiffness and load to failure were similar for all three repair methods under monotonic loading. This suggests that though fixation with three divergent K-wires does not create compression across the fracture line, the presence of the three K-wires is able to adequately resist the load applied to the constructs in the model used in this study. However, this study did not assess fracture healing nor assess construct stability under cyclical or rotational loading.

These results are consistent with those reported in a similar study comparing fixation methods for stabilization of proximal femoral physeal fracture in immature dogs (11). In that study, stiffness was similar in constructs stabilized with a single lag screw (3.5 mm) and three divergent K-wires (1.1 mm). For both repair methods, stiffness reported in our study was higher than reported by Tillson et al.; even though we used a smaller lag screw (2.7 mm rather that 3.5 mm) and the same sized K-wires. However, this is likely because our study evaluated mechanical properties in femurs from mature dogs while Tillson et al. evaluated femurs from immature dogs (11).

Stiffness, load to failure and interfragmentary compression were not significantly different in constructs stabilized with two Orthofix Pins and a 2.7 mm lag screw (with anti-rotational K-wire) when subjected to monotonic loading. This suggests that fixation of canine femoral neck fractures with two Orthofix pins would be a clinically acceptable technique. Insertion of the Orthofix pins was easier and required less time compared to the insertion of lag screws in the author's opinion. The ease of inserting the Orthofix pins has been reported previously; and the decreased time required to insert an Orthofix pin compared to a screw in lag fashion has been documented (7-9, 12, 13). However, a potential challenge with the insertion of the Orthofix pins in clinical patients is selection of the appropriate length implant. In this study, the pins were inserted such that they penetrated the articular surface of the femoral head, ensuring maximal purchase of the proximal cortex. However, penetration of the articular surface of the femoral head in a clinical patient would results in significant joint damage. Selection of the appropriate length pin to avoid damage to the articular cartilage in clinical patients would be based on radiographic measurements of the ipsilateral and contralateral proximal femurs and intraoperative measurements obtained once the fracture site was visualized.

Stiffness and load to failure for all three techniques evaluated were significantly less than in intact (control) femurs. However, previously reported clinical results suggest that insertion of a bone screw in lag fashion (and anti-rotational K-wire) and insertion of divergent K-wires are acceptable techniques for stabilization of small animal femoral neck fractures (1-6, 14, 15). The results of the study reported here indicate that placement of two medium Orthofix pins would provide similar mechanical stability.

This study also evaluated the compression generated by the insertion of a 2.7 mm lag screw and two medium Orthofix pins to stabilize transverse femoral neck fractures. Compression (PSI), area of compression (in^2), and compressive force (lbf) appeared similar between a single 2.7 mm lag screw and two medium Orthofix pins.

Clinical reports describing the results of canine femoral neck fractures stabilized with a screw placed in lag fashion and divergent K-wires list many potential complications, including avascular necrosis of femoral head, femoral neck narrowing (apple coring), degenerative joint disease, nonunion, and implant failure (1, 2, 6, 14-16). Interfragmentary compression of the fracture, adequate stability, and precise anatomic reduction are recommended to minimize complications. The study reported here was performed *in vitro* and did not evaluate potential complications of the three repair methods. However, based on the stiffness and load to failure data, all three repair methods appear to provide adequate stability to withstand the monotonic loads applied to the constructs; and the creation of interfragmentary compression with the use of a bone screw in lag fashion and with insertion of Orthofix pins was confirmed.

There are several limitations to this study. The use of only 10 constructs in each group tested mechanically, and five constructs in each group assessing compression, may have led to a type II statistical error. Increasing the number of femora in each group would have strengthened the study's power and perhaps identified other significant differences among groups. Also, to ensure maximal purchase of the proximal cortex, all of the implants used in this study penetrated the articular surface of the femoral head. In the clinical situation, the use of shorter implants to avoid penetration of the joint surface would likely result in reduced construct stiffness, load to failure, and compression; and may have a greater effect when using a lag screw or Orthofix pins since bone purchase in the trans-cortex would be eliminated. The study was also performed *in vitro*, so determination of bone healing and potential complications of each repair method were not assessed.

The study reported here was performed using cadaveric femora from beagle dogs weighing 9-15 kg; and no significant differences were found among the three repair methods evaluated in simulated femoral neck fractures in dogs of this size. Lambrechts et. al. published the results of a cadaveric study evaluating four methods of repairing femoral neck fractures in femora from larger dogs (average weight = 23.9 kg, range = 19.4 - 32.8 kg). The methods evaluated included a 4.0 mm cancellous screw placed in lag fashion with a 1.6 mm anti-rotational K-wire, two 2.0 mm K-wires inserted in parallel fashion, two 2.0 mm K-wires inserted in divergent fashion, and three 2.0 mm K-wires inserted in parallel fashion. Their conclusion was that fixation with either a lag screw or three 2.0 mm K-wires was sufficiently strong to resist a force of 3 times body weight and would be appropriate for repair of femoral neck fractures in dogs of this size (5). The study reported by Lambrechts et al. evaluated repair methods in larger femora and using larger implants, but both studies indicate that repair of femoral neck fractures with a lag screw or three K-wires provides sufficient mechanical strength, though implants of appropriate size for the patient should be selected.

FOOTNOTES

[a] General Digital Calipers 143, General Tools and Instruments Co. LLC., New York, NY, USA.

[b] Model 4208 sagittal saw, Stryker Instruments, Kalamazoo, MI, USA.

[c] Technovit- Jorgensen Laboratories Inc. Loveland ,CO USA.

[d] Point-to-point Reduction Forceps, Synthes, Paoli, PA, USA.

[e] 1.1 mm diameter Kirschner wires, Synthes, Paoli, PA, USA.

[f] 2.7 mm cortical bone screw, Synthes, Paoli, PA, USA.

[g] Orthofix Magic pin, Orthofix Inc., McKinney, TX, USA.

[h] Model 4208 drill, Stryker Instruments, Kalamazoo, MI, USA.

[i] Bionix 858 Test System with upgraded controller from Test Resources (Shakopee, MN), MTS, Eden Prairie, MN, USA.

[j] Medium Fuji prescale Pressurex film, Sensor Products Inc., East Hanover, NJ, USA.

[k] Sensor Products Inc., East Hanover, NJ, USA.

[l] Topaq, Sensor Products Inc., East Hanover, NJ, USA.

[m] SAS Institute, Inc., Cary, NC, USA

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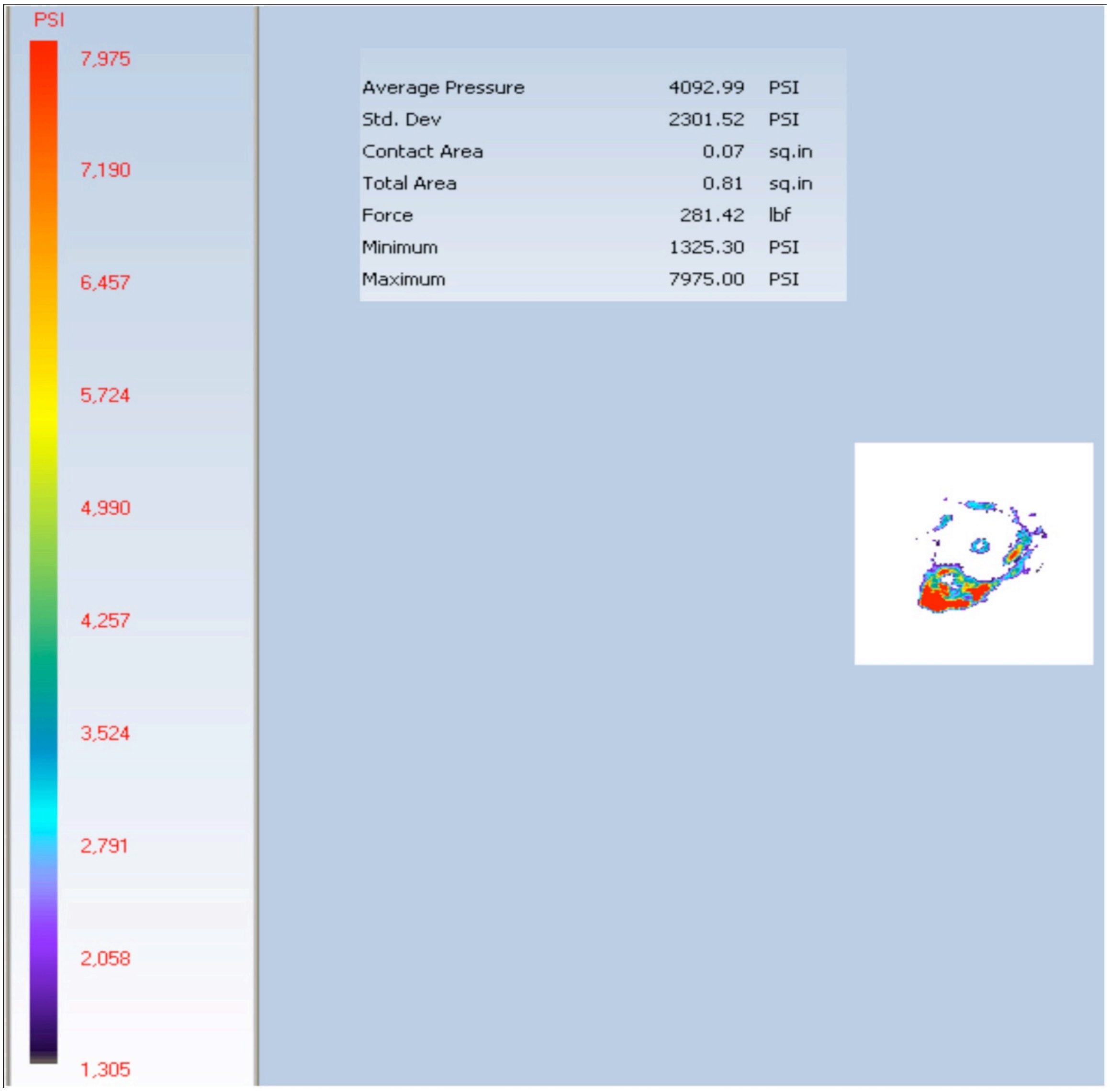
CHAPTER III

CONCLUSION

The results of this study indicate that stiffness and load to failure are similar for canine femoral neck fractures stabilized with a 2.7 mm cortical screw placed in lag fashion (with an anti-rotational K-wire), two medium Orthofix Pins, and three 1.1 mm divergent K-wires. Compression, compressive force and compressive area are similar for canine femoral neck fractures stabilized with a 2.7 mm cortical screw in lag fashion and two medium Orthofix pins. Stabilization of canine femoral neck fractures with Orthofix pins may be an acceptable means of fixation, though additional studies are indicated to further assess their mechanical properties and clinical efficacy.

APPENDIX

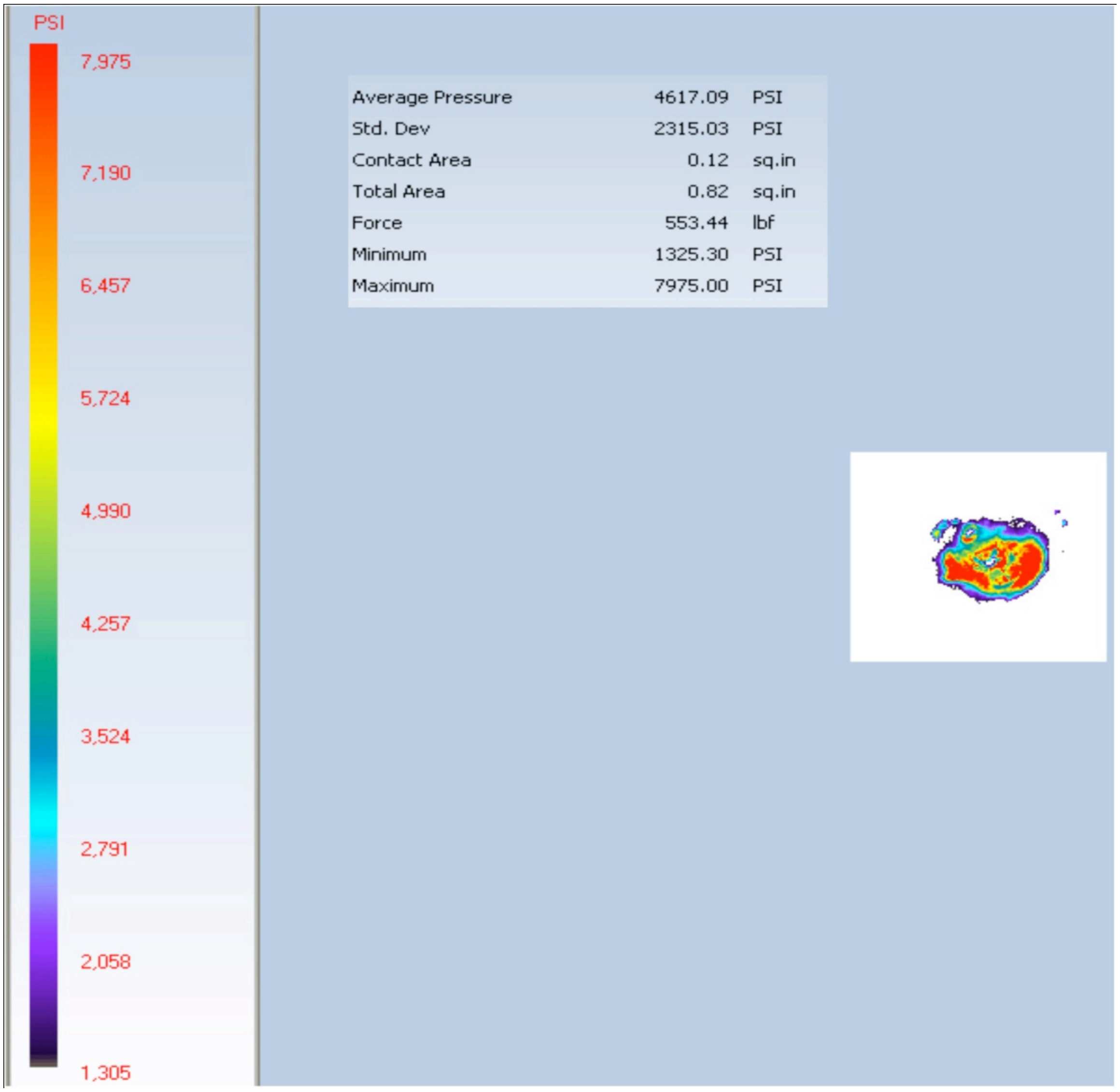
COMPRESSION ANALYSIS FOR LAG SCREWS AND ORTHOFIX PINS



Average Pressure	4092.99	PSI
Std. Dev	2301.52	PSI
Contact Area	0.07	sq.in
Total Area	0.81	sq.in
Force	281.42	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 4

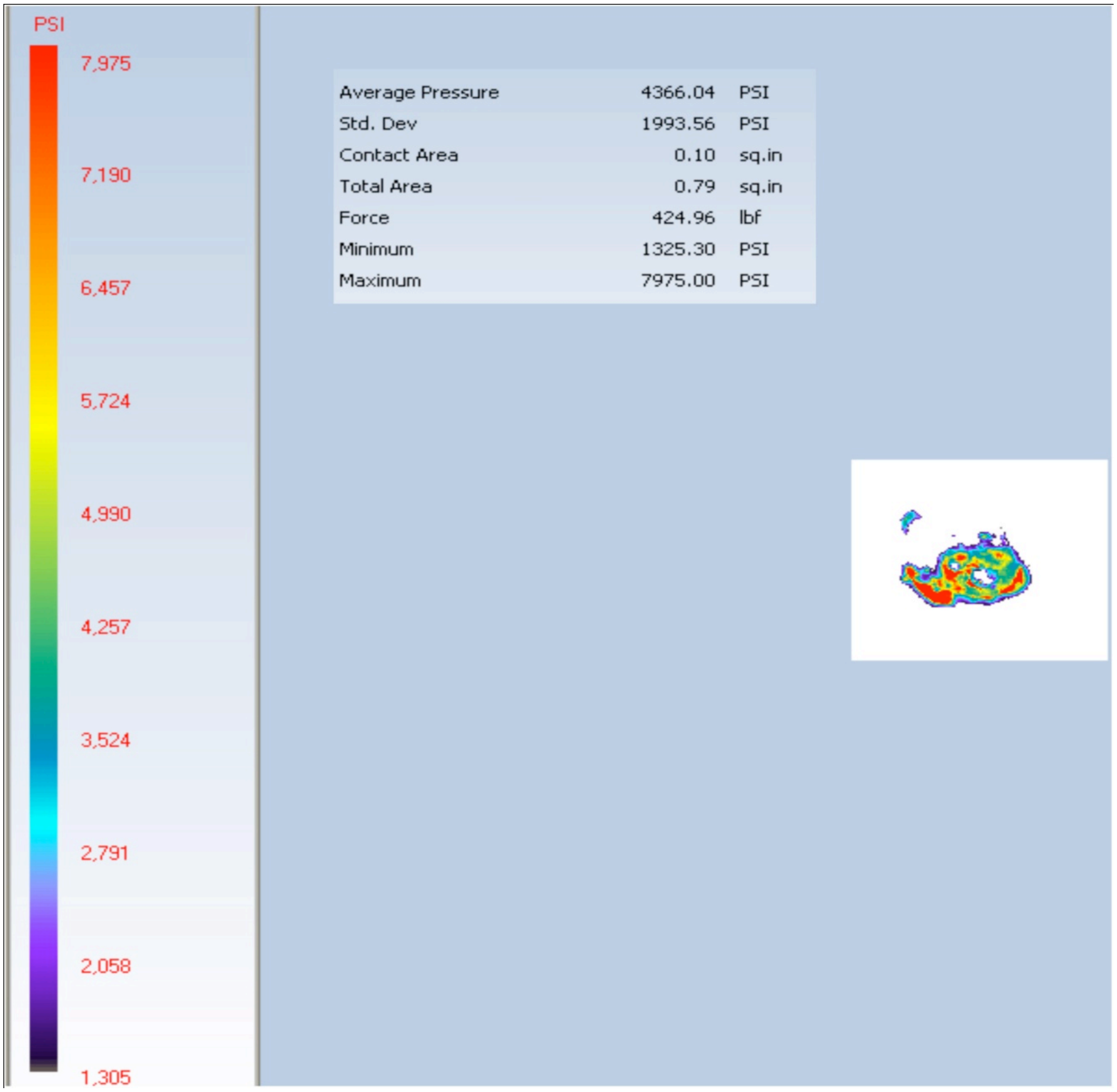
Compression analysis for lag screw #1



Average Pressure	4617.09	PSI
Std. Dev	2315.03	PSI
Contact Area	0.12	sq.in
Total Area	0.82	sq.in
Force	553.44	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 5

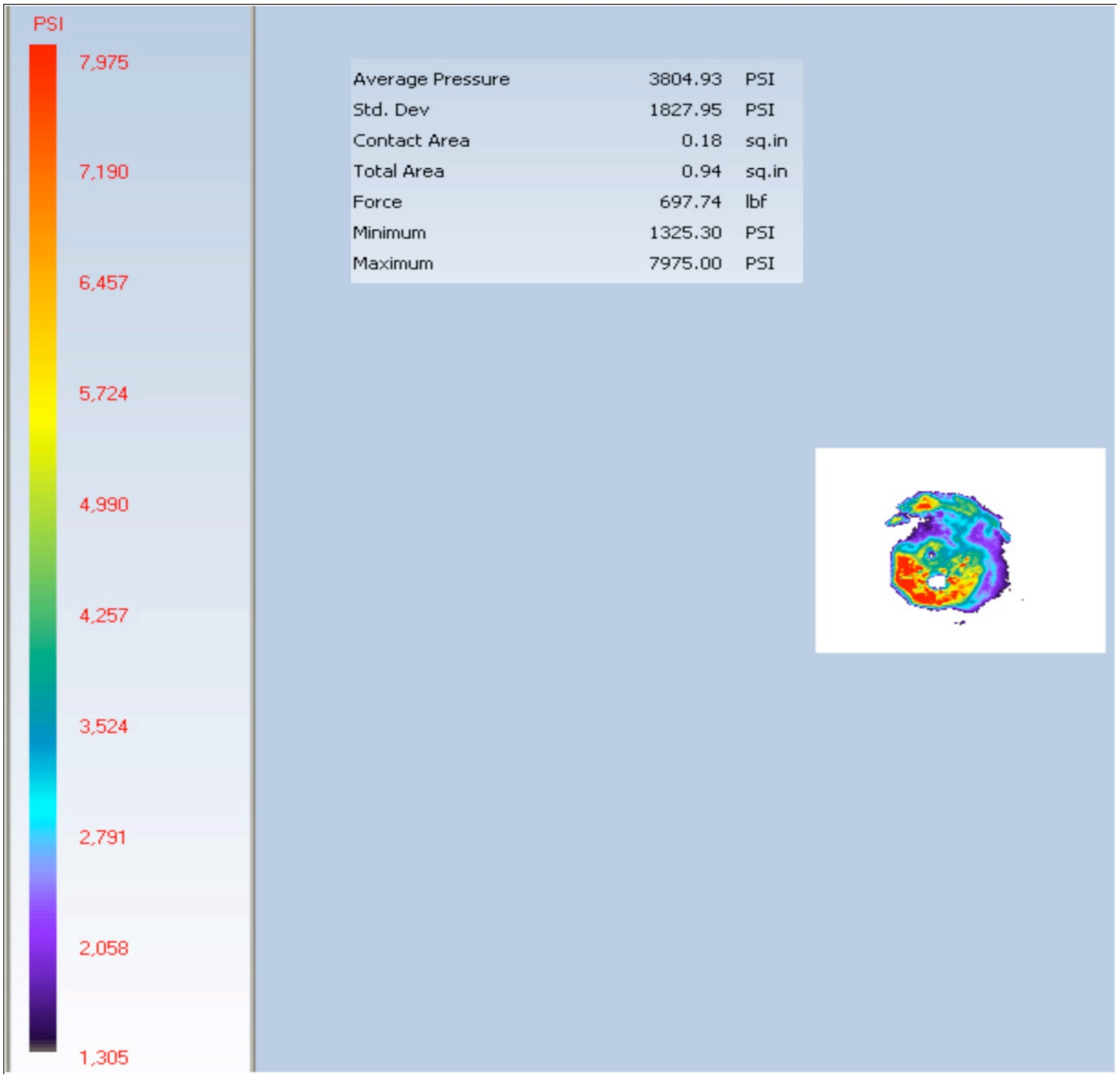
Compression analysis for lag screw #2



Average Pressure	4366.04	PSI
Std. Dev	1993.56	PSI
Contact Area	0.10	sq.in
Total Area	0.79	sq.in
Force	424.96	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 6

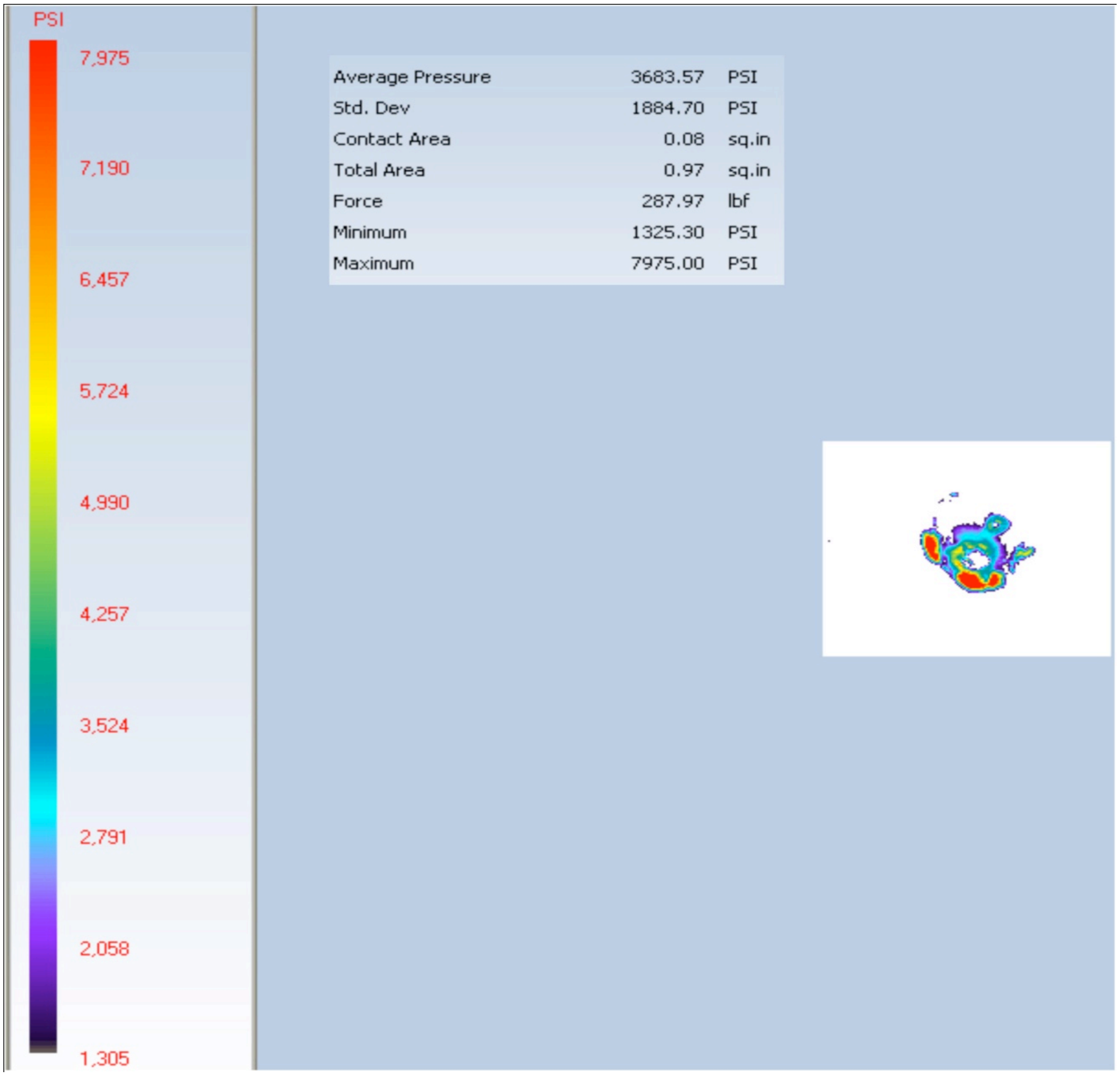
Compression analysis for lag screw #3



Average Pressure	3804.93	PSI
Std. Dev	1827.95	PSI
Contact Area	0.18	sq.in
Total Area	0.94	sq.in
Force	697.74	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 7

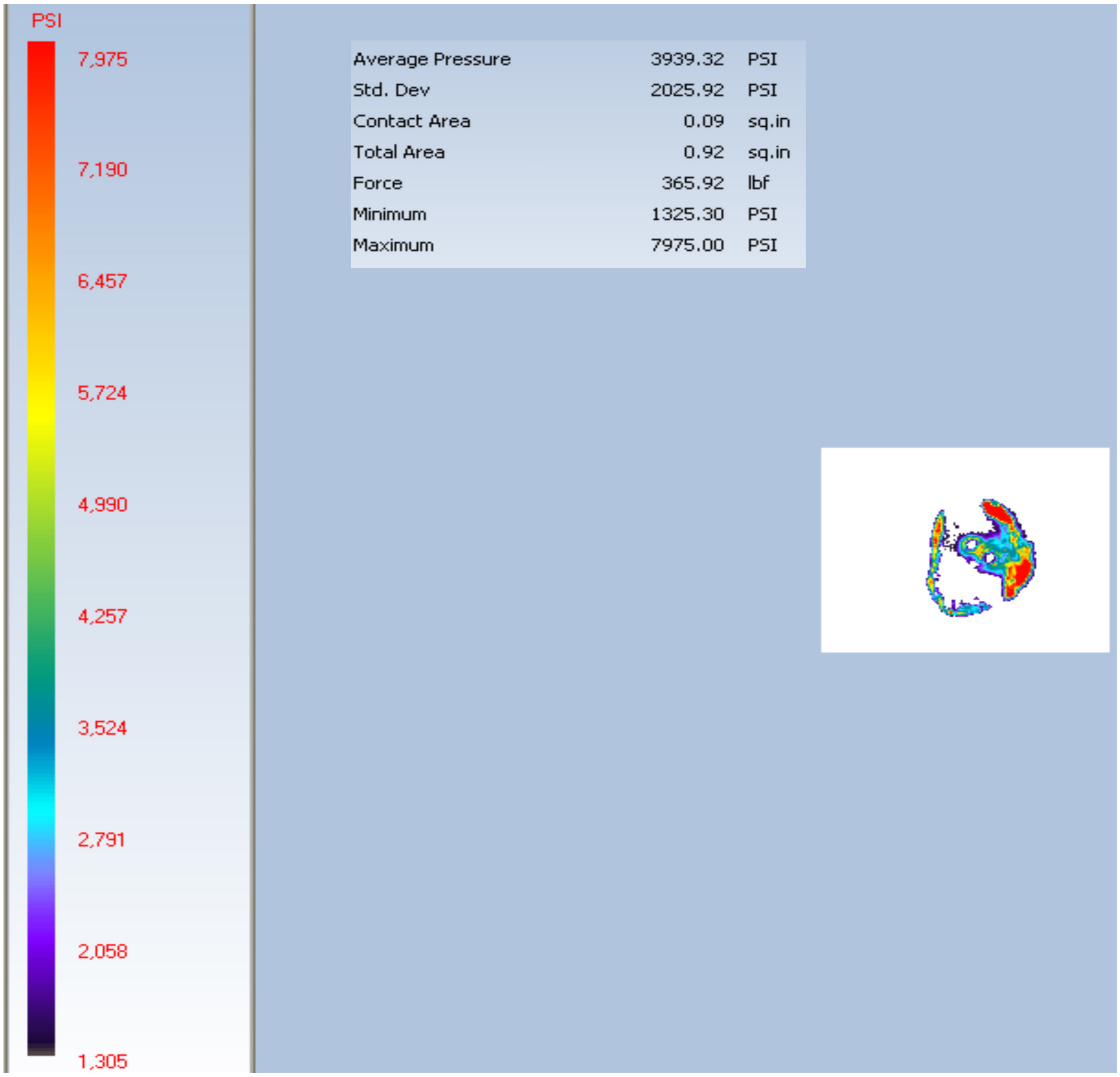
Compression analysis for lag screw #4



Average Pressure	3683.57	PSI
Std. Dev	1884.70	PSI
Contact Area	0.08	sq.in
Total Area	0.97	sq.in
Force	287.97	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 8

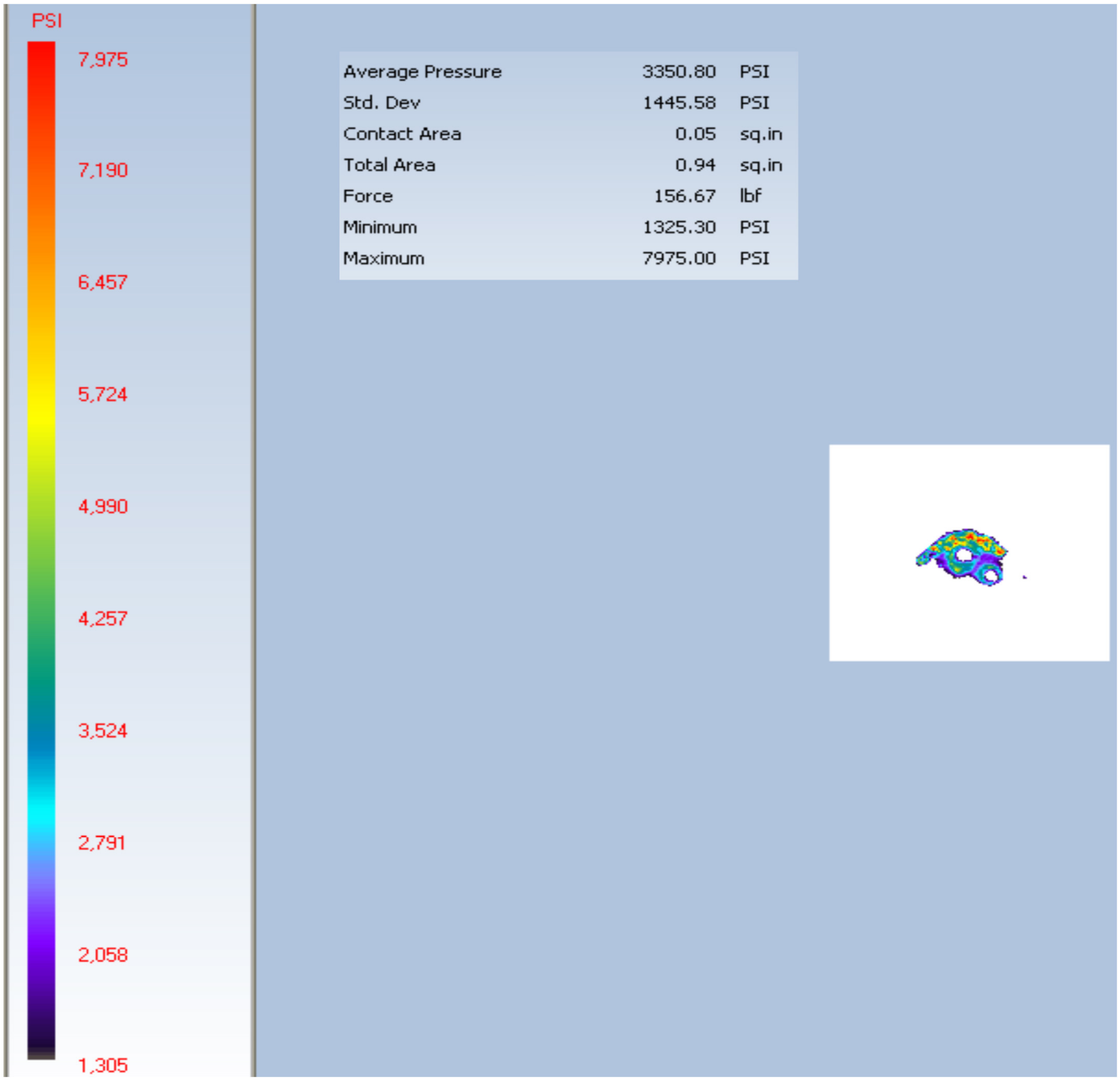
Compression analysis for lag screw #5



Average Pressure	3939.32	PSI
Std. Dev	2025.92	PSI
Contact Area	0.09	sq.in
Total Area	0.92	sq.in
Force	365.92	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 9

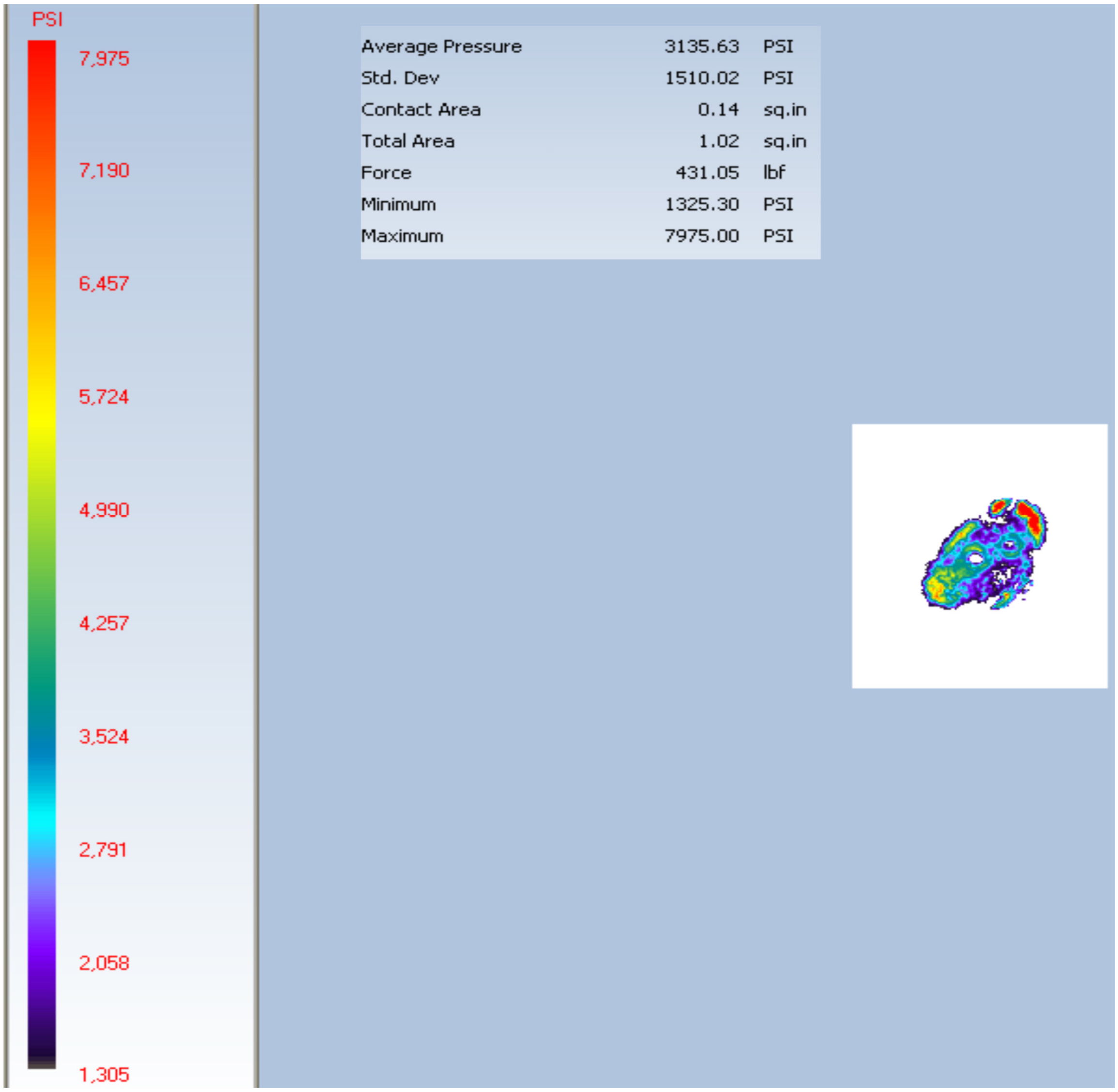
Compression analysis for Orthofix pin #1



Average Pressure	3350.80	PSI
Std. Dev	1445.58	PSI
Contact Area	0.05	sq.in
Total Area	0.94	sq.in
Force	156.67	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 10

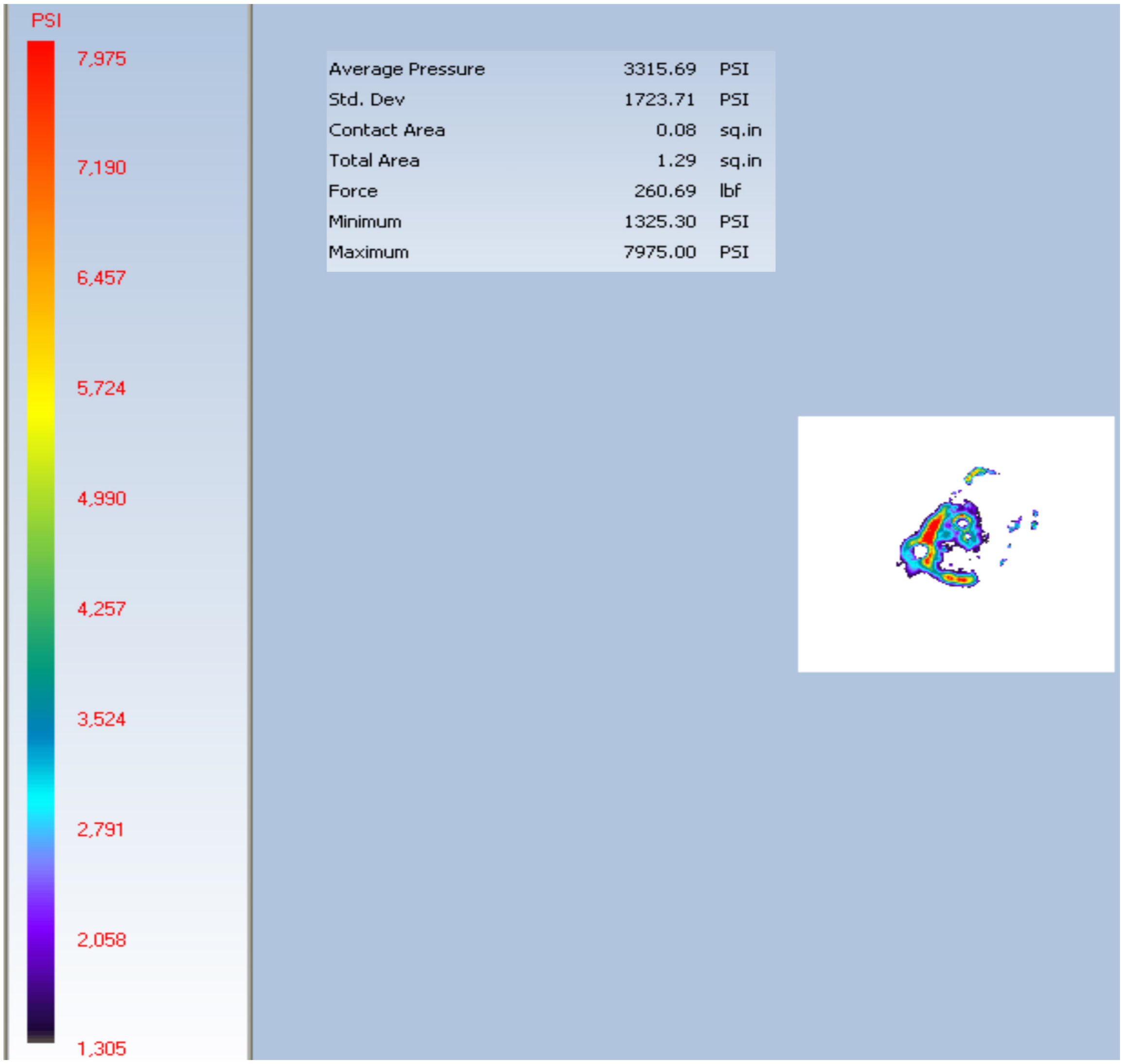
Compression analysis for Orthofix pin #2



Average Pressure	3135.63	PSI
Std. Dev	1510.02	PSI
Contact Area	0.14	sq.in
Total Area	1.02	sq.in
Force	431.05	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 11

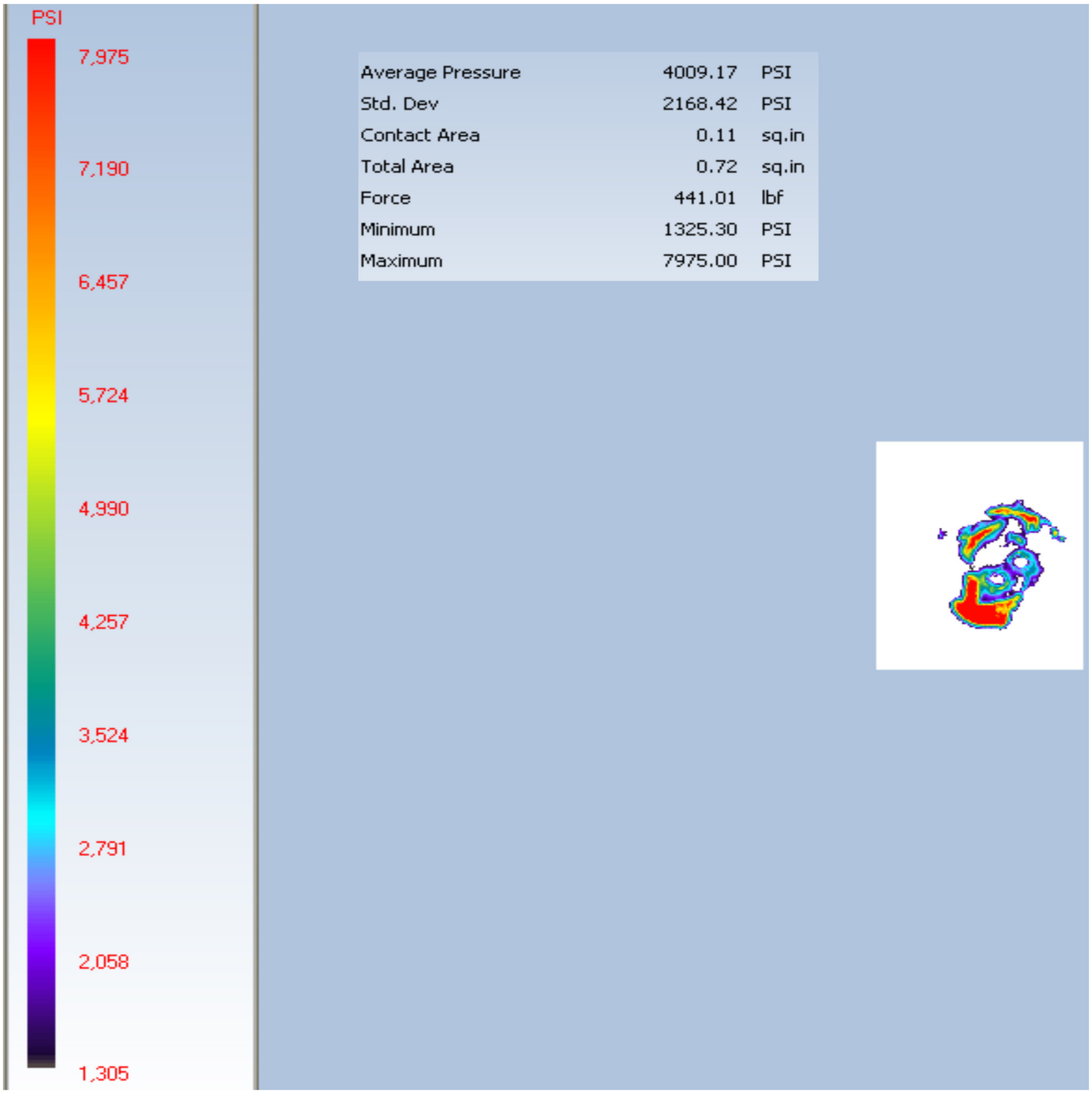
Compression analysis for Orthofix pin #3



Average Pressure	3315.69	PSI
Std. Dev	1723.71	PSI
Contact Area	0.08	sq.in
Total Area	1.29	sq.in
Force	260.69	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 12

Compression analysis for Orthofix pin #4



Average Pressure	4009.17	PSI
Std. Dev	2168.42	PSI
Contact Area	0.11	sq.in
Total Area	0.72	sq.in
Force	441.01	lbf
Minimum	1325.30	PSI
Maximum	7975.00	PSI

Figure 13

Compression analysis for Orthofix pin #5