In vitro biomechanical comparison of three methods for internal fixation of femoral neck fractures in dogs

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Keywords
Femoral neck fractures, Orthofix pin, compression, lag screw, divergent pins

Summary
The in vitro biomechanical properties of three methods for internal fixation of femoral neck fractures were evaluated. Fifty cadaveric femora from Beagle dogs were used. Ten intact femora served as controls. In 40 femora, an osteotomy of the femoral neck was performed to simulate a transverse fracture. With the remaining 30 femora, three repair methods (two medium Orthofix pins, a 2.7 mm cortical bone screw placed in lag fashion and an anti-rotational Kirschner wire, or three divergent 1.1 mm Kirschner wires) were used to stabilize the osteotomies, and 10 osteotomies were stabilised per repair method. These 30 femora where then subject to monotonic loading to failure. Construct stiffness and load to failure were measured. In the remaining 10 femora, pressure sensitive film was placed at the osteotomy site prior to stabilization with either two Orthofix pins (n = 5) or a screw placed in lag fashion (n = 5) to determine the compressive pressure (MPa), compressive force (kN) and area of compression (cm²). 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.

Introduction
Canine femoral neck fractures typically occur in dogs less than one year of age and are usually associated with trauma (1, 2). The majority are simple basilar fractures, however, comminuted fractures can occur (3). Non-surgical therapy consisting of analgesia and cage rest often results in non-union; these animals will typically retain pelvic limb lameness and will show signs of pain on manipulation of the limb (1, 3–5). Surgical correction of the fracture is recommended to restore function (1–3). Comminuted femoral neck fractures are typically managed with femoral head and neck osteotomy or total hip replacement. Simple fractures of the femoral neck are typically managed with internal fixation (1, 3–5). 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, 3). 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 [K-wires]) and normograde insertion of three divergent K-wires (1, 3, 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, 3, 4, 7). 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, 3, 4, 7).

Orthofix pins, when properly applied, create interfragmentary compression and are technically easier to insert than bone screws placed in lag fashion (9–11). While no glide hole is needed, it is necessary for the thread engagement in the near cortex to strip during insertion so that a lag effect is produced. Orthofix pins can also be inserted as easily as traditional K-wires (12). Orthofix pins are used in human orthopaedic 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 surgery has been for repair of humeral condylar fractures (9–11, 13). Long-term clinical and radiographic outcome was reportedly good and Orthofix pins were found to provide adequate strength when physiological shear loads were applied (10, 11). To the authors’ knowledge, there are no

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¹ Orthofix Magic Pin®; Orthofix Inc., McKinney, TX, USA
reports evaluating the use of Orthofix pins to stabilize femoral neck fractures in dogs.

This study compared the in vitro mechanical properties of canine femoral neck fractures stabilized with two medium Orthofix pins, 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 placed in lag fashion when applied to a femoral neck fracture model. We hypothesized that the mechanical properties of constructs stabilized with a lag screw and with Orthofix pins would be similar, and would be greater than constructs stabilized with divergent K-wires. We also hypothesized that compression generated at the fracture site would 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 two- to four-year-old Beagle dogs with body weights ranging from 9–15 kg. The dogs were euthanatized 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. 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 greater trochanter and the blade was oriented the same for all osteotomies to ensure consistency. Osteotomies were held in anatomical reduction with pointed reduction bone forceps while fixation was applied. Anatomical reduction was confirmed visually in each construct.

Osteotomized femora in Group K were stabilized by inserting three K-wires (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 exited 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 femora in Group S were stabilized by inserting a 2.7 mm diameter cortical bone screw 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 hole using a 2.0 mm drill bit. 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 was inserted proximal and parallel to the screw. It also penetrated the articular surface of the femoral head and was cut flush.

Fig. 1 Cranial-caudal radiographic view of a femoral neck osteotomy stabilized with two medium Orthofix pins. Arrowheads indicate the level of the osteotomy site.

The distal end of each femur was potted with polymethyl methacrylate (PMMA) to facilitate mechanical testing. Forty femora were used for mechanical testing and 10 femora were used for compression analysis.

Fixation of femora for axial loading

Ten femora were randomly assigned to each of four groups:
• Group I: Intact group (intact femoral neck- no osteotomy).
• Group K: Osteotomy stabilized with three 1.1 mm divergent K-wires.
• Group S: Osteotomy stabilized with a 2.7 mm cortical bone screw placed in lag fashion and a 1.1 mm anti-rotational K-wire.
• Group O: Osteotomy stabilized with two medium Orthofix pins (shaft diameter = 2.0 mm, thread diameter = 1.6 mm) with washers.

No osteotomy was performed on femora in Group I. Femora in Groups K, S, and O were prepared by performing a sagittal osteotomy perpendicular to the femoral neck axis at the base of the femoral neck with a bone saw. The proximal aspect of the saw blade was positioned just medial to the greater trochanter and the blade was oriented the same for all osteotomies to ensure consistency. Osteotomies were held in anatomical reduction with pointed reduction bone forceps while fixation was applied. Anatomical reduction was confirmed visually in each construct.

This study compared the in vitro mechanical properties of canine femoral neck fractures stabilized with two medium Orthofix pins, 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 placed in lag fashion when applied to a femoral neck fracture model. We hypothesized that the mechanical properties of constructs stabilized with a lag screw and with Orthofix pins would be similar, and would be greater than constructs stabilized with divergent K-wires. We also hypothesized that compression generated at the fracture site would be similar in constructs stabilized with a bone screw in lag fashion and Orthofix pins.

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Osteotomized femora in Group O were stabilized by inserting two medium Orthofix pins\(^k\) (with washers) across the osteotomy site. A washer was placed over the threaded portion of the pin shaft and rested against the smooth portion of the pin shaft (chamfer). A drill\(^k\) 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 (\(\text{Fig. 1}\)). All pins were inserted by one surgeon (SCF). 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 materials testing machine\(^j\) (\(\text{Fig. 2}\)). The potted portion of the distal femur was placed into a custom container. The construct 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 aluminium 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.

Interfragmentary compression testing

Ten femora 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 pressure sensitive film\(^i\) was placed in the osteotomy site. The film was covered with plastic to protect the film from oils within the bone. Pointed reduction forceps\(^e\) 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 pressure film was collected. Humidity and temperature remained constant during testing. The film samples were digitally analyzed by commercially available software\(^f\) to determine compressive pressure (MPa), compressive force (KN), and area of compression (cm\(^2\)) across the osteotomy site (\(\text{Fig. 3 and 4}\)).

Statistical Analysis

An analysis of variance was conducted for each of the outcomes of the monotonic and compression testing using the ANOVA procedure in a statistical software program\(^c\). If the treatment effect was found to be significant (\(p < 0.05\)), Tukey’s multiple compari-

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\(^{k}\) Model 4208 drill: Stryker Instruments, Kalamazoo, MI, USA
\(^{j}\) Bionix 858 Test System with upgraded controller from Test Resources (Shakopee, MN): MTS, Eden Prairie, MN, USA
\(^{d}\) Medium Fuji prescale Pressure film: Sensor Products Inc., East Hanover, NJ, USA
\(^{e}\) Topaq: Sensor Products Inc., East Hanover, NJ, USA
\(^{c}\) SAS for Windows v9.2: SAS Institute, Inc., Cary, NC, USA
son tests of the means were conducted when appropriate.

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 I, K, S, and O respectively. There was not any 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 I, K, S, and O 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 K, S, and O (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 I, K, S, and O 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 K, S, and O (p = 0.34).

The mean compression generated at the osteotomy in constructs stabilized with a 2.7 mm lag screw was 28.36 ± 2.67 MPa. The mean compression generated at the osteotomy in constructs stabilized with two Orthofix pins was 0.61 ± 0.19 cm². 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 2.00 ± 0.79 KN. The mean compressive force generated at the osteotomy in constructs stabilized with two Orthofix pins was 1.47 ± 0.54 KN. There was no significant difference in the mean compressive force created by the two repair methods (p = 0.26).

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 (7). 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 (1, 5, 6, 14, 15). Orthofix 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 (9–11). However, to our knowledge, 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 (1.1 mm). 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.

In addition, 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 mm⁴, 0.71 mm⁴, and 0.38 mm⁴, respectively; suggesting that constructs stabilized with a lag screw and anti-rotational K-wire would be stiffer (16). 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 (4). 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

Table 1: Results of mechanical and compression testing data (mean ± standard deviation) collected from canine femoral neck fractures stabilized with a 2.7 mm cortical screw placed in lag fashion with an anti-rotational Kirschner wire, two medium Orthofix Pins, and three 1.1 mm divergent Kirschner wires.

<table>
<thead>
<tr>
<th>Construct (group)</th>
<th>Diameter (mm)</th>
<th>Load to failure (N)</th>
<th>Stiffness (N/mm)</th>
<th>Compression (MPa)</th>
<th>Compressive force (KN)</th>
<th>Area of compression (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control / Intact (I)</td>
<td>13.46 ± 0.71</td>
<td>2158.60 ± 331.5*</td>
<td>1406.50 ± 336.7*</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Lag screw (S)</td>
<td>13.43 ± 0.53</td>
<td>797.40 ± 183.99</td>
<td>802.12 ± 164.45</td>
<td>28.36 ± 2.67</td>
<td>2.00 ± 0.79</td>
<td>0.71 ± 0.26</td>
</tr>
<tr>
<td>Kirschner wires (K)</td>
<td>13.31 ± 0.67</td>
<td>785.12 ± 412.52</td>
<td>698.23 ± 225.20</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Orthofix pins (O)</td>
<td>13.42 ± 0.53</td>
<td>630.87 ± 158.85</td>
<td>688.82 ± 293.71</td>
<td>24.48 ± 2.73</td>
<td>1.47 ± 0.54</td>
<td>0.61 ± 0.19</td>
</tr>
</tbody>
</table>

Key: * = significant difference between intact group compared to all other treatments. No other significant differences were noted between treatment groups. N/A = not applicable.
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 than 3.5 mm) and the same sized K-wires. However, this is probably because our study evaluated mechanical properties in femora from mature dogs while Tillson et al. evaluated femora from immature dogs (4).

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 authors’ 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 (9–11, 13, 17). 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 result 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 (1–3, 5–7, 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 (MPa), area of compression (cm²), and compressive force (KN) 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), osteoarthritis, nonunion, and implant failure (1–3, 7, 15, 18). Interfragmentary compression of the fracture, adequate stability, and precise anatomical 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, thus 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; 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 three times body weight and would be appropriate for repair of femoral neck fractures in dogs of this size (14). 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.

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 to evaluate these constructs under cyclical loading and to assess clinical efficacy are warranted.
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Conflict of interest
None declared.

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