The use of fully threaded headless cannulated screws for femoral neck fracture fixation in small-breed dogs show promise in cadaveric study

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OBJECTIVE
To biomechanically evaluate the stability of internal fixation methods for femoral neck fractures in small-breed dogs. Furthermore, the possibility of replacing the headed screw with fully threaded headless cannulated screws in the fixation method was assessed.

METHODS
The study was conducted from December 12, 2023, to February 7, 2024. A total of 18 femurs from 9 canine cadavers were used in this study. After a simple neck fracture was created, in group A (n = 6), the fracture was stabilized with three 1.1-mm parallel Kirschner wires (K-wires). In group B (n = 6), a 3.0-mm partially threaded cannulated screw and an antirotation pin were used. In group C (n = 6), a 2.5-mm fully threaded headless cannulated screw and an antirotation pin were used. A mechanical test was conducted to apply a single axial compressive load to the femoral head.

RESULTS
9 adult small-breed dogs weighing 3.6 to 8.3 kg (mean ± SD; 5.9 ± 1.6). The mean maximum failure load was highest in group C (495 ± 81 N), followed by group B (454 ± 50.4 N), and then group A (222 ± 21.6 N). Significant differences in maximum failure load were observed between groups A and B as well as groups A and C but not between groups B and C.

CONCLUSION
The use of fully threaded headless cannulated screws presents a promising method for internal fixation of canine femoral neck fractures.

CLINICAL RELEVANCE
To demonstrate the potential stability and reliability of fully threaded headless cannulated screws.

Keywords: dogs, femoral neck fracture, internal fixation, fully threaded headless cannulated screw, cadaveric study
In human femoral neck fractures, the most common stable fixation method involves 3 partially threaded cannulated screws that are placed parallelly in an inverted triangle configuration. Partially threaded cannulated screws demonstrate the benefits of reduced invasiveness of soft tissue, preserved blood supply, decreased intraoperative bleeding, and reduced surgical time. The smooth shaft of a partially threaded screw serves as a gliding hole, while the threaded part engages with the far cancellous or cortical bone. When the screw head is compressed against the near cortex, it generates interfragmentary compression and functions as a lag screw.

The fully threaded headless cannulated screw is a headless, cannulated, conical, fully threaded, cancellous, variable-stepped thread pitch screw. From the tip to the tail, the diameter gradually increases and the pitch gradually decreases. The tapered tip engages the bone with each turn of the thread to translates faster insertion. Thus, as the screw enters the bone, it produces interfragmentary compression at the fracture site. Various biomechanical studies have systematically evaluated the use of headless cannulated screws in metacarpal fracture fixation and confirmed its better biomechanical performance than that of K-wires. A recent clinical study demonstrated that fully threaded headless cannulated screws minimize femoral neck shortening and reduce other complications of femoral neck fractures such as fixation failure and non-union. Headless cannulated screws have been used for canine humeral condylar fractures and sacroiliac luxation and radiocarpal fractures in dogs and cats. However, to the best of the authors’ knowledge, there is a lack of clinical or biomechanical studies regarding the use of fully threaded headless cannulated screws for canine femoral neck fractures.

The objectives of this study were to compare the maximum axial failure load and mode among the 3 fixation methods for canine femoral neck fractures and to assess the feasibility of replacing a headed screw with a fully threaded headless cannulated screw for fixation. The 3 fixation methods were three 1.1-mm parallel K-wires, a 3.0-mm partially threaded cannulated screw with an antirotation pin, and a 2.5-mm fully threaded headless cannulated screw with an antirotation pin. The authors hypothesized that the biomechanical properties of a fully threaded headless cannulated screw were similar to those of a headed screw on a single axial compression test but superior to those of the K-wire fixation method.

**Methods**

**Cadaveric collections and preparation**

Cadaveric femurs were obtained from small-breed adult dogs weighing less than 10 kg that were euthanized for reasons unrelated to the present study. For inclusion, the dog underwent orthopedic examinations to confirm the absence of musculoskeletal diseases. The cadavers were frozen at −70°C until sample collection and thawed at room temperature for the sampling process. The coxofemoral and femorotibial joints were disarticulated, and the femur was carefully dissected and cleared of all soft tissue. A craniocaudal radiograph of the femur was obtained to confirm the absence of osseous changes and assess the appropriate length of the implants. The samples were covered in gauze soaked with 0.9% saline solution and frozen at −70°C until use. Before the surgical procedure, the frozen specimen was thawed to room temperature over 24 h.

**Experimental procedure**

The 18 femurs were randomly assigned to the 3 groups (groups A, B, and C) using a random list generator. To create a simple neck fracture, the osteotomy was planned at the femoral neck base perpendicular to the femoral neck axis, which was at an angle of 50° to the horizontal line perpendicular to the anatomic axis of the femur shaft. The osteotomy was reduced to its normal position and held with pointed reduction forceps until the fixation was completed. The length of all the implants was pre-measured using radiographs to ensure that the end of the implant was positioned within the epiphysis. This was done to prevent penetration of the articular cartilage of the femur head. The anatomical reduction of all the femur samples was visually confirmed.

**Group A (three 1.1-mm parallel K-wires)**

In group A, three 1.1-mm parallel K-wires were inserted in a normograde manner using a low-speed surgical power tool (Jeil Medical) to avoid thermal damage. The wires were inserted from the lateral aspect of the femur, parallel to the long axis of the femoral neck, following the inclination angle inherent to each femur. The inclination angle is defined as the angle between the line bisecting the femoral head and the narrowest point of the femoral neck, and the anatomic axis of the femur. The first K-wire was inserted adjacent to the third trochanter at the caudodistal aspect of the greater trochanter, and it was positioned perpendicular to the fracture line. The second and third K-wires were inserted proximal to the first K-wire using the AO parallel K-wire guide. The K-wires were inserted parallel and equidistant to each other. The tips of the K-wires were bent and cut (Figures 1 and 2).

**Group B (3.0-mm partially threaded cannulated screw with a 1.1-mm antirotational pin)**

In group B, a 3.0-mm partially threaded cannulated screw (Figure 3) and a 1.1-mm antirotation pin were used. The 1.1-mm antirotation K-wire was inserted in a normograde manner from a point more proximal than that of the cannulated screw entry. It traversed the bone between the greater trochanter and femoral head without penetrating the trochanteric fossa. During screw insertion, the K-wire...
The 3.0-mm cannulated screw system was used to fix the partially threaded screws in this group. A 1.1-mm guide wire was inserted adjacent to the third trochanter at the caudodistal aspect of the greater trochanter up to the premeasured length, perpendicular to the fracture line. The guide wire length was measured using a cannulated depth gauge. A 2.0-mm cannulated drill bit (Arthrex Inc) was threaded over the inserted guide wire and drilled up to the measured depth. A 3.0-mm partially threaded cannulated cancellous screw (QuickFix screw; Arthrex Inc) of the appropriate length was inserted over the guide wire and tightened until interfragmentary compression was achieved. After confirmation of the appropriate screw fixation, the guide wire was removed. The tip of the antirotation wire was bent and cut to prevent migration (Figures 1 and 2).

**Group C (2.5-mm fully threaded headless cannulated screw with a 1.1-mm antirotation pin)**

In group C, a 2.5-mm fully threaded headless cannulated screw (Figure 3) and a 1.1-mm antirotation pin was used. The 1.1-mm antirotation K-wire was inserted using the same technique as that in group B.

The 2.5-mm cannulated screw system was used to fix the fully threaded screws in this group. A 0.8-mm guide wire was inserted at the same entry point as that of the 1.1-mm guide wire in Group B. The guide wire length was measured using a cannulated depth gauge. A 2.0-mm cannulated drill bit (Arthrex Inc) was threaded over the inserted guide wire and drilled up to the premeasured length, while preventing the distraction of the distal fragment. Following countersinking with a profile drill, a 2.5-mm fully threaded headless cannulated screw (Arthrex Inc) was inserted and tightened using a 1.5-mm cannulated hexalobe screwdriver. After removal of the guide wire, the final 2 to 3 mm of the

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**Figure 1**—Illustrations of the 3 internal fixation methods for a simulated femoral neck fracture. The study was conducted from December 12, 2023, to February 7, 2024, using a total of 18 femurs from 9 canine cadavers. Following the creation of a simple neck fracture, different stabilization methods were used across the groups: in group A (n = 6), the fracture was stabilized using three 1.1-mm parallel Kirschner wires (A). In group B (n = 6), a 3.0-mm partially threaded cannulated screw and a 1.1-mm antirotation pin were used (B). In group C (n = 6), a 2.5-mm fully threaded headless cannulated screw and a 1.1-mm antirotation pin were used (C). After fracture fixation, a single axial compressive mechanical test was performed.

**Figure 2**—Images of the 3 internal fixation methods for a simulated femoral neck fracture as described (Figure 1). A—Three 1.1-mm parallel Kirschner wires were used. B—3.0-mm partially threaded cannulated screw and a 1.1-mm antirotation pin were used. C—2.5-mm fully threaded headless cannulated screw and a 1.1-mm antirotation pin were used.
A 1.5-mm noncannulated hexalobe screwdriver was used to ensure optimal placement. After confirming the position of the leading and trailing edges of the screw beneath the bone surface, the screwdriver was removed. The tip of the antirotation wire was bent and cut to prevent migration (Figures 1 and 2). Finally, the intramedullary screw beneath the cortical bone was radio graphically confirmed (Figure 4).

**Biomechanical testing**

The femoral diaphysis was cut at the junction of the upper two-thirds and lower one-third of the femoral length. Subsequently, the lower half of the upper two-thirds of the femur was fixed to a wooden board, while simulating the normal standing joint angle by abducting the long axis of the femur by 21° toward the machine during fixation. Two 2.0-mm pins were inserted through the femoral shaft into the wooden boards. To prevent sample rotation or dislodgement, a total of 5 screws were inserted along the medial (n = 3) and lateral (2) aspects of the femur into the wooden board (Figure 5).

The inferior portion of the wooden board was secured to the lower jig of the testing machine (Instron 4467; Instron). A self-designed 3-D model was mounted to the upper jig to apply a compressive load to the femoral head. This model was specifically...
designed to accurately apply axial loading, ensuring that only the femoral head was engaged without crossing the fracture line. It was printed using polycarbonate material, exhibiting properties closely resembling cortical bone, thus ensuring adequate stiffness.23 The upper jig was fixed to a 3-kN load cell, which was connected to the crosshead of the testing machine. The compressive load was applied to the proximal aspect of the femoral head, without any preload, at a constant rate of 50 mm/min4,6 until failure.

Failure was defined as implant breakage or bending, complete fracture of the femoral neck, or sudden drop in the load-displacement curve.

Statistical analysis

All statistical analyses were conducted using SPSS (version 29.0.2.0; SPSS Inc; IBM). Given that there were 3 groups, all of which had a sample size < 10, a Kruskal-Wallis test and post hoc Mann-Whitney U test were employed. A confidence coefficient of 95% was achieved for the 3 methods using the Bonferroni correction. Consequently, P < .017 was considered to indicate statistical significance in the Mann-Whitney U test.

Results

A total of 18 cadaveric femurs were obtained from 9 small-breed adult dogs that weighed 3.6 - 8.3 kg (mean ± SD; 5.9 ± 1.6). During the axial compression test, the mean ± SD maximum failure loads were 222 ± 21.6 N (range, 195 to 247 N), 454 ± 50.4 N (range, 382 to 515 N), and 495 ± 81 N (range, 401 to 583 N) for groups A, B, and C, respectively. The mean maximum failure load was the highest in group C. The maximum failure load was significantly different between groups A and B (P = .002 < .017) and between groups A and C (P = .002 < .017). However, there was no significant difference in maximum failure load between groups B and C (P = .485 > .017; Figure 6). As described in previous studies, considering the average cadaver weight of 5.9 kg in this study, the load applied to the hindlimb during walking, trotting, and galloping was 23 N, 43 N, and 66 N, respectively, and 230 N when propelling the body forward using 1 leg.5,6,27

All the samples failed due to ventral displacement of the femoral head and neck, which opened the dorsal fracture line. In group A, implant failure consistently occurred due to K-wire bending (n = 6). In group B, failure occurred due to bending of the K-wire and screw (n = 5) or K-wire bending and screw breakage (1). In group C, failure occurred due to bending of the K-wire and screw (n = 4) or K-wire bending and screw breakage (2). The femurs in groups B and C did not demonstrate screw pull-out or displacement.

Discussion

In this study, the biomechanical features following internal fixation of femoral neck fractures using 3 different methods were compared in cadaveric dogs. The assessed methods included three 1.1-mm parallel K-wires, a 3.0-mm partially threaded cannulated screw with a 1.1-mm antiorotation pin, and a 2.5-mm fully threaded headless cannulated screw with a 1.1-mm antiorotation pin. The fully threaded headless cannulated screw was chosen due to its ability to prevent complications caused by screw head movement, such as soft tissue irritation. Furthermore, it provides sufficient biomechanical strength for fracture stabilization in humans.12 A recent clinical study by Sun et al,9 demonstrated that fully threaded headless cannulated screws could minimize femoral neck shortening and reduce the incidence of other complications associated with femoral neck fractures, including fixation failure and nonunion. The proposed hypothesis was that the biomechanical properties of a fully threaded headless cannulated screw were similar to those of a headed screw in a single axial compression test and superior to those of the K-wire fixation method. In this study, the 2.5-mm fully threaded headless cannulated screw with 1.1-mm antiorotation pin fixation and the 3.0-mm partially threaded cannulated screw with antiorotation pin fixation required higher loads for failure than the three 1.1-mm parallel K-wires fixation. The study results indicate that the fully threaded headless cannulated screw may be a viable alternative to current methods for internal fixation of canine femoral neck fractures.

For this study, the method of inserting 3 parallel K-wires was chosen instead of the divergent insertion method. The 3 parallel K-wires enable biologically continuous physeal growth, whereas divergent K-wires can cause a “locking effect,” which can
lead to premature closure of the growth plate.\textsuperscript{19} Mechanically, the parallel K-wires distribute the force equally between the pins and cause dynamic compression at the fracture site. However, the divergent K-wires do not distribute the force evenly between the pins. In a divergent configuration, the load at the fracture site is borne by a single K-wire, which can lead to implant failure.\textsuperscript{4,6} A study\textsuperscript{28} comparing the fixation methods in slipped capital femoral epiphysis determined that the biomechanical strength of the 3 K-wire fixation method was 45\% greater than that of the 2 K-wire fixation method and 60\% greater than that of the 1 K-wire fixation method. Thus, the 3 parallel K-wire fixation method was deemed an acceptable option in this study.

Two types of screws were selected in this study: a partially threaded cannulated screw and a fully threaded headless cannulated screw. The threaded screw in lag fashion is used in skeletally mature animals because of its potential to cause premature physeal closure due to interfragmentary compression. This choice is based on its demonstrated ability to offer superior stability when compared to the multiple pinning technique. Each screw was fixed in a different manner. The partially threaded cannulated screw can achieve compression when the threaded part engages the bone beyond the fracture line. Therefore, a smaller femoral head diameter or fragment will increase the probability of incomplete thread engagement.\textsuperscript{23} After fixation, the soft tissue may be irritated by the protrusion of the screw head. Conversely, the fully threaded headless cannulated screws offer the advantage of rapid insertion and compression regardless of the position of the threaded portion. Furthermore, once the fixation has been completed, the screw is buried intramedullary. This ensures that there is no protrusion above the cortex and no soft tissue irritation.

The peak vertical force of a dog’s hindlimb is reportedly 40\%, 75\%, and 115\% of the body weight during walking, trotting, and galloping, respectively.\textsuperscript{25,26} With the use of this calculation and considering the average body weight in this study (5.9 kg), the estimated peak vertical force of the hind limbs during walking, trotting, and galloping was 23, 43, and 66 N, respectively. The maximum failure loads for groups A, B, and C were 222 ± 21.6 N, 454 ± 50.4 N, and 495 ± 81 N, respectively. These results indicate that the specimens in all the groups demonstrated sufficient stability during walking, trotting, and galloping. However, from a mechanical perspective of the hip joint, when only one hind leg propels the body forward, the hip joint reaction force is 3 to 4 times the body weight (230 N).\textsuperscript{4,6,27} In this study, group A was associated with an increased risk of implant failure. However, groups B and C demonstrated higher maximum failure loads than group A, which indicated that the fixations in groups B and C were strong enough to withstand the forces experienced during propelling. Therefore, in small active dogs, K-wire fixation alone may not provide sufficient stability.

The maximum failure loads of the partially threaded cannulated screw and fully threaded headless cannulated in this study differed from those of previous studies. As previously reported,\textsuperscript{11} the fully threaded headless cannulated screw demonstrated a higher biomechanical stability than the ordinary partially threaded cannulated screw in the treatment of vertical femoral neck fractures with Pauwel angles of 50°, 60°, and 70°. However, in this study, there was no significant difference in the maximum failure load between the 2 screws. In the study of Zhang et al.,\textsuperscript{11} a synthetic 3-D human bone model was employed, and 3 large-diameter screws were arranged in an inverted triangle pattern. In contrast, in the current study, canine cadavers weighing < 10 kg were employed, and a single small-diameter screw was inserted in a parallel pattern. These differences may have influenced the biomechanical results.

All implant failures occurred due to ventral displacement of the fracture fragment and opening of the dorsal fracture line. In the samples in which K-wires were used, the femoral head had undergone ventral displacement due to pin bending. This finding is consistent with those of previous in vitro studies.\textsuperscript{4,6} However, migration of the screw, such as screw pull-out or screw cut-out, was not identified in the current study. This finding differs from that of a clinical cohort study by Sun et al\textsuperscript{10} on femoral neck fractures in humans in which lateral migration occurred with partially threaded cannulated screws and medial loosening occurred with fully threaded headless cannulated screws. This difference may be attributed to the fact that a single axial compression test was conducted in the current study and that cyclic loading was not measured. The compression mechanism differs from the loosening mechanism that occurs due to repeated loading.

This study has several limitations. First, the weight of the cadavers was limited to < 10 kg. Further studies are required to determine the reliability of using a 2.5-mm fully threaded headless cannulated screw in dogs weighing > 10 kg. Second, all the soft tissues surrounding the cadaveric femurs were removed. This excluded the influence of muscles in vivo, and there was a deviation from the natural loading conditions. This could have potentially caused the deviations in the loads experienced from that in actual clinical situations. Third, this study did not accurately reflect the movement of the actual hip joint. Despite conducting the biomechanical experiments with a normal standing joint angle of 21° abduction, only a single axial compressive test was performed, and the clinically relevant cyclic loading was not evaluated. Finally, the small number of specimens in each experimental group may have influenced the mechanical results. Additional studies with larger sample sizes in each group are required.

Nevertheless, the findings of this study indicate that the use of fully threaded headless cannulated screws could be an efficient method for internal fixation of canine femoral neck fractures. Further studies are required to validate the clinical application and...
long-term complication rates of using fully threaded headless cannulated screws in dogs and cats as a minimally invasive surgical approach for the fixation of canine femoral neck fractures. This approach can eliminate the need for an open procedure and minimize soft tissue damage, thereby, making it a promising option for clinical use.

In conclusion, the study findings demonstrate the effectiveness of fully threaded headless cannulated screws for the internal fixation of a canine femoral neck fracture under a single axial compressive load test. Compared to other headed screws, the headless screws are biomechanically stable and show potential as a reliable method of internal fixation for femoral neck fractures. However, their reliability in active small-breed dogs requires additional investigation. Further studies are necessary to evaluate their performance under cyclic loading conditions and in vivo clinical studies.

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