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EXPERIMENTAL LAB RESEARCH

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Arthroscopic-assisted hip toggle stabilization in cats: An ex vivo feasibility study

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Abstract

Objective: To describe arthroscopic-assisted hip toggle stabilization (AA-HTS) in cats, evaluate its feasibility and associated rate of iatrogenic injury, and assess deviations from planned surgical technique.

Study design: Ex vivo study.

Animals: Skeletally mature cat cadavers ($n = 7$).

Methods: Preoperative pelvic computed tomography (CT) was performed for surgical planning and to identify the ideal femoral bone tunnel projection. Ultrasound-guided transection of ligament of head of femur was performed. Following exploratory arthroscopy, AA-HTS was performed using a commercially available aiming device. Surgical time, intraoperative complications, and feasibility of technique were recorded. Iatrogenic injury and technique deviations were assessed by postoperative CT and gross dissection.

Results: Diagnostic arthroscopy and AA-HTS were successfully performed in all 14 joints. Median (range) surgical time was 46.5 (29-144) min, including 7 (3-12) min for diagnostic arthroscopy and 40 (26-134) min for AA-HTS. Intraoperative complications occurred in 5 hips, related to bone tunnel creation (4) and toggle dislodgment (1). Toggle passage through the femoral tunnel was the most challenging component of technique, recorded as mildly difficult in 6 joints. No damage to periarticular/intrapelvic structures was identified. Minor articular cartilage damage (<10% total cartilage area) was identified in 10 joints. Thirteen deviations (8 major, 5 minor) in surgical technique from preoperative planning were identified in 7 joints.

Conclusion: In feline cadavers AA-HTS was feasible but was associated with a high rate of minor cartilage injury, intraoperative complications, and technique deviations.

Clinical significance: Hip toggle stabilization using an arthroscopic-assisted approach may be an effective technique for management of coxofemoral luxation in cats.

1 | INTRODUCTION

Hip toggle stabilization (HTS) is one of the most commonly performed open techniques for management of coxofemoral luxation in cats.[1–5] The goal of HTS is to maintain coxofemoral reduction until joint capsular healing and periarticular fibrosis occur.[6] Long-term (>6 months) reluxation rates in retrospective studies involving 48 and 14 cats treated with HTS was 11.1% and 14.3%, respectively.[1,5] Excellent outcomes (no reluxation with lameness resolution) of arthroscopic-assisted HTS (AA-HTS) were reported in 2 canine case reports with 6 months follow-up.[7,8] As far as to the authors' knowledge, there are no descriptions of AA-HTS in cats.

No peer-reviewed studies describe feline hip arthroscopy. In dogs, coxofemoral arthroscopy offers numerous advantages over traditional open surgical techniques, including decreased postoperative pain and morbidity, increased visibility, and increased precision.[9–12] In cats with coxofemoral luxation, arthroscopy offers the potential to assess damage to intra-articular structures and debride the ligament of the head of the femur (LHF).[13]

Study objectives were to (1) describe the technique of AA-HTS in feline cadavers, (2) evaluate its feasibility and associated rate of iatrogenic injury, and (3) evaluate for rate of deviations from preoperative planned surgical technique. We hypothesized that AA-HTS would be (1) possible to perform in all hips, (2) associated with no substantial damage to intra-articular or extra-articular structures, and (3) associated with a low rate of technique deviations.

2 | METHODS

2.1 | Specimens

Fourteen pelvic limbs from 7 feline cadavers euthanized for reasons unrelated to this study were included. Sex, breed, and postmortem bodyweight were recorded. Ethical approval was obtained from the primary author's institution (AREC-E-20-16-Mullins). Cadavers were stored in a −20 °C freezer until thawed for use. Forty-eight hours prior to intervention, cadavers were defrosted at room temperature. Both pelvic limbs were clipped from the cranial iliac wings to stifles and dorsal to ventral midline.

2.2 | Preoperative preparation

All cats underwent preoperative orthopedic examination, which included hip manipulation through a range of motion and palpation for crepitus, Bardens and Ortolani tests.[6] Cats with any abnormalities (eg, reduced range of motion, crepitus, abnormal anatomic landmarks) or positive Bardens or Ortolani tests were excluded. A 16-slice helical computed tomography (CT) scanner (SOMATOM Scope, Siemens, Erlangen, Germany) was used. Pelvic CT was performed with cadavers in dorsal recumbency and the femurs extended caudally. Transverse sections of 0.6 mm slice thickness were obtained from the sacrum to ischium. DICOM (Digital Imaging and Communications in Medicine) images were uploaded to Horos (Horosproject.org; Annapolis, Maryland) and reviewed by 2 authors (JER, SH) for hip dysplasia, osteoarthritis, and/or femoral/acetabular fractures, which were exclusion criteria. Images were reviewed for surgical planning by 2 authors (JER, RAM). The ideal femoral bone tunnel projection, consisting of a line extending from the fovea capitis to the lateral femoral cortex at the level of the third trochanter, but without perforating the ventral aspect of the neck with a 2.7 mm drill bit, was drawn on CT multiplanar reconstruction (MPR) images. The distance from the ideal femoral bone tunnel entry point to the proximal aspect of the greater trochanter was measured in the frontal plane (Figure 1). Following CT, ultrasound-guided LHF transection was performed by a board-certified radiologist (SH). Cadavers were positioned in dorsal recumbency with pelvic limbs abducted (frog leg position). A 65 beaver blade was introduced into the ventrocaudal aspect of the joint and the LHF was transected. The procedure was considered successful with a positive Bardens test.

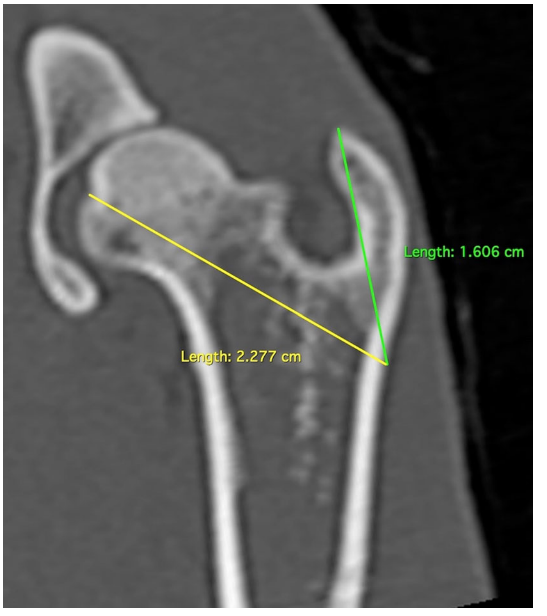

FIGURE 1 Multiplanar reconstruction computed tomographic frontal plane image demonstrating measurement of the distance from the ideal femoral tunnel entry point to the most proximal aspect of the greater trochanter.

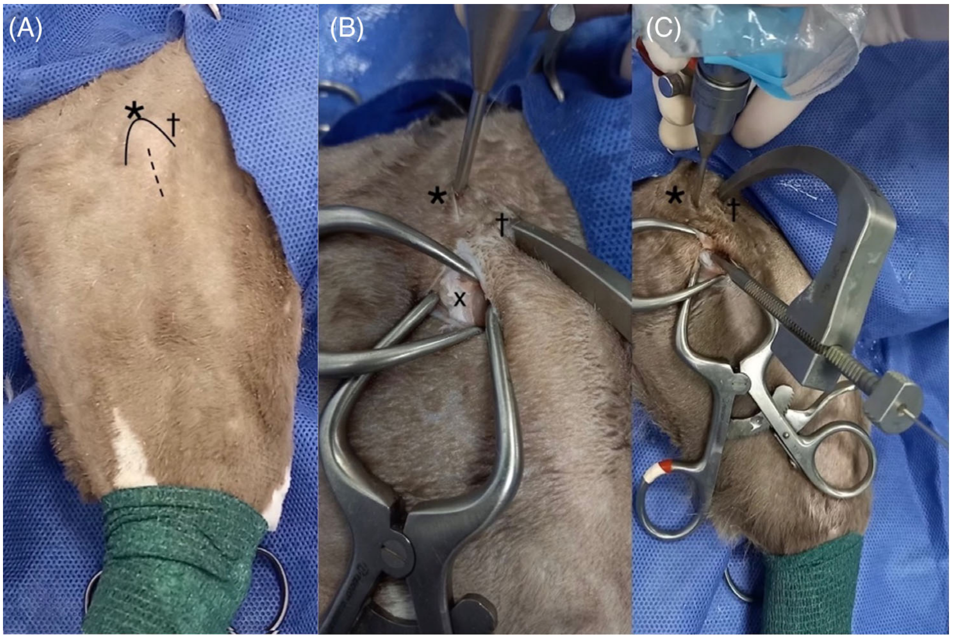

FIGURE 2 Series of intraoperative images. The greater trochanter is marked with the curved continuous line, the arthroscopic portal with an asterisk, the instrument portal with a dagger and the mini approach to the lateral femur with a broken line (2A); The scope and the intra-articular guide have been placed in the arthroscopic and instrumental portals, respectively, and the mini approach has been performed. The location for the entry point of the femoral bone tunnel is marked with an x (2B); The Kirschner wire has been placed through the intra-articular guide. For all images, dorsal is to the top and cranial is to the right (2C).

2.3 | Surgical technique

Cadavers were positioned in lateral recumbency with the hip being operated uppermost. The limb was positioned in a neutral position, perpendicular to the spine. The first side operated in each cadaver was the contralateral side of the previous operated hip, with the first hip of cadaver 1 decided by coin toss. All procedures were performed over 5 consecutive days by a third-year European College of Veterinary Surgeons (ECVS) resident-in-training (JER) under the supervision of an ECVS Diplomate (RAM). Exploratory arthroscopy was performed as previously described in dogs and cats.[9,13] Creation of the arthroscope portal commenced by insertion of a 20 gauge hypodermic needle perpendicular to the skin just proximal to the greater trochanter, with mild distal limb traction applied by the assistant (Figure 2A). The joint was aspirated and distended with 5 mL of saline. A ~ 3-5 mm stab incision was created in a proximodistal direction alongside the hypodermic needle using a no. 11 blade and dilated using a straight hemostat. A 1.9 mm 30 degree oblique arthroscope was used (Stryker, Michigan). The instrument portal was established using the same technique in the craniolateral aspect of the joint. Fluid egress occurred through the arthroscope and instrument portals and a separate egress portal was not placed. Mild distal limb traction was applied throughout the procedure. Commencement of the arthroscopic approach was defined as intra-articular hypodermic needle insertion and completion defined as intra-articular probe visualization. Difficulty of the arthroscopic approach was graded as easy (first attempt placement of portals), mildly difficult (≤3 attempts), moderately difficult (>3 attempts), or unsuccessful (impossible to perform). Exploratory arthroscopy was standardized in all cases. A constant flow of fluid was provided using a motorized fluid pump (Arthrex Continuous Wave III, Arthrex Vet Systems, Naples, Florida) with pressure set at 50 mmHg. Intra-articular structures inspected and probed included the femoral head, acetabulum, labrum, synovium, transverse ligament, and LHF, with each structure recorded as visualized or not. The LHF was recorded as completely or partially transected. Any identified articular cartilage injury (ACI) was recorded.

After exploratory arthroscopy, fibers of the LHF were removed using a 2 mm arthroscopic shaver (Saber Tooth 2.0 mm AR-7200SR, Arthrex, Naples, Florida) introduced through the instrumental portal (Video S1). The tip of the arthroscopic guide (Bio-Compression Screw C-Ring Guide, AR-5026G, Arthrex) was inserted through the instrument portal and positioned on the dorsal aspect of the fovea capitis under arthroscopic guidance (Video S2). A ~1 cm skin incision was made over the lateral femoral cortex tunnel entry point at the third trochanter at a distance from the most proximal point of the greater trochanter based on preoperative CT measurements (Figure 2B). The other end of the guide was secured at this location and, following arthroscopic confirmation of correct intra-articular guide positioning, a 1.1 mm Kirschner wire (k-wire) was drilled from lateral to medial (Figure 2C) until interference of the k-wire with the pointed tip of the arthroscopic guide was felt. The guide was removed and the k-wire advanced until visible intra-articularly. In the first hip of cadaver 1, the k-wire was over drilled with a 2.7 mm cannulated drill bit, with the

FIGURE 3 Metal toggle with 2 attached strands of suture mounted on the swaged end of the passing needle.

intent of exiting at the fovea capitis, manipulating limb position, and advancing the drill bit through the fossa. In the subsequent 13 hips, the k-wire was advanced directly through the center of the acetabular fossa under arthroscopic visualization (Video S3) and then over drilled with the 2.7 mm cannulated drill bit (Video S4). The arthroscopic shaver was introduced intra-articularly through the femoral tunnel and used to remove any remaining fibers of the LHF that could interfere with toggle passage (Video S5). To facilitate toggle passage, limb position was adjusted until there was no resistance to shaver passage through both tunnels. The shaver was removed and a 2.0 mm metal toggle with 2 attached strands of 150 lb. ultrahigh molecular-weight polyethylene (Mini TightRope, Arthrex) was carefully mounted on the swaged end of the passing needle (Figure 3) and passed through both tunnels from lateral to medial (Video S6). Following toggle passage, the suture was pulled on sharply, securing it on the medial acetabulum. The arthroscope was removed, the hip put through a range of motion, the suture slack removed, and suture tied with hand-tied knots on the lateral femur using the metal button. The same procedure was performed on the contralateral hip.

2.4 | Intraoperative complications

Intraoperative complications were defined as any intraoperatively recognized deviations from the planned surgical course between skin incision and closure.[42]

2.5 | Postoperative CT and gross dissection

Repeat CT was performed as previously described and reviewed by one author (SH). Positioning of implants and bone tunnels was evaluated and any technique deviations recorded. Ideal femoral and acetabular tunnel positioning was from the lateral femur at the level of the third trochanter to the fovea capitis (without breaching the confines of bone) and the acetabular fossa, respectively. Ideal suture button position was in direct contact with bone on the lateral femur and that of the toggle was in direct contact with bone in the correct orientation medial to the acetabulum. Following postoperative CT, gross dissection was performed by one author (JER) via a ventral approach to the pelvic canal and craniolateral approach (with disarticulation) to the hip. All relevant neurovascular structures (sciatic and obturator nerves, femoral artery and vein) were evaluated for injury. Osteotomies of the cranial and caudal pubic rami were performed and intrapelvic structures (urethra, colon/rectum, obturator nerve, +/− uterus) evaluated for injury. The femoral artery and vein were evaluated by extension of the ventral approach to the medial aspect of the hip. A bilateral craniolateral approach to the hip was performed to evaluate the position of bone tunnels, articular cartilage, periarticular musculature, and sciatic nerve. Ideal positioning of femoral and acetabular bone tunnels, metal toggle and button was as defined on postoperative CT. Surgical implants were removed and the joint luxated. Articular cartilage of the femur and acetabulum was evaluated for injury prior to and after India ink staining (Winsor and Newton Ink, London, England).

2.6 | Feasibility

The feasibility of AA-HTS was defined as overall successful completion of the procedure and was divided into 4 components including feasibility of (i) femoral tunnel creation, (ii) acetabular tunnel creation, (iii) toggle passage through the femoral tunnel, and (iv) toggle passage through the acetabular tunnel. Each component was separately classified as easy to perform (achieved on first attempt), mildly difficult (≤3 attempts), moderately difficult (>3 attempts), or unsuccessful (not possible to perform).

2.7 | Iatrogenic injury

Assessment of iatrogenic injury to the intra-articular/periarticular structures was performed and divided into

5 components including injury to (i) articular cartilage, (ii) periarticular musculature (other than previously described related to arthroscopic approach in dogs[9,14]), (iii) neurovascular structures (sciatic and obturator nerves, femoral artery/vein), (iv) osseous structures, and (v) intrapelvic structures (urethra, colon/rectum, +/− uterus). Articular cartilage injury (ACI) was classified as partial (no subchondral bone exposure) or full thickness (subchondral bone exposure), assessed grossly using India ink. Total dimensions (width and length) of ACI were also measured (in mm) with a surgical ruler. Total injury area was calculated in mm^2 based on the shape of the lesion (rectangular area = width × length; circular area = πr^2). A significant ACI was defined as >10% total cartilage area. For this calculation, total cartilage area was determined from photographs of the coxofemoral joint from a 3.4 kg feline cadaver using commercially available software (ImageJ version 1.53, National Institutes of Health, Bethesda, Maryland), and was calculated as 55.7 mm^2 for the acetabulum and 152.5 mm^2 for the femoral head.

2.8 | Technique deviations

Deviations were described as any modifications of ideal surgical technique based on postoperative CT and gross dissection and divided into 2 components including positioning of (i) implants (button and toggle) and (ii) femoral and acetabular bone tunnels. The position of the lateral femoral cortex tunnel entry point and femoral head tunnel exit point were further classified as ideal, minor deviation (≤2 mm from ideal position) or major deviation (>2 mm from ideal position).

2.9 | Statistical analysis

Continuous variables were tested for normality using the Shapiro-Wilk test. Normally distributed continuous variables are presented as mean (SD). Non-normally distributed data are presented as median and range (minimum and maximum). Categorical variables are presented as frequencies. Statistical analyses were performed using statistical software (SPSS Statistics Version 24, IBM, New York, USA).

3 | RESULTS

3.1 | Signalment

Fourteen coxofemoral joints from 7 feline cadavers were included, with 6 males and 1 female. Six were domestic shorthair and 1 was British shorthair. Mean (SD) postmortem bodyweight was 3.9 (0.8) kg.

3.2 | Preoperative assessment

No significant abnormalities were identified on preoperative orthopedic or CT examination. A positive Bardens test was identified after transection of the LHF in all limbs. Mean (SD) distance from the most proximal aspect of the greater trochanter to the lateral femoral cortex tunnel entry point was 16.1 (1.7) mm.

3.3 | Surgical technique

The arthroscopic approach was successful in all joints. The mean (SD) time for completion was 4 (1) minutes, with approach classified as easy in 13 joints and mildly difficult in 1 joint in which insertion of the arthroscopic cannula required a second attempt. Identification of all intra-articular structures was possible in 12 of 14 joints. In both joints of the first operated cat, the transverse ligament was not identified. The femoral head, acetabular labrum, and synovium were observed in all joints and were normal. The LHF was observed in all joints and was partially transected in them all. Acetabular cartilage was observed in all joints and was grossly normal in 9 joints. Of 5 joints with ACI, a small (∼2-3 mm) linear, partial thickness ACI was identified on the cranial aspect of the acetabulum in 2 joints, on the cranial and caudal aspects of the acetabulum in 2 joints, and on the caudal aspect of the acetabulum in 1 joint. The median time for completion of exploratory arthroscopy was 3 min, with a range of 1-7 min. The median overall time taken for arthroscopic approach and exploratory arthroscopy was 7 min, with a range of 3-12 min.

The AA-HTS was successfully performed in all joints. Femoral bone tunnel creation was performed on first attempt in 11 joints and on second attempt in 3 joints. Acetabular bone tunnel creation was performed on first attempt in 14 joints. However, in 1 cat (first cadaver), the femoral bone tunnel was inadvertently created by advancing the cannulated drill bit over the 1.1 mm k-wire without advancement of the k-wire through the acetabular fossa. Toggle passage through the femoral tunnel was performed on first attempt in 8 joints, on second attempt in 5, and on third attempt in 1 joint. Toggle passage through the acetabular tunnel was performed on first attempt in 11 joints, on second attempt in 2, and on third attempt in 1 joint. The median duration of AA-HTS was 40 min, with a range of 26-134 min. The median was 41 min for the first 7 hips, with a range of 31-134 min.

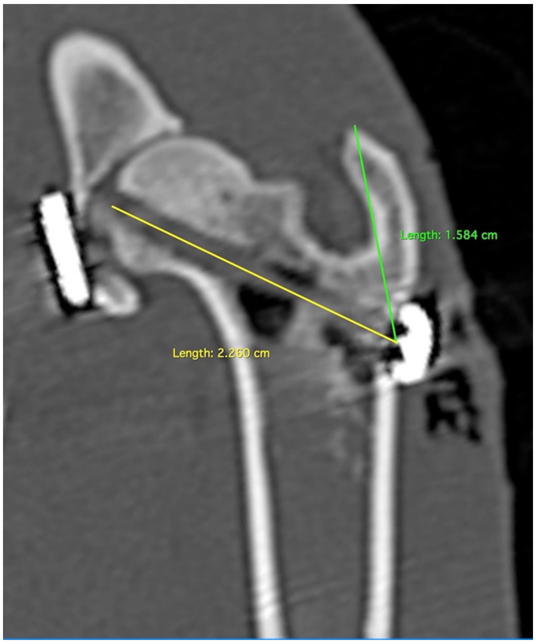

FIGURE 4 Postoperative multiplanar reconstruction computed tomographic frontal plane image of the same hip in Figure 1 demonstrating ideal position of implants and bone tunnels.

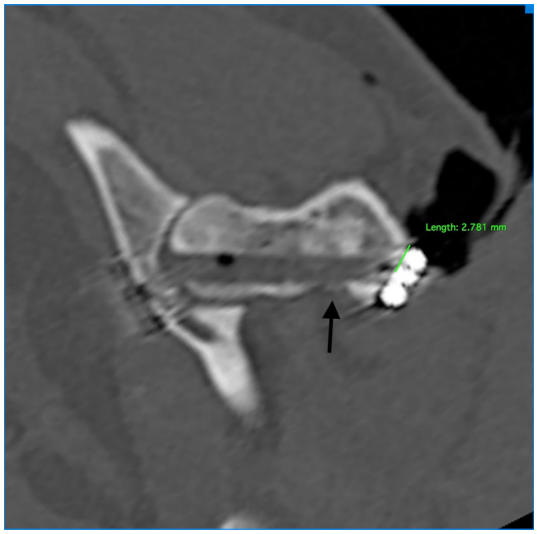

FIGURE 5 Postoperative multiplanar reconstruction computed tomographic dorsal plane image demonstrating partial breach of the caudal femoral cortex (black arrow) with caudal deviation of the lateral femoral cortex tunnel entry point and ideal positioning of the femoral head tunnel exit point.

For the last 7 hips, the mean was 36.5 min, with a range of 26-49 min. The median overall surgical time for the entire arthroscopic-assisted procedure was 46.5 min with a range of 29-144 min.

3.4 | Intraoperative complications

Intraoperative complications were encountered in 5 joints. The k-wire exited on the first attempt cranial and dorsal to the fovea capitis in 1 joint; it was redrilled and exited in the ideal position on second attempt. The acetabular tunnel was unintentionally created in 1 joint but it happened to be positioned in the ideal position (acetabular fossa). The toggle passage through the femur was unsuccessful in 1 femur, in which the toggle became lodged within the femoral tunnel, just medial to the lateral cortex. The toggle was removed by careful manipulation to align it within the tunnel using a k-wire and it was subsequently placed successfully on the second attempt. In 2 joints, the cannulated drill bit was partially advanced by mistake over the k-wire within the femoral tunnel without advancement of the k-wire through the acetabular fossa, and in both cases the k-wire was inadvertently removed at the time of the drill bit removal. In 1 joint, replacement of the k-wire through its original path was unsuccessful and the bone tunnel had to be completed by advancing the drill bit through the already partially drilled tunnel without the guide of a k-wire. In the other case, the cannulated drill bit was reintroduced into the partially drilled tunnel and used as a guide to reintroduce the k-wire back through its original path successfully. The k-wire was successfully placed, advanced through the acetabular fossa under arthroscopic guidance, and overdrilled with the cannulated drill bit.

3.5 | Postoperative computed tomography

All toggles and metal buttons were correctly positioned, in correct orientation, and in contact with bone on the medial aspect of acetabulum and on the lateral femur, respectively (Figure 4). The acetabular bone tunnel was positioned in the acetabular fossa in all cases. The femoral bone tunnel position was suboptimal in 7 femurs, with 2 deviations in 6 femurs (total of 13 deviations). The lateral femoral cortex tunnel entry point was suboptimal (relative to preoperative measurements) in 7 femurs and included deviations of 1 mm distal in 1, 1 mm proximal and caudal in 2, 3 mm proximal in 2, and 3 mm proximal and caudal in 2. The femoral head tunnel exit point was 4 mm ventrally deviated in 1, being outside the femoral fovea and breaching the ventral aspect of the femoral head; and 2 mm ventrally deviated in 1, being partially inside the femoral fovea. Partial breach of the caudal femoral cortex, entering the intertrochanteric fossa, was identified in the 4 femurs with caudal deviation (Figure 5).

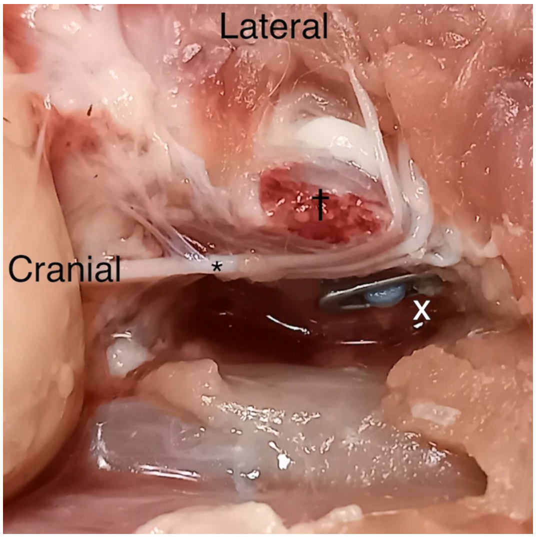

FIGURE 6 Gross dissection following pubic ostectomy (dagger) demonstrating the toggle (x) firmly positioned on the medial aspect of the acetabulum dorsal to the obturator nerve (asterisk).

3.6 | Postoperative gross dissection

No damage to intrapelvic structures was identified. All toggles were firmly positioned on the medial aspect of the acetabulum, in contact with bone, dorsal to the obturator nerve in all cases without gross evidence of nerve injury in any case (Figure 6). No damage to either femoral artery or vein was identified. Metal buttons were firmly positioned on the lateral surface of the femur in contact with bone in all cases. The sciatic nerve was in close proximity (within 10 mm) to the arthroscopic portal but without injury. No significant injury to periarticular musculature or bone was identified in any case. The acetabular bone tunnel was positioned in the acetabular fossa in all cases. The lateral femoral cortex tunnel entry point was located on the lateral femur in 10 cases (Figure 7A) and caudolateral in 4 cases. The center of the lateral femoral cortex tunnel entry point was suboptimal in 7 femurs and included deviations of 1 mm distal in 1, 1 mm proximal and caudal in 2, 3 mm proximal in 2, and 3 mm proximal and caudal in 2. The femoral head tunnel exit point was suboptimal in 2 and included ventral displacement of 2 mm in 1 (partially outside the fovea capitis) and ventral deviation of 4 mm in 1 (outside

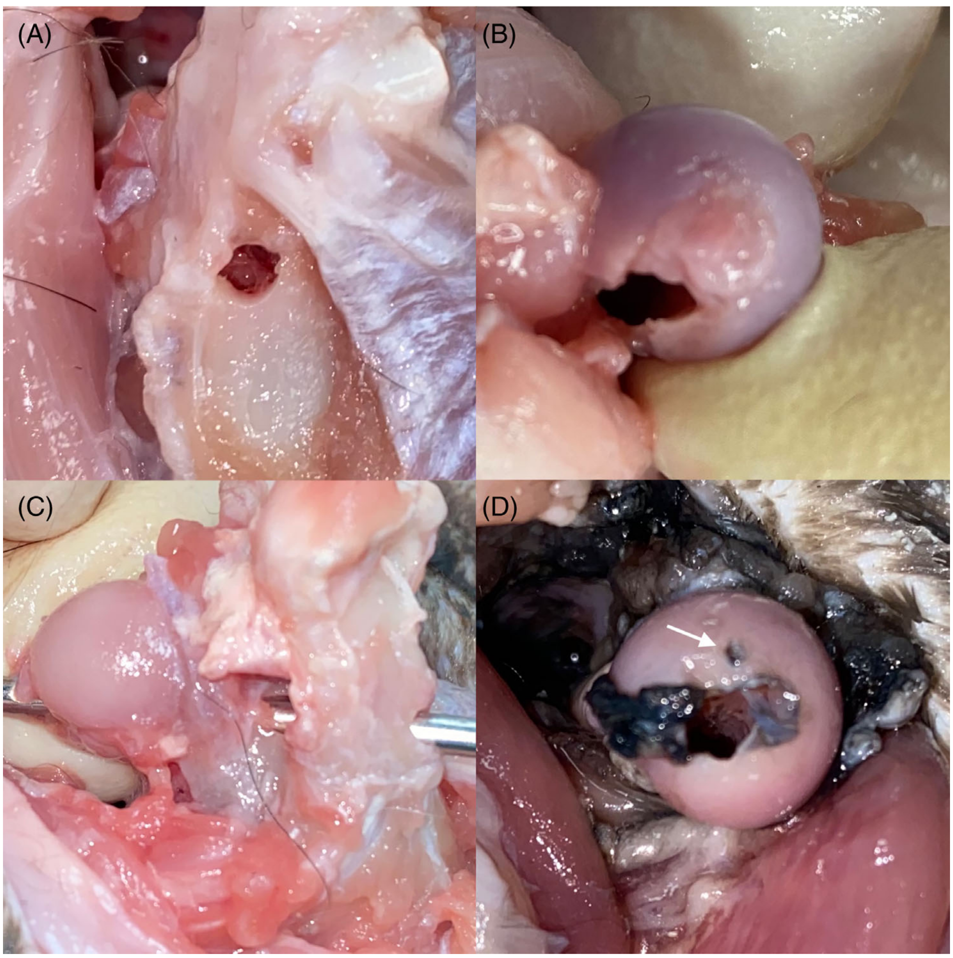

FIGURE 7 Series of gross dissection images. Figure 7A: ideal entry point on the lateral femur. Figure 7B; major ventral deviation of the exit point on femoral head. Figure 7C; partial breach of caudal femoral cortex (asterisk) and entry into intertrochanteric fossa. Figure 7D; cartilage damage (white arrow) created by the misplaced Kirschner wire dorsal to the fovea after India ink application.

the fovea capitis) (Figure 7B), with the measurement from the perimeter of the fovea to the furthest point of the perimeter of the hole. Partial breach of the caudal femoral cortex, entering the intertrochanteric fossa, was identified in 4 (Figure 7C).

Articular cartilage injury was documented in 10 joints, affecting the femoral head in 9 and the acetabulum in 5. The ACI of the femoral head included 2 with suboptimal position of the femoral tunnel exit point (as previously described), 9 with 2 mm diameter round partial thickness abrasion ACI on the dorsal femoral head (in region of where the arthroscopic cannula would have been positioned intraoperatively), and 1 with 1 mm diameter round full thickness ACI (compatible with incorrect k-wire placement for creation of the femoral bone tunnel) (Figure 7D). Acetabular ACI included 2 with 3 mm partial thickness linear damage in the cranioventral aspect of the acetabulum and 3 with 2 mm partial thickness linear damage in the cranioventral and caudoventral aspects of the acetabulum (Figure 8). Additionally, a 2 mm diameter partial thickness ACI was identified on the dorsal aspect of 1 acetabular labrum, at the level of the arthroscopic cannula.

3.7 | Feasibility

Arthroscopic-assisted hip toggle stabilization was successfully completed in all joints. Femoral and acetabular bone tunnel creation was considered easy in 11 and 14 joints, respectively, and mildly difficult in 3 and 0 joints, respectively. Toggle passage through the femoral and acetabular tunnels was classified as easy in 8 and 11 joints and mildly difficult in 6 and 3 joints, respectively.

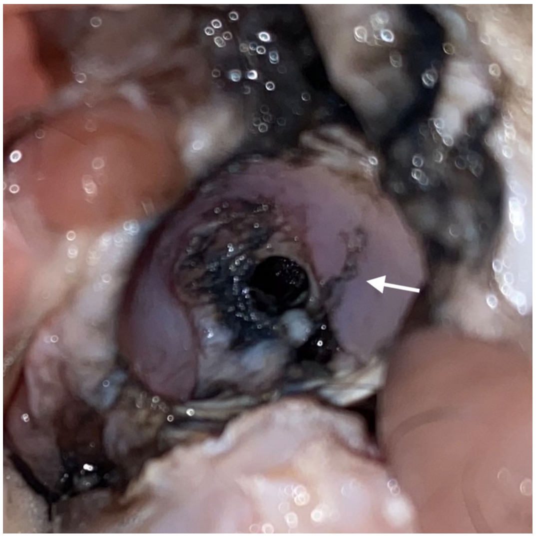

FIGURE 8 Gross dissection image demonstrating linear cartilage damage (white arrow) on the cranioventral aspect of the acetabulum after application of India ink. Dorsal is to the top of the image and cranial is to the right.

3.8 | Iatrogenic injury

No damage to periarticular musculature, neurovascular structures, osseous structures, or intrapelvic structures (urethra, colon/rectum, uterus) was documented in any cadaver. Articular cartilage injury was identified in 10 joints on gross dissection and graded minor (<10% total cartilage area) in all cases.

3.9 | Technique deviations

Thirteen deviations (8 major and 5 minor) were identified in 7 femurs. No deviations related to the acetabular bone tunnel were identified. Deviations encountered include 7 (3 minor and 4 major) related to the lateral femoral cortex tunnel entry point, 4 (all major) related to the femoral bone tunnel trajectory, and 2 (1 major and 1 minor) related to the femoral head tunnel exit point. No deviations occurred in the last 4 joints operated.

4 | DISCUSSION

The main findings of this study are that AA-HTS (1) was successfully performed in all joints, (2) was not associated with significant damage to intra-/extra-articular structures, but (3) was associated with a high rate of intraoperative complications (5 of 14 joints), ACI (10 of 14 joints) (albeit minor in most cases) and technique deviations (7 of 14 joints). Despite this high rate of deviations, 12 of 14 femoral head tunnel exit points were located completely within the fovea capitis.

Our first hypothesis was that it would be possible to perform AA-HTS in all joints. No previous peer-reviewed studies describe hip arthroscopy or AA-HTS in cats. This hypothesis was based on the fact that feline hip arthroscopy is reported to be possible to perform in a primary surgical textbook,[13] and a technique similar to that employed in this study was successfully performed in a canine clinical case.[8] Overall, our results provide evidence that it is possible to perform AA-HTS in feline cadavers.

We hypothesized that AA-HTS would not be associated with significant damage to intra-/extra-articular structures. No in vivo or ex vivo studies have evaluated damage to intra-/extra-articular structures following feline open-HTS. In a canine ex vivo study,[14] positioning of periarticular structures (sciatic nerve, caudal gluteal and lateral circumflex femoral artery) relative to arthroscopic portals using a technique similar to ours was evaluated. Similar to our study, the sciatic nerve in that study was close to the arthroscopic portal (mean 9 mm caudal to arthroscope portal, range, 6-15) but without injury thereto or any other periarticular structures.[14] In our study, gross dissection of intrapelvic structures identified all toggles positioned a few millimeters dorsal to the obturator nerve without injury in any case. As far as we are aware, positioning of the toggle relative to obturator nerve has not been described previously. Acetabular tunnel and toggle placement excessively ventral could potentially cause impingement of the nerve in cats. In a canine case report,[15] severe pain was associated with bilateral impingement of the obturator nerve with callus associated with the free section of the pubic bone after bilateral triple pelvic osteotomy. In our study, minor (<10% articular surface) ACI involving the acetabulum or femoral head was identified in 10 of 14 joints and the clinical significance of this is uncertain. Some degree of ACI may have occurred during LHF transection, therefore potentially overestimating the true rate of ACI associated with AA-HTS. In a canine ex vivo study in which the femoral tunnel was created using fluoroscopic anteversion and inclination angles,[16] femoral head ACI was detected in 9 of 12 joints. No previous studies compare ACI following open or AA-HTS in dogs or cats. In a canine ex vivo study comparing ACI injury following medial parapatellar mini-arthrotomy versus arthroscopy,[17] ACI was identified in 92.9% stifles that underwent arthroscopy compared with 28.6% joints that underwent mini-arthrotomy. Despite this, stifle arthroscopy is associated with reduced short-term postoperative morbidity compared with open arthrotomy.[18] Further feline studies are required to compare outcomes and degree of ACI associated with open versus AA-HTS.

No feline in vivo studies evaluated the rate of deviations associated with open-HTS. Our third hypothesis was that AA-HTS would be associated with a low rate of technique deviations. This was not supported by the results of our study, with deviations from the planned preoperative technique identified in 7 of 14 joints, all of which were related to femoral bone tunnel creation. Despite this, the overall rate of deviations in our study was lower than in previous canine cadaveric studies.[16,19] In 1 study in which femoral bone tunnels were created based on fluoroscopic anteversion and inclination angles, 9 of 12 tunnels did not exit at the fovea capitis.[16] In another canine cadaveric study,[19] using a patient-specific 3D-printed drill guide, the femoral bone tunnel exited partially outside the fovea capitis in 12 of 19 joints and completely outside in 4 joints. Conversely, despite the overall high rate of deviations related to femoral bone tunnel creation in our study, 12 of 14 femoral head tunnel exit points were located at the fovea capitis, with 1 partially outside the fovea capitis and the other completely outside the fovea capitis. In both femurs of cadaver 1, the femoral tunnel exited ventral to the fovea capitis. In subsequent cats, the guide tip was placed just dorsal to the fovea capitis instead of directly over its center, with elimination of this deviation in subsequent cadavers. Due to the small size of the feline coxofemoral joint and the relatively large size of the pointed tip of the aiming device, particular attention was given in our study to making certain with arthroscopic visualization that the tip did not move during manipulation of the extra-articular component of the guide in preparation for drilling. Breach of the caudal femoral cortex into the intertrochanteric fossa was identified in 4 femurs, likely because the femoral tunnel was started too caudally. The ideal lateral femoral cortex tunnel entry point in our study was at the level of the third trochanter, with no breach of intertrochanteric fossa identified when the tunnel was started at this ideal position. All cases of breach of the caudal femoral cortex into the intertrochanteric fossa were classified as major deviations because of the potentially severe postoperative implications of this deviation, including the increased risk of femoral neck fracture. These deviations highlight the importance of correct positioning of femoral tunnel entry and exit points. No deviations related to acetabular tunnel were identified in our study. The rate of deviations related to acetabular bone tunnel creation has previously been reported as 0-37.5%.[16,19,20] In those studies,[16,19,20] the acetabular bone tunnel was created without arthroscopic visualization.

Toggle passage through the femoral tunnel was the most frequent difficulty in our study, recorded as mildly difficult in 6 joints. A toggle inserter was not commercially available for the toggle used here and the toggle had to be carefully passed through both tunnels attached to the passing needle available with the kit. In 1 hip, the toggle disengaged and became lodged within the femoral tunnel. This could likely have been avoided had a commercially available toggle inserter been available. In 1 report in which intra-articular toggle detachment occurred,[8] the toggle had to be manually inserted through the acetabular tunnel using an arthroscopic grasper and meniscal probe. Numerous other minimally invasive techniques are described for toggle passage in previous reports.[7,8,19–21]

A number of intraoperative complications occurred in our study including cranial and dorsal misplacement of a k-wire in the femoral head on first attempt, unintentional acetabular tunnel creation in 1 joint, and inadvertent over drilling of the k-wire without advancement of the k-wire through the acetabular fossa. None of these complications was considered likely to affect patient outcome in a clinical case. In a previous ex vivo study in which investigators used fluoroscopy to guide k-wire insertion from the lateral femur to fovea capitis, the k-wire bent during placement in 3 joints, either at the femoral neck or intra-articularly.[21] Shearing of the k-wire occurred during subsequent drilling at the location of the bend, resulting in the need to abort the procedure.[21] This complication was not encountered in our study. We believe that the rate of technique deviations, intraoperative complications and ACI may be reduced with greater experience in performing AA-HTS in cats and this is supported by the fact that no deviations, complications or ACI were identified in the last 4 joints operated. This highlights the importance of undertaking training in cadavers prior to performance in clinical cases.

Limitations include the ex vivo nature of the study, with a relatively small number of cadavers. The clinical outcome including postoperative complications could not be evaluated and this warrants further in vivo studies. In clinical cases, tearing of the joint capsule may make capsular distension difficult and result in extravasation of lavage fluid as well as a potentially greater tendency for reluxation during the procedure resulting in a more technically demanding procedure and greater ACI. The technique also requires a reduced hip. Traction that was applied to the limb could potentially result in luxation in clinical cases. Such factors could result in a higher rate of complications than observed in our study. Clinically normal cats were included herein and therefore the time taken to perform the approach and complete exploratory arthroscopy was short and may not be reflective of the clinical situation with traumatic disruption of normal anatomy. It is possible that some ACI identified herein may have been related to ultrasound-guided LHF transection rather than the AA-HTS procedure, however, ACI associated with the former tended to be manifested as linear cuts with minimal collateral cartilage damage. We attempted to manually luxate the coxofemoral joint of a feline cadaver prior to performing this study and it resulted in proximal femoral fracture rather than hip luxation. While arthroscopic LHF transection may have been possible, we believe that this may have been associated with greater ACI due to the small working space in the feline hip.

Compared with open-HTS, a slightly larger femoral tunnel is required for toggle passage with AA-HTS. This is because the toggle has to be inserted from lateral to medial instead of inserting it through the acetabular tunnel and passage of the strands of ultrahigh molecular-weight polyethylene from the fovea capitis to the lateral femoral cortex. This has several important implications for the AA-HTS technique including decreased margin for error, increased risk of ACI, greater risk of femoral fracture because of weakening of the femoral neck, and potentially more serious consequences in the event of misplacement.

The results of our study suggest that feline AA-HTS is feasible in feline cadavers but was associated with a high rate of minor ACI, intraoperative complications and technique deviations. Despite the high rate of minor ACI, some of which may have been related to preoperative transection of the LHF, a very high rate of femoral head tunnel exiting at the fovea capitis was identified in this study. Care should be taken to avoid acetabular tunnel creation and toggle placement excessively ventral, which could potentially result in impingement of the obturator nerve in cats. The clinical benefits of AA-HTS over an open approach are currently unknown. Further studies are required to confirm our results in clinical cases.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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