Complications associated with total hip arthroplasty in four large nondomestic felids

Lauren P. Kane, DVM, MS^{1,2*}; James L. Cook, DVM, PhD³; Kate E. Archibald, DVM⁴; W. Kirk Suedmeyer, DVM⁵; Jennifer N. Langan, DVM¹; Michael J. Adkesson, DVM, MBA¹

¹Chicago Zoological Society, Brookfield Zoo, Brookfield, IL

²Illinois Zoological and Aquatic Animal Residency Program, Department of Veterinary Clinical Medicine, College of Veterinary Medicine, University of Illinois, Urbana, IL

³Missouri Orthopaedic Institute, University of Missouri, Columbia, MO

⁴Omaha's Henry Doorly Zoo and Aquarium, Omaha, NE

⁵Kansas City Zoo, Kansas City, MO

*Corresponding author: Dr. Kane (laurenkanedvm@gmail.com)

<https://doi.org/10.2460/ajvr.21.10.0161>

CASE DESCRIPTION

A 9-year-old 37-kg sexually intact male snow leopard (*Panthera uncia*) with no history of lameness but radiographic evidence of right femoral subluxation and flattening of both femoral heads, 2 juvenile (< 1 year old) 25-kg sexually intact male cheetahs (*Acinonyx jubatus*) with unilateral hind limb lameness resulting from trauma, and an 11-year-old 110-kg sexually intact female Amur tiger (*Panthera tigris altaica*) with a 2-year history of left hip joint osteoarthritis were examined.

CLINICAL FINDINGS

No clinically relevant clinical findings other than hip joint problems were identified. All 4 felids underwent staged bilateral (snow leopard) or unilateral (cheetahs and tiger [*Panthera tigris*]) total hip arthroplasty (THA).

TREATMENT AND OUTCOME

In the snow leopard, both femoral THA components were found to be luxated 1 year after surgery. Treatment consisted of autogenous corticocancellous rib graft augmentation of the dorsal acetabular rims and synthetic suture capsulorrhaphies. The snow leopard lived for an additional 4 years with no additional THA-related complications. In the other 3 animals, catastrophic complications (luxation in the cheetahs and femoral fracture in the tiger) occurred shortly after THA. The THA implants were removed, and excision arthroplasty was performed. Long-term outcomes were good in all 3.

CLINICAL RELEVANCE

Findings underscore the challenges associated with THA in large nondomestic felids. Given the high risk for early catastrophic failure as a result of luxation or fracture, plans must be made and resources must be available in case revision surgery or implant removal with excision arthroplasty becomes necessary.

In 1999, a 9-year-old 37-kg sexually intact male snow leopard (*Panthera uncia*; case 1) with no history of lameness was evaluated during a quarantine examination. Radiography revealed right femoral subluxation and flattening of both femoral heads with large exostoses on the craniodorsal rim of the acetabula (**Figure 1**). Less than 50% of the right femoral head was within the acetabulum. Sclerosis was noted in both acetabula and femoral heads. Both hip joints had a high angle of inclination (coxa valga) with a femoral neck angle > 130°, compatible with hip dysplasia. Staged bilateral total hip arthroplasty (THA) was advised and approved by the Species Survival Plan administrators as the treatment option most likely to restore desired function, including breeding activities. A decision was made to perform right THA first because the right hip joint was more severely affected.

The leopard was anesthetized with tiletamine-zolazepam (5.4 mg/kg, IM) administered via a blow dart and was intubated with a 7-mm-internal-diameter endotracheal tube. Anesthesia was maintained with 2% isoflurane in oxygen delivered at a rate of 2 L/min. An epidural injection of preservative-free morphine sulfate (0.11 mg/kg) was administered, and a transdermal fentanyl patch (100 µg/h) was applied to the right side of the cervical area 1 hour prior to surgery. The snow leopard received lactated Ringer solution (5 mL/kg/h, IV) throughout the surgical procedure.

THA instrumentation and implants (K-9 II; Smith & Nephew Richards Inc) were selected on the basis of commercial availability, size of the snow leopard, and anatomic similarities to dogs. After preparation and draping for aseptic surgery,

Figure 1—Ventrodorsal radiographs of a 9-year-old snow leopard (*Panthera uncia*) with a history of bilateral hip joint degeneration (case 1). A—On the initial radiograph, right femoral subluxation and flattening of both femoral heads with large exostoses on the craniodorsal rim of the acetabula are evident. B—Staged bilateral total hip arthroplasty (THA) was performed, but both femoral components were luxated on a radiograph obtained 1 year after the second surgery. C—Treatment consisted of autogenous corticocancellous rib graft augmentation of the dorsal acetabular rims; the snow leopard lived for an additional 4 years with no additional THA-related complications.

a craniolateral approach with partial tenotomy of the deep gluteal muscle was made, and arthrotomy was performed to expose the hip joint. With the use of a guide and sagittal saw, a femoral neck osteotomy was performed, and the femoral head was removed. The acetabulum was reamed to the appropriate diameter and depth, and a high-molecular-weight polyethylene acetabular cup was seated in the prepared socket and fixed in place with polymethylmethacrylate bone cement (dough-type methylmethacrylate; Zimmer Inc). The femoral intramedullary canal was then drilled, reamed, and broached to allow for placement of the femoral stem prosthesis with fixation in polymethylmethacrylate bone cement. Cefazolin powder (1 g) was mixed with each batch of bone cement used.

The THA components were manually reduced and assessed for positioning and stability, and range of motion of the hip joint was judged to be appropriate. The surgical site was lavaged with sterile saline (0.9% NaCl) solution. The joint capsule, tenotomy, and deep fascia were closed with size-0 polydioxanone. The superficial fascia was closed with 2-0 polydioxanone, and the subcutaneous tissues were apposed with 3-0 polydioxanone. A subdermal suture line was placed with 4-0 poliglecaprone 25. The skin incision was closed with stainless steel staples.

The snow leopard recovered from anesthesia without complications and began using the leg the evening after surgery without any observable limp. During the recovery period, the snow leopard was maintained in a 20 X 30-foot indoor habitat with concrete flooring and hay bedding and no access to climbing structures. No additional long-term analgesia was provided.

Six weeks after surgery, the snow leopard was anesthetized for recheck radiography. The right hip joint continued to appear stable, and the animal was transferred to its regular exhibit but with all climbing structures removed. The leopard was noted to use the

right leg preferentially when ambulating up an incline, but all other observed movement was considered normal.

Six months after the initial surgery, the leopard had gained 2.5 kg, and its keepers reported an improvement in the animal's attitude. Therefore, left THA was performed as described for the right hip. Postoperative radiography demonstrated good positioning of the femoral implant and acetabular cup. The right hip joint had a nearly imperceptible cement line between the acetabulum and the acetabular cup. To lessen potential long-term effects of stress on the hips, access to climbing structures was eliminated for 1 year after left THA.

On recheck radiographs obtained during a routine examination performed 1 year later during the breeding season, both femoral THA components were found to be luxated (Figure 1). Revision surgery was performed on both hip joints during a single anesthetic episode. This consisted of autogenous corticocancellous rib graft augmentation of the dorsal acetabular rims and synthetic suture capsulorrhaphies. The primary THA implants were all retained. The snow leopard recovered from the procedure without complications and, over the next 6 months, continued to gain weight and ambulate with nearly indiscernible lameness. The snow leopard lived for an additional 4 years with no additional THA-related complications.

In 2015, an 8-month-old 20-kg hand-reared sexually intact male cheetah (*Acinonyx jubatus*; case 2) was examined after a fight with a conspecific that had resulted in acute left hind limb lameness. The cheetah was treated with meloxicam (0.1 mg/kg, PO, q 24 h) and tramadol (2.5 mg/kg, PO, q 12 h) and was housed in an 8 X 8-foot habitat with a concrete floor and no access to climbing structures. Over the next month, the animal exhibited variable lameness and would walk with the hind limbs abnormally adducted. The cheetah was anesthetized with ketamine (3.5 mg/kg), medetomidine (0.05 mg/kg), and midazolam (0.1 mg/kg) administered IM by means of hand injection, and radiography revealed bilateral capital physeal fractures and a chronic nonhealing malunion of the right femoral neck. Atipamezole (0.14 mg/kg, IM) was administered, and the cheetah recovered uneventfully from anesthesia. Trazodone (7 mg/kg, PO, q 24 h) was added to the treatment regimen.

Two months later, the cheetah was anesthetized with the same protocol, and a recheck examination revealed moderate bilateral pelvic muscle wasting, bilateral hip joint crepitus, moderate decreased range of motion of the right hip joint, and mild decreased range of motion of the left hip joint. Pelvic radiography revealed bilateral femoral head and neck lysis, osteophyte formation on the medial aspect of the right intertrochanteric fossa, and shallowing of

the left acetabulum with osteophyte formation along the margin, consistent with progressive degenerative joint disease (DJD).

One month later, the cheetah had gained 6 kg. The cheetah was again anesthetized with the same protocol and intubated with an 11-mm-internal-diameter endotracheal tube. Anesthesia was maintained with 2% isoflurane in oxygen delivered at a rate of 2 L/min, and the right hip region was prepared and draped for aseptic surgery. THA instrumentation and implants (BFX Total Hip System; Biomedtrix) were selected on the basis of commercial availability, size of the cheetah, modularity options, and anatomic similarities to dogs requiring THA. The surgical approach and technique were the same as described for case 1. A cementless acetabular cup (28 mm), cementless femoral stem (No. 7), and femoral head (17 mm) were implanted. Two loops of 18-gauge orthopedic wire were placed around the proximal aspect of the femur in a cerclage fashion because of concerns related to cortical thinning and decreased bone density. An autogenous cancellous bone graft from the right iliac wing was also placed around the proximal aspect of the femur. The joint capsule could not be fully apposed because of severe fibrosis, but fascia, subcutaneous tissue, and skin were closed in routine fashion, followed by application of skin staples. Histologic examination of the femoral head revealed epiphysiolysis of unknown origin. Postoperative radiography revealed appropriate implant placement, positioning, and reduction. During surgery, the cheetah received fluids IV and cefazolin (29 mg/kg, IV, q 90 min for 3 doses). After surgery, treatment with trazodone and meloxicam was continued as previously prescribed, and treatment with amoxicillin-clavulanic acid (16.5 mg/kg, PO, q 12 h for 10 days) was started. The animal was maintained in a 5 X 5-foot indoor pen with nonslip flooring and ample soft padding.

Initially, the cheetah was unable to stand without assistance, but over the first 2 weeks after surgery, ambulation on the right hind limb slowly improved such that the animal was appropriately weight-bearing with only mild lameness. However, a day later, the cheetah was noted to be acutely non-weight-bearing lame on the right hind limb. Radiography confirmed luxation of the femoral prosthesis.

Two weeks later, the cheetah was anesthetized for revision surgery of the right hip joint. Multiple attempts to reduce the THA prostheses were unsuccessful, and the decision was made to explant the THA prostheses and complete an excision arthroplasty on the basis of concerns regarding local bone quality, implant function for required range of motion, and capabilities for limiting postoperative activities. To address remaining concerns regarding proximal femoral bone integrity and quality, 3 cortical screws were placed in a lateral-to-medial direction in an attempt to prevent fissuring and greater trochanter avulsion.

The cheetah's lameness worsened over the month following revision surgery. Radiography revealed avulsion of the right greater trochanter as well as severe DJD of the left hip joint. The cheetah

was anesthetized 3 weeks later for pin and tension band stabilization of the right greater trochanter as well as left femoral head ostectomy. Postoperative radiography showed appropriate trochanteric reduction and fixation and excision arthroplasty.

A month later, the cheetah's hand-reared demeanor allowed for initiation of physical therapy consisting of sit-to-stand behaviors, controlled leash walks, walking in sand, and jumping up and down from low platforms. Throughout the next 5 months, the cheetah's ambulation improved with continued physical therapy, and the lameness completely resolved. Recheck radiography showed pin migration as well as caudal acetabular proliferation warranting pin and tension band implant removal. No additional concerns were reported after implant removal, and at 7 years of age, the cheetah was able to comfortably ambulate with a near-normal gait in an outdoor yard that contained climbing structures.

In 2015, a 9-month-old 25-kg hand-reared sexually intact male cheetah (case 3), a littermate of case 2, was examined after falling off a bench. The cheetah was anesthetized as described for case 2, and radiography revealed a Salter-Harris type II fracture of the right capital femoral epiphysis (**Figure 2**). The next day, the fracture was surgically repaired via open reduction and internal fixation with divergent transcervical-transphyseal Kirschner wires (three 0.062-inch-diameter wires and one 0.035-inch-diameter wire) and a 2.7-mm interfragmentary positional screw. The cheetah recovered in a 5 X 5-foot pen with nonslip flooring, and treatment with tramadol (2 mg/kg, PO, q 12 h), meloxicam (0.08 mg/kg, PO, q 24 h), and trazodone (8 mg/kg, PO, q 24 h) was initiated.

Six weeks later, recheck radiography showed lucency around the pins and screw suggestive of possible osteomyelitis. The cheetah was anesthetized, an epidural injection of preservative-free morphine sulfate (0.05 g/kg) was administered, and the previously placed femoral neck pins and screw were removed. Aerobic culture yielded an *Enterococcus* sp, and treatment with amoxicillin-clavulanic acid was started on the basis of results of susceptibility testing. The cheetah recovered uneventfully in a 10 X 10-foot indoor pen with nonslip flooring and began placing appropriate weight on the limb.

Five months later, the cheetah was anesthetized because of progressive lameness, and pelvic radiography revealed severe DJD of the right hip. A discussion of surgical options ultimately resulted in a decision to perform THA because this individual had a better gait and more extensive muscling of the affected limb, compared with case 2.

Two months later, the cheetah had gained 17 kg, and right THA was performed as described for case 2 with the same THA instrumentation and implants. A 28-mm canine acetabular cup, number 6 canine femoral stem, and 17-mm +3 canine femoral head were implanted (**Figure 2**). The animal recovered in a 4 X 8-foot indoor pen with nonslip flooring. During the immediate postoperative period, the cheetah had mild weight-bearing lameness that improved

Figure 2—Ventrodorsal radiographs of a 9-month-old cheetah (*Acinonyx jubatus*; case 3) with right hind limb lameness after falling off a bench. A—A simple noncomminuted right femoral neck fracture (arrow) was diagnosed. B—Fracture repair with pins and a screw was attempted, but osteomyelitis developed, requiring implant removal. Therefore, right THA was performed. C—Radiography performed 6 weeks after surgery revealed a nonclinically apparent luxation of the right femoral prosthesis. D—The THA implants were removed, and excision arthroplasty was performed. At 7 years of age, the cheetah was able to comfortably ambulate with a near-normal gait in an outdoor yard that contained climbing structures.

Figure 3—Dorsal-plane (A) and transverse-plane (B) CT images and 3-D reconstructions (C and D) of the hip joints of an 11-year-old Amur tiger (*Panthera tigris altaica*) with a 2-year history of hip joint osteoarthritis (case 4). A and B—There are severe degenerative changes of the left hip joint characterized by periarticular osteophytes (open arrows), subchondral bone sclerosis (white arrowheads), resorptive changes of the left femoral head (white arrows), periarticular osteophytes of the left hip joint (open arrow), and multiple intra-articular osseous bodies (white asterisks). C and D—Similar changes can be seen on the 3-D reconstructions of the hip joints.

over the next few weeks with the addition of physical therapy as described for case 2. Postoperative pelvic radiography performed 6 weeks after surgery revealed a nonclinically apparent luxation of the right femoral prosthesis.

Two weeks later, the cheetah was anesthetized for revision surgery to explant the THA prostheses and complete an excision arthroplasty, as described for case 2 (Figure 2). The cheetah recovered well with cage rest and controlled leash walks. Continued improvement was noted over the next few weeks with no additional complications. At 7 years of age, the cheetah was able to comfortably ambulate with a near-normal gait in an outdoor yard that contained climbing structures.

In 2020, an 11-year-old 110-kg sexually intact female Amur tiger (*Panthera tigris altaica*; case 4) with a 2-year history of hip joint osteoarthritis was examined. The tiger was receiving tramadol (2.7 mg/kg, PO, q 12 h) and gabapentin (3.6 mg/kg, PO, q 12 h) because of hind limb stiffness when ambulating. The tiger was anesthetized with ketamine (2.7 mg/kg), midazolam (0.18 mg/kg), and medetomidine (0.03 mg/kg) delivered IM with a dart and intubated with an 18-mm-internal-diameter endotracheal tube. Anesthesia was maintained with 2% to 3% isoflurane in oxygen delivered at a rate of 2 L/min. Physical examination revealed severe decreased range of motion of the hip joints, with the left worse than the right and severe left hind limb muscle atrophy. Whole-body CT revealed severe left hip DJD with severe femoral head and neck sclerosis and moderate right hip DJD with intra-articular synovial osteochondromas and peri-articular fractures of the acetabular margins (Figure 3). The tiger was continued on gabapentin and tramadol for 90 days prior to switching to amantadine (2 mg/kg, PO, q 24 h).

Given previous experiences with THA in large felids and the fact that commercially available canine and human THA instrumentation and implants would not be amenable to use in this tiger, Arthrex Inc was contacted regarding development and production of a custom-designed patient-specific system for this case. Over the subsequent 6 months, the company's engineers and product managers worked with the authors to model, design, and virtually test a THA system for this tiger.

Six months later, the tiger was anesthetized for THA of the left hip joint with the same anesthetic protocol used previously. After preparation and draping for aseptic surgery, a craniolateral approach to the left hip joint with partial vastus lateralis tenotomy and arthroto-my was performed. Gluteal tenotomy was intention-

Figure 4—Lateral radiograph of the tiger in Figure 3 obtained immediately after left THA with custom-designed, patient-specific femoral and acetabular prostheses.

ally avoided on the basis of concerns regarding postoperative stability. The joint capsule was noted to be severely thickened with robust, global adhesions to the surrounding musculature making femoral head and acetabular exposure extremely tedious and difficult. Once adequate exposure was achieved, femoral neck osteotomy was performed with a proprietary patient-specific osteotomy guide and sagittal saw, and the femoral head was removed. Adequate exposure of the acetabulum required meticulous dissection with capsular releasing incisions, fibrous tissue resection, and proliferative bone and osteophyte debridement. Once adequate exposure was achieved, a proprietary patient-specific osteotomy guide and reamers were used for sequential reaming of the acetabulum to the desired diameter and depth. Multiple trial implantations of the acetabular prosthesis were attempted with subsequent soft tissue and bone resections to allow for adequate access and proper seating. Eventually, the custom-designed patient-specific cementless acetabular prosthesis (outer diameter, 51 mm; internal diameter, 32 mm) composed of titanium; a 3-D, open-celled titanium scaffold to allow for bone and tissue ingrowth (Bio-SYNC; Arthrex Inc); and ultrahigh-molecular-weight polyethylene was well seated into the prepared bed, and both cranial (30 mm) and caudal (25 mm) 5.5-mm titanium flange screws were effectively placed. After placement of the acetabular prosthesis, a proprietary patient-specific osteotomy guide, pins, drill bits, and reamers were used to prepare a socket in the femoral neck and proximal portion of the femur for the femoral prosthesis. The femoral neck was extremely sclerotic, and the lateral femoral cortex was markedly thickened. After the socket was tapped twice and impinging tissue at the medial aspect of the greater trochanter was debrided, a titanium, cannulated femoral prosthesis with the same 3-D, open-

celled titanium scaffolding (outer diameter, 15 mm; length, 44 mm) was screwed into the socket and fully seated. A lateral cortical titanium locking screw with titanium washer was then inserted. A cobalt-chromium femoral head (outer diameter, 32 mm; +0) was placed on the femoral neck prosthesis, and with slow and careful leverage and traction, the joint was reduced. Stability and range of motion were assessed, and both were considered excellent.

The joint capsule was apposed with cruciate mattress sutures of 2-0 polydioxanone. The vastus lateralis tenotomy was repaired with horizontal mattress sutures of 2-0 polydioxanone, the fascia was apposed with a simple continuous pattern with 2-0 polydioxanone, and the subcutaneous tissues were apposed with a simple continuous pattern with 2-0 polydioxanone. Bupivacaine (5.3 mg/kg) was injected peri-incisionally at the time of surgical closure. The skin was then apposed with a continuous intradermal pattern of 3-0 polyglactin 910, and tissue glue was placed over the cleaned and dried incision. Postoperative radiography (**Figure 4**) was performed prior to moving the patient into the recovery area. Despite the long (> 10 hours) anesthetic event, the tiger recovered uneventfully and had normal mentation 1 hour after isoflurane delivery was discontinued. The tiger was hospitalized in a 10 X 6-foot stall with nonslip plywood covering half the floor, ample straw bedding, and no climbing structures.

Treatments during surgery consisted of Lactated Ringer solution IV, cefazolin (22 mg/kg, IV, q 90 min for 6 doses), cefovecin (8 mg/kg, SC), and robenacoxib (1 mg/kg, PO, via gavage).

The day after surgery, the tiger was anesthetized because of concerns that it was tucking its left hind limb at an abnormal angle when sitting. On examination, a left femoral fracture with dislodgement of the femoral prosthesis was palpable. Radiography confirmed a left proximal femoral fracture through the femoral socket with luxation and caudolateral displacement of the femoral prosthesis. The tiger recovered uneventfully and was maintained on analgesic medications as previously prescribed.

Two days later, the tiger was anesthetized for removal of the THA implants, excision arthroplasty, and femoral fracture repair. Fracture reduction and stabilization were accomplished with three 3.2-mm-diameter pins, two 16-gauge tension band wires, two 0.062-inch interfragmentary threaded Kirschner wires, and two 16-gauge cerclage wires. Postoperative radiography showed appropriate reduction, alignment, and implant placement. Following anesthetic recovery, the tiger was moderately toe-touching lame on the left hind limb, which continued to improve over the next 2 weeks.

On day 14, recheck radiography showed bent and displaced pins and wires with loss of fracture reduction, suggestive of impending fixation failure. The tiger was continued on gabapentin and amantadine as previously prescribed as well as hydromorphone (0.02 mg/kg, PO, q 12 h) and meloxicam (0.1 mg/kg, PO, q 24 h).

On day 21, fracture repair revision surgery was performed. The previously placed implants were removed and submitted for aerobic and anaerobic bacterial culture, which produced no growth. The fracture was reduced and stabilized with a 5.6-mm-diameter intramedullary pin, a 2.7 to 3.5 hook plate and screws (Arthrex Inc), and a 4.5 to 6.5 distal femoral osteotomy plate and screws (Arthrex Inc). The surgical incision was closed as previously described. Postoperative radiography showed appropriate reduction, alignment, and implant placement. Once again, moderate postprocedural lameness was present, which improved over time.

Recheck radiography 2 weeks later revealed maintenance of reduction, alignment, and implant placement with evidence of initial healing. The tiger continued to eat well while hospitalized and slowly increased its use of and weight-bearing on the left hind limb. Recheck radiography in another 2 weeks showed bridging callus formation with continued maintenance of reduction, alignment, and implant placement. The tiger was discharged from the hospital with only a mild gait abnormality when ambulating. Seventy days after the initial surgery, the tiger was released from all activity restrictions. At that time, the tiger was able to ambulate with only mild gait abnormalities and no evidence of discomfort when using the affected leg.

Discussion

DJD is the progressive destruction of 1 or more joint components.¹ In felids, the hip joints are the most commonly affected appendicular joints.² In nondomestic felids, hip DJD has been best described in snow leopards but has also been documented in other large felids, including cheetahs and tigers (*Panthera tigris*).³⁻¹⁰

In companion animals, several surgical techniques are routinely performed to address deterioration of hip joint health and function, including THA, pelvic and femoral osteotomies, and femoral head and neck ostectomy.¹¹⁻¹³ The goal of THA is to mitigate hip joint pain while improving hind limb function.¹⁴ Femoral head and neck ostectomy is an excision arthroplasty designed to relieve pain secondary to abnormal bony contact in hip joints with end-stage DJD.^{15,16} Femoral head and neck ostectomy is also used as a salvage procedure after failed THA.

The present report described 4 large felids that underwent THA for treatment of hip DJD secondary to presumed hip dysplasia, avascular necrosis, trauma, and primary osteoarthritis. In the snow leopard (case 1), staged bilateral THA was associated with long-term success after revision surgery. In the 2 cheetahs and Amur tiger, unilateral THA failed as a result of prosthesis luxation or femoral fracture, and in each of these 3 cases, removal of the THA implants and excision arthroplasty resulted in acceptable outcomes. Taken together, these cases illustrate the challenges of consistently obtaining successful outcomes after THA in large felids, while also verifying the efficacy of implant removal

and excision arthroplasty as a salvage procedure for failed THA in these species.

THA is commonly performed in dogs and humans for treatment of hip DJD secondary to hip dysplasia, trauma, avascular necrosis, or osteoarthritis.^{14,17,18} and numerous cemented and cementless implant systems are commercially available for use in these species.^{14,19} The choice of which system to use is based on a number of patient-related factors, the specific indication for THA, and the surgeon's preference. Overall complication rates following THA are reportedly < 20%,²⁰ with the most commonly reported complications in both species consisting of luxation, femoral fracture, implant loosening, implant wear, and infection.²¹ THA complications can be exceptionally challenging to manage.¹⁶

For the cases described in the present report, the decision to pursue THA was made by a team of veterinarians, animal caretakers, curators, and administrative officials and was based on factors known to influence outcomes after surgical treatment of hip joints, including patient age and size, severity of clinical signs, diagnostic imaging findings, expected activities, and surgeon experience.¹⁷ Despite detailed planning, each THA was associated with postoperative complications. Given the timing and nature of these complications, we suspect that they resulted from loads and moments that exceeded the capacities of the implants and bones. Domestic cats apply greater peak vertical force in the forelimbs than the hind limbs,²² but large nondomestic felids apply greater forces in their hind limbs.²³ In addition, large nondomestic felids have heavy hind limb bones, a relatively small volume of muscle in the hip region, large psoas muscles, and extreme hip joint ranges of motion,²³ all of which likely contribute to a higher risk for early catastrophic failure after THA. In an attempt to mitigate this risk for failure in the Amur tiger, a custom-designed, patient-specific THA instrumentation and implant system was modeled, virtually tested, and manufactured. This system was specifically designed to provide stability with full hip joint range of motion without impingement, rigid initial fixation, and rapid bone ingrowth. These design features were subjectively and radiographically documented to be effective with respect to initial function; however, catastrophic failure by proximal femoral fracture occurred within the initial 24 hours after surgery so that efficacy could not be further assessed.

Another major factor that may have accounted for THA failure in these cases was the inability to completely control postoperative activities. Activities that put high loads and moments on the implants, bones, and artificial articulations or that exceed the limits of joint motion, especially during the initial postoperative period, can cause catastrophic failure as a result of luxation or fracture.²⁴ Control of activities in nondomestic large felids is extremely challenging. Methods of control employed in each of these cases consisted of medical management, monitored recovery, flooring and padding considerations, and confinement.

Perioperative analgesia varied in these cases, consisting of peri-incisional injection of liposomal

bupivacaine, epidural injection of morphine, and transdermal fentanyl patch application, and was based on peer-reviewed evidence, availability, and the attending veterinarians' preferences.²⁵ Postoperative medical management mainly consisted of orally administered NSAIDs, opioids, and anxiolytics.²⁶ In particular, robenacoxib or meloxicam was used for postoperative analgesia on the basis of their documented efficacy for control of perioperative pain and inflammation associated with orthopedic surgery in cats.²⁷ Opioids have been the mainstay of perioperative pain management in companion animals and dampen afferent nociceptive transmission in the peripheral nervous system and CNS.²⁸ Tramadol, a synthetic opioid, increases activity and quality of life in geriatric cats with osteoarthritis²⁹ and was part of the multimodal therapy in the 2 cheetahs described in the present report. Additional analgesic treatments consisted of gabapentin and amantadine. Gabapentin is used for long-term pain management in cats with osteoarthritis owing to a lower risk of adverse effects, compared with NSAIDs.³⁰ Amantadine is used in cats with chronic pain, as seen with osteoarthritis.^{31,32} Trazodone, an anxiolytic, was also used as a preventative measure to reducing activity. Trazodone causes reduced anxiety and appreciable sedation characterized by activity reduction in domestic felids.³³

Postoperative care in domestic animals that have undergone THA includes restricting activities to small areas with nonslip flooring; avoiding running, jumping, and use of stairs; confinement to a kennel, crate, or pen; and supported leash-walking for 6 to 8 weeks after surgery.²⁴ Although patients described in the present report were restricted to small enclosures with single-level, nonslip flooring and no climbing structures, the level of activity restriction used for cats and dogs was not feasible for these nondomestic felids. Similarly, splints, slings, or hobbles were not used for any of these cases because repeated handling for bandage care was not feasible and there was a risk of foreign body ingestion.³⁴ The hand-reared, tractable nature of the 2 cheetahs in this case series allowed for controlled leash walks and physical therapy exercises. These postoperative measures are heavily reliant on animal demeanor and may not be appropriate for many animals.

In conclusion, outcomes in the present case series may help inform the future use of THA in large nondomestic felids. For any future attempts, veterinarians should carefully consider all preoperative, intraoperative, and postoperative variables in constructing a plan to mitigate potential mechanisms for failure. Preoperative considerations should include acclimation to the postoperative environment to prevent disorientation and unpredictable or unstable reactions to a new environment. THA instrumentation, implants, and surgical techniques must account for anatomic and biomechanical differences in these species, compared with companion animals. Multimodal medical management, including NSAIDs, opioids, supplemental analgesics such as gabapentin or amantadine, and anxiolytics to prevent over-

activity during the immediate postoperative period should be considered. Innovative strategies to improve postoperative recovery and restrict postoperative activity are needed. Considerations may include the use of padded stalls, suspension slings, or prolonged sedation. Finally, given the high risk for early catastrophic failure as a result of luxation or fracture, plans must be made and resources must be available in case revision surgery or implant removal with excision arthroplasty becomes necessary. Fortunately, these salvage procedures appeared to result in acceptable and functional outcomes after failed THA in these species.

Acknowledgments

No third-party funding or support was received in connection with this report or the writing or publication of the manuscript. The authors declare that there were no conflicts of interest.

The authors thank Dr. Eric Hostnik for CT image interpretation and figure rendering for case 4. Arthrex Inc designed and manufactured the patient-specific THA implant used in case 4.

References

1. Lascelles BDX. Feline degenerative joint disease. *Vet Surg.* 2010;39(1):2–13. doi:10.1111/j.1532-950X.2009.00597.x
2. Lascelles BDX, Henry JB, Brown J, et al. Cross-sectional study of the prevalence of radiographic degenerative joint disease in domesticated cats. *Vet Surg.* 2010;39(5):535–544. doi:10.1111/j.1532-950X.2010.00708.x
3. Barton L, Young A, Hall E, Phalen DP. A retrospective radiological study of degenerative arthropathies of captive large cats: prevalence, severity, and distribution. Abstract in: *Proceedings of the Zoo and Wildlife Health Conference*. European Association of Zoo and Wildlife Veterinarians; 2019:35.
4. Berthet M, Besz A, Averil S, Quintard B. Management of a severe hip lesion in a breeding male Amur tiger (*Panthera tigris altaica*). Abstract in: *Proceedings of the Zoo and Wildlife Health Conference*. European Association of Zoo and Wildlife Veterinarians; 2019:92.
5. Kärkkäinen M, Wahlberg C. Coxofemoral dysplasia in the snow leopard (*Panthera uncia*). A roentgenological evaluation of the coxofemoral joints of 9 snow leopards. *Int Pedigree Book Snow Leopards*. 1984;4:113–122.
6. Leininger RW. Bilateral coxofemoral dysplasia in a snow leopard. Abstract in: *Proceedings of the American Association of Zoo Veterinarians Conference*. American Association of Zoo Veterinarians; 1983:26–28.
7. Rothschild BM, Rothschild C, Woods RJ. Inflammatory arthritis in large cats: an expanded spectrum of spondyloarthropathy. *J Zoo Wildl Med.* 1998;29(3):279–284.
8. Suedmeyer WK, Cook JL, Tomlinson JL, Crouch DT. Bilateral total hip replacement in a snow leopard (*Uncia uncia*) with bilateral hip dysplasia. Abstract in: *Proceedings of the American Association of Zoo Veterinarians Conference*. American Association of Zoo Veterinarians; 2000:545–548.
9. Whiteside DP, Remedios AM, Black SR, Finn-Bodner ST. Meloxicam and surgical denervation of the coxofemoral joint for the treatment of degenerative osteoarthritis in a Bengal tiger (*Panthera tigris tigris*). *J Zoo Wildl Med.* 2006;37(3):416–419. doi:10.1638/05-078.1
10. Paul HA, Bargar WL, Leininger R. Total hip replacement in a snow leopard. *J Am Vet Med Assoc.* 1985;187(11):1262–1263.
11. Liska WD, Doyle N, Marcellin-Little DJ, Osborne JA. Total hip replacement in three cats: surgical technique, short-

- term outcome and comparison to femoral head ostectomy. *Vet Comp Orthop Traumatol*. 2009;22(6):505–510. doi:10.3415/VCOT-08-09-0087
12. Rawson EA, Aronsohn MG, Burk RL. Simultaneous bilateral femoral head and neck ostectomy for the treatment of canine hip dysplasia. *J Am Anim Hosp Assoc*. 2005;41(3):166–170. doi:10.5326/0410166
 13. Tarvin GB. Corrective osteotomies for treatment of selected hip joint disorders. In: Bojrab MJ, ed. *Current Techniques in Small Animal Surgery*. WB Saunders; 1983:605–610.
 14. Liska WD. Total hip replacement indications for the non-dysplastic hip. Abstract in: *Proceedings of the American College of Veterinary Surgery Symposium*. American College of Veterinary Surgery; 2011.
 15. Harper TAM. Femoral head and neck excision. *Vet Clin North Am Small Anim Pract*. 2017;47(4):885–897. doi:10.1016/j.cvsm.2017.03.002
 16. Fitzpatrick N, Law AY, Bielecki M, Girling S. Cementless total hip replacement in 20 juveniles using BFX arthroplasty. *Vet Surg*. 2014;43(6):715–725. doi:10.1111/j.1532-950X.2014.12214.x
 17. Harper TAM. INNOPLANT total hip replacement system. *Vet Clin North Am Small Anim Pract*. 2017;47(4):935–944. doi:10.1016/j.cvsm.2017.03.003
 18. Jankovits DA, Liska WD, Kalis RH. Treatment of avascular necrosis of the femoral head in small dogs with micro total hip replacement. *Vet Surg*. 2012;41(1):143–147. doi:10.1111/j.1532-950X.2011.00925.x
 19. Schiller TD. BioMedtrix total hip replacement systems: an overview. *Vet Clin North Am Small Anim Pract*. 2017;47(4):899–916. doi:10.1016/j.cvsm.2017.03.005
 20. Forster KE, Wills A, Torrington AM. Complications and owner assessment of canine total hip replacement: a multicenter internet based survey. *Vet Surg*. 2012;41(5):545–550. doi:10.1111/j.1532-950X.2012.01015.x
 21. Bergh MS, Gilley RS, Shofer FS, Kapatakin AS. Complications and radiographic findings following cemented total hip replacement: a retrospective evaluation of 97 dogs. *Vet Comp Orthop Traumatol*. 2006;19(3):172–179.
 22. Schnabl E, Bockstahler B. Systemic review of ground reaction force measurements in cats. *Vet J*. 2015;206(1):83–90. doi:10.1016/j.tvjl.2015.05.017
 23. Hudson PE, Corr SA, Payne-Davis RC, Clancy SN, Lane E, Wilson AM. Functional anatomy of the cheetah (*Acinonyx jubatus*) hindlimb. *J Anat*. 2011;218(4):363–374. doi:10.1111/j.1469-7580.2010.01310.x
 24. Harper TAM. Conservative management of hip dysplasia. *Vet Clin North Am Small Anim Pract*. 2017;47(4):807–821. doi:10.1016/j.cvsm.2017.02.007
 25. Barletta M, Reed R. Local anesthetics: pharmacology and special preparation. *Vet Clin North Am Small Anim Pract*. 2019;49(6):1109–1125. doi:10.1016/j.cvsm.2019.07.004
 26. Whiteside DP, Black SR. The use of meloxicam in exotic felids at the Calgary Zoo. Abstract in: *Proceedings of the American Association of Zoo Veterinarians Conference*. American Association of Zoo Veterinarians; 2004:342–345.
 27. Speranza C, Schmid V, Giraudel JM, Seewald W, King JN. Robenacoxib versus meloxicam for the control of perioperative pain and inflammation associated with orthopaedic surgery in cats: a randomised clinical trial. *BMC Vet Res*. 2015;11:79. doi:10.1186/s12917-015-0391-z
 28. Hellyer PW, Gaynor JS. Acute post-surgical pain in dogs and cats. *Compend Contin Educ Pract Vet*. 1998;20:140–153.
 29. Guedes AGP, Meadows JM, Pypendop BH, Johnson EG. Evaluation of tramadol for treatment of osteoarthritis in geriatric cats. *J Am Vet Med Assoc*. 2018;252(5):565–571. doi:10.2460/javma.252.5.565
 30. Robertson SA. Managing pain in feline patients. *Vet Clin North Am Small Anim Pract*. 2008;38(6):1267–1290. doi:10.1016/j.cvsm.2004.08.001
 31. Rychel JK. Diagnosis and treatment of osteoarthritis. *Top Companion Anim Med*. 2010;25(1):20–25. doi:10.1053/j.tcam.2009.10.005
 32. Lascelles BD, Gaynor JS, Smith ES, et al. Amantadine in a multimodal analgesic regimen for alleviation of refractory osteoarthritis pain in dogs. *J Vet Intern Med*. 2008;22(1):53–59. doi:10.1111/j.1939-1676.2007.0014.x
 33. Orlando JM, Case BC, Thomson AE, Griffith E, Sherman BL. Use of oral trazodone for sedation in cats: a pilot study. *J Feline Med Surg*. 2016;18(6):476–482. doi:10.1177/1098612X15587956
 34. Schlag AN, Hayes GM, Taylor AQ, et al. Analysis of outcomes following treatment of craniodorsal hip luxation with closed reduction and Ehmer sling application in dogs. *J Am Vet Med Assoc*. 2019;254(12):1436–1440. doi:10.2460/javma.254.12.1436