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# Total hip arthroplasty to address chronic hip luxation with pseudoacetabulum formation in seven dogs

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**Abstract**

**Objective:** To compare the outcome of dogs treated with total hip arthroplasty (THA) for chronic hip luxation and pseudoacetabulum formation to that of dogs with simple hip dysplasia and secondary osteoarthritis.

**Study design:** Retrospective, case-controlled study.

**Animals:** Seven dogs with pseudoacetabulum (group 1) and 21 matched control dogs (group 2).

**Methods:** Each dog in group 1 was matched with three control dogs, primarily according to similarity of THA implant type and size. Patterns of radiographic pathology were characterized in each dog. Outcome measures included operative time, acetabular cup position/orientation (inclination angle, angle of lateral opening, version angle) complications, and long-term outcomes. Outcome measures were compared between groups using linear regression ($P = .05$).

**Results:** The presence of a pseudoacetabulum was associated with ilial remodeling and heterotopic bone formation concentric to the luxated femoral head. Exposing the native acetabulum and reducing the prosthesis were surgically challenging. The mean (SD) operative time of dogs in group 1 (96 [18] minutes) was longer than that of dogs in group 2 (63 [14] minutes; $P = .00002$). Cup position/orientation was not different between dogs in group 1 and group 2. One intraoperative complication and two minor postoperative complications occurred in group 1 dogs. All dogs had good long-term outcomes.

**Conclusion:** Total hip arthroplasty in dogs with a pseudoacetabulum was more challenging than in control dogs. However, the procedure provided good to excellent long-term clinical outcomes in all dogs.

**Clinical significance:** Surgeons should be prepared for the specific surgical challenges associated with THA in dogs with pseudoacetabulum formation.

## 1 | INTRODUCTION

Luxation of the hip accounts for approximately 90% of all luxations in the dog.[1] In the acute case, closed reduction can be attempted. If closed reduction is unsuccessful, open reduction with joint stabilization is recommended in dogs with normal hip conformation.[1] Conversely, in dogs with chronic luxation, hip dysplasia, osteoarthritis, or irreparable articular fractures, open reduction and stabilization of the joint is not indicated. Luxation in these dogs is best addressed by femoral head and neck ostectomy[2] or by total hip arthroplasty (THA).[3]

 

Pozzi et al[3] demonstrated that THA can be successful in dogs with acute traumatic hip luxation. In that study, the median time between the traumatic event and surgery was 9 days. In people with a more chronic hip luxation, a phenomenon known as pseudoacetabulum has been described, whereby the luxated femoral head forms a novel ersatz articulation with the adjacent ilium.[4-8] Most of these human cases occur secondary to hip dysplasia.[4,8,9] However, pseudoacetabulum can develop following traumatic hip luxation[5] and luxation after THA.[6] The predisposing factors that lead to pseudoacetabulum formation in luxated hips in man are not known. Chronically luxated hips that form a pseudoacetabulum are more likely to cause clinical disability and become symptomatic earlier compared with chronically luxated hips without pseudoacetabulum formation.[4,9]

Total hip arthroplasty is the treatment of choice for people with chronic hip luxation, with or without pseudoacetabulum formation.[4,10-13] Placement of the acetabular cup in the original acetabulum is recommended to restore normal hip mechanics and limb length.[10,11] Significant challenges accompany performance of THA in these patients, however, including the presence of a narrow proximal femoral canal,[14] difficulty identifying the native acetabulum, poor bone quality associated with the original acetabulum, and acetabular rim attrition.[4,11] In addition, muscle contracture and periarticular fibrosis associated with the chronically luxated hip can make reduction of the femoral prosthesis into the acetabular cup challenging.

To the best of our knowledge, pseudoacetabulum formation has not been described in the veterinary literature. In this article, we report a series of seven dogs with chronic hip luxation and pseudoacetabulum formation treated by THA. We designed this retrospective, case-controlled study to compare the outcome of THA in dogs with pseudoacetabulum to that in dogs with simple hip dysplasia and secondary osteoarthritis. We hypothesized that THA would be a practical treatment for dogs with chronic hip luxation and pseudoacetabulum formation but that increased technical difficulty, compared with THA in dogs with standard dysplastic/osteoarthritic joints, would be associated with an increased duration of surgery and anesthesia.

## 2 | MATERIALS AND METHODS

### 2.1 | Study design

Medical records (2013-2017) of all THA surgeries performed at The Ohio State University Veterinary Medical Center (OSU VMC) and Skylos Sports Medicine were reviewed to identify dogs with pseudoacetabulum, which were classified as group 1. Inclusion criteria included a history of pelvic limb lameness localizing to the hip, evidence of pseudoacetabulum formation according to either radiography or computed tomography (CT), and performance of ipsilateral THA. Each pseudoacetabulum dog was matched with three control dogs selected from the OSU medical database, which were classified as group 2. The control cohort included dogs in which degenerative joint disease secondary to hip dysplasia had been diagnosed with the absence of a pseudoacetabulum and managed by THA. Selection of group 2 dogs was based primarily on the similarity of type and size of the prosthetic stem and cup implanted, with weight and breed matched as closely as possible.

Information retrieved included signalment, body weight, anesthesia time, operative time, results of preoperative screening bloodwork, and the type and size of the implanted femoral stem, femoral head, and acetabular cup. Body condition score was not consistently recorded in the medical records and was thus not evaluated. In addition, any evidence of intraoperative or postoperative complications were recorded. A complete radiographic series included orthogonal views of both the pelvis and the femur. In cases in which CT data had been acquired, three-dimensional bone models were created to help determine the feasibility of THA. These bone models were used primarily to assess the distribution of acetabular bone stock and the likelihood of achieving an adequate press-fit. An open-source three-dimensional segmentation software program was used to create digital bone models from the CT DICOM (Digital Imaging and Communication in Medicine) images.[15] Physical bone models were created by using an in-house three-dimensional printer (MakerBot Replicator 2X; MakerBot, New York, New York). Dogs that lacked a minimum of 8-week postoperative orthopedic and radiographic findings were excluded from this study.

Radiographs of group 1 dogs were measured for displacement distance (DD) on both the preoperative and postoperative radiographs. Displacement distance was defined as the distance from the original location of the acetabulum (defined by superimposition of the mirror image of the contralateral acetabulum) to the femoral head in the pseudoacetabulum (preoperatively) or to the prosthetic femoral head (postoperatively) on both the lateral and the ventrodorsal views (Figure 1). Postoperative radiographs of dogs in both group 1 and group 2 were assessed for implant positioning and orientation; radiographic measurements were performed by one observer (J.D.). Specific acetabular parameters assessed included the measurement of the angle of lateral opening (ALO), version angle, and the angle of inclination.[16] The femoral stem was assessed for version angle and orientation in the frontal and sagittal plane relative to the femoral long axis on the craniocaudal and lateral projections, respectively. The femoral stem was assessed for depth of seating, version angle, and angulation in the frontal (varus/valgus) and sagittal plane (cranial-caudal tilt) relative to the femoral long axis on the craniocaudal and lateral projections, respectively.

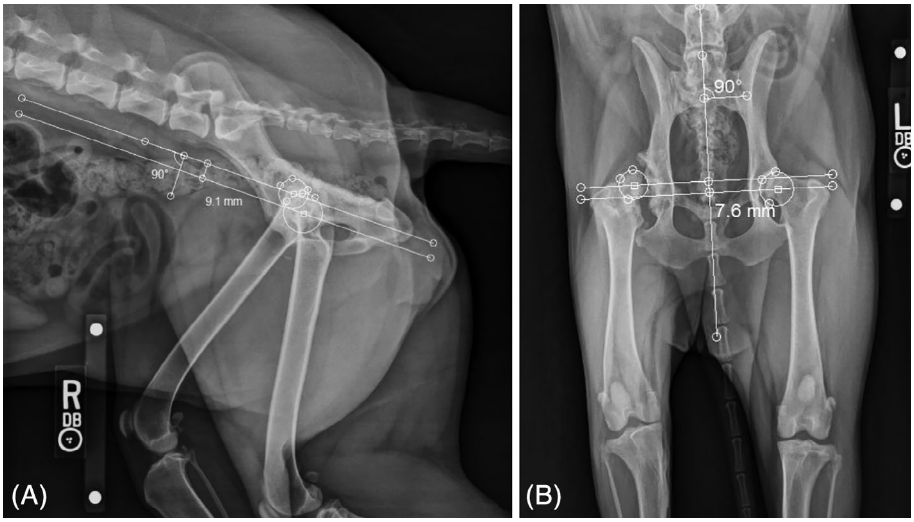


**FIGURE 1** Preoperative radiographic images of dog 4. A best-fit circle was placed on the luxated femoral head and the contralateral acetabulum in both views. On the lateral projection (A), a line parallel to the ventral floor of the vertebral column was passed through the center of both circles. The distance between these two lines perpendicularly was the dorsal displacement distance (DD). On the ventrodorsal view (B), a line bisecting the pelvis was established. Additional lines perpendicular to this line were passed through the center of both circles. The distance between these two lines was the cranial DD

Additional outcome assessment for dogs in group 1 was performed by means of an online or phone-based owner questionnaire. This questionnaire was an amalgamation of the validated Helsinki Chronic Pain Index and Liverpool Osteoarthritis in Dogs questionnaires (Appendix S1).[17] The questionnaire consists of 21 questions specific to the dog's lifestyle and mobility after THA. This follow-up was performed to assess long-term (>12 months) outcome post-THA in the dogs with a pseudoacetabulum.

## 2.2 | Data analysis

Variables of cup position, inclination angle, and version angle as well as anesthesia time and operative time were compared between groups 1 and 2 by means of a linear regression that controlled for matching groups and the matching variable weight, with fixed effects ('lme4' package of R [R Version 3.4.0; R Foundation for Statistical Computing, Vienna, Austria]).[18] Angle of lateral opening was not continuous, being recorded in bins of 5° increments from 40° to 60°. Thus, ALO measurements were treated as ordinal categories and compared between groups 1 and 2 via an asymptotic linear-by-linear association test ('coin' package of R).[19] Statistical analyses were performed in R Version 3.4.0 (R Foundation for Statistical Computing) running with R Studio version 11.0.143 (RStudio, Boston, Massachusetts). Descriptive statistics for parametric data are expressed as mean (SD), with nonparametric data expressed as median (range). Significance was set at $P < .05$.

# 3 | RESULTS

## 3.1 | Animals

Seven dogs (one intact male, three neutered males, three spayed females) were included in the pseudoacetabulum group (group 1), and 21 dogs (two intact males, six neutered males, 13 spayed females) were included in the control group (group 2). Among the 311 THA performed at OSU VMC during the study period, six dogs with a pseudoacetabulum were identified, representing an overall incidence of 2% at this institution. Data for the remaining dog from group 1 were acquired from Skylos Sports Medicine. Breeds represented included mixed breed (n = 7; 2/7 pseudoacetabulum); German shepherd (n = 5; 2/5 pseudoacetabulum); golden retriever (n = 3; 1/3 pseudoacetabulum); Labrador retriever (n = 2; 1/2 pseudoacetabulum); Great Pyrenees (n = 2; 1/2 pseudoacetabulum); and n = 1 each of Saint Bernard, Rottweiler, catahoula leopard, wirehaired pointing griffon, Brittany spaniel, chow chow, Siberian husky, boxer, and Bouvier des Flandres. Dogs in group 1 were older (53 [20] months) than the dogs in group 2 (24 [19] months, $P = .005$). There was no difference in bodyweight between dogs in group 1 (33.5 [7.8] kg) and dogs in group 2 (32.5 [7.9] kg, $P = .78$). All dogs in both groups had normal preoperative complete blood count and serum biochemistry profiles. Orthopedic examination findings for all dogs in group 1 included pain, crepitus, and decreased extension on manipulation of the affected hip joint, with the presence of moderate to severe ipsilateral thigh muscle atrophy. All dogs in group 1 presented with a history of chronic pelvic limb lameness. Five of the seven dogs in group 1 were adopted from animal shelters between 3 weeks and 6 months prior to presentation. Consequently, the duration of lameness and any history of trauma was not uniformly available (Table 1).

## 3.2 | Radiographic factors

Preoperative, immediate, and 2- to 3-month postoperative radiographs were available for review for all dogs; preoperative CT results were was also acquired for four of the seven dogs. A dysplastic contralateral hip was detected in only one

**TABLE 1** Pertinent clinical information for all seven pseudoacetabulum cases

| Dog | Weight, kg | Age, y | Clinical history | Orthopedic comorbidities | BioMedtrix implants used | Complications |
|---|---|---|---|---|---|---|
| 1 | 44.3 | 7 | Lameness of ~2 years duration; unknown history of trauma | None | 30-mm cup, No. 9 LB-stem[a], 17-mm (+0) head | Fissure of the craniomedial femoral cortex |
| 2 | 21.4 | 6 | Persistently lame after a fall on ice ~2 months prior to presentation | None | 24-mm cap, No. 7 LB-stem[a], 17-mm (+0) head | None |
| 3 | 36.3 | 5 | Persistently lame since adoption from shelter 6 weeks prior to presentation with unknown prior history | Grade II/IV MPL at presentation; previous ipsilateral femoral fracture repair with IM pin, removed at THA surgery | 22-mm cup, No. 6 stem, 14-mm (+1) head | 6-mm subsidence and mild retroversion of stem |
| 4 | 27.5 | 3 | Persistently lame since adoption from shelter 3 weeks prior to presentation with unknown prior history | Dysplastic left coxofemoral joint; chronic Salter-Harris III fracture of right capital physis | 24-mm cup, No. 8 stem, 17-mm (+0) head | None |
| 5 | 38.7 | 3 | Persistently lame since adoption from shelter 6 weeks prior to presentation with unknown prior history | Chronic right articular olecranon fracture, repaired by referring veterinarian 1 mo before THA | 26-mm cup, No. 9 stem, 17-mm (+0) head | None |
| 6 | 26.4 | 5 | Persistently lame since adoption from shelter 6 months prior to presentation with unknown prior history | None | 26-mm cup, No. 6 collared stem, 17-mm (+6) head | None |
| 7 | 40.0 | 2 | Persistently lame since adoption from shelter 3 weeks prior to presentation with unknown prior history | None | 28-mm cup, No. 9 collared stem, 17-mm (+0) head | None |

Abbreviations: IM, intramedullary; LB, locking bolt; MPL, medial patellar luxation; THA, total hip arthroplasty.

of the seven dogs in group 1, with the other six dogs found to have normal contralateral joint conformation. All dogs in group 1 were found to have complete cranial and dorsal displacement of the femoral head from the native acetabulum. The presence of a pseudoacetabulum was associated with the development of a crater of heterotopic bone that was primarily dorsal and cranial to the luxated femoral head in all dogs (Figure 2). In six of the seven dogs in group 1, the ilial bone subjacent to the luxated femoral head developed sclerosis and remodeling (Figure 2). The seventh dog had the least developed pseudoacetabulum, consistent with this being the earliest presentation of such pathology in this case series, and had THA performed before pronounced bony remodeling had occurred, as was evident in the other dogs. Computed tomography helped to visualize the remodeling of the cortical bone of the caudal ilial body and further revealed the well-defined, heterotopic new bone formation which was concentric with the luxated femoral head (Figure 3).

## 3.3 | Operative factors

The anesthetic protocol used in each dog varied slightly according to the attending anesthesiologist. All dogs received cephazolin (22 mg/kg IV) after induction and every 90 minutes thereafter while the dog was under general anesthesia. All dogs were treated by cementless (BioMedtrix BFX; BioMedtrix, Whippany, New Jersey) THA, performed in a standardized fashion (BioMedtrix universal canine hip system; surgical technique for BFX cementless and CFX cemented implants; BioMedtrix, Boonton, New Jersey; released August 28, 2007). All surgeries were performed by or under the supervision of one surgeon (J.D.). For all dogs in group 1, manual traction on the limb was not sufficient to reduce the prosthesis. To help overcome significant soft tissue tension, the tip of a narrow Hohmann retractor was placed under the ventral aspect of the ischium immediately caudal to the acetabulum and used as a lever against the

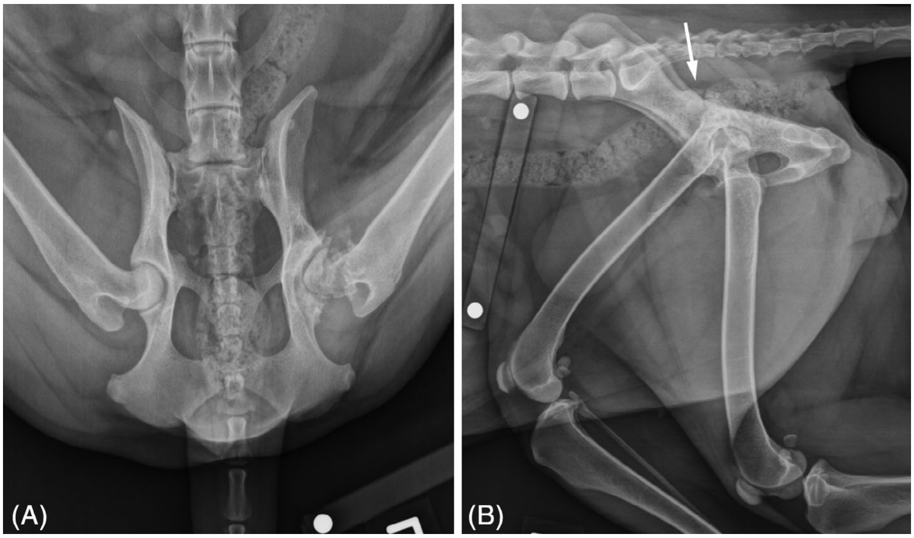


**FIGURE 2** Preoperative ventrodorsal (A) and lateral (B) pelvis radiographic images of dog 2. The left femoral head is luxated cranially and dorsally. On the ventrodorsal radiographic image (A), the femoral head appears misshapen and there is periarticular osteophytosis and some soft tissue mineralization, with the appearance of acetabular infilling and some associated sclerosis of the bone medial and cranial to the femoral head. Of note is the difficulty in diagnosing hip luxation based on the ventrodorsal view. On careful evaluation of the lateral radiographic image (B), heterotopic new bone was identified cranial and dorsal (arrow) to the luxated femoral head

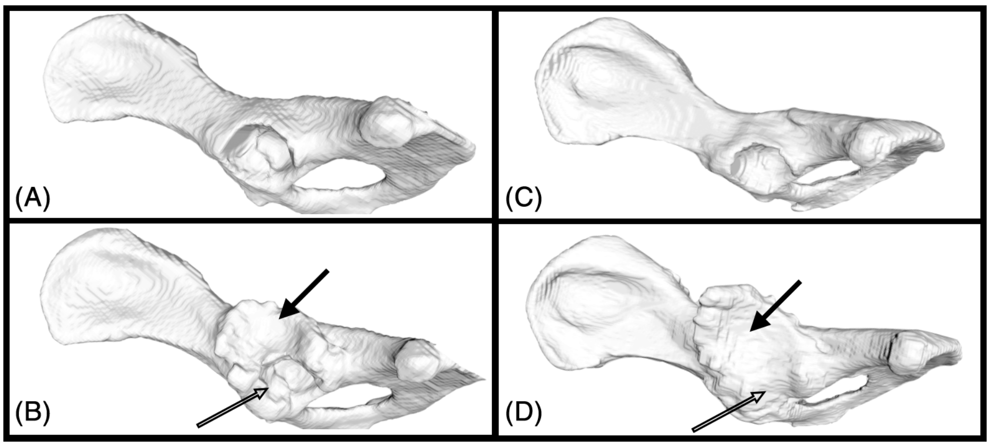


**FIGURE 3** Computed tomographic reconstruction of the pelvis of dog 2 (A,B) and dog 4 (C,D) illustrating the normal (A,C) and pseudoacetabulum affected (B,D) sides. Note that the hemipelves in panes A and C have been flipped horizontally for ease of comparison. On the affected side, the pseudoacetabulum (solid arrows) is located craniodorsally to the native acetabulum (open arrows). Note the well-defined concentric new bone formation, with remodeling of the subjacent ilial body, around the location of the luxated femoral head (digitally removed to enhance visualization) in this region

femoral neck.[20] The mean (SD) operative time for dogs in group 1 was 96 (18) minutes and that for group 2 was 63 (14) minutes. The operative times were longer for dogs in group 1 vs those for dogs in group 2 ($P$ = .0002). The median difference in operative times between the two groups was 30 minutes (range, 5-61; $P$ = .001). The duration of anesthesia for dogs in group 1 (203 ± 24 minutes) was longer than that for dogs in group 2 (173 ± 30 minutes) but did not reach our significance threshold when controlling for weight ($P$ = .081).

There were no differences between the two groups with regard to cup inclination angle ($P$ = 0.955), version angle ($P$ = .109), or ALO ($P$ = .205). Preoperatively, the DD of the femoral head for dogs in group 1 was 7.2 (4.5) mm cranially and 20.5 (11.1) mm dorsally. Postoperatively, in all dogs, the acetabular prosthesis was seated at the level of the native acetabulum, with a cranial DD of only 2.2 mm (1.9 mm). In three of the seven dogs in group 1, a postoperative dorsal DD was not obtained because of inadequately positioned lateral radiographic projections. In the four dogs

**TABLE 2** Measured DD in all pseudoacetabulum cases preop and postop

| Dog | Preop dorsal, mm | Preop cranial, mm | Postop dorsal, mm | Postop cranial, mm |
|---|---|---|---|---|
| 1 | 32.2 | 1.1 | 0.2 | 1.6 |
| 2 | 15.1 | 0.5 | 6.7 | 3.9 |
| 3 | 38.6 | 8.7 | N/A[a] | −1.5 |
| 4 | 9.1 | 7.6 | N/A[a] | 0.7 |
| 5 | 15.3 | 13.2 | N/A[a] | 4.2 |
| 6 | 7.0 | 11.4 | 1.4 | 3.2 |
| 7 | 26.3 | 8.2 | 2.8 | 3.6 |

Abbreviations: DD, displacement distance; N/A, data not available; Postop, postoperatively; Preop, preoperatively.
[a]A postop dorsal DD was not obtainable because of obliquely positioned lateral pelvis radiographs.

in which a postoperative dorsal DD could be measured, the average postoperative DD was 2.8 (2.5) mm (Table 2). Although immediate postoperative stem alignment and positioning were not compared statistically, there were no apparent differences between the groups in regard to them. Adaptive remodeling characterized by medialization of the greater trochanter and/or lateralization of the proximal medial femoral cortex was observed in a number of dogs in both groups, and femoral conformational abnormalities did not appear to be overrepresented in group 1 compared with group 2 (Figure 4).

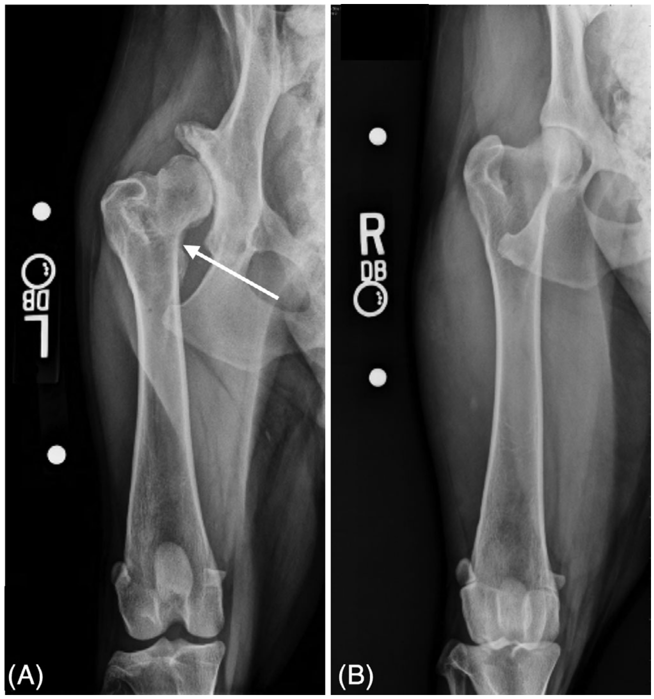


**FIGURE 4** Craniocaudal radiographic view of the affected (A) and normal contralateral (B) femur in dog 1. Heterotopic new-bone formation is noted cranially to the luxated femoral head. Note the lateralization of the proximomedial femoral cortex (arrow) and the medialization of the greater trochanter in the affected femur, which contrasts with the normal contralateral side. Similar findings were found in several dogs in both groups

## 3.4 | Owner questionnaires

The owners of four dogs in group 1 returned completed questionnaires. The mean (SD) interval between surgery and completion of the questionnaire was 30 (10) months. Two of the four owners reported "slight" lameness in their dog, with both of these owners describing this lameness as very rare episodes of "stiffness." All four dogs were noted currently to walk a minimum of 1 to 2 miles each day, with all dogs either willing or very willing to walk, trot, gallop, and jump. All owners assessed their dog's mobility to be either "good" or "very good," with none of the four dogs receiving anti-inflammatory or any other analgesic medication. Three of the four dogs were noted "hardly-ever" or "never" to vocalize in pain; the fourth dog "sometimes" vocalized in pain, which the owner assessed to be discomfort in his right thoracic limb from a previous olecranon fracture. In assessing their dog's ability to lie down and rise, all owners noted that their dog could perform these activities with "ease" or "great ease." All owners similarly noted that ease of movement after exercise or after rest was "hardly ever" difficult to "never" difficult. The owner of an additional dog that did not complete the questionnaire reported that the dog (31 months postoperatively) was clinically doing very well and had a full return to all activities within 6 months of surgery. Overall, the owner-perceived outcome of quality of life post-THA was good to excellent with no major concerns.

## 3.5 | Complications

Overall, three complications associated with THA in dogs with pseudoacetabulum formation were documented; no complications were reported for the dogs in group 2. One dog in group 1 developed a fissure of the craniomedial femoral cortex intraoperatively. The fissure occurred during hip reduction and was immediately repaired by using one double-loop cerclage placed proximal to the lesser trochanter and four single-loop cerclage wires about the proximal diaphysis (Figure 5). No radiographically identifiable fissures were visible on the immediately postoperative radiographs; the dog recovered and healed uneventfully. This dog also developed marked transient edema of the surgically treated leg postoperatively. This edema had completely resolved 3 weeks postoperatively. A second dog had subsidence (6 mm) and retroversion of the femoral stem into a normoverted position, noted on the 11-week postoperative radiographs. Despite the stem movement, the articulation

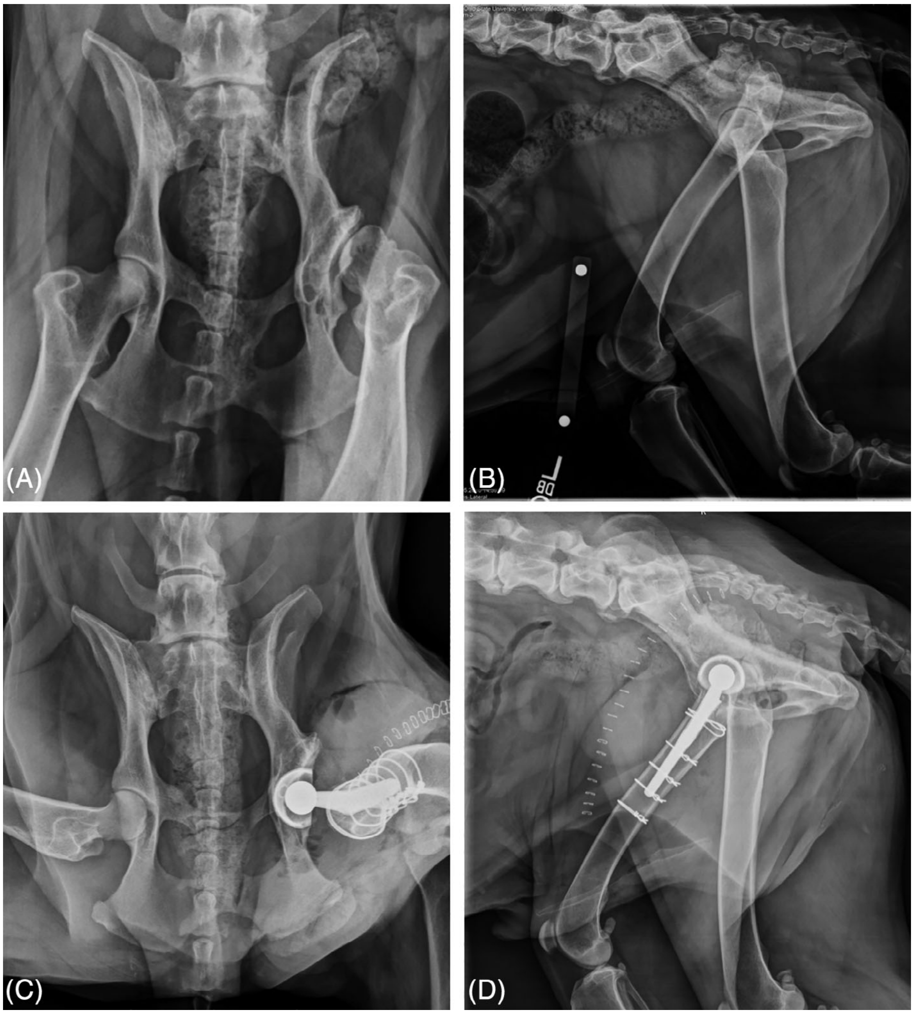


**FIGURE 5** Ventrodorsal (A,C) and mediolateral (B,D) pelvis radiographic images of dog 1 preoperatively (A,B) and immediately postoperatively (C,D). Note how the femoral head is luxated almost directly dorsally (B) and how the cup prosthesis has been inserted at the level of the native acetabulum (C,D). A femoral fissure noticed intraoperatively was repaired with one double-loop cerclage placed proximal to the lesser trochanter and four single-loop cerclage wires placed distal to the lesser trochanter

between the femur and acetabulum remained stable and orthopedic examination of that joint was unremarkable, including a normal and comfortable range of motion. This dog was also determined to have grade II/IV () left-sided medial patellar luxation (MPL) ipsilateral to the pseudoacetabulum at the initial presentation. At the 11-week post-THA recheck examination, the dog was found to have persistent left pelvic limb lameness. This lameness was attributed to the patellar luxation, with an otherwise normal orthopedic examination. Surgical intervention involving tibial tuberosity transposition and lateral capsular/fascial imbrication was performed at this time. The dog recovered uneventfully, and, at a 4-month post-MPL surgery recheck examination, the dog was noted to be walking well with no lameness, pain, or patellar luxation identified. In the early postoperative period, some of the dogs in group 1 were noted to drag their foot during the swing phase of gait. No neurological deficits were identified in any of these dogs. The foot dragging was transient and was probably associated with decreased hip flexion caused by abnormal coxofemoral soft tissue tension. In all of the dogs at the 2- to 3-month follow-up examination, there was no foot dragging, and there was a dramatic increase in the range of motion in hip flexion.

## 4 | DISCUSSION

Total hip arthroplasty is a successful treatment for a multitude of debilitating conditions of the hip, including hip dysplasia and hip luxation.[3,21] Clinical disability caused by hip dysplasia with secondary osteoarthritis is the most common indication for THA in dogs.[22,23] Less frequently, complete hip luxation can occur in dogs secondary to hip dysplasia; however, these dogs tend to present with a history of recent trauma and acute deterioration in their clinical signs.[3] We report seven dogs with a history and radiographic signs consistent with chronic traumatic craniodorsal hip luxation with pseudoacetabulum development. Six of the seven dogs had a normal contralateral hip. Despite having hip dysplasia, the seventh dog had evidence of a chronic Salter-Harris III femoral capital fracture-luxation as a prelude to pseudoacetabulum. These findings provide evidence that hip dysplasia was not implicated in the etiopathogenesis, with a traumatic event suspected to have occurred in all dogs.

In most of the dogs presented here, the femoral head luxated more dorsally than cranially (Table 2). Consequently, the hip luxation was not obvious (Figure 2) on the ventrodorsal radiograph in many cases. Careful scrutiny of orthogonal radiographic projections can help identify a pattern of change, in particular concentric dorsal heterotopic ossification around a luxated femoral head, that can help discriminate between the pseudoacetabulum case and the more classic dysplastic/osteoarthritic joint or the luxoid case.[24] We found that CT data, when available, were very helpful in delineating the position and morphology of pseudoacetabulum; this should be considered in similar cases, especially when the radiographic findings are ambiguous. Failure to recognize the presence of a pseudoacetabulum may result in placement of the acetabular component at this ersatz location. Placement of the acetabular prosthesis at the level of the pseudoacetabulum in man has been associated with higher rates of complications, in particular aseptic acetabular cup loosening, compared with placement at the true acetabulum.[25]

Both operative time and anesthesia time were longer for the dogs in group 1 compared with those for the control dogs in group 2. While the components of surgery were not individually timed, subjectively, acetabular preparation was the greatest contributor to increased duration of surgery. With chronic cranial and dorsal displacement of the femoral head and the associated periarticular fibrosis and muscle shortening, caudal and distal retraction of the femur to develop appropriate exposure to the true acetabulum was found to be a significant challenge. Furthermore, working around the cranial border of the cranially displaced femur to enable appropriate acetabular bed preparation and ultimately cup placement was another challenge that likely had a large influence on the increased operative times. Obstruction of the acetabular bed by the more cranially located femur precluded the use of the standard cup impactor to introduce the cup in some dogs. In this scenario, the cups were placed by hand and then impacted incrementally by using the CFX femoral stem impactor and mallet until the cup was adequately seated and was stable enough to allow insertion of the standard impactor. This involved placing the CFX femoral stem impactor on the metal rim of the cup, avoiding contact with, and subsequent damage to, the polyethylene cup liner. Despite this challenge, all cups were placed at the location of the native acetabulum, and the cups were all appropriately retroverted, with no differences in cup version angles found between dogs in group 1 and group 2. Reduction of the femoral component into the acetabular prosthesis was an additional challenge that contributed to increased operative and anesthesia time. With an average dorsal and cranial displacement of 21 mm and 7 mm, respectively, significant tension and leverage was required to fatigue the periarticular soft tissues and enable appropriate reduction of the prosthesis. The described femoral cortical fissure occurred in a dog with greater than 30 mm of dorsal femoral displacement. Reduction of the prosthesis and repair of this cortical fissure were likely the main contributors to this dog having the longest surgical time (125 minutes) of all dogs in this study. Strategies such as placing the acetabular cup more dorsally or medially, creating a more distal femoral osteotomy, and/or distalization of the femoral component can be employed to assist in overcoming tension and thus facilitating reduction of the prosthesis. None of these were performed in the dogs presented here, however, because of our preference to engineer an anatomic hip locus. Overall, the surgery time was 52% longer for dogs in group 1 compared with for dogs in group 2; this provides evidence that THA in dogs with a pseudoacetabulum presents a level of difficulty far above that of a dog with standard hip dysplasia, and this should be borne in mind by the surgeon before undertaking such cases.

The craniomedial femoral fissure noted in one dog from group 1 developed during distal and caudal retraction of the femur during prosthesis reduction. When a femoral fissure is noted during THA when using this implant system, it ordinarily occurs during terminal broaching or stem impaction.[26] This finding however, should prompt one to assess for fissuring postreduction in dogs with hip luxation, especially when the hip is chronically luxated and reduction is challenging. This dog also developed transient postoperative edema in the surgically treated limb. This surgery involved a challenging hip reduction and a fissure fracture repair, both of which theoretically may have contributed to the edema formation. Another dog from group 1 developed subsidence and retroversion of the stem during the convalescence period. This dog was noted preoperatively to have pelvic torsion and had also previously sustained a femoral fracture that was repaired with an intramedullary pin, which was removed at the time of THA. The stem was positioned in excessive anteversion and proximal to the optimal level of insertion according to radiographs obtained immediately after surgery. Severe lateralization of the proximomedial femoral cortex and medialization of the greater trochanter likely contributed to the inadequate initial seating of the stem in this dog, which in turn presumably precipitated the subsequent stem subsidence.[27] Fortunately, the clinical outcomes were very good, including radiographic evidence of osseointegration and normoversion after subsidence of the stem to a more appropriate level. The overall complication rate associated with THA in this study was low, with only three complications encountered in all dogs (28 THA; Table 1). However, it is important to note that all three complications occurred in dogs in the pseudoacetabulum group.

While our overall low complication numbers precluded meaningful statistical comparisons between the two groups, the two dogs that experienced complications were both in group 1. This is well above the expected complication rate in dogs undergoing THA with similar implants.[23] Theoretically, had the pseudoacetabulum not been recognized preoperatively or intraoperatively in our dogs and the acetabular cup been placed at the ersatz location, our complication rate for group 1 dogs may have been even higher, as has been documented in man.[25]

Chronic hip luxation with pseudoacetabulum formation in man is most commonly associated with congenital dislocation of the hip (CDH). Total hip arthroplasty is the treatment of choice for people with clinical disability relating to CHD.[4,13] A major risk with performance of THA in these patients, however, is the development of a femoral and/or sciatic nerve palsy, with reported rates of this complication as high as 17%.[12,28] It has been shown in man that acute limb lengthening, by relocating the chronically luxated femur distally by greater than 2.7 cm, increases the risk of peroneal nerve palsy.[29] No nerve deficits were detected in any dog in this study despite the fact that femoral displacement extended as far dorsally as 3.9 cm in some dogs reported here (Table 2).

The current study had a number of limitations. Because of the retrospective nature of the study, there was variability in the implants used. All dogs were implanted with BioMedtrix BFX implants; however, newer modified versions of the BFX stems were used in some dogs, including the use of a BFX stem with lateral locking bolt in two dogs and a collared stem in another two dogs, both designed to help prevent stem subsidence (Table 1).[30,31] The only stem complication (subsidence) noted was in a dog with a stem not specifically modified to help prevent subsidence. Assessment of dogs with pseudoacetabulum treated by THA with no variability in implants used may give a truer reflection of the complication rate associated with these cases. The main complication of THA in people with chronic hip luxation is aseptic acetabular cup loosening, which can occur years after implantation. A longer follow-up period would be required to definitively rule out this and other complications that could occur in the long term. Despite having long-term follow-up via owner-completed questionnaires or telephone communication, we had this in only five of the seven dogs in group 1; furthermore, our inability to directly perform an orthopedic examination renders definitive conclusions regarding long-term outcomes challenging to make. It is important to note that all dogs were operated on by or under the supervision of an experienced, high-volume surgeon (>120 THA/year). The complication rate reported here may underestimate the complication rate that might be encountered by a less experienced surgeon operating in similar cases. Finally, the magnitude of femoral head luxation and our ability to restore the acetabulum to its native location was assessed by calculating a DD. The accuracy of these measurements is reliant on appropriate radiographic positioning, and even the most subtle malpositioning may have affected our measurements.

Careful scrutiny of orthogonal pelvic radiographs is required to discern a repeatable pattern of ilial new bone formation and remodeling around the luxated femoral head in dogs with a pseudoacetabulum. Performance of THA in dogs with a pseudoacetabulum presented a relatively high degree of surgical difficulty, resulting in longer surgery and anesthesia times compared with THA in dogs with simple hip dysplasia and osteoarthritis. In all dogs, the cup was seated in the original acetabular bed, remote from the pseudoacetabulum.

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## CONFLICT OF INTEREST

Jonathan Dyce is a paid consultant for BioMedtrix. The authors declare no additional conflict of interests related to this project.

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## SUPPORTING INFORMATION

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

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