Ultrasound is an accurate imaging modality for diagnosing hip luxation in dogs presenting with hind limb lameness

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OBJECTIVE
To determine the accuracy of ultrasound for diagnosing hip luxation in dogs presenting for hind limb lameness.

METHODS
24 client-owned dogs presenting with pelvic limb lameness and concern for hip luxation were enrolled in this prospective diagnostic accuracy study from April 1, 2021, to July 1, 2022. An experienced ultrasonographer and a novice ultrasonographer, both masked to the diagnoses, performed hip ultrasonography using a point-of-care ultrasound machine. The experienced evaluator also performed a more comprehensive ultrasonography with a high-end ultrasound machine to characterize concurrent pelvis and hip disease. Pelvic radiographs served as the criterion standard for the diagnosis of hip luxation.

RESULTS
Ultrasonographic diagnosis of hip luxation demonstrated high accuracy, ranging from 84.2% to 100% for detecting the presence of luxation and 80.6% to 98.1% for diagnosing the direction of luxation for the novice and experienced evaluators, respectively, with substantial interevaluator agreement (κ = 0.722). Compared to radiographs, ultrasound accurately diagnosed the presence of osteoarthrosis with almost perfect agreement (κ = 0.913) and the presence of fractures of the femoral head/neck and the nonaxial portions of the pelvis with substantial intermodality agreement (κ = 0.775). In 36% of patients, ultrasound identified injury to soft tissue structures that contribute to hip stability, including the gluteal muscles, gemelli, and joint capsule.

CONCLUSIONS
Ultrasound can be utilized to accurately diagnose the presence of hip luxation and document concurrent hip and pelvic disease.

CLINICAL RELEVANCE
Applications include the use of ultrasonography as part of a routine point-of-care protocol to catalogue injuries in patients with acute trauma and in mobile practice or remote settings where radiography is not readily available.

Keywords: ultrasonography, musculoskeletal, coxofemoral, dislocation, joint

With improved technology, portability, and affordability, there has been significant expansion in the use of ultrasound in veterinary practice. In addition to use in specialty hospitals, ultrasound is increasingly used in emergency and general practice clinics,\(^1,2\) especially for point-of-care ultrasound examinations.\(^3,4\) As an imaging modality, ultrasound is paramount in providing timely and clinically relevant information for directing patient management for a broad variety of disease processes. Prior studies have evaluated its usefulness in diagnosing nonorthopedic conditions such as pulmonary contusions,\(^5\) cardiogenic pulmonary edema,\(^6\) and aspiration pneumonia\(^7\) and in detecting and removing migrating foreign bodies.\(^8,9\) Applications of ultrasonography for musculoskeletal injuries are also rapidly expanding, with recent publications highlighting its utility for diagnosing and/or monitoring iliopsoas,\(^10\) shoulder,\(^11\) supraspinatus and biceps tendon,\(^12\) and elbow disease.\(^13\)
Hip (coxofemoral) luxation is widely recognized as the most common type of joint dislocation in dogs. Diagnosis of hip luxation in dogs is most often made through a combination of physical examination and radiographic findings, with radiographs also being useful for characterizing the direction of luxation, detecting the presence of other disease (eg, fractures, osteoarthritis), and assisting with clinical decision-making for treatment (eg, closed vs open reduction). Radiographs are also commonly used to assess the maintenance of closed reduction of hip luxation. In other species, including horses, cows, and humans, ultrasound is commonly used for the diagnosis of hip disease. However, to our knowledge, there are no prior clinical studies evaluating the utility of ultrasonography for diagnosing hip luxation in dogs.

In our previous work, we established ultrasound as an accurate imaging modality for diagnosing the presence of hip luxation in canine cadavers, even when performed by novices to the technique. The objective of the current study was to establish the utility and accuracy of hip ultrasonography for diagnosing hip luxation in clinical patients, as well as to determine the ability of ultrasound to diagnose concurrent pelvic injuries, especially those that may be contraindicators for performing closed hip reduction. Our hypothesis was that hip ultrasonography would be accurate in diagnosing both the presence and direction of luxation in patients presenting with clinical concern for hip luxation. Additionally, we hypothesized that ultrasound would accurately detect hip osteoarthrosis and fractures involving the dorsal and lateral cortical margins of the pelvic bones (ilium, acetabulum, ischium) but would not characterize the presence of more axial fractures (eg, pubis, pelvic symphysis).

Methods

Animals

Dogs presenting to the Cornell University Hospital for Animals from April 1, 2021, to July 1, 2022, with pelvic limb lameness were prospectively enrolled in this diagnostic accuracy study with informed owner consent. Inclusion parameters were pelvic limb lameness and concern for potential hip luxation based on the initial physical examination by the attending clinician. Exclusion parameters were instability for sedation for radiography, wounds with extensive subcutaneous gas limiting ultrasound examination, and extensive osseous trauma to the pelvis/hip region (eg, comminuted fractures) that significantly distorted normal anatomic landmarks. This study was approved by the Cornell University IACUC (2020-0112).

Study design

The study design is shown as a flowchart in Figure 1. Dogs presenting to the Cornell University Hospital for Animals with pelvic limb lameness had physical examinations performed by the attending veterinarian. Patients with concerns for possible hip luxation had pelvic radiography performed (DX-G/NX digital radiography system; Agfa-Gevaert NV). Patients with hind limb lameness and clinical concern for hip luxation that was confirmed with radiography were offered enrollment in the study, and written informed client consent was obtained. Following the radiographic examination, an American College of Veterinary Radiology resident experienced in hip ultrasonography ("experienced evaluator") and an American College of Veterinary Surgeons (ACVS) resident with minimal prior experience in hip ultrasonography ("novice evaluator") were notified of patient enrollment to perform hip ultrasonography. Two ACVS residents with similarly limited prior experience with hip ultrasonography performed the "novice" ultrasound examinations, with one performing the majority of the examinations and the other assisting when the primary ACVS resident was unavailable. Both the experienced and novice evaluators were masked to which limb had a hip luxation and the direction of hip luxation. A small number (n = 4) of normal control patients (without presence of hip luxation) were randomly selected for inclusion in the study from dogs presenting to the orthopedic service with hind limb lameness; the ultrasonographers were masked to the inclusion of these patients. Both the experienced and novice evaluators independently performed focused ultrasonography of bilateral hip joints using a small, portable point-of-care ultrasound machine (M-Turbo 15-MHz linear probe or M-Turbo 8-5-MHz microconvex probe; Fujifilm Sonosite Inc). Patients were positioned in either sternal or lateral recumbency for the examinations, as dictated by patient comfort. The ultrasound probe
was in either medial-to-lateral or lateral-to-medial orientation, per clinician preference, and the examinations were performed by moving the probe from cranial to caudal along the dorsolateral aspect of the pelvis, starting at the iliac wing and extending to the tuber ischii, as described in a prior publication. The evaluators were not permitted to palpate or manipulate the limb prior to or during the ultrasonography. They independently recorded the presence of hip luxation (yes or no) and, if present, the direction of hip luxation (craniodorsal, caudodorsal, cranioventral, caudoventral) for both hip joints.

Following the initial ultrasonography, the experienced evaluator performed a more comprehensive ultrasonography of the pelvis and bilateral hips using a high-end ultrasound machine (Epiq-5 12-5-MHz linear probe or Epiq-5 12-3-MHz microconvex probe; Koninklijke Philips NV). Patients were positioned in sternal recumbency, the ultrasound probe was in either medial-to-lateral or lateral-to-medial orientation, per ultrasonographer preference, and the examinations were performed along the dorsolateral aspect of the pelvis, as referenced above. The following information was documented: presence of hip luxation; direction of luxation; presence of fractures of the femoral head, neck, or greater trochanter; presence of acetabular fractures; presence of osteophytes and/or enthesophytes; assessment of soft tissue material or mineral fragments within acetabulum when the femoral head was luxated; and assessment of concurrent soft tissue injuries associated with hip luxation. For patients in which closed reduction was recommended by the attending clinician, ultrasonographic guidance was used to confirm complete replacement of the femoral head within the acetabulum, which was also subsequently confirmed radiographically. The experienced evaluator retrospectively reviewed the

Figure 2—Representative hip ultrasound images from the dogs enrolled in the study described in Figure 1. A—Normal left hip joint with appropriate seating of the femoral head (asterisk) within the acetabulum (caret; probe orientation lateral to medial). B—Craniodorsal right hip luxation with the femoral head (asterisk) located dorsolateral to the iliac wing (probe orientation medial-lateral). C—Abnormal echogenic material within the empty left acetabular cavity (arrow) in a caudoventral hip luxation, with the greater trochanter (pound symbol) displaced caudoventrally relative to the acetabulum (caret; probe orientation lateral-medial). D—Abnormal thickness of the deep gluteal muscle with hypoechoic and disrupted fiber pattern (double plus symbol; probe orientation lateral-medial). Images were acquired on a high-end ultrasound unit with either a 12-5-MHz linear probe (A, C, and D) or 12-3-MHz microconvex probe (B). The greater trochanter is denoted by the pound symbol.
radiographs, independent of and masked to the ultrasound examinations, to document the presence of osseous and soft tissue abnormalities of the pelvis, hip joints, and bilateral femoral heads/neck.

**Statistical analysis**

Statistical analyses were performed in consultation with a statistician (Cornell Statistical Consulting Unit) with commercial software (Excel, Microsoft Corp; SPSS Statistics, version 29, IBM Corp). The data were determined to have a nonparametric distribution by use of the Shapiro-Wilk test for normality. The overall accuracy of ultrasound was determined as percentage agreement in comparison with radiographs for the experienced evaluator, novice evaluator, and combined accuracy for the hips imaged by both evaluators. Sensitivity, specificity, and positive and negative predictive values were calculated for imaging performed by the experienced and novice evaluators independently. The Cohen κ statistic was used to compare agreement (inter-rater reliability) of ultrasonography results for presence of luxation (yes or no) between the experienced and novice evaluators. A descriptive analysis was performed on the ability of ultrasonography to assess for concurrent hip joint disease at the time of luxation, with percentage agreement calculated in comparison to radiography for those findings commonly diagnosed radiographically (eg, osteophytes, fractures). The Cohen κ statistic was also used to assess agreement between ultrasonographic and radiographic diagnoses of any pelvic and femoral head/neck fractures, femoral head/neck and nonaxial pelvic fractures, and hip osteoarthrosis. The κ interpretation categories were as follows: ≤0, no agreement; 0.01 to 0.20, none to slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, substantial agreement; and 0.81 to 1.00, almost perfect agreement.

**Results**

Enrolled dogs (n = 24) consisted of the following breeds: mixed breed (8), Doodle mix (2), Labrador Retriever (3), Golden Retriever (1), Border Collie (2), Jack Russell Terrier (1), Rough Collie (1), Shih Tzu (1), German Shepherd Dog (1), Miniature Poodle (1), Pomeranian (1), Great Pyrenees (1), and Dachshund (1). There were 5 intact males, 6 neutered males, 1 intact female, and 12 spayed females. Dogs ranged in age from 6 months to 17 years, and weights ranged from 1.9 to 48.4 kg. Two of the enrolled dogs that presented with unilateral pelvic limb lameness had normal bilateral hips on radiography and were used as normal controls. Three of the enrolled dogs that presented with unilateral pelvic limb lameness had normal bilateral hips on radiography and were used as normal controls. Three of the enrolled dogs had their ultrasonographies performed in close time proximity to the administration of sedation for obtaining radiographs. Sixteen of the nonsedated patients were receiving pain control medications for their injuries at the time their ultrasound examination was performed (most commonly methadone, 0.2 mg/kg, IV, q 6 h as needed, or fentanyl, 3 µg/kg/h, IV, constant rate infusion).

Of the 22 enrolled dogs with hip luxation, 21 dogs had unilateral hip luxation, with 6 of these involving the left hip and 15 involving the right hip, and 1 dog had bilateral hip luxation. Distribution for the direction of hip luxation was as follows: craniodorsal (n = 19), caudoventral (3), cranoventral (1), and caudodorsal (0). Most of the dogs presented for pelvic limb lameness secondary to trauma (n = 21), with vehicular trauma being the most common (14), but unwitnessed trauma (3; all suspected vehicular trauma), a slip/fall event (3), and injury during restraint (1) were also included. Causes for pelvic limb lameness in the remaining 2 dogs were postoperative total hip replacement complication (femoral prosthetic luxation) and osteoarthrosis in combination with an intramedullary spinal cord tumor. Outcomes for the 22 enrolled dogs with hip luxation were as follows: femoral head ostectomy (n = 12), closed reduction (6), open reduction with toggle-pin fixation (2), limb amputation (1), and no treatment (1; chronic osteoarthrosis with subluxation). Of the 6 dogs that had closed reduction performed, 4 were successful without recurrence and 2 failed or recurred, with subsequent femoral head ostectomy performed.

The experienced evaluator performed ultrasonography on all enrolled dogs (n = 24), as well as the 3 with recheck examinations, totaling 54 hip ultrasound examinations. An accurate diagnosis for both presence

<table>
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<th>RAD (n)</th>
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RAD = Radiography. US = Ultrasonography.
and direction of luxation was made in 53 (98.1%) hips, correctly identifying 100% of nonluxated hips, correctly identifying the presence of luxation in 100% of luxated hips, and correctly diagnosing the direction of femoral head luxation in 95.8% (23/24) of luxated hips. Examples of the ultrasonographic appearance of a nonluxated hip joint and a luxated hip joint are shown in Figure 2. The 1 hip examination that was incorrectly characterized had a femoral head fracture; the evaluator identified the presence of a luxation and the presence of a fracture but could not correctly determine the position of the femoral head due to shadowing from the fracture fragment. The experienced evaluator’s sensitivity, specificity, positive predictive value, and negative predictive value for diagnosing the presence of a hip luxation with ultrasound was 100% for each. The novice evaluators collectively performed ultrasonography on 18 of the 24 enrolled dogs, totaling 36 hip ultrasound examinations. An accurate diagnosis for both presence and direction of luxation was made in 29 (80.6%) hips.

![Figure 2](image1.png)

**Figure 2**—Ultrasonographic appearance of a nonluxated hip joint (A) and a luxated hip joint (B). The nonluxated hip joint (A) shows the femoral head (asterisk) is completely seated within the acetabulum. The luxated hip joint (B) shows the femoral head (asterisk) is subluxated and there is a fracture fragment (arrows) in the acetabulum.

![Figure 3](image2.png)

**Figure 3**—Comparative hip ultrasound images (high-end unit) and radiographs of osteoarthrosis from dogs enrolled in the study described in Figure 1. A—Left hip ultrasound of a dog with a history of bilateral hip dysplasia and presenting with acute right hind limb lameness associated with right hip luxation. On the ultrasound image (12-5-MHz linear probe, lateral-medial orientation), there are medium-size osteophytes (arrows) on the femoral head (asterisk) and acetabulum (caret). The femoral head is incompletely seated within the acetabulum. B—Ventrodorsal radiograph of the left hip corresponding to panel A demonstrating osteophytes (arrows) on the acetabulum and femoral head and subluxation of the femoral head relative to the acetabulum. In addition, there is flattening and sclerosis of the acetabulum, additional periarticular new bone formation along acetabular margins, a joint-associated mineral body, and thickening of the femoral neck with enthesophyte formation. C—Right hip ultrasound of a dog presenting for left hind limb lameness associated with left hip luxation. On the ultrasound image (12-5-MHz linear probe, medial-lateral orientation), there is a small osteophyte (arrow) on the femoral head (asterisk) and a normal acetabulum (caret). D—Ventrodorsal radiograph of the right hip corresponding to panel C in which a femoral head osteophyte is not detected.
correctly identifying 88.2% (15/17) of nonluxated hips, correctly identifying the presence of luxation in 84.2% (16/19) of hips, and correctly diagnosing the direction of femoral head luxation in 73.7% (14/19) of luxated hips. The novice evaluator’s sensitivity, specificity, positive predictive value, and negative predictive value was as follows: sensitivity, 84.2%; specificity, 82.4%; positive predictive value, 84.2%; and negative predictive value, 82.4%. For the 18 dogs imaged bilaterally by both evaluators (total of 72 hip ultrasound examinations), overall accuracy was 93.1% (67/72) for presence of luxation and 88.9% (64/72) for both presence and direction of luxation. The data demonstrated substantial inter-rater agreement between the experienced and novice evaluators (κ = 0.722; P < .001).

To assess the diagnostic utility of ultrasound for detecting concurrent hip and pelvis disease in patients presenting for hip luxation, the comprehensive ultrasound examination findings were compared with radiographic findings (Table 1). There was no change in the diagnosis of the presence or direction of hip luxation between the point-of-care ultrasound machine and the high-end ultrasound machine. Ultrasound detected the presence of osteophytes and or enthesis associated with the hip joint in 2 patients that were not detected on radiography (associated with the acetabulum in one patient and associated with the femoral head/neck in the second patient. Table 1; Figure 3). For fracture detection, ultrasound accurately characterized pelvic and femoral head/neck fractures in 6 cases, as compared to radiography that detected fractures in 12 cases. Ultrasound accurately detected all fractures in the acetabulum (Figure 4) and femoral head/neck, though in 1 patient a small (3-mm) acetabular margin fracture was diagnosed on ultrasonography that was not detected radiographically. Ultrasound detected 2 of 3 fractures in the ischium, with the undetected fracture involving the ischiatic table (Figure 4). None of the pubis fractures (n = 4) nor an avulsion fracture of the ligament of the

**Figure 4**—Comparative hip ultrasound images (high-end unit) and radiographs of fractures from dogs enrolled in the study described in Figure 1. A—Ventrodorsal pelvis radiograph of a dog presenting for unknown trauma (suspected vehicular trauma). On the radiograph there is a right craniodorsal hip luxation (asterisk), right ischiatic table fracture and left ischiatic body fracture (thick black arrows), bilateral pubis fractures (thin black arrows), and a left sacroiliac luxation (thick black arrow). Bilateral pelvic ultrasound by use of a dorsolateral probe position detected the hip luxation, the sacroiliac luxation, and the left ischiatic body fracture and did not detect the right ischiatic table or bilateral pubis fractures. B—Left lateral pelvis radiograph corresponding to panel A with the right craniodorsal hip luxation (asterisk), bilateral ischial fractures (thick white arrows), and pubic fracture (thin black arrow). C—Ultrasound image of the left ischiatic body corresponding to panel A demonstrating the fracture segments (thin white arrows) separated by the fracture line and a small amount of abnormal, hypoechoic material in the near-field adjacent to the fracture line and segments (12-5-MHz linear probe, lateral-medial orientation). D—Ventrodorsal pelvis radiograph of a dog presenting for unnoticed (suspected vehicular trauma). There are bilateral acetabular fractures (right acetabular fracture segments, caret; left acetabular fracture segments, double caret) and a left craniodorsal hip luxation (asterisk). E—Left lateral pelvis radiograph corresponding to panel D with the bilateral acetabular fractures (right, caret; left, double caret), left craniodorsal hip luxation (asterisk), and a pubis fracture (thin black arrow). F—Right hip ultrasound corresponding to panel D demonstrating the mildly displaced right acetabular fracture segments (caret) and subluxation of the femoral head (asterisk; 12-5-MHz linear probe, medial-lateral orientation). The greater trochanter is denoted by the pound symbol.
Discussion

The results of this study supported our primary hypothesis that hip ultrasonography would be accurate in diagnosing both the presence and direction of luxation in patients presenting with clinical concern for hip luxation. The level of accuracy (80.6% to 98.1%), sensitivity (84.2% to 100%), and specificity (82.4% to 100%) for ultrasonography diagnosis of hip luxation was good to excellent, performing comparable to or better than the reported diagnostic accuracy of commonly utilized imaging examinations for the detection of joint disease, such as the radiographic detection of shoulder osteochondrosis/osteochondritis dissecans (accuracy, 88.9%; sensitivity, 88.5%; specificity, 90%) and ultrasonographic detection of shoulder osteochondrosis/osteochondritis dissecans (accuracy, 82.6%; sensitivity, 92%; specificity, 60%).

However, this study also documented that the level of experience with hip ultrasonography impacts the level of accuracy. As such, focused training to improve general ultrasonographic knowledge and skills, anatomic knowledge of the hip/pelvis, and the performance of hip ultrasonography will be important for successful incorporation of the use of ultrasonography to diagnose hip disease into clinical practice.

Results of the current study also supported our secondary hypothesis that ultrasonography would accurately detect the presence of hip osteoarthritis and fractures involving the dorsal and lateral osseous margins of the pelvis. However, ultrasonography did not allow for full characterization of fractures (eg, number and position of fragments). As anticipated, given the limitations in ultrasonography of osseous structures, fractures of the axial portions of the pelvic bones were not detected on ultrasonography. Thus, while ultrasonography has the capability to identify the presence of complete fractures along the weight-bearing axis of the pelvis, it cannot characterize the full extent of traumatic pelvic injuries and alternative imaging modalities (eg, radiography, CT) should be utilized to best characterize full extent of injury/disease.

Soft tissue injuries were better characterized on ultrasonography, with several patients (36%) exhibiting
injury and/or disruption to important muscular stabilizers of the hip region and to the hip joint capsule. Given the importance of these structures for providing stability to the hip joint, injury to these structures could result in abnormal laxity of the joint or abnormal weight-bearing. In addition, several dogs had abnormal echogenic material (which may represent tissue, hemorrhage, or fibrin) within the acetabulum. This material potentially could limit seating of the femoral head in the acetabulum with reduction of the hip luxation. These findings raise the question of whether the severity and type of soft tissue injuries could influence outcomes in hip luxation patients for whom closed reduction is pursued and be a fruitful avenue of future research.

Demographic data from this study agreed with prior studies that have documented craniodorsal luxation as the most common direction of hip luxation and trauma, specifically vehicular trauma, as the most common cause for hip luxation. Surgical treatments were more commonly pursued for dogs in this study, with approximately 50% of enrolled dogs having a luxation amenable to closed reduction. This rate seems low but is likely reflective of the referral nature of the caseload at our institution, in which cases with polytrauma are more likely to be referred to a tertiary care facility while those with an isolated hip luxation with no or minimal trauma may be more commonly managed at general practice and regional emergency hospitals. In this cohort of dogs, closed reduction was successful in two-thirds of cases, consistent with previously reported success rates ranging from 30% to 85%.

The results of this study were limited by small sample sizes, both with the number of enrolled dogs and the number of evaluators. Sample sizes were too low to compare accuracy for diagnosing the different directions of femoral head luxation. Given the study design and case selection, evaluator bias may have been an additional limitation of this study. While there were no cases in which the diagnosis of the presence and direction of hip luxation changed between the 2 ultrasound machines, the ability for the machines to detect other abnormalities (eg, muscle injury) was not compared between the point-of-care and more sophisticated ultrasound machines. An additional limitation of this study was having a single reviewer of the ultrasound and radiographic imaging for diagnosing additional disease/injury to the pelvis and hip region.

In summary, the results of this study support ultrason as an accurate imaging modality for diagnosing the presence and direction of hip luxation in dogs. Hip/pelvic ultrasonography also has the ability to detect the presence of concurrent osseous and soft tissue trauma, though additional imaging (eg, radiography, CT, MRI) will be required to fully characterize the extent of injuries in many dogs presenting with traumatic etiologies for luxation. Applications include cataloguing injuries in patients presenting for acute trauma (eg, vehicular trauma) and use in ambulatory and remote settings where other imaging modalities are not readily available.

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Disclosures

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