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ORIGINAL INVESTIGATION

WILEY

Computed tomographic arthrography is a useful adjunct to survey computed tomography and arthroscopic evaluation of the canine shoulder joint

Caroline R. Eivers[1] | Nuria Corzo-Menéndez[2] | Sarah H. Austwick[3] | David G. Thomson[2] | Sarah M. Gibson[2] | Ian Handel[1] | Tobias Schwarz[1]

[1]Royal (Dick) School of Veterinary Studies and Roslin Institute, University of Edinburgh, Roslin, UK
[2]Davies Veterinary Specialists, Hitchin, UK
[3]Austwick Veterinary Services Ltd, Luton, UK

Correspondence
Tobias Schwarz, Royal (Dick) School of Veterinary Studies, Roslin Institute, University of Edinburgh, Roslin, EH25 9RG, UK.
Email: tobias.schwarz@ed.ac.uk

Abstract

The aim of this retrospective, methods comparison study was to assess the diagnostic utility of computed tomographic arthrography in the assessment of various intraarticular shoulder pathologies in dogs in comparison with survey computed tomography (CT), using arthroscopic examination as the reference standard. Computed tomography, computed tomographic arthrography, and arthroscopic findings of 46 scapulohumeral joints of dogs with forelimb lameness were reviewed retrospectively. Predefined sites were assessed for the presence or absence of disease. If a lesion was present, a prespecified pathology was designated. Computed tomographic arthrography was found to be a safe technique which provided a superior diagnostic efficacy relative to survey CT for the assessment of the biceps tendon and biceps tendon sheath (sensitivity 71%, specificity 75%, positive likelihood ratio 2.9, negative likelihood ratio 0.38) and humeral head cartilage (sensitivity 65%, specificity 97%, positive likelihood ratio 19, negative likelihood ratio 0.37). Computed tomography and computed tomographic arthrography provided additional diagnostic information to arthroscopy in regard to osteophytosis, subchondral defects, and joint mice. Computed tomographic arthrography alone was of limited diagnostic value for assessment of the medial and lateral glenohumeral ligaments (sensitivity 13% and 0%, specificity 1% and 78%, positive likelihood ratios unmeasurable and 0, negative likelihood ratios 0.88 and 1.29, respectively) and the subscapularis tendon (sensitivity 14%, specificity 98%, positive likelihood ratio 5.7, negative likelihood ratio 0.88). Computed tomographic arthrography is therefore a useful adjunct to survey CT and arthroscopic evaluation of the canine shoulder joint, however, is not a replacement for these techniques.

KEYWORDS
CT, CT-Arthroscopy, dog, glenohumeral joint, shoulder

1 | INTRODUCTION

Intraarticular shoulder pathology is a frequent cause of thoracic limb lameness in the dog.[1,2] Determining the exact cause of shoulder lameness is often challenging, and various imaging techniques have been described.[1,3–6] Principal pathologies include bicipital tenosynovitis, biceps brachii tendon rupture, bicipital mineralizing tendinopathy, subscapularis tendon rupture, medial and lateral glenohumeral ligament rupture, osteochondrosis, osteochondrosis dissecans of the humeral head and intertubercular groove joint mice, fractures, luxations, arthritis, and neoplasia.[5,7–10] Arthroscopy has been advocated as the ‘gold standard’ for assessment of intraarticular structures of the canine shoulder.[2,11]

Computed tomography (CT) is frequently used in the diagnosis of shoulder lameness,[6,10] however, its inherently limited soft tissue contrast resolution restricts its diagnostic ability for intraarticular structures. The use of contrast medium introduced into the joint cavity overcomes this limitation, by delineating the margins of the synovial and cartilaginous structures. Positive contrast arthrography of the canine shoulder has been reported to aid in the diagnosis of osteochondrosis disorder,[12] bicipital tenosynovitis,[13] aseptic arthritis,[14] osteochondromatosis,[15] rupture of the biceps brachii tendon sheath,[16] and neoplasia.[17] Computed tomography and computed tomography arthrography have been demonstrated in canine cadavers to describe, in detail, the intraarticular structures of the normal canine shoulder.[18,19] To the authors' knowledge, an extensive comparison of CT and computed tomography arthrography of the canine shoulder in clinical cases has not yet been reported.

Although considered the 'gold standard' for intraarticular assessment, arthroscopy is invasive, expensive, and requires general anesthesia. Furthermore, it does not allow for the assessment of extraarticular sources of lameness. Magnetic resonance imaging (MRI), with or without arthrography, has been shown as a useful diagnostic technique for visualizing normal musculotendinous and capsuloligamentous structures of the canine shoulder and diagnosing injuries.[20–22] MRI benefits from significantly improved soft tissue contrast resolution compared to CT, however is also more expensive, time consuming, and requires general anesthesia in veterinary patients due to the long duration for image acquisition. Computed tomography, on the other hand, is more widely available and less expensive compared to MRI, is noninvasive, and benefits from a short acquisition time. The use of intraarticular contrast medium improves the soft tissue differentiation of CT,[19,23] and the technique can be performed under sedation. Computed tomography images are not hindered by susceptibility artefact, commonly seen in small animal MR images due to the presence of a subcutaneous microchip between the shoulders, which may interfere with interpretation.[24] In humans, computed tomography arthrography is considered superior to magnetic resonance arthrography for the assessment of articular cartilage due to its superior spatial resolution.[25] In diagnosing intraarticular pathology of the human shoulder, computed tomography arthrography has been demonstrated as a sensitive and accurate technique in identifying chondral, fibrocartilaginous, and intraarticular ligamentous lesions using diagnostic arthroscopy as the reference standard.[23,26,27]

The aim of this study was to assess the diagnostic utility of computed tomography arthrography in the assessment of various intraarticular shoulder pathologies in dogs with forelimb lameness in comparison with survey CT, using arthroscopic evaluation as a reference standard. The findings of CT, computed tomography arthrography, and arthroscopy were also compared directly.

2 | MATERIALS AND METHODS

The study had a retrospective, methods comparison design. Case records of dogs that presented with forelimb lameness, localized by orthopedic exam to the scapulohumeral joint, and underwent CT, computed tomography arthrography, and arthroscopy at Davies Veterinary Specialists between April 2008 and July 2013 were reviewed. To be included in this study, all shoulders must have undergone CT, computed tomography arthrography, and subsequent arthroscopy within 1 month. Medical records were reviewed for adverse effects post computed tomography arthrography. All decisions for subject inclusion or exclusion were made by two board-certified veterinary radiologists and a veterinary surgeon with 20 years of experience in referral orthopedic surgery. The hospital director approved use of the patient data. The sample size was based on a consensus of the authors, who considered that the number of patients included would result in sufficient statistical power.

2.1 | Imaging evaluation

All CT studies were reviewed by a board-certified veterinary radiologist blinded to the signalment, clinical history, imaging reports, and final diagnosis of each dog. Images were reviewed in a randomized order using a dedicated DICOM image viewer (OsiriX version 5.5, OsiriX Imaging Software, OsiriX Foundation, Geneva, Switzerland) in a soft tissue window (window level: 250, window width: 900) and a bone window (window level: 1000, window width: 4000) for the survey CT studies, and a soft tissue window (window level: 600, window width: 1700) and a bone window (window level: 1000, window width: 4000) for the computed tomography arthrography studies. An inverted blur convolution filter was applied for assessment of soft tissue and joint structures. Image quality was subjectively assessed prior to lesion inspection. The radiologist was permitted to use multiplanar reconstruction at their discretion to evaluate CT and computed tomography arthrography images.

Arthroscopy videos were recorded by normal domestic DVDs and were reviewed by a veterinary surgeon with 20 years of experience in referral orthopedic surgery, blinded to the signalment, clinical history, imaging reports, and final diagnosis of each dog. Images were reviewed in a randomized order. Where videos were not available, data were retrieved from clinical records.

Predetermined anatomical zones were evaluated using CT, computed tomography arthrography, and arthroscopy, which included the subscapularis tendon, biceps brachii tendon, the subchondral and juxtaarticular bone of the scapula, humeral head, and intertubercular groove, cartilage of the humeral head, medial and lateral glenohumeral ligaments, and the synovium. Structures were first classified as normal or abnormal. If abnormal, a prespecified pathology or pathologies were designated via subjective assessment. For tendons, prespecified pathologies included thickening, interruption, mineralization, and compression. For osseous structures, prespecified pathologies included osteophytosis, subchondral bone defects, and fractures. For the humeral cartilage, prespecified pathologies included fibrillation, underrunning/flap formation, and full defects. For the glenohumeral ligaments, prespecified pathologies included thickening and interruption. Lastly, for the synovium, prespecified pathologies included effusion for CT, irregular filling for computed tomography arthrography, thickening for arthroscopy, and joint mice for all modalities.

2.2 | Statistical analysis

Arthroscopy was used as the reference standard for the definitive diagnosis of intraarticular shoulder pathology. Sensitivity, specificity, positive and negative likelihood ratios, Cohen's Kappa, and accuracy were calculated for CT and computed tomography arthrography lesion detection in each predetermined anatomical structure using an epidemiological calculator (EpiTools, Ausvet Pty Ltd).[28] Statistical analyses were performed by a third-year radiology resident with the guidance of a statistician. Statistical significance was defined as $P < 0.05$.

3 | RESULTS

A total of 46 scapulohumeral joints from 45 dogs were included in the study. Two dogs were excluded due to suboptimal image quality. Arthroscopy videos were available for 36 shoulders. The remaining 10 shoulders had written surgical reports only.

Dogs ranged in age from 6 months to 10 years with a median of 4 years. Twenty-six dogs were male and 20 were female. A wide range of breeds were represented which included 14 Labrador retrievers, five border collies, five German shepherd dogs, four crossbreeds, three great Danes, two Rottweilers, two English springer spaniels, two Cocker Spaniels, a Rhodesian Ridgeback, German Shorthaired Pointer, Flat Coated Retriever, Standard Poodle, Staffordshire Bull Terrier, Shetland Sheepdog, Alaskan Malamute, Boxer, Dalmatian, and a Golden Retriever.

Forty-one dogs were imaged under sedation and four dogs were imaged under general anesthesia using the same dual-slice CT scanner (GE Highspeed Dual, Milwaukee, USA). Dogs were positioned in sternal recumbency, with the forelimbs extended, and the head placed centrally between the forelimbs. All images were acquired in axial mode using 120 kV, 70–100mAs, a slice thickness of 0.6 mm or 1 mm, and a field of view large enough to include the entire shoulder joint and surrounding soft tissues, from the distal scapula to the proximal third of the humerus. All images were reconstructed using high frequency algorithms.

For arthrography, dogs were placed in lateral recumbency. A 1:3 ratio of iohexol (Omnipaque™ 300, Oslo, Norway) and sterile water for injection resulting in an iodine concentration of 75 mg iodine/ml was administered, aseptically, into the scapulohumeral joint using a technique previously described.[5,29] This iodine concentration was found to be optimal in a previous study.[19] The total volume injected ranged between 3.5 and 5 ml. Subsequently, dogs were repositioned into sternal recumbency with the limbs extended,[19] and images were acquired as previously described for CT. The diagnostic quality of the computed tomography arthrography examinations was considered to be sufficient in all studies. No adverse effects were observed during or after arthrography.

An arthroscopic examination of the shoulder was performed on all dogs in the study, using a standard compartmental lateral approach, where care was taken to thoroughly evaluate all articular components. Findings were recorded onto the patients' clinical notes, and video images were obtained in most cases.

TABLE 1 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of subscapularis tendon lesions

	CT	CTA
Sensitivity	14.3% (0.36–57.9)	14.3% (0.36–57.9)
Specificity	97.5% (86.8–99.9)	97.5% (86.8–99.9)
Positive likelihood ratio	5.70	5.70
Negative likelihood ratio	0.88	0.88
Kappa coefficient*	0.17 (–0.19 to 0.52)	0.17 (–0.19 to 0.52)
Accuracy	0.85	0.85

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect. CT, computed tomography; CTA, computed tomographic arthrography.

3.1 | Subscapularis tendon

Computed tomography and computed tomography arthrography detected lesions in two of 47 subscapularis tendons, including thickening (2). Arthroscopy detected lesions in seven of 47 subscapularis tendons, including interruption (5) and thickening (2). Interruptions identified were all tears, while none were complete. One false positive result was detected by CT and computed tomography arthrography, which was thickening. Both CT and computed tomography arthrography had a sensitivity of 14% and specificity of 98%. Results are summarized in Table 1.

3.2 | Biceps brachii tendon and tendon sheath

Computed tomography detected biceps lesions in two of 47 shoulders, and computed tomography arthrography in 15/47 shoulders. Arthroscopy detected biceps lesions in seven of 47 shoulders, including thickening (2) and interruption (5). Ten false positives detected by computed tomography arthrography included compression of the biceps tendon (4), thickening (3), mineralization (2), and interruption (1) (Figure 1A–C). Computed tomography had a sensitivity of 14% and specificity of 98%, while computed tomography arthrography had a sensitivity of 71% and specificity of 75%. Results are summarized in Table 2.

3.3 | Scapula

Computed tomography detected lesions in 24/47 scapulae, and computed tomography arthrography in 16/47 scapulae. Arthroscopy detected lesions in three of 47 scapulae, including osteophytosis (2) and a subchondral defect (1). False positives detected by CT and computed tomography arthrography were due to osteophytosis (in 21 and 13 shoulders, respectively). Computed tomography had a sensitivity of 100% and specificity of 52%, while computed tomography arthrography had a sensitivity of 100% and specificity of 70%. Results are summarized in Table 3.

3.4 | Humeral head

Computed tomography detected lesions in 25/47 humeri, and computed tomography arthrography in 22/47 humeri. Arthroscopy detected lesions in 13/47 humeri, including osteophytosis (1) and subchondral defects (12). False positives detected on CT included osteophytosis (10) and subchondral defects (3). False positives detected on computed tomography arthrography included osteophytosis (7) and subchondral defects (3). Arthroscopy detected two subchondral lesions that were not detected on CT or computed tomography arthrography. Computed tomography had a sensitivity of 92% and specificity of 62%, while computed tomography arthrography had a sensitivity of 92% and specificity of 71%. Results are summarized in Table 4.

3.5 | Humeral cartilage

Computed tomography detected lesions in three of 47 humeri, and computed tomography arthrography in 12/47 humeri (Figure 2). Arthroscopy detected lesions in 17/47 humeri, including fibrillation (3), underrun cartilage/OC flap (8), and defects (7). Computed tomography only detected defects (2), while computed tomography arthrography detected defects (8) and underrun cartilage (8). Computed tomography had a sensitivity of 19% and specificity of 100%, while computed tomography arthrography had a

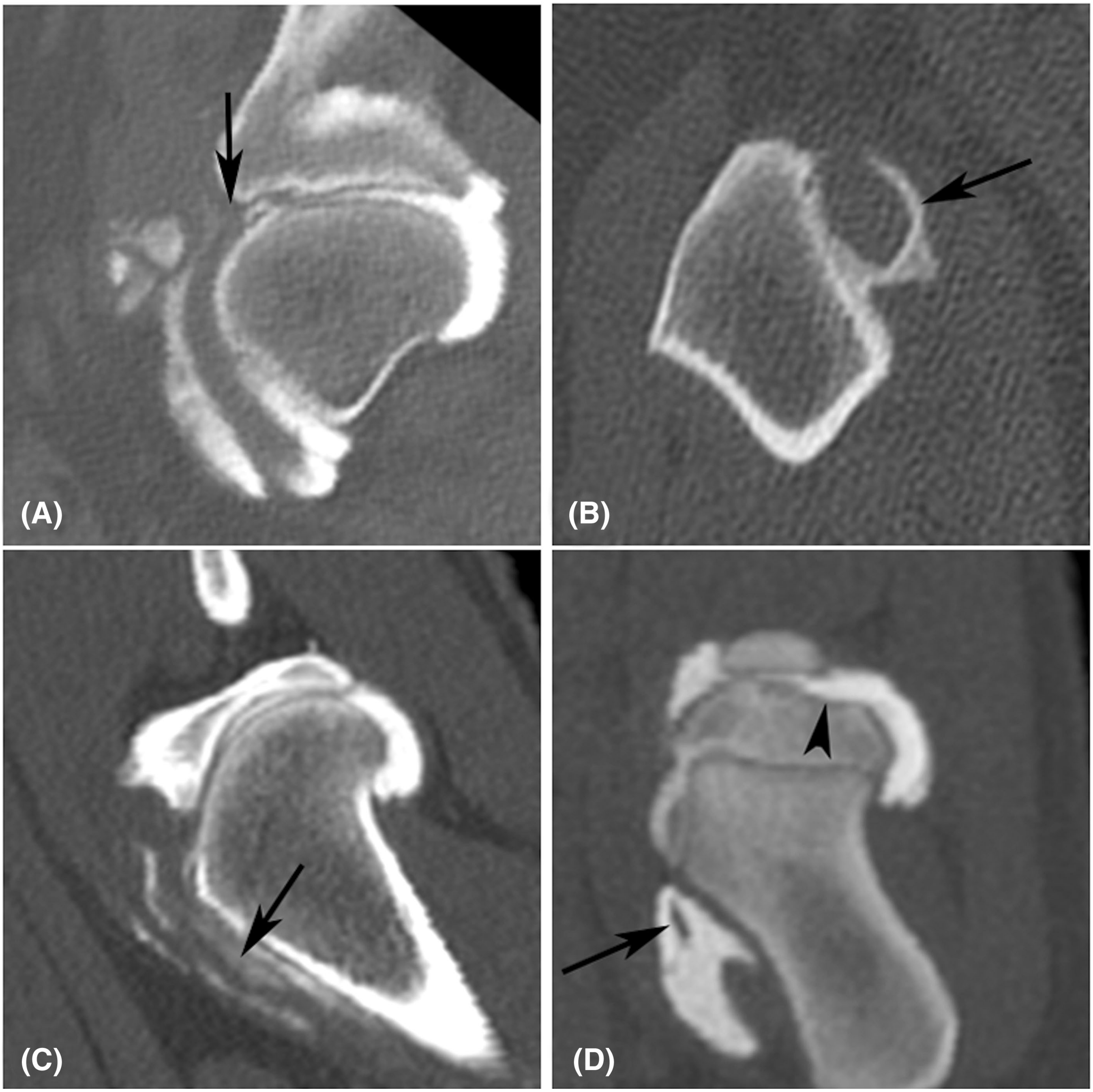

FIGURE 1 A, Computed tomographic arthrography image of biceps tendon compression (arrow) by an enlarged, partially mineralized supraspinatus tendon. B, Computed tomography image of a mineralised biceps tendon sheath (arrow). C, Computed tomographic arthrography image of biceps tendon interruption (arrow). D, Computed tomographic arthrography image of a joint mouse (arrow) within the biceps tendon sheath. A subchondral defect at the humeral head (arrowhead) is also present

TABLE 2 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of biceps brachii tendon and tendon sheath lesions

	CT	CTA
Sensitivity	14.3% (0.36–57.9)	71.4% (29.0–96.3)
Specificity	97.5% (86.8–99.9)	75.0% (58.8–87.3)
Positive likelihood ratio	5.70	2.90
Negative likelihood ratio	0.88	0.38
Kappa coefficient*	0.17 (–0.19 to 0.52)	0.32 (0.04–0.60)
Accuracy	0.85	0.74

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.CT, computed tomography; CTA, computed tomographic arthrography.

TABLE 3 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of articular scapular lesions

	CT	CTA
Sensitivity	100% (29.2–100)	100 (29.2–100)
Specificity	52.3 (36.7–67.5)	70.5 (54.8–83.2)
Positive likelihood ratio	2.10	3.40
Negative likelihood ratio	0.00	0.00
Kappa coefficient*	12.3 (0.01–0.26)	0.23 (0.01–0.46)
Accuracy	0.55	0.74

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.CT, computed tomography; CTA, computed tomographic arthrography.

sensitivity of 65% and specificity of 97%. Results are summarized in Table 5.

3.6 | Intertubercular groove

Computed tomography detected lesions in 23/47 humeri, and computed tomography arthrography in 19/47 humeri. Arthroscopy detected lesions in three of 47 humeri including osteophytosis (3). False positives detected by CT and computed tomography arthrography included osteophytosis (20 and 16, respectively). No subchondral defects were detected by any imaging modality. Computed tomography had a sensitivity of 100% and specificity of 55%, while computed tomography arthrography had a sensitivity of 100% and specificity of 63%. Results are summarized in Table 6.

3.7 | Medial glenohumeral ligament

Computed tomography detected lesions in none and computed tomography arthrography in one of 47 medial glenohumeral ligaments. Arthroscopy detected lesions in eight medial glenohumeral ligaments, including thickening (1) and interruption (7). One case of interruption, identified on arthroscopy but not on CT or computed tomography arthrography, was described as a total rupture. This ligament was not always distinguishable on computed tomography arthrography. Computed tomography had a sensitivity of 0% and specificity of 100%, while computed tomography arthrography had a

TABLE 4 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of humeral head lesions

	CT	CTA
Sensitivity	92.3 (64.0–99.8)	92.3 (64.0–99.8)
Specificity	61.8 (43.6–77.8)	70.6 (52.5–84.9)
Positive likelihood ratio	2.40	3.10
Negative likelihood ratio	0.12	0.11
Kappa coefficient*	0.42 (0.20–0.64)	0.52 (0.29–0.75)
Accuracy	0.70	0.77

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.
CT, computed tomography; CTA, computed tomographic arthrography.

sensitivity of 13% and specificity of 100%. Results are summarized in Table 7.

3.8 | Lateral glenohumeral ligament

Computed tomography detected lesions in none and computed tomography arthrography in 10/47 lateral glenohumeral ligaments (Figure 3). Arthroscopy detected lesions in two lateral glenohumeral ligaments including interruption (2). False positives detected by computed tomography arthrography included thickening (6) and interruption (3). This ligament was not always distinguishable on computed tomography arthrography. Computed tomography had a sensitivity of 0% and specificity of 100%, while computed tomography arthrography had a sensitivity of 13% and specificity of 78%. Results are summarized in Table 8.

3.9 | Synovium

Computed tomography detected synovial lesions in 28/47 shoulder joints, and computed tomography arthrography in 14/47 shoulder joints. Arthroscopy detected synovial lesions in 25 shoulder joints, including synovitis (25), determined by thickening of the synovium (i.e., synovitis). This was considered to correspond in CT to effusion of the scapulohumeral joint, and in computed tomography arthrography to correspond to irregularity of the synovium. Computed tomography and computed tomography arthrography detected joint mice in the bicipital tendon sheath in five and six shoulders, respectively, none of which were detected by arthroscopy (Figure 1D). Computed tomography had a sensitivity of 76% and specificity of 56%, while computed tomography arthrography had a sensitivity of 44% and specificity of 86%. Results are summarized in Table 9.

4 | DISCUSSION

In the 46 canine shoulders that underwent CT, computed tomography arthrography, and arthroscopy, there was a mixed level of sensitivities, specificities, agreement, and accuracy between imaging and arthroscopic findings. The diagnostic utility of computed tomography arthrography in the assessment of various arthroscopically confirmed

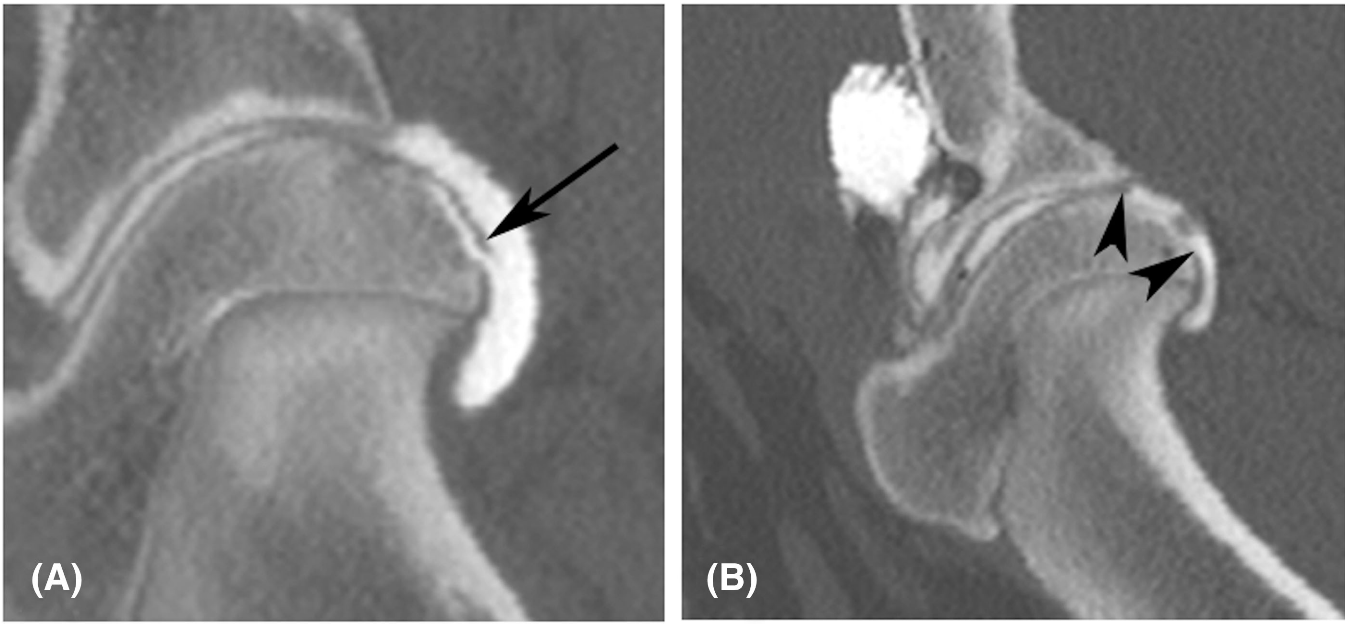

FIGURE 2 A, Computed tomographic arthrography image of underrun cartilage (arrow) and a subchondral bone defect at the humeral head. B, Computed tomographic arthrography image of a cartilage defect (between the two arrowheads)

TABLE 5 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of humeral cartilage lesions

	CT	CTA
Sensitivity	18.8 (4.1–45.7)	64.7 (38.3–85.8)
Specificity	100 (88.8–100)	96.7 (82.8–99.9)
Positive likelihood ratio	–	19.00
Negative likelihood ratio	0.81	0.37
Kappa coefficient*	0.23 (0.01–0.46)	0.66 (0.43–0.88)
Accuracy	0.72	0.85

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.CT, computed tomography; CTA, computed tomographic arthrography.

TABLE 6 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of intertubercular groove lesions

	CT	CTA
Sensitivity	1 (0.2924–1)	1 (0.2924–1)
Specificity	0.55 (0.39–0.70)	0.6364 (0.4777–0.7759)
Positive likelihood ratio	2.20	2.80
Negative likelihood ratio	0.00	0.00
Kappa coefficient*	0.13 (−0.01 to 0.28)	0.18 (−0.00 to 0.37)
Accuracy	0.57	0.66

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.CT, computed tomography; CTA, computed tomographic arthrography.

TABLE 7 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of medial glenohumeral ligament lesions

	CT	CTA
Sensitivity	0% (0–36.9)	12.5% (0.32–52.7)
Specificity	100% (91.0–100)	100% (91.0–100)
Positive likelihood ratio	N/A	–
Negative likelihood ratio	1.00	0.88
Kappa coefficient*	–	0.19 (−0.13 to 0.52)
Accuracy	0.83	0.85

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.CT, computed tomography; CTA, computed tomographic arthrography.

shoulder pathologies exceeded that of survey CT for the biceps tendon, biceps tendon sheath, and humeral head cartilage.

Although used as the reference standard for the purposes of this study, arthroscopy has been shown to miss valid lesions that are identified by CT, particularly those located in the joint periphery or deep to the synovial lining.[10,30,31] In the current study, only intraarticular structures were assessed in order to minimize this bias. It is likely, however, that some of the 'false positive' lesions detected by CT/computed tomography arthrography were valid findings, and this statistical terminology should not be misinterpreted as definitively erroneous lesions.

For detection of subscapularis tendon pathology, both CT and computed tomography arthrography had equally poor sensitivity (14%) and agreement (0.167) relative to arthroscopy. Arthroscopic examination is limited to the tendon insertion and distal aspect of the tendon, whereas the complete musculotendinous unit is able to be evaluated on CT/computed tomography arthrography. In light of this it would perhaps be expected that CT/computed tomography arthrography would have identified more lesions than arthroscopy however this was not the case. Both CT and computed tomography arthrography failed to detect five cases of interruption suggesting

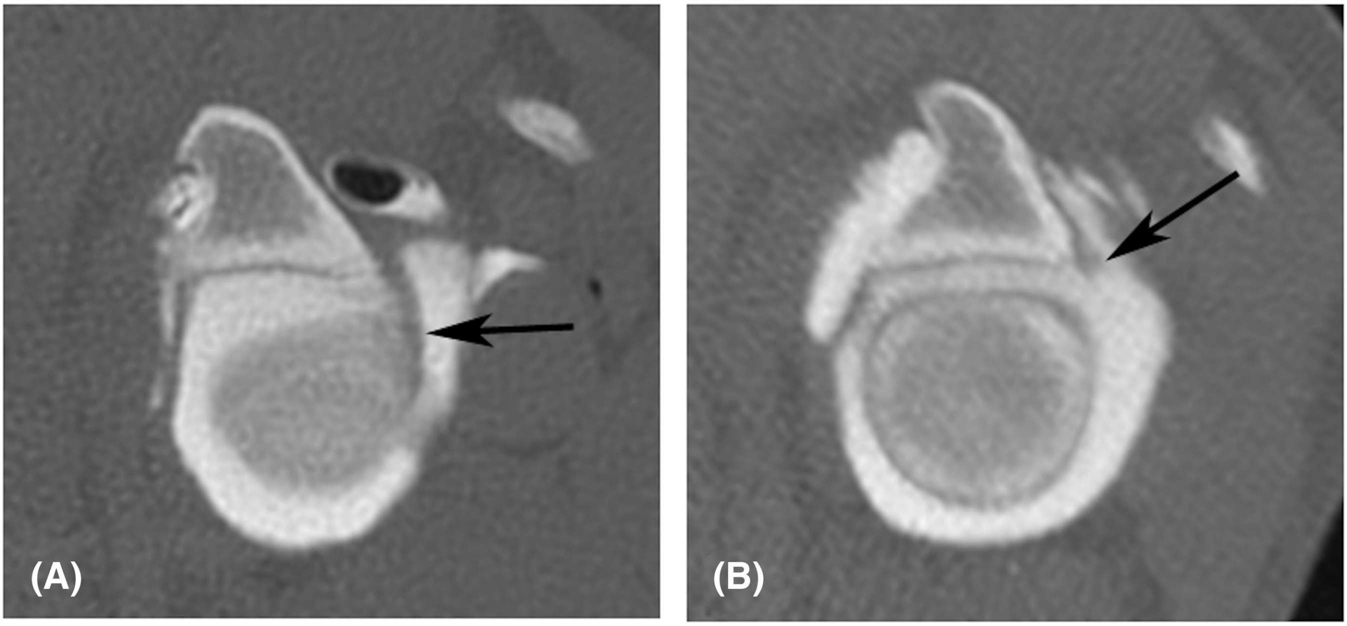

FIGURE 3 A, Computed tomographic arthrography image of a normal lateral glenohumeral ligament (arrow). B, Computed tomographic arthrography image of an interrupted lateral glenohumeral ligament (arrow)

TABLE 8 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of lateral glenuhumeral ligament lesions

	CT	CTA
Sensitivity	0% (0–84.2)	0% (0–84.2)
Specificity	100% (92.1–100)	77.8 (62.9–88.8)
Positive likelihood ratio	N/A	0.00
Negative likelihood ratio	1.00	1.29
Kappa coefficient*	–	−0.08 (−0.17 to 0.02)
Accuracy	0.96	0.74

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.CT, computed tomography; CTA, computed tomographic arthrography.

TABLE 9 Diagnostic performance of computed tomography and computed tomographic arthrography in detection of synovial lesions

	CT	CTA
Sensitivity	76.0% (54.9–90.6)	44.0% (2.4–65.1)
Specificity	55.9% (36.4–79.3)	86.3% (65.1–97.1)
Positive likelihood ratio	1.90	3.20
Negative likelihood ratio	0.41	0.65
Kappa coefficient*	0.35 (0.09–0.62)	0.29 (0.05–0.53)
Accuracy	0.68	0.64

Notes. *Rated as: 0, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.CT, computed tomography; CTA, computed tomographic arthrography.

that these modalities have limited ability in identifying tears of the subscapularis tendon. A possible explanation for this is the limited joint space in the medial compartment of the shoulder joint, which prevents complete filling with arthrographic contrast medium. The subscapular recess is readily visible on computed tomography arthrography, however, this is located proximomedially in the joint, which is proximal to the area where subscapular tears can occur.[4] Partial tearing of this tendon identified surgically has also been reported as missed by MRI.[4]

Computed tomographic arthrography outperformed CT in the detection of biceps tendon and tendon sheath pathology with a sensitivity of 71% vs. 14%. Specificity for computed tomography arthrography was lower than CT due to the higher number of lesions detected relative to arthroscopy, which included compression, thickening, mineralization, and interruption. Compression of the biceps tendon is likely not appreciable on arthroscopy due to the lack of visibility of its distal extremity.[16,32,33] Furthermore, if the compression is due to enlargement of the supraspinatus tendon,[32,33] then the cause is also left unidentifiable via arthroscopy while identifiable on computed tomography arthrography. Mineralization of the biceps tendon and/or tendon sheath was not identified on arthroscopy, however, this is a valid finding on CT. Direct visualization of the biceps brachii tendon via arthroscopy has previously been recognized as superior to radiography and ultrasonography.[5,34,35] The results of the current study suggest that arthroscopy is perhaps not the ideal test for comprehensive evaluation of the biceps tendon and tendon sheath.

In regard to osseous pathology, CT and computed tomography arthrography performed similarly in detection of lesions at the glenoid cavity, intertubercular groove, and humeral head. Out of 13 arthroscopically confirmed lesions, CT and computed tomography arthrography failed to detect two subchondral bone lesions identified by arthroscopy, however detected three other subchondral bone lesions, which were not identified by arthroscopy. A previous study found that arthroscopy identified only 64% of osteochondral lesions identified on CT examination of canine scapulohumeral joints.[10] Arthroscopic evaluation is limited to surface defects and may fail to detect lesions in deeper structures.[31,36] Based on these results and those of previous studies, survey CT is sufficient for identification of osseous lesions and provides extra, valuable information to that of arthroscopy.

Furthermore, both CT and computed tomography arthrography identified far more lesions attributable to osteophytosis compared to arthroscopy which reflects the limitations of arthroscopy in regard to the boundaries of the joint space. Computed tomography identified a higher number of osteophytotic lesions compared with computed tomography arthrography, likely due to the lack of highly attenuating intraarticular contrast medium, which can efface osteophytes on the periarticular margins. A survey CT should therefore always precede a computed tomography arthrography study.

Computed tomography arthrography outperformed CT in the detection of cartilage lesions, with a sensitivity of 65%, specificity of 97%, and agreement of 0.66. This was an expected finding as positive contrast medium delineates the cartilage contour.[19] The failure of computed tomography arthrography to detect fibrillation, a superficial splitting of the articular cartilage, likely reflects the limitations of the spatial resolution of this modality. A recent study of computed tomography arthrography of the ovine stifle, which used gross anatomy and histological assessment as the reference standard, reported a sensitivity of 90% and specificity of 97%.[37] The only modest agreement between computed tomography arthrography and arthroscopy in the current study is difficult to explain, but could be in part due to artifacts, such as partial volume, as well as the slight deviation from the optimal protocol for the assessment of scapulohumeral joint structures, as established by a previous publication.[19] The use of a medium frequency image reconstruction algorithm and administration of an iodine concentration of 60 mg iodine/ml for the arthrogram may have increased lesion conspicuity in the current study.

Both CT and computed tomography arthrography performed poorly in the detection of medial and lateral glenohumeral ligament pathology. CT failed to identify any lesions as these structures are not visible without the aid of intraarticular contrast medium. While visible on computed tomography arthrography, sharp visualization of all margins of these ligaments was not always possible, as previously expressed.[19] Computed tomography arthrography failed to detect nine lesions identified by arthroscopy, which was unexpected. Subtle interruption of these ligaments visible on arthroscopy may require detail, which is beyond the resolution capacity of computed tomography arthrography, however computed tomography arthrography also failed to identify one complete rupture of the medial glenohumeral ligament. The canine medial glenohumeral ligament is a V-shaped structure with two or three separate proximal and a common distal bone attachment sites.[38] The orientation of its fibers changes with the flexion angle of the joint, making assessment of integrity difficult. It has been reported in human patients that despite the presence of contrast medium, the glenohumeral ligaments are sometimes not separated from the joint capsule and are thus not observed.[39,40] The limited degree of medial compartment distension of the joint capsule that can be achieved with arthrography limits delineation of the medial glenohumeral ligament. This suggests that computed tomography arthrography with the described protocol is not a reliable technique for assessment of glenohumeral ligament pathology in the dog. Further studies are needed to investigate whether an optimized imaging protocol is sufficiently sensitive for these ligamentous lesions. The low number of arthroscopically confirmed lesions (10 out of 47 shoulders), also limits the statistical reliability of these results.

Computed tomography outperformed computed tomography arthrography in the detection of synovial pathology with a sensitivity of 76% vs. 44%. Effusion identified on CT was not able to be assessed on computed tomography arthrography due to the introduced contrast medium volume, and likewise was not able to be assessed on arthroscopy as the joints were infused with saline prior to entry with the arthroscopy in order to maximize visibility. Irregularity of the synovium identified on computed tomography arthrography was not as sensitive for identifying synovitis. Both modalities identified joint mice in the bicipital bursa, which were not identified by arthroscopy. Arthrography has been advocated as the technique of choice to demonstrate joint mice within the bicipital tendon sheath,[8] and this could be extended to computed tomography arthrography.

No adverse reactions were observed in this study population. Potential risks of positive contrast arthrography include the introduction of infection, synovial irritation, hemorrhage, postprocedural pain, contrast extravasation, and systemic reactions. According to published data these complications are considered rare.[5,8,18,41,42] Iohexol, used in this study, is a nonionic, low osmolar monomeric agent, which causes minimal synovial inflammation.[8] The risk of infection is minimized by the use of aseptic technique. Chemotoxicity and resultant fluid influx is significantly less than that of hyperosmolar ionic media due to low osmolarity, and the absence of carboxyl groups and sodium ions.[42–44] Systemic reactions to contrast media are associated with hypertonicity, the risk of which is significantly reduced with low osmolar nonionic agents.[29] Furthermore, adverse reactions to contrast media are dose-dependent, and the relatively small volumes administered for arthrography diminish this risk. Positive contrast arthrography with low-osmolar, nonionic contrast medium is therefore considered a safe, well tolerated procedure.

Limitations of this study include the relatively low prevalence of confirmed pathology at various anatomical sites, in particular at the lateral glenohumeral ligament, intertubercular groove, glenoid cavity, and subscapularis tendon. Because this study was performed on client-owned dogs, a more complete macroscopic or histological confirmation of lesions could not be accomplished without increasing patient morbidity. Interobserver reliability data was not obtained due to the use of only one observer for each imaging modality. Lastly, a number of previously published optimized CT settings were not applied,[19] due to commencement of this retrospective work before these methods were published. It is therefore possible that some soft tissue lesions in the study were overlooked.

In conclusion, computed tomographic arthrography provides a superior diagnostic efficacy relative to survey CT for the assessment of the biceps tendon, tendon sheath, and humeral head cartilage. Computed tomographic studies provide additional diagnostic information to arthroscopy in regard to osteophytosis, subchondral defects, and joint mice of the canine shoulder joint. Computed tomography arthrography provides additional diagnostic information to arthroscopy in regard to the biceps tendon and tendon sheath, however is of limited diagnostic value for assessment of the glenohumeral ligaments and subscapularis tendon. Computed tomography arthrography is therefore a useful adjunct to survey CT and arthroscopic evaluation of the canine shoulder joint, however cannot replace these techniques. Further studies with an optimized CT technique and increased lesion prevalence are required to fully establish the utility of computed tomography arthrography for the detection of canine shoulder lesions.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

- **(a)** Conception and Design: Corzo-Menéndez N, Austwick SH, Thomson DG, Eivers CR, Handel I, Schwarz T
- **(b)** Acquisition of Data: Schwarz T, Thomson DG, Austwick SH, Corzo-Menéndez N, Gibson SM
- **(c)** Analysis and Interpretation of Data: Eivers CR, Corzo-Menéndez N, Handel I

Category 2

- **(a)** Drafting the Article: Eivers CR, Corzo-Menéndez N
- **(b)** Revising Article for Intellectual Content: Eivers CR, Schwarz T, Corzo-Menéndez N, Thomson DG, Austwick SH, Gibson SM, Handel I

Category 3

- **(a)** Final Approval of the Completed Article: Eivers CR, Schwarz T, Corzo-Menéndez N, Thomson DG, Austwick SH, Gibson SM, Handel I

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