Veterinary Surgery
38:144–153, 2009

INVITED REVIEW

# Diagnostic Imaging of Canine Elbow Dysplasia: A Review

CRISTI R. COOK, DVM, MS, Diplomate ACVR and JAMES L. COOK, DVM, PhD, Diplomate ACVS

Canine elbow dysplasia (CED) is a common developmental disorder of the cubital joint of dogs. CED is comprised of fragmented medial coronoid process (FMCP), ununited anconeal process (UAP), osteochondrosis (OC), and elbow incongruity. Multiple imaging modalities have been used to assess this complex of disorders and the severity of the pathologic changes. Radiography has been used as a surveying tool for assessment of CED for many years. Recently, alternate techniques and modalities have expanded our knowledge of CED and our clinical approach to this disorder. Nuclear medicine has been used to aid in localizing lameness to the elbow joint. Ultrasonography has proven helpful for imaging the soft tissue structures adjacent to the joint as well as superficial bone abnormalities, including visualization of FMCP. Computed tomography and magnetic resonance imaging are advanced imaging modalities that allow visualization of the elbow in multiple planes and into three-dimensional reconstructions, thus allowing lesions to be more accurately and comprehensively visualized. Assessment of elbow incongruity in particular has been benefitted by these advanced imaging techniques because of the importance of sagittal and dorsal plane imaging and reconstructions for accurately determining the relationships between radial and ulnar articular surfaces. Comparative studies using multiple techniques and imaging modalities with correlation to reference standards and patient outcomes will be vital to continued progress in this area.


**Keywords:** elbow, radiography, computed tomography, magnetic resonance imaging, ultrasonography, nuclear medicine, canine

## INTRODUCTION

CANINE ELBOW dysplasia (CED), a common developmental disorder of the cubital joint of dogs, is comprised fragmented medial coronoid process (FMCP), ununited anconeal process (UAP), osteochondrosis (OC), and elbow incongruity, alone or in combination. Although the epidemiology, etiopathogenesis, diagnosis, and treatment of CED have been extensively investigated, the ideal diagnostic approach for accurately and consistently determining the presence and extent of CED has not been established. Our objective was to review the literature on diagnostic imaging for CED, synthesize current concepts and develop a framework for optimal diagnostic algorithms to establish early diagnosis, grading of pathologic changes, and staging progression of CED to direct treatment options and determine prognosis.

Radiography has been as the standard-of-care imaging modality for diagnosis, grading, and registry of CED. For accurate and complete radiographic assessment of elbow disorders, 4 projections should be evaluated: standing-angle (also termed neutral or extended) mediolateral, flexed mediolateral, craniocaudal, and craniolateral–15°–caudomedial oblique.[1–3]

In large breed dogs, the anconeal process of the ulna is a separate center of ossification. The physis associated with the anconeal ossification center is seen radiographically in the immature dogs until 20–22 weeks of age.[4,5] If

From the Comparative Orthopaedic Laboratory, University of Missouri – Columbia, Columbia, MO.
Address reprint requests to Dr. Cristi R. Cook, DVM, MS, Diplomate ACVR, Veterinary Medical Teaching Hospital, University of Missouri – Columbia, 900 East Campus Drive, Columbia, MO 65211. E-mail: cookcr@missouri.edu.
Submitted April 2008; Accepted July 2008

0161-3499/09
doi:10.1111/j.1532-950X.2008.00481.x

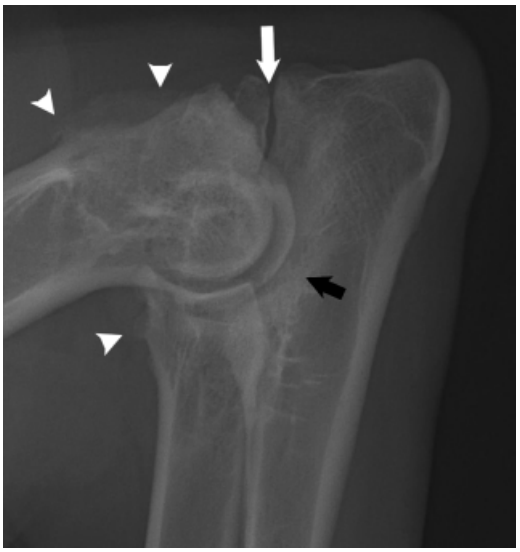

**Fig 1. Flexed mediolateral projection of the elbow. An ununited anconeal process is seen as a radiolucent line between the anconeal process and proximal aspect of the ulna (arrow). Notice the secondary changes, bone proliferation, on the proximal radius, anconeus and medial epicondyle (arrowheads) and trochlear sclerosis (black arrow).**

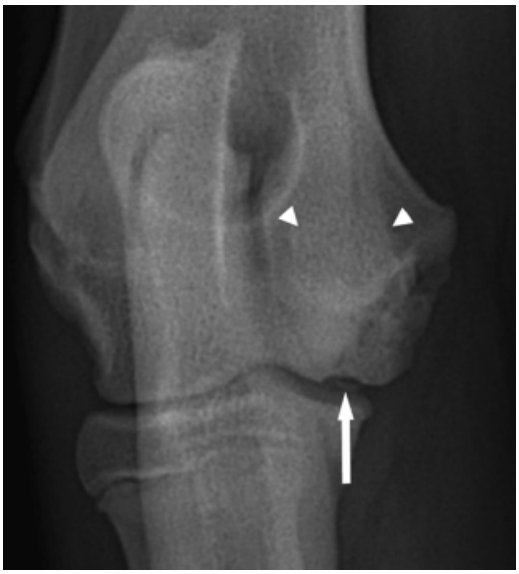

**Fig 3. Craniolateral–15°–caudomedial oblique projection. Radiolucent flattening of the medial aspect of the distal humeral condyle. A mineralized fragment (arrow) is seen distal to the lucency. There is surrounding sclerosis of the medial aspect of the humeral condyle (arrowhead).**

the physis remains radiographically visible beyond this time, it is considered ununited. An UAP is best diagnosed on a flexed mediolateral projection and appears radiographically as a discrete or irregularly marginated radiolucent gap between the anconeal process and proximal ulna (Fig 1). A flexed mediolateral projection avoids superimposition of the medial humeral epicondyle and the anconeal process allowing clear observation of the process. The physis associated with the medial humeral epicondyle is superimposed over the anconeal process on extended mediolateral projections, and because it does not normally close radiographically until after closure of the anconeal physis, a superimposed normal medial humeral epicondylar physis may be confused for UAP if the flexed mediolateral projection is not performed (Fig 2).[4]

Although radiographic changes associated with UAP are not consistently noted on other projections, all 4 recommended projections should be obtained and evaluated because of the potential for concurrent disorders.[6]

Elbow OC lesions occur almost exclusively on the weight-bearing surface of the distal medial humeral condyle.[1,2,4,5,7] OC is observed as a radiolucency, an irregularity, flattening, or defect in the subchondral bone of the articular margins of the humeral condyle. Most often, there is associated sclerosis of the subchondral bone surrounding the radiolucency. OC lesions can be identified on lateral (neutral and flexed) and craniocaudal projections, but are generally best identified on craniocaudal or cranial 15° lateral–caudomedial oblique projections (Fig 3).[1,2,4,5,7] "Kissing lesions", thought to result from

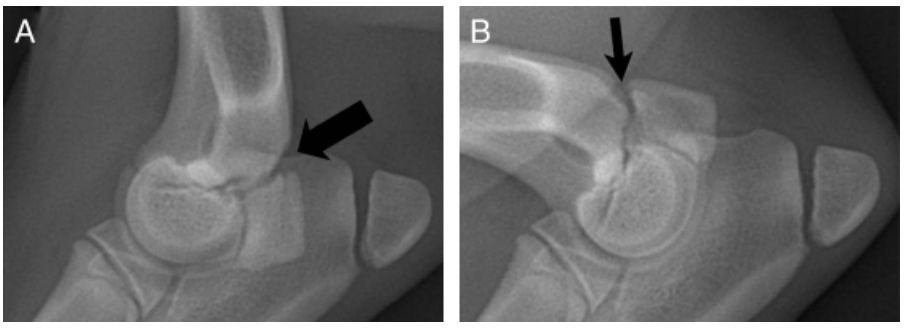


**Fig 2. Elbow of an immature dog. (A) Mediolateral projection. Note the radiolucent line superimposed over the anconeal process (arrow). (B) Flexed mediolateral projection showing the anconeal process is fused and the radiolucent line (arrow) actually is from the medial epicondylar physis.**

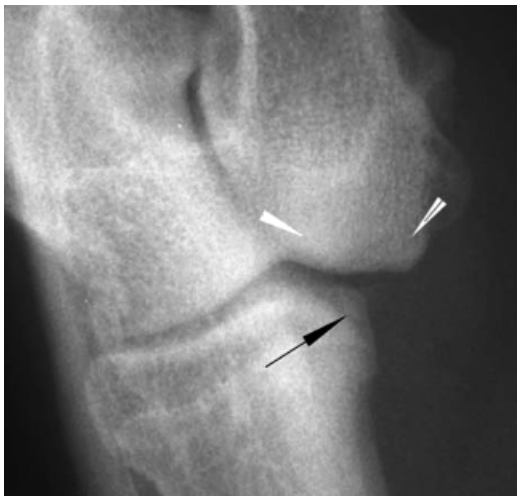

**Fig 4. Craniolateral–15°–caudomedial oblique projection. Kissing lesion with sclerosis of the humeral condyle (arrowheads) adjacent to the fragmented medial coronoid process (FMCP) (arrow).**

erosive changes in articular cartilage and subchondral bone associated with FMCP, also occur on medial aspect of the humeral condyle and appear as subchondral sclerosis with or without associated lucency or concavity of the articular margin of the condyle (Fig 4). In some cases, kissing lesions can be distinguished from OC lesions by presence of subchondral lucency or sclerosis of a surface of the radius or ulna, adjacent to the humeral condylar OC lesion.[4,6,7]

Whereas UAP and OC are typically diagnosed definitively by comprehensive radiographic assessment, presence and severity of FMCP and elbow incongruity can be difficult to diagnose with certainty using radiography.[1,7–12] FMCP is often considered a "rule out" diagnosis made when there is radiographic evidence of elbow osteoarthritis without definitive radiographic evidence of UAP, OC, trauma, or incongruity.[1,3,7] A radiographically distinct osteochondral fragment is rarely identified because of the 2-dimensional nature of radiographic projections of the complex 3-dimensional anatomy of the canine elbow joint and the wide spectrum of pathology involving cartilage and/or bone that occurs with FMCP.[7] Thus, radiographic findings associated with FMCP should be carefully investigated on multiple projections. Radiographic findings associated with elbow dysplasia and osteoarthritis secondary to FMCP include proximal anconeal osteophytosis, proximal radial osteophytosis, and subchondral sclerosis of the semilunar notch and medial coronoid process of the ulna on flexed mediolateral and craniocaudal projections (Fig 5).[1–7] The radiographic appearance of the medial coronoid silhouette can be useful determining the likelihood of FMCP. The normal medial coronoid process is observed radiographically as a sharply marginated triangular-shaped area of subchondral bone with its silhouette superimposed over the radial head and the joint surface on the extended medial lateral projection (Fig 6A). On the craniocaudal projection, the medial coronoid process is a distinct, triangular process, extending from the proximomedial aspect of the ulna (Fig 6B). In medial coronoid disease, radiographic changes involving the medial coronoid process can include flattening, rounding, proliferation, distinct fragmentation, or an ill-defined margin on 1 or more projections (Fig 7). Use of a distomedial–proximolateral oblique projection of the elbow enhances identification of medial coronoid abnormalities and fragmentation.[13] Because of these limitations, radiographic diagnosis of FMCP requires careful, comprehensive assessment of craniocaudal, mediolateral, and oblique projections for all of the potential radiographic abnormalities described above when CED is suspected. However, it is important to recognize that FMCP and other elbow pathology cannot be definitively ruled out based on an absence of radiographic changes.

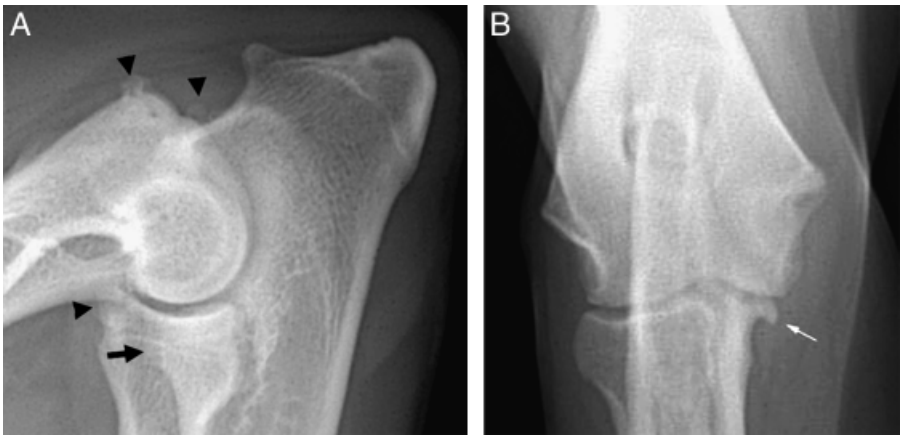


**Fig 5. (A) Mediolateral projection of the elbow with indistinct proximal margin of the medial coronoid process (arrow). There are osteophytes along the medial epicondyle, anconeal process and radial head (arrowheads). (B) Craniocaudal projection of the same elbow showing osteophytes along the medial ulna (arrow). Diagnosis: fragmented medial coronoid process.**

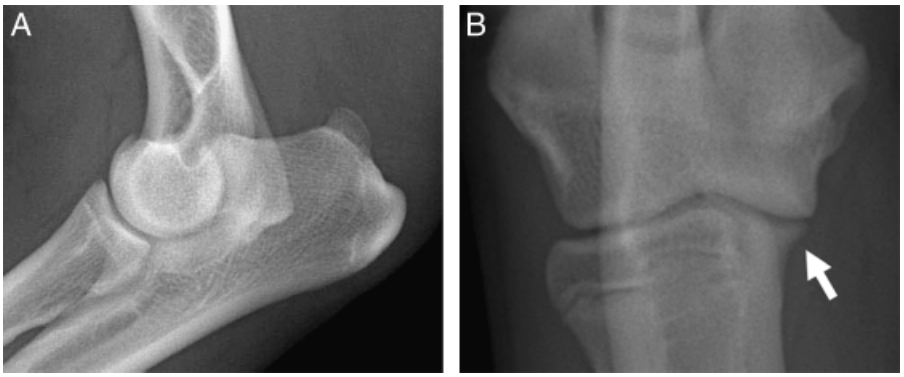


**Fig 6. Normal medial coronoid process. (A) mediolateral and (B) craniocaudal projection of the elbow showing a normal medial coronoid process (arrow).**

Despite use of a variety of in vitro and in vivo techniques, radiographic determination of elbow incongruence remains challenging.[9,10,12,14–17] Radiographic sensitivity for detection of moderate to severe incongruency ($>2$ mm) is high, regardless of beam angle[15]; however, other studies report lower sensitivity because of the complex anatomy of the elbow and limitations associated with identifying a 3-dimensional structure on a 2-dimensional image.[9,17] Although Wind[18] stated that incongruency could not be affected by positioning others disagree, concluding that radiography was not sensitive enough to evaluate the elbow effectively because of superimposed structures and the influence of positioning.[9,17] Mason et al. reported low sensitivity among board certified radiologists when evaluating multiple radiographic projections when asked if the joint was normal or abnormal and evaluate for radio-ulnar incongruence.[9] The shape of the trochlear notch is also affected by positioning, therefore caution should be taken when evaluating this finding.[17]

Elbow registries have been formed to reduce the incidence of elbow dysplasia in the canine population.[19,20] Based on radiographic interpretation, elbows are identified as normal or dysplastic with presence of arthrosis, and/or the presence of 1 or more of the following changes: UAP, OC, malformation or FMCP or incongruity.

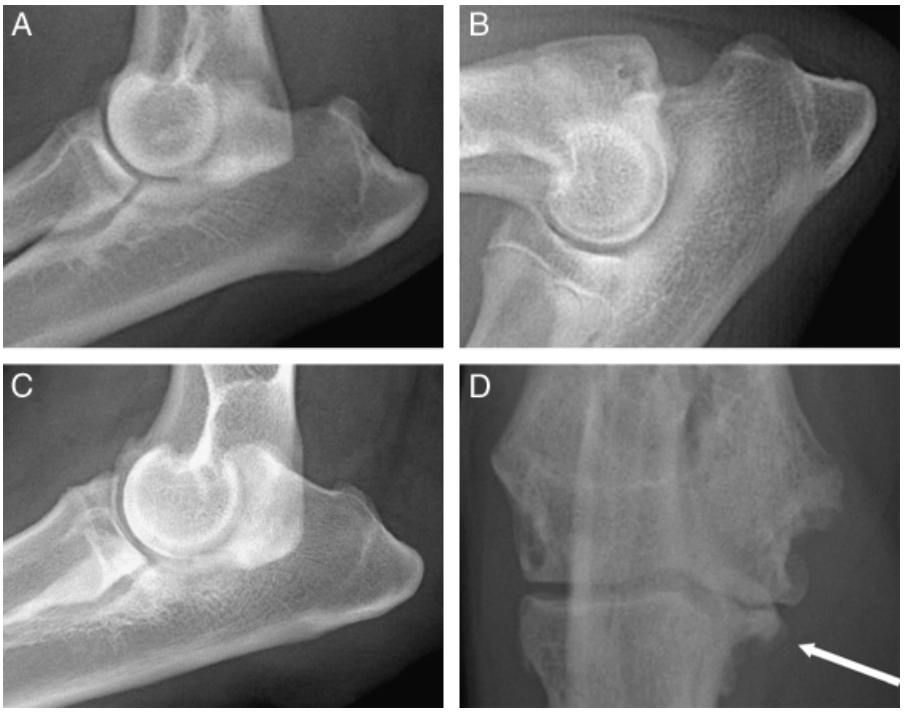


**Fig 7. (A) Ill-defined medial coronoid process (MCP) margins, (B) flattening of MCP, (C) irregular MCP margins, and (D) craniocaudal projection with osteophytosis of the MCP (arrow) There are also osteophytes and enthesiophytes along the medial condyle and epicondyle.**

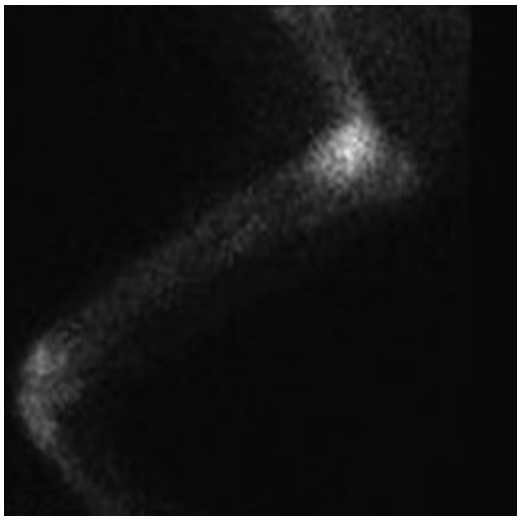

**Fig 8. Nuclear scintigraphy scan showing diffuse uptake of the elbow joint.**

We performed 2 prospective studies assessing forelimb lameness in dogs[21,22] in an attempt to correlate radiographic assessment of CED with clinical signs. FCMP was the most common diagnosis in both studies, and sensitivity, specificity, and likelihood ratios, indicated that radiography was clinically useful for diagnosis of elbow pathology. Because radiography is widely available, efficient, cost effective, and does not typically require general anesthesia, comprehensive radiographic assessment will likely continue to be a valuable component of the diagnostic algorithm for CED. However, the complexity of the elbow joint, substantial variation in radiographic appearances, and an inability to directly assess articular cartilage pathology, make reliance on radiography as a sole diagnostic modality incomplete for optimal clinical progress. Thus other modalities including nuclear scintigraphy, computed tomography (CT), magnetic resonance imaging (MRI), and/or arthroscopy may be necessary for definitive diagnosis.

*Nuclear Scintigraphy*

For CED, scintigraphy has been used for localizing the origin of thoracic limb lameness and/or facilitating detection of early or subtle pathologic changes in the elbow joint[23–25] before anatomic changes are evident on radiographs. To date, soft tissue phase imaging has been less for elbow disorders than in other joints,[23–25] which may reflect the relatively small amount of soft tissue surrounding the joint, technical limitations, or a true lack of soft tissue pathology in CED. During the bone phase, radiopharmaceuticals are incorporated with hydroxyapatite in bone preferentially localizing where there is increased bone production and vascularity. Because the elbow joint is small and CED often involves the entire joint, scintigraphic changes are typically observed as an overall increase in radiopharmaceutical uptake that is localized to the elbow joint (Fig 8). Focal increased uptake may occur in the proximal aspect of the ulna with UAP, distal humeral condyle for OC, or base of the semilunar notch with FMCP.[23] Scintigraphy has high sensitivity for detection of presence or absence of elbow joint disease and for lesion localization to the joint, but no diagnostic benefit over survey radiographs for definitive diagnosis of the specific type of elbow disease.[23]

$^{99m}$Technetium phosphonates are typically used for scintigraphy of joint tissues because of their short half-life, availability, and relatively low cost. Scintigraphic imaging requires a license for handling radiopharmaceuticals, appropriate radiation isolation facilities, personnel trained in radiation handling and safety, and documentation of radioisotope usage. After radiopharmaceutical administration, the patient and any biologic waste must be isolated, the time varying depending on country and state regulations. Consequently, because of these requirements and regulations, nuclear scintigraphy is often limited to academic institutions and large private referral centers, diminishing its availability and application.[26] Other disadvantages include the relatively low specificity and relatively poor image resolution compared with other techniques.

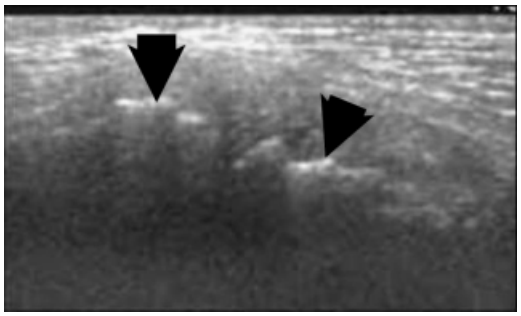

**Fig 9. Ultrasound image of the medial aspect of the elbow joint showing irregular periarticular margins consistent with osteophyte formation (arrows).**

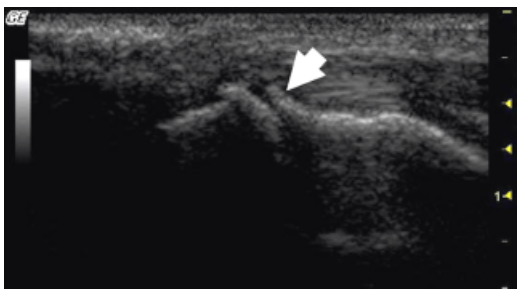

**Fig 10. Ultrasound image of a normal medial coronoid process. Note the sharp margins of the coronoid process (arrow).**

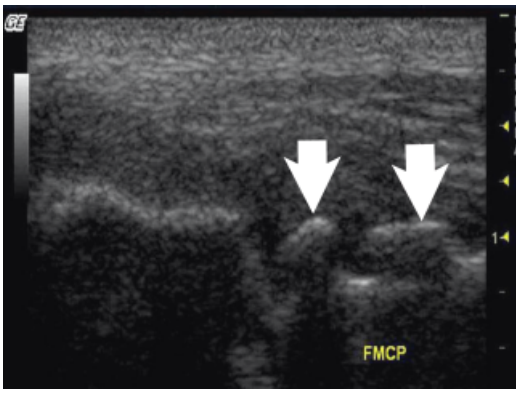


**Fig 11. Ultrasound image of irregular margins of the medial coronoid process (arrows), consistent with a fragment of the medial coronoid, which was confirmed on arthroscopy.**

*Ultrasonography*

In dogs, ultrasonography is selectively used for imaging musculoskeletal soft tissues (tendons, ligaments, menisci, muscles) and less commonly for bone and articular cartilage.[27–30] Ultrasound imaging bone and cartilage is limited by depth of penetration and ability to clearly distinguish tissue architecture because of the high acoustic impedance of bone, which is more dense and less compressible than soft tissues. At the soft tissue–bone interface, most sound is reflected leaving relatively little to create an image of the deeper tissues, resulting in a sharp hyperechoic line representing the normal, intact cortical or subchondral bone with distal acoustic shadowing.[27] Osteophytes or abnormal bone can be recognized ultrasonographically as irregular, hyperechoic lines, extending from the cortical margins of the bone (Fig 9). Fractures or open physes are recognized by discontinuities in the hyperechoic line of a normal bone margin. Thinning of the hyperechoic line is indicative of a destructive process of bone.

In dogs and cats, ultrasonography yields more clinically useful diagnostic information in larger diarthrodial joints (shoulder, stifle) compared with a smaller joint like the elbow[27–30]; however, the ultrasonographic appearance of the canine elbow has been reported.[27–30] In the normal canine elbow, the medial coronoid process appears as a sharply marginated process along the medial aspect of the joint (Fig 10). With FMCP, the surface of the medial coronoid process is often irregular with proliferation or distinct fragmentation (Fig 11). When medial coronoid process pathology results from incomplete or abnormal endochondral ossification, the medial coronoid process may have the echogenicity of fibrous or soft tissue, instead of normal bone with distal acoustic shadowing (Fig 12). The anconeal process can be identified with sagittal and transverse imaging of the caudal aspect of the joint. UAP can be diagnosed by noting an irregularity or ''break'' in the cortical bone margin on these projections.[29,30] Elbow OC lesions are difficult to image with ultrasound because of their location in the joint in conjunction with the anatomical complexity of overlying cortical bone surfaces and the associated distal acoustic shadowing. To our knowledge, elbow joint incongruity has not been evaluated by ultrasound and would likely be difficult for these same reasons.

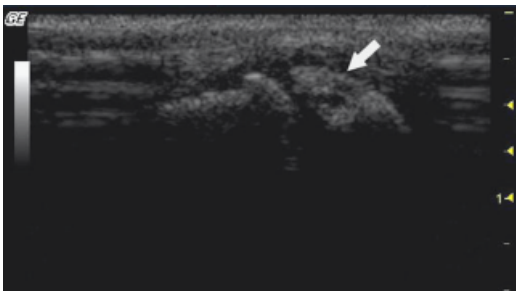

**Fig 12. Ultrasound image of the medial coronoid process with incomplete calcification (arrow).**

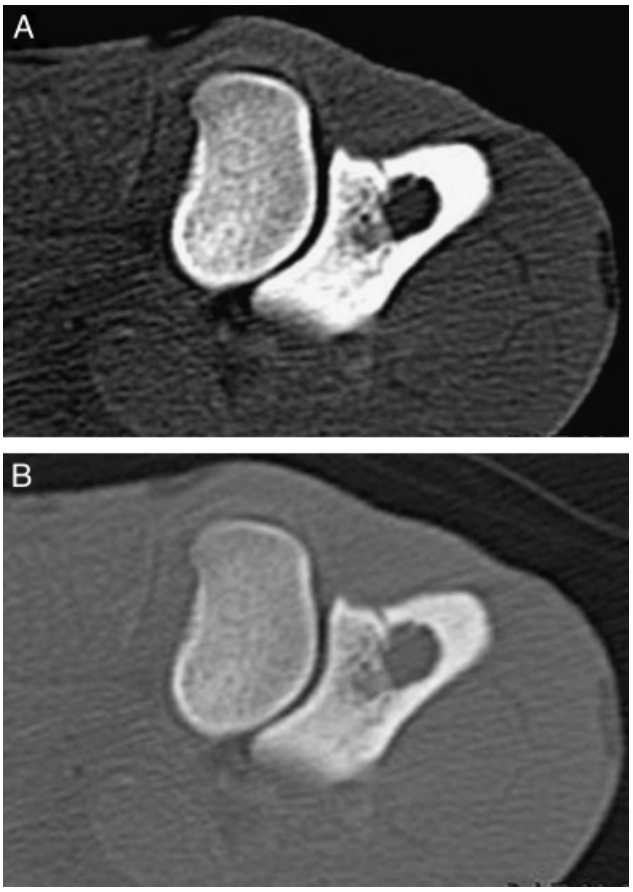


**Fig 13. Transverse computed tomography (CT) image of a normal medial coronoid process (MCP) at the level of the radial head: (A) window width = 1500 HU and (B) same image at 3500 HU.**

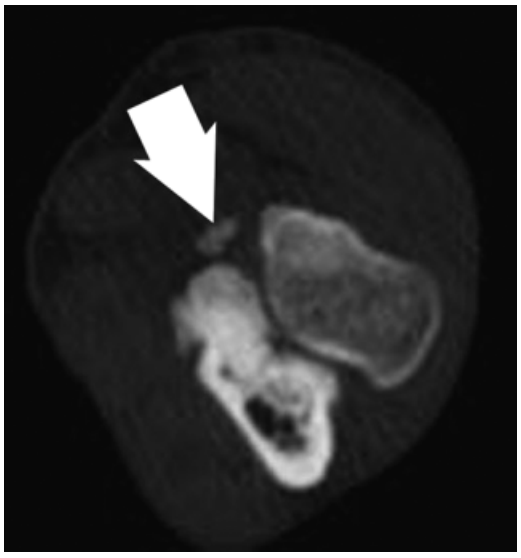

**Fig 14. Transverse computed tomography (CT) of an abnormal shape of the medial coronoid process (MCP) with a distinct fragment (arrow) and irregularity of the radial incisure (courtesy of Dr. Kristen O'Dell).**

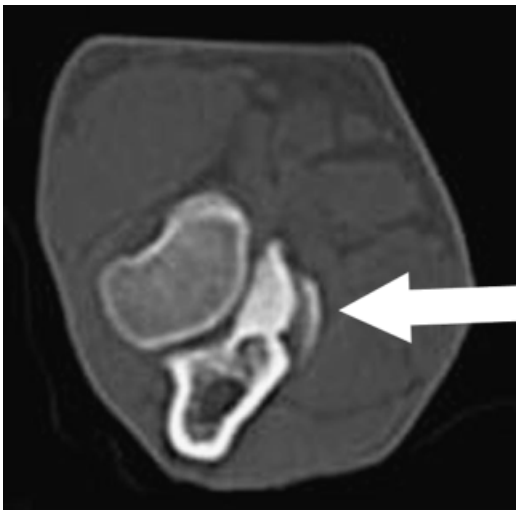

**Fig 15. Transverse computed tomography (CT) image of sclerosis of the medial coronoid process (MCP) and proliferation (arrow).**

*Computed Tomography*

Diagnostic use of CT for musculoskeletal imaging has increased.[31–33] For CED, the multislice cross-sectional imaging of CT alleviates problems of superimposition improving examination of tissue anatomy and architecture. An ability to adjust the window and level of Houndsfield units (HU) allows simultaneous quality imaging of bone and soft tissue. Three-dimensional image reconstruction is an added enhancement providing additional information on anatomic relationship and extent of changes. Disadvantages include a requirement for general anesthesia, cost of equipment purchase, use, and maintenance, and exposure to ionizing radiation.

Multiple studies have examined the value of CT for diagnostic imaging of the canine elbow.[1,8,10–12,31–35] Recommendations for performing elbow CT in dogs include scanning from the point of the olecranon to 2 cm distal to the radial head. Scan thickness should be 1 or 2 mm with an overlapping slice index of 0.5 or 1 mm for reconstructing imaging planes, after initial scan. When evaluating elbow scans, window widths of 1500 and 3500 HU and a window level of 500 HU should be used (Fig 13). CT allows excellent delineation and differentiation of the medial and lateral coronoid processes, the medial and lateral aspects of the humeral condyle, the radial incisure, and radial head. Transverse, sagittal, and dorsal imaging planes at both 1500 and 3500 HU are best for identifying the radial incisure, trochlear defects, subchondral bone (normal or sclerotic), fragments, and incongruity of the humeroulnar, humeroradial, and radioulnar joints. Transverse images at 3500 HU are considered optimal for identifying hypoattenuating lesions (lucencies) of the medial coronoid process.[33] UAP and OC have been identified using CT, but because they are typically readily identified on radiographs, there have seemingly been no focused efforts on CT-imaging of these disorders in the canine elbow. With CT, UAP is best seen on a sagittal plane reformatted image as a hypoattenuating line (either partial or complete) between the anconeal process and the proximal aspect of the ulna. OC lesions are best identified on a sagittal or dorsal plane reformatted image as a lucency or flattening of the medial aspect of the humeral condyle with surrounding subchondral bone sclerosis.[1,32]

CT provides complete imaging of articular subchondral bone but not articular cartilage. Thus, with CT many subchondral bone changes associated with FMCP and OC including sclerosis, fissures, necrosis, cysts, and fragmentation are detectable. Similar to radiographs, the CT appearance of FMCP can be highly variable. Imaging planes and imaging windows/levels can contribute to the variability.[33] Medial coronoid process abnormalities identified by CT include abnormal shape, sclerosis, osteophytosis, distinct or separate fragments, fissures or in situ fragments, lucency or hypoattenuation, and associated radial incisure irregularities or lucencies (Figs 14 and 15).[1,32] The medial coronoid process ossifies by 22–24 weeks of age in dogs, so if the dog is $>6$ months and there is hypoattenuating tissue within the medial coronoid process on CT, the medial coronoid process is considered abnormal.

CT has been the most widely used diagnostic modality to assess incongruity of the humeroradioulnar joint and is reportedly affected by positioning.[12,17] Radio-ulnar incongruency (RUI) was recently evaluated with the elbow in extension, a standing angle (135°), and in supination, or pronation.[12] Pronation had an effect on RUI, resulting

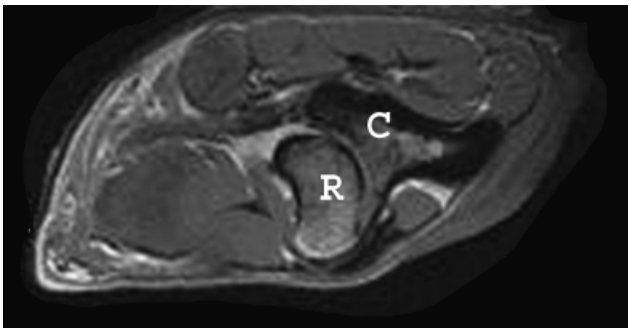


**Fig 16. Transverse T1-weighted magnetic resonance imaging (MRI) image of the medial coronoid process (MCP): R, radial head; C, medial coronoid process.**

in elevation of the apex of the medial coronoid process with the opposite effect noted with supination. On joint extension (160°), there was a cranial translation of the ulna, increasing the space between the radius and ulna at the ulnar incisure.[12] Reconstructed images from dorsal and sagittal planes are useful for accurately determining incongruity of the radius and ulna.[1,34,35] The most reliable reconstruction plane is the mid-coronoid oblique plane, because it allows the most accurate measurement of radioulnar congruence.[10,11]

*Magnetic Resonance Imaging*

For CED, MRI allows imaging in multiple planes (transverse, dorsal, sagittal) without repositioning the patient or reformatting the image information (Fig 16). Furthermore, use of a multitude of sequence types allows better delineation of medullary bone, subchondral bone, soft tissue, cartilage and tissue interfaces.[36–38] Whereas CT provides better resolution for imaging bone, MRI is more sensitive for subtle changes in bone architecture including bone marrow lesions ("bone bruising") and is the only modality allowing tissue differentiation at the bone–cartilage interface.[36–38]

MRI also has limitations for imaging the canine elbow because of the relatively small size of the joint, complex articulations, and thin articular cartilage surfaces of the humerus, radius, and ulna.[37,38] For these reasons, MR arthrography (MRA), using gadolinium-DTPA, has been recommended for imaging the canine elbow.[39] MRA allows improved lesion identification and classification for FMCP and subchondral lesions.[39] Gradient echo fast imaging with steady-state precession (GE FISP) sequence is most useful when compared with spin echo and fat saturation sequences.[38] Use of a small surface coil configuration is also highly recommended for CED to get improved signal-to-noise ratio. All MRI planes, dorsal, sagittal, and axial/transverse, are potentially useful for diagnosis of elbow disorders.

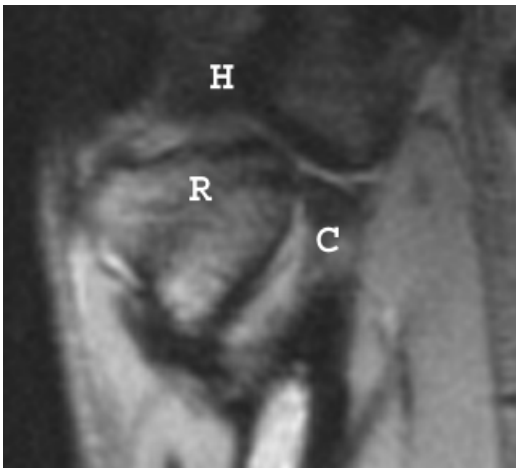


**Fig 17. Dorsal FSE proton density magnetic resonance imaging (MRI) image of the medial coronoid process (MCP): H, humerus; R, radius; C, medial coronoid process.**

To our knowledge, MR diagnosis of UAP has only been described in a single case,[32] where UAP was seen as a hyperintense cleft between the proximal aspect of the ulna and the anconeal process on sagittal plane, 3-dimensional Fourier transform echo gradient fast imaging sequence. Similarly, MR characteristics of canine elbow OC lesions have not been well described. OC lesions would be best evaluated in sagittal and dorsal planes, and would be seen as thickening of the articular cartilage of the medial aspect of the humeral condyle, flattening of the condylar surface, and/or cartilage erosions/irregularities most often with associated subchondral bone lesions. Small articular cartilage lesions without subchondral changes may be difficult to definitively image because of an inability to clearly distinguish the thin apposing articular cartilage surfaces in this region.[32,37–40] Sensitivity for detecting lesions on the medial humeral condyle with MR was 77% and 72% for radiography whereas for FMCP, accuracy of MR for detection of medial coronoid abnormalities was 95.5% compared with 77% for radiography.[40] MR was 91% sensitive for detection of nonfragmented, nonmineralized or mineralized medial coronoid processes.[40] Administration of gadolinium provided no additional benefit for detection of mineralized and unmineralized, nondisplaced coronoid processes. These authors stated that the detection may have been improved by allowing more time and manipulating the joint through a complete range of motion so that gadolinium could fill the spaces between the fragments (Fig 17).

Elbow incongruity using MR has been assessed examining the relationship between the humeral trochlea and ulnar notch at multiple locations, and differences between large-breed, small-breed, and chondrodysplastic breed dogs.[36] In large-breed dogs, there was a smaller articular gap at the level of the anconeal process and a wider gap at

the center of the trochlear notch. It was concluded that large-breed dogs may not have the ability to compensate for incongruity between the radius and ulna, resulting in the potential for failure of normal endochondral ossification of the anconeus and coronoid process.

Compared with disorders of the canine shoulder and stifle, elbow MRI is still in its infancy and not routinely performed. Correlations of canine elbow MR findings with arthroscopic, gross, and/or histologic examinations are needed to improve diagnosis and understanding of CED.

*Comparison of Modalities*

To our knowledge there has been no comprehensive direct comparison of the all imaging modalities for diagnosis of CED. Arthroscopy has been compared with CT and radiography for assessment of CED[41,42] and RUI.[12] Arthroscopy (sensitivity, 94%; specificity, 81.9%) is reportedly superior to CT (sensitivity, 85%; specificity, 45.8%) and radiography (sensitivity, 99.3%; specificity, 42.4%) for diagnosing RUI. Using surgical findings as the reference standard for FMCP, comparison of different radiographic techniques (plain film, xeroradiography, linear tomography, arthrography, CT) identified CT as most accurate (86.7%), sensitive (88.2%), and with the highest negative predictive value (84.6%).[41] A combination of plain-film radiography with linear tomography improved accuracy, approaching that of CT alone.[41]

A recent comparison of CT with arthroscopy for assessment of FMCP showed that these procedures were complementary for MCP assessment. Identification of an MCP fragment on CT was significantly correlated with finding a fragment arthroscopically. Fragmentation of cartilage alone, as well as nondisplaced fragments, were often not detected by CT imaging, but were detected using probing on arthroscopic assessment. Microcracks and fissures diagnosed consistently with CT imaging were often not detected during routine arthroscopy but could be verified when burring was used based on CT data. Another important finding of these investigators was that incompletely mineralized osteophytes at the apex of the MCP that are associated with the joint capsule may mimic FMCP on CT.[42] Direct comparison of MRI to CT and arthroscopy is needed to determine utility for early diagnosis and clinically relevant characterization of all components of CED.

## CONCLUSIONS

Many imaging modalities have been studied for their usefulness in optimally characterizing and diagnosing elbow pathology in dogs. Because of the complex articulation of the canine elbow joint, abnormalities of the medial coronoid process can be difficult to delineate with survey radiographs until secondary changes are relatively marked. Nuclear scintigraphy may be useful in localizing the cause of lameness to a joint in more subtle cases, but is not specific for determining cause or severity. Ultrasonography can be used to identify medial coronoid fragments and associated secondary bone proliferation, as well as abnormal nonmineralized coronoid processes, and may be useful for evaluating soft tissue involvement in CED. CT has promise for evaluation of the entire joint, allowing multiplanar observation of the radial head and medial coronoid process, as well as joint congruency. MRI provides similar advantages for imaging CED and also allows for direct imaging of articular cartilage, cartilage–bone interfaces, and bone marrow lesions. Limitations of MRI include expense, availability and, in relation to the elbow joint, potential lack of distinction between the cartilage of the humerus and cartilage of the radius and ulna. Advanced imaging of the elbow has tremendous potential for furthering our understanding of disease mechanisms, providing earlier diagnosis, determining treatment indications and options, and providing valuable prognostic information for client communication. Comprehensive research is needed to determine precise protocols and imaging planes, indications for each modality, and the clinical relevance of the diagnostic findings.

How does diagnostic musculoskeletal imaging in veterinary medicine move forward? We believe that optimal progression requires an outcomes based, correlative approach of radiographic and advanced imaging modalities with physical examination and other diagnostic, surgical, and histopathologic findings in conjunction to determine their relative contribution and value to provide the best possible patient care and improved client communication.

## REFERENCES

1. Reichle JK, Park RD, Bahr AM: Computed tomographic findings of dogs with cubital joint lameness. Vet Radiol Ultrasound 41:125–130, 2000
2. Voorhout G, Hazewinkel AW: Radiographic evaluation of the canine elbow joint with special reference to the medial humeral condyle and the medial coronoid process. Vet Radiol Ultrasound 28:158–165, 1987
3. Berry CR: Evaluation of the canine elbow for fragmented medial coronoid process. Vet Radiol Ultrasound 33:273–276, 1992
4. Wisner ER, Pollard RE: Orthopedic diseases of young and growing dogs and cats, in Thrall DE (ed): Textbook of Veterinary Diagnostic Radiology (ed 5). St. Louis, MO, Saunders Elsevier, 2007, pp 268–283
5. Boulay JP: Fragmented medial coronoid process of the ulna in the dog. Vet Clin N Am 28:51–74, 1998
6. Meyer-Lindenberg A, Fehr M, Nolte I: Co-existence of ununited anconeal process and fragmented medial coronoid process of the ulna in the dog. J Small Anim Pract 47:61–65, 2006
7. Hornof WJ, Wind AP, Wallack ST, et al: Canine elbow dysplasia: the early radiographic detection of fragmentation of

the coronoid process. Vet Clin N Am 30:257–266, 2000
8. De Rycke LM, Gielen IM, van Bree H, et al: Computed tomography of the elbow joint in clinically normal dogs. Am J Vet Res 63:1400–1407, 2002
9. Mason DR, Schulz KS, Samii VF, et al: Sensitivity of radiographic evaluation of radio-ulnar incongruence in the dog in vitro. Vet Surg 31:125–132, 2002
10. Holsworth IG, Wisner ER, Scherrer WE, et al: Accuracy of computed tomographic evaluation of canine radio-ulnar incongruence in vitro. Vet Surg 34:108–113, 2005
11. Kramer A, Holsworth IG, Wisner ER, et al: Computed tomographic evaluation of canine radioulnar incongruence in vivo. Vet Surg 35:24–9, 2006
12. Wagner K, Griffon DJ, Thomas MW, et al: Radiographic, computed tomographic, and arthroscopic evaluation of experimental radio-ulnar incongruence in the dog. Vet Surg 36:691–698, 2007
13. Haudiquet PR, Marcellin-Little DJ, Stebbins ME: Use of the distomedial–proximolateral oblique radiographic view of the elbow joint for examination of the medial coronoid process in dogs. Am J Vet Res 63:1000–1005, 2002
14. Samoy Y, Van Ryssen B, Gielen I, et al: Review of the literature: elbow incongruity in the dog. Vet Comp Orthop Traumatol 19:1–8, 2006
15. Blond L, Dupuis J, Beauregard G, et al: Sensitivity and specificity of radiographic detection of canine elbow incongruence in an in vitro model. Vet Radiol Ultrasound 46:210–216, 2005
16. Gemmill TJ, Clements DN: Fragmented coronoid process in the dog: is there a role for incongruency? J Small Anim Pract 48:361–368, 2007
17. Murphy ST, Lewis DD, Shiroma JT, et al: Effect of radiographic positioning on interpretation of cubital joint congruity in dogs. Am J Vet Res 59:1351–1357, 1998
18. Wind AP: Elbow incongruity and developmental elbow diseases in the dog: part I. J Am Anim Hosp Assoc 22:711–724, 1986
19. International Elbow Working Group: 2001. International elbow protocol (http://www.iewg-vet.org)
20. Orthopedic Foundation for Animals: Examining elbow dysplasia, Columbia, MO, USA (http://www.offa.org), 2006
21. Cogar SM, Cook CR, Curry SL, et al: Prospective evaluation of medium and large breed dogs assessing modalities for differentiating shoulder pathology as a source of forelimb lameness. Vet Surg 37:132–141, 2008
22. Cook JL, Cook CR: Bilateral shoulder and elbow arthroscopy in dogs with forelimb lameness: diagnostic findings and treatment outcomes. Vet Surg 39: 225–233, 2009
23. Schwarz T, Johnson VS, Voute L, et al: Bone scintigraphy in the investigation of occult lameness in the dog. J Small Anim Pract 45:232–237, 2004
24. Metcalf MR: Preliminary clinical use of combined blood pool and bone phase radionuclide imaging in dogs. Vet Radiol Ultrasound 26:117–122, 1985
25. Poteet BA: Small animal skeletal scintigraphy, in Daniel GB, Berry CR (eds): Textbook of Veterinary Nuclear Medicine (ed 2). Raleigh, NC, American College of Veterinary Radiology, 143–164, 2006
26. Berry CR, Daniel GB: Radiation safety, personnel radiation monitoring, and licensing issues, in Daniel GB, Berry CR (eds): Textbook of Veterinary Nuclear Medicine (ed 2). Raleigh, NC, American College of Veterinary Radiology, 121–128, 2006
27. Samii VF, Long CD: Musculoskeletal system, in Nyland TG, Mattoon JS (eds): Small Animal Diagnostic Ultrasound (ed 2). Philadelphia, PA, Saunders, 2002, pp 267–284
28. Lamb CR, Wong K: Ultrasonographic anatomy of the canine elbow. Vet Radiol Ultrasound 46:319–325, 2005
29. Kramer M, Gerwing M, Hach V, et al: Sonography of the musculoskeletal system in dogs and cats. Vet Radiol Ultrasound 38:139–149, 1997
30. Knox VW, Sehgal CM, Wood AKW: Correlation of ultrasonographic observations with anatomic features and radiography of the elbow joint in dogs. Am J Vet Res 64:721–726, 2003
31. De Rycke LM, Gielen IM, van Bree H, et al: Computed tomography of the elbow joint in clinically normal dogs. Am J Vet Res 63:1400–1407, 2002
32. Reichle JK, Snaps F: The elbow. Clin Tech Small Anim Pract 14:177–186, 1999
33. Tromblee TC, Jones JC, Bahr AM, et al: Effect of computed tomography display window and image plane on diagnostic certainty for characteristics of dysplastic elbow joints in dogs. Am J Vet Res 68:858–871, 2007
34. Gemmill TJ, Hammond G, Mellor D, et al: Use of reconstructed computed tomography for the assessment of joint spaces in the canine elbow. J Small Anim Pract 47:66–74, 2006
35. Gemmill TJ, Mellor D, Clements DN, et al: Evaluation of elbow incongruency using reconstructed CT in dogs suffering fragmented coronoid process. J Small Anim Pract 46:327–333, 2005
36. Janach KJ, Breit SM, Künzel WW: Assessment of the geometry of the cubital (elbow) joint of dogs by use of magnetic resonance imaging. Am J Vet Res 67:211–218, 2006
37. Probst A, Modler F, Kunzel W, et al: Demonstration of the articular cartilage of the canine ulnar trochlear notch using high-field magnetic resonance imaging. Vet J 1–8, 2007
38. Snaps FR, Saunders JH, Park RD, et al: Comparison of spin echo, gradient echo and fat saturation magnetic resonance imaging sequences for imaging the canine elbow. Vet Radiol Ultrasound 39:518–523, 1998
39. Snaps FR, Park RD, Saunders JH, et al: Magnetic resonance arthrography of the cubital joint in dogs affected with fragmented medial coronoid process. Am J Vet Res 60:190–193, 1999
40. Snaps FR, Balligand MH, Saunders JH, et al: Comparison of radiography, magnetic resonance imaging, and surgical findings in dogs with elbow dysplasia. Am J Vet Res 58:1367–1370, 1997
41. Carpenter LG, Schwarz PD, Lowry JE, et al: Comparison of radiologic imaging techniques for diagnosis of fragmented medial coronoid process of the cubital joint in dogs. J Am Vet Med Assoc 203:78–83, 1993
42. Moores AP, Benigni L, Lamb CR: Computed tomography versus arthroscopy for detection of canine elbow dysplasia lesions. Vet Surg 37:390–398, 2008