Effect of computed tomography display window and image plane on diagnostic certainty for characteristics of dysplastic elbow joints in dogs

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Objective—To test the effects of computed tomography (CT) image plane and window settings on diagnostic certainty for CT characteristics associated with dysplastic elbow joints (elbow joint dysplasia) in dogs and to provide optimal display guidelines for these CT characteristics.

Sample Population—CT images of 50 dysplastic elbow joints from 49 lame dogs and 10 elbow joints from 5 sound dogs.

Procedures—CT image data were obtained in transverse, sagittal, and dorsal planes. Each plane was examined by use of 3 Hounsfield unit (HU) window settings. Two veterinary radiologists independently evaluated sets of CT images for evidence of 7 CT characteristics. Effect of elbow joint status, image plane, and window settings on diagnostic certainty for these CT characteristics was tested by use of a visual analogue scale.

Results—Diagnostic certainty for abnormalities of the medial coronoid process (MCP) and radial incisure was highest in the transverse plane, subchondral defects or sclerosis of the trochlea humeri was highest in the dorsal plane, and joint incongruity was highest in the sagittal plane. Certainty for hypoattenuating subchondral defects or fissures was highest at 2,500 or 3,500 HUs, whereas certainty for subchondral sclerosis was highest at 1,500 HUs and lowest at 3,500 HUs.

Conclusions and Clinical Relevance—Diagnostic certainty for CT characteristics of elbow joint dysplasia in dogs was affected by image display variables. Diagnostic certainty for altered subchondral bone density was primarily influenced by window settings, whereas structural MCP abnormalities and joint incongruity were influenced most by image plane.


A dysplastic elbow joint (elbow dysplasia) is one of the most common causes of forelimb lameness in dogs. Elbow dysplasia is used to describe developmental abnormalities of the elbow joint in dogs and encompasses 4 primary lesions (FCP, ununited anconeal process, osteochondrosis or osteochondritis dissecans, and elbow joint incongruity) as well as the lesser known conditions of patella cubiti and ununited medial epicondyle. Of all these conditions, FCP is the most common. Elbow dysplasia typically affects young, rapidly growing large-breed dogs and frequently results in progressive and debilitating osteoarthritis. Because osteoarthritis is irreversible, early diagnosis and surgical intervention have been advocated to provide the best possible clinical outcome.

Computed tomography is a noninvasive imaging technique that uses radiography and computers to create sectional images of anatomic structures. Because of the complexity of the canine elbow joint, CT has become an established tool for diagnosis and treatment planning in dogs with lameness localized to the elbow region. Compared with other radiographic imaging modalities, CT has the highest diagnostic accuracy and sensitivity for detecting FCP. However, diagnostic sensitivity for elbow joint abnormalities may be affected by variations in CT image quality. In our experience, CT images of canine elbow joints may be misinterpreted and clinically important lesions overlooked when images are displayed with inappropriate window settings.

ABBREVIATIONS

FCP  Fragmented medial coronoid process
CT  Computed tomography
MCP  Medial coronoid process
HU  Hounsfield unit
VAS  Visual analogue scale
or when planar-reformatted images are not provided. Several studies have revealed that an observer’s ability to detect lesions can be significantly affected by CT image display, and this exposes the potential for misinterpretation and misdiagnosis. However, to our knowledge, there are no reports of studies that have investigated the effect of window settings or use of multiplanar reconstruction on observer performance for detection of bone lesions. Furthermore, we are not aware of any data-based recommendations for optimal display of CT images of the canine elbow joint.

On the basis of our experience and review of the literature, we hypothesized that diagnostic certainty for CT characteristics of elbow dysplasia would be affected by the CT display window, reformatted image plane, or both. Understanding how CT display settings can influence diagnostic certainty is important to help avoid misinterpretation of CT images of canine elbow joints. This information is also important for maximizing diagnostic certainty for the detection of morphologic abnormalities within the elbow joint so that CT can be implemented as a screening tool for early detection of elbow dysplasia in dogs and to facilitate surgical planning. Information gained from the study reported here should be of use for studies in which abnormal CT characteristics of elbow joints are compared with surgical findings and postoperative outcome in dogs with elbow dysplasia.

The objective of the study reported here was to test the effects of CT image window and plane on observers’ diagnostic certainty for CT characteristics reportedly associated with elbow dysplasia in dogs. A second objective of the study was to provide guidelines for optimal display of these CT characteristics.

Materials and Methods

Sample population—Medical records of the Veterinary Medical Teaching Hospital at Texas A&M University for dogs with elbow dysplasia between 1999 and 2003 were reviewed. Inclusion criteria were large-breed dogs (body weight > 20 kg) with a clinical history of lameness isolated to at least 1 elbow joint, elicitation of signs of pain in the elbow region during lameness examination, original CT image data of the elbow joints available on archived storage media, and recorded arthroscopic or surgical findings from at least 1 elbow joint.

Seventy-two dogs meet the clinical criteria; however, 23 dogs were eliminated because of insufficient surgical records. For this group of 49 dogs, information on 50 surgically explored dysplastic elbow joints was selected for use in the study. For dogs with bilateral disease, the CT images of the right or left limb were randomly selected for evaluation.

Five sound large-breed dogs were selected from a purpose-bred colony of dogs maintained at Texas A&M University to serve as negative control animals for the study. Selected dogs were Labrador Retriever–Hound crossbreds with sex-linked, protein-losing nephropathy and were chosen because they had a body conformation and stature similar to those of the sample population of dogs with dysplastic elbow joints. Selected control dogs were examined by a board-certified veterinary surgeon and determined to be clinically free of elbow joint disease.

CT examination—After completion of the orthopedic examination, elbow joints of the clinically normal dogs were scanned in accordance with the same protocol that had been used for the dogs with elbow dysplasia. Results of CT examination of the elbow joints of the negative control dogs were evaluated by one of the authors (TCT) and considered to be normal.

Briefly, clinically normal dogs were medicated with acepromazine maleate (0.025 mg/kg, IM), glycopyrrolate (0.011 mg/kg, IM), and hydromorphone (0.1 mg/kg, IM). Anesthesia was induced by administration of propofol (4 to 6 mg/kg, IV) and maintained by administration of isoflurane (2.0% to 2.5%) and oxygen. Dogs were positioned in sternal recumbency within a plastic and foam trough, with the forelimbs secured parallel to each other in forward extension. Images were obtained by use of a third-generation CT scanner with 25-cm field of view, 130 mA, and 120 kV and a bone algorithm. Transverse images were obtained as contiguous 1.0-mm slices from the point of the olecranon to 2 cm distal to the radial head. Sagittal plane reformatted images were created as 1.5-mm contiguous slices and oriented parallel to the long axis of the MCP and between the epicondyles to include lateral coronoid processes and MCPs of the ulna, the trochlear notch, and entire articular surfaces of the radial head and humeral condyle. Dorsal plane reformatted images were created as 1.5-mm contiguous slices oriented perpendicular to the long axis of the MCP to include the entire articular surface of the humeral condyle and trochlear notch of the ulna.

Original CT image data from the 50 dysplastic elbow joints were loaded from archived magnetic optical disks onto a CT workstation at Texas A&M University. The CT images of normal and dysplastic elbow joints were filmed by use of transparent laser-printed film at a rate of 12 frames/sheet, which typically required 2 sheets of film/joint. Each elbow joint was filmed in transverse, reformatted sagittal, and reformatted dorsal planes. Transverse images were acquired perpendicular to the long axis of the ulna, sagittal images were acquired in a plane parallel to the long axis of the MCP, and dorsal images were acquired perpendicular to the long axis of the MCP. For each plane, images were filmed by use of 3 display window widths (1,500, 2,500, and 3,500 HUs), which served as high-, intermediate-, and low-contrast images, respectively. Images with a window width of 1,500 and 2,500 HUs were displayed at a level of 300 HUs, and images with a window width of 3,500 HUs were displayed at a level of 500 HUs. Selected display window settings were the same as those used in other studies.

Nine film sets were generated for each elbow joint (540 films for all 60 elbow joints). Film sets were composed of images from 1 elbow joint filmed in 1 plane and 1 window. Each film set was assigned a random identification number to prevent patient recognition by the investigators. All film sets were then combined and randomized with regard to window and plane. Film sets were allocated to 2 equal batches (270 film sets/batch). Both batches were sent to each investigator for evaluation; thus, each investigator evaluated all 540 film sets.
CT evaluation and VAS—Two board-certified veterinary radiologists with similar expertise in evaluating CT images (JC) and AMB) independently evaluated all film sets. The observers were unaware of the clinical and surgical findings for each dog. Each observer was asked to evaluate each film set for 7 characteristics reported as possible indicators of elbow dysplasia.

The 7 characteristics were hypoattenuating subchondral MCP defects; MCP fissure (in situ fragment); discrete MCP fragment; irregular margination or hypoattenuating defects of the radial incisure of the ulna; subchondral sclerosis of the trochlea humeri; hypoattenuating subchondral defect, erosion, or flattening of the trochlea humeri; and incongruity of the humeroradial, humeroulnar, or radioulnar joints. The MCP hypoattenuating subchondral defects were defined as irregular hypoattenuating foci (presumed to be osteomalacia) within subchondral bone of the MCP that may have been separate or coalescing but did not form a cleavage line or fragment; the MCP may have been

Figure 1—Transverse CT images of a normal canine elbow joint (A) and canine elbow joints with a hypoattenuating subchondral defect (white arrow; B), an in situ fissure (black arrowheads; C), and a discrete fragment of the MCP (D). Notice in panel D the irregularity of the radial incisure with hypoattenuating subchondral defects (black arrows). Images are displayed at a window width of 3,500 HUs and a level of 500 HUs.
abnormally shaped but was still intact (Figure 1). The MCP fissure (in situ fragment) was identified as a linear or curvilinear hypoattenuating structure that likely indicated a subchondral fissure or a nondisplaced or partially attached osteochondral fragment; it was usually detected on the lateral margin or apex of an MCP. Discrete MCP fragment (ie, FCP) was a clearly identifiable mineralized fragment separate from the MCP; it often varied in size, number of fragments, and degree of displacement. Radial incisure irregularity represented loss of a normal smooth cortical margin. It was often evident as an irregular contour or focal indentations and also evident as focal, hypoattenuating subchondral cyst-like lesions. Subchondral sclerosis of the trochlea humeri was identified as increased attenuation of subchondral bone of the humeral condyle opposing the MCP (Figure 2). A subchondral hypoattenuating defect or flattening of the trochlea humeri (which represented erosive lesions or osteochondritis dissecans) was defined as focal concave defects or flattening of the articular margin of the trochlea; these defects usually were associated with subchondral hypoattenuation with a

Figure 2—Transverse (A and B) and dorsal (C and D) plane CT images of canine elbow joints at the trochlea humeri. Panels A and C represent a normal elbow joint. In panels B and D, notice the appearance of subchondral sclerosis (white arrow). In panel D, notice the hypoattenuating subchondral defect (black arrowheads) with surrounding sclerosis. Images are displayed at a window width of 3,500 HUs and a level of 500 HUs.
surrounding zone of sclerosis and may also have been associated with an FCP or calcified cartilage flap. Joint incongruity was recognized as widening of or loss of parallelism between articular surfaces of the humerus, radius, and ulna, with or without step defects between the articular surface of the radius and lateral coronoid process of the ulna (Figure 3).

A VAS was used by each of the 2 observers to record the diagnostic certainty for each CT characteristic. The VAS consisted of a 15-cm horizontal line. The left end of the line (0 cm) represented that the observer believed the CT characteristic was definitely not detected, the right end of the line (15 cm) represented that the observer believed the CT characteristic was definitely detected, and the center of the line (7.5 cm) represented that the observer was unable to determine whether the CT characteristic was detected or not detected. The category of unable to determine was used for characteristics considered equivocal as a result of an inappropriate window or plane, filming artifacts, or other technical factors. Each observer placed a mark on the VAS at the point that reflected their degree of certainty that the CT characteristic for each film set was detected or not detected; VAS scores were then created by measuring (to the nearest millimeter) the distance from the left end of the line to the mark. The observers were not required to conclude whether an elbow joint was normal or dysplastic.

Each observer was provided with representative examples of the 7 CT characteristics as well as CT images (transverse, sagittal, and dorsal planes) of normal elbow joints that could be used as a reference during the evaluation period. The reference examples were obtained from dogs that were not part of the study population.

Additional space on the VAS data sheets was provided to enable observers to provide comments. Voluntary comments from the observers regarding specific CT characteristics were recorded.

Statistical analysis—Dogs were assigned a priori to 1 of 2 elbow joint status categories (clinically normal [control group] or clinically abnormal [dysplastic group]) by one of the investigators (TCT). Statistical analyses were performed by use of a commercially available software program. Least squares means were used to estimate combined observer certainty for a specific CT characteristic, and differences of the least squares means were used to detect whether the combined observer diagnostic certainty differed between certainty levels for elbow joint status, window setting, or plane. The VAS scores were transformed by use of an arcsine square root transformation (i.e., transformed \( x = \arcsin(\sqrt{x/15}) \)) to represent the degree of diagnostic certainty for a specific CT characteristic on a 15-point scale, where 0 represented complete uncertainty and 15 represented absolute certainty that a specific CT characteristic was detected or not detected. Effects of elbow joint status, display window, and image plane on diagnostic certainty were analyzed by use of a split-plot ANOVA, starting from a full model. One-, 2-, and 3-way interactions of these main effects were also tested. Interaction effects that were significant \( (P \geq 0.2) \) were not tested further.

Table 1—The CT image-display variables that had the greatest effect on diagnostic certainty for 2 observers for each CT characteristic in 50 dysplastic elbow joints of 49 dogs.

<table>
<thead>
<tr>
<th>CT characteristic</th>
<th>Image-display variables</th>
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<tr>
<td>MCP hypoattenuating subchondral defect</td>
<td>Transverse plane at 2,500 or 3,500 HUs</td>
</tr>
<tr>
<td>MCP fissure</td>
<td>Transverse plane at 2,500 or 3,500 HUs</td>
</tr>
<tr>
<td>Discrete MCP fragment (i.e., FCP)</td>
<td>Transverse or sagittal plane at 1,500, 2,500, or 3,500 HUs</td>
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<tr>
<td>Radial incisure irregularity</td>
<td>Transverse plane at 1,500, 2,500, or 3,500 HUs</td>
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<tr>
<td>Sclerosis of trochlea humeri</td>
<td>Dorsal or transverse plane at 1,500 HUs</td>
</tr>
<tr>
<td>Subchondral defect of trochlea humeri</td>
<td>Dorsal plane*</td>
</tr>
<tr>
<td>Joint incongruity</td>
<td>Sagittal plane at 1,500, 2,500, or 3,500 HUs</td>
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*Greatest diagnostic certainty for only 1 of 2 observers.
Results

Study population—Computed tomography images of 50 dysplastic elbow joints (28 left and 22 right) of 49 affected dogs (including both elbow joints of 1 dog) and 10 elbow joints of 5 clinically normal dogs were included in the study. Clinically normal dogs included 3 sexually intact males and 2 sexually intact females. All clinically normal dogs were 9 months old with a median body weight of 23.9 kg (range, 20.7 to 28.6 kg). The group of dogs with elbow dysplasia included 25 males (14 sexually intact) and 24 females (7 sexually intact). Median age of dogs with dysplastic elbow joints was 23 months (range, 7 to 120 months); median age for males was 18 months (range, 7 to 104 months), and median age for females was 26 months (range, 9 to 120 months). Median body weight of dogs with elbow dysplasia was 34.1 kg (range, 21.8 to 65.0 kg); median body weight for males was 36.4 kg (range, 22.7 to 65.0 kg), and median body weight for females was 32.3 kg (range, 21.8 to 40.7 kg). The dysplastic group included 14 Labrador Retrievers, 11 Rottweilers, 6 Golden Retrievers, 6 mixed-breed dogs, 2 Chow Chows, 2 German Shepherd Dogs, and 2 Newfoundlands. Other breeds represented included 1 each of Black and Tan Coonhound, Blue Heeler, Bouvier des Flandres, Boxer, Flat-coated Retriever, and Saint Bernard.

VAS analysis—Regarding the VAS scoring method, there was a distinct observer effect on VAS scores. This was unexpected and presumed to result from the way in which observers used the VAS scale. One observer had a categoric style for scoring diagnostic certainty (ie, marks were made at the extremities to denote absolute certainty that the CT characteristic was detected or not detected or were made at the center to denote absolute uncertainty, with few marks in between). In contrast, the other observer used a continuous style for scoring, with few marks at the extreme ends of the lines. Despite these differences in scoring style, interobserver variance was relatively low for most CT characteristics. Image display settings that yielded the greatest effect on diagnostic certainty for each CT characteristic were summarized (Table 1).

MCP hypoattenuating subchondral defect—Diagnostic certainty that subchondral defects of the MCP were detected or not detected was significantly greater at 2,500 or 3,500 HUs, compared with diagnostic certainty at 1,500 HUs. This was expected because hypoattenuating defects are more visible in low-contrast images as a result of a decrease in image noise (ie, image graininess caused by statistical fluctuations in the number of detected x-ray photons; Figure 5).

MCP fissure (in situ fragment)—In general, diagnostic certainty that MCP fissures were detected or not detected was significantly greater in normal than in...
dysplastic elbow joints. Diagnostic certainty for MCP fissures was affected more by elbow joint status ($P < 0.001$) than by any other single effect. Combined effects of elbow joint status and plane ($P < 0.001$) affected diagnostic certainty more than any single variable. Window had no effect on diagnostic certainty (ie, when there was an FCP, it was visible in all windows). In normal elbow joints, diagnostic certainty that FCPs were not detected was greatest ($P < 0.001$) for the transverse plane.

However, unexpected results were found for dysplastic elbow joints. Diagnostic certainty that FCPs were detected or not detected was higher in normal elbow joints than in dysplastic elbow joints, regardless of image plane or window (Figure 7). Combined effects of elbow joint status and plane ($P < 0.001$) affected diagnostic uncertainty more than any single variable. Window had no effect on diagnostic certainty (ie, when there was an FCP, it was visible in all windows). In normal elbow joints, diagnostic certainty that FCPs were not detected was greatest ($P < 0.001$) for the transverse plane.

Discrete MCP fragment (ie, FCP)—Diagnostic certainty that MCP fragments were detected or not detected was higher in normal elbow joints than in dysplastic elbow joints, regardless of image plane or window (Figure 7). Combined effects of elbow joint status and plane ($P < 0.001$) affected diagnostic certainty more than any single variable. Window had no effect on diagnostic certainty (ie, when there was an FCP, it was visible in all windows). In normal elbow joints, diagnostic certainty that FCPs were not detected was greatest ($P < 0.001$) for the transverse plane.

Radial incisure irregularity and hypopattenuating subchondral defects—Both observers recorded nearly absolute certainty that radial incisure irregularities were detected or not detected in the transverse plane, regardless of window (Figure 8). Image plane had the strongest effect ($P < 0.001$) on diagnostic certainty, followed by elbow joint status ($P < 0.001$). Diagnostic certainty was greater ($P < 0.001$) for the transverse plane than for any other plane because the radial incisure is most visible in this plane. Also, display window had no effect on diagnostic certainty ($P = 0.082$).

Subchondral sclerosis of the trochlea humeri—Display window affected diagnostic certainty for the subchondral sclerosis of the trochlea humeri more than any other effect evaluated in the study. Combined effects of elbow joint status and window width (1,500 and 3,500 HUs) had the greatest effect on diagnostic certainty.
Because the observers.

Similar to results for other CT

Image plane (i.e., FCPs) were detected or not detected in canine elbow joints and the effects of elbow joint status, plane, plane within normal elbow joints, plane within dysplastic elbow joints, and window settings used to display CT images. See Figure 6 for remainder of key.

Figure 7—Arcsine transformed mean ± SD diagnostic certainty that discrete MCP fragments (ie, FCPs) were detected or not detected in canine elbow joints and the effects of elbow joint status, plane, plane within normal elbow joints, plane within dysplastic elbow joints, and window settings used to display CT images. See Figure 6 for remainder of key.

Figure 8—Arcsine transformed mean ± SD diagnostic certainty that radial incisure irregularity was detected or not detected in canine elbow joints and the effects of elbow joint status, plane, plane within normal elbow joints, plane within dysplastic elbow joints, and window settings used to display CT images. See Figure 6 for remainder of key.

certainty (P < 0.001), but single variables had no effect. In normal elbow joints, diagnostic certainty that subchondral sclerosis was detected or not detected was greatest for the dorsal plane at 3,500 HUs (P = 0.008) but least for 1,500 HUs (P < 0.001), whereas window width of 2,500 HUs had no effect (P = 0.59; Figure 9).

In dysplastic elbow joints, there was an opposite but expected pattern. Diagnostic certainty for subchondral sclerosis of the trochlea humeri was greatest at 1,500 HUs (P < 0.001) for both the dorsal and transverse planes, but it was least at 3,500 HUs (P < 0.001; Figure 9). These findings were expected because the dorsal plane best depicts the articulation between the trochlea humeri and MCP, and sclerosis is accentuated in high-contrast window settings (Figure 10).

Subchondral defects of the trochlea humeri—Diagnostic certainty that subchondral defects of the trochlea humeri were detected or not detected was greatest in normal elbow joints, whereas in dysplastic elbow joints, diagnostic certainty was unexpectedly low (Figure 11). Combined effect of elbow joint status and plane had a greater effect on diagnostic certainty (P < 0.001) than separate effects of elbow joint status (P < 0.001) or plane (P = 0.004). Window had no effect on diagnostic certainty. In normal elbow joints, diagnostic certainty was significantly (P < 0.001) different for the dorsal plane, compared with results for other planes, regardless of window. This plane best displays the articulation.

However, in dysplastic elbow joints, the dorsal plane was associated with the least diagnostic certainty for subchondral defects of the trochlea humeri. This discrepancy was considered to be an effect of interobserver variation. When VAS scores were analyzed for each observer, differences in diagnostic certainty were discovered. For one of the observers, elbow joint status and plane had the greatest combined effect on diagnostic certainty (P < 0.001), although elbow joint status (P < 0.001) or plane (P < 0.0001) also had moderate effects. This observer had the greatest diagnostic certainty (P < 0.001) for trochlear defects in the dorsal plane, whereas diagnostic certainty for the other observer was only affected by elbow joint status (P < 0.001).

Joint incongruity—Image plane (P < 0.001) had the strongest effect on diagnostic certainty for joint incongruity, followed by elbow joint status (P < 0.001). Also, window had no effect on diagnostic certainty for joint incongruity (Figure 12). Similar to results for other CT characteristics, diagnostic certainty that incongruity was detected or not detected was significantly (P < 0.001) greater in normal elbow joints than in dysplastic elbow joints. Greatest diagnostic certainty was for the sagittal plane (P < 0.001) because this plane best displays the articulations between the radius, ulna, and humerus.

Period of evaluation—Because the observers evaluated the film sets in 2 batches (ie, periods), there was a possibility that this may have affected diagnostic certainty. Therefore, an analysis was performed on all variables to determine the effects of period (ie, batch 1 vs batch 2) on diagnostic certainty. The certainty for subchondral defects of the trochlea humeri was the only variable affected by period, which was found only when period and image plane were combined (P = 0.015 and P = 0.037, respectively, for the 2 observers). For a specific plane or period, there were no significant effects on diagnostic certainty for either observer. This suggests that each observer had a slight increase in their diagnostic certainty for subchondral defects of the trochlea humeri during evaluation of the second batch of film sets, but such period effects were not observed for any other CT variables. Because of the many tests performed, the F values were too low to indicate true differences.
Discussion

The ability to detect a lesion by CT is dependent on the resolution of the imaging system, attenuation characteristics of the lesion, amount of background image noise (signal-to-noise ratio), and limitations of human vision.\textsuperscript{19,21,26} Visibility of high-contrast lesions is limited by image spatial resolution and sharpness, whereas low-contrast lesions are limited by image noise.\textsuperscript{7,28} Image noise is determined in part by the milliamperes, reconstruction algorithm, and display window settings.\textsuperscript{26,28} Manipulation of the display window does not affect CT image data but does alter the image signal-to-noise ratio, and this can significantly affect an observer’s ability to detect lesions.\textsuperscript{18,20,21,26,28} Window width is the range of HU values (ie, shades of gray) above and below the central gray color (ie, level) of the window. Window width determines image contrast (extent of gray scale), and window level determines image brightness. Typically, as the window level increases, the image will appear darker. The window level should be set at the HU of the tissue of interest, and window width should reflect the range of tissues on either side of the level for which discrimination is needed. Tissues displayed in a narrow window are represented by fewer shades of gray, which emphasizes the variations in local tissue x-ray attenuation and results in a high-contrast image. Narrow display windows optimize contrast resolution for structures with low inherent contrast, such as soft tissues or organs. However, because of the fluctuation of HU values, image noise is magnified in narrow display windows.\textsuperscript{28} Wide display windows compress the varia-

Disagreement between observers and possible confounding factors—For several CT characteristics for the 540 film sets, there was complete observer disagreement for MCP hypoattenuating subchondral defects (n = 34), MCP fissure (45), discrete MCP fragments (15), radial incisure irregularity (28), sclerosis of the trochlea humeri (51), erosive lesion or osteochondritis dissecans (21), and joint incongruity (40). For MCP subchondral defects and discrete MCP fragments (ie, FCP), observer differences were equal for positive and negative diagnostic certainty (ie, there was no observer bias). When there were observer differences, one of the observers had greater diagnostic certainty for detecting an MCP fissure, whereas the other observer was more equivocal. Comments provided by observers to explain equivocal responses for abnormalities of the MCP (subchondral defects, fissures, and fragments) included that the reformatted image plane was off the axis or that the MCP was not completely included in the reformatted sagittal images. There was no observer bias for radial incisure irregularity, hypoattenuating subchondral defects, or a combination of these abnormalities. The variable, as defined for the study, included both hypoattenuating defects and margin irregularities. When a specific elbow joint had 1 condition but not the other, observers may have been unsure as to how to respond. In most cases, when only one of the conditions existed, the observers recorded that condition on the data sheet.

For subchondral sclerosis of the trochlea humeri, subchondral defects of the trochlea humeri, and joint incongruity, observer differences typically were biased. One observer had greater diagnostic certainty for evidence of trochlear sclerosis, whereas the other observer believed that there was no evidence of this characteristic. In contrast, 1 observer detected subchondral defects of the trochlea humeri in more than twice as many film sets, compared with results for the other observer. For one of the observers, diagnostic certainty for the defined characteristic was reduced in some dysplastic elbow joints when there was additional or incidental subchondral hypoattenuating defects or cyst-like lesions within the epicondyle or adjacent to the olecranon fossa. This observer also detected humeroulnar and humeroradial incongruity in twice as many film sets as the other observer. Overall, the most common technical artifacts indicated in the film sets included incomplete evaluation of the MCP because of planar images that were off the axis (n = 21) and partial volume averaging (4). Neither observer indicated a difficulty in interpretation of joint incongruity.
tion in tissue HU values and result in a low-contrast image. Wide windows optimize spatial and contrast resolution for tissues with high inherent contrast (eg, bones and lungs) or for evaluation of a wide range of tissues.\textsuperscript{30,31} Because local HU variations are minimized, low-contrast images have a decreased amount of image noise.\textsuperscript{20,28}

Selection of the proper window width and level for the tissue of interest is crucial because important information will be obscured or lost when an image is too light or too dark or has too little or too much contrast.\textsuperscript{20,32} The advantage of viewing images at a CT workstation is that the operator can readily manipulate the brightness and contrast to optimally display all tissue types while scrutinizing the image. Furthermore, the operator can precisely modify reformatted image planes that best reveal anatomic relationships or lesions within the elbow joint, whereas image manipulation is impossible once images are filmed. However, not all clinicians have access to on-site CT equipment and therefore rely on human diagnostic imaging centers to provide CT. The potential disadvantage of filmed images obtained from these
Diagnostic certainty is the confidence of an observer that a lesion does or does not exist. Because it is a subjective phenomenon, the use of a VAS was considered appropriate for quantifying observer diagnostic certainty for the study. Visual analogue scales are useful in human and veterinary studies to assess the quality of sleep and severity of pain and to measure diagnostic certainty.\textsuperscript{25,33-36} A major advantage of the VAS is that it provides measurement on a continuous scale and eliminates categoric constraints placed on observers who use numeric rating scales. The VAS also permits the use of parametric statistical analyses, which have a higher power than nonparametric analyses.\textsuperscript{25,33-36} One disadvantage is that use of a VAS requires an experienced observer. In addition, it can be difficult to determine whether small incremental changes in VAS scores are statistically significant or clinically important.\textsuperscript{25,36}

In the study reported here, differences in VAS scoring style between observers had an unexpected effect on diagnostic certainty scores. This likely contributed to the unexpected results for some CT characteristics. High interobserver variability has also been reported in other imaging studies.\textsuperscript{37,38} Lesion detection during diagnostic imaging is affected by a phenomenon known as observer noise, which refers to the inherent physiologic or psychologic aspects of the decision-making process and constitutes a source of human error.\textsuperscript{37,39} Observer noise is not important for lesion detection in images with a narrow window but becomes important for images displayed in a wide window setting.\textsuperscript{27,36} Despite observer variation in our study, there was good overall agreement for differentiating normal from dysplastic elbow joints. In a clinical setting, CT images may be interpreted by observers who have varying degrees of experience and training or differences in interpretation style. Analysis of results revealed that image interpretation may vary (sometimes significantly) among radiologists.

The selection of 2 observers for the study was intended to simulate image interpretation in a realistic clinical scenario. We accepted there would be some observer bias. There was no attempt to randomize the interpretation sequence of CT characteristics in the data sheets, so it is possible that evaluation of the characteristics in the same sequence could have affected the decision-making process of an observer.

The authors believe that regardless of the actual sequence, most radiologists would evaluate CT images of the elbow joint in a systematic manner, much as they would for any other diagnostic modality. We chose to have the observers evaluate film sets independently to minimize internal bias. Time and financial constraints prevented determination of observer diagnostic certainty for all available planes or windows for a specific elbow joint. In reality, most radiologists who interpret such images typically have access to a computer workstation with multiplanar capability and would evaluate all images collectively before arriving at a final diagnosis, rather than making a diagnosis on the basis of a
single plane or window. However, for other clinicians who do not have such access to CT workstations, the evaluation of elbow joints is substantially limited by the windows and planes that are provided on filmed images. For the latter, it is extremely important that the appropriate images are provided to maximize diagnostic certainty.

For the study reported here, the control dogs were chosen on the basis that their stature and body conformation were similar to those for the group of dogs with elbow dysplasia. A limitation of the study was that there was not closer matching for age and body weight between the control and dysplastic groups. Although the mean age and body weight of the control dogs were less than those with elbow dysplasia, the control dogs were at or near skeletal maturity. Size of the elbow joints was not considered to be sufficiently different between the groups to influence observer performance. Similarly, the age difference between groups was considered unlikely to affect observer diagnostic certainty. The canine MCP is completely ossified by 22 to 24 weeks of age,24,25 therefore, hypoattenuating areas of the MCP in dogs ≥ 6 months old are abnormal.42 Several authors have claimed that characteristic degenerative changes are radiographically apparent by 7 to 12 months of age in most dogs with elbow dysplasia. For that reason, a 9-month-old dog with radiographic evidence of elbow dysplasia would likely have detectable abnormalities in CT images.

However, it is possible to misidentify dogs with elbow dysplasia as being normal dogs when they have minimal or no degenerative changes evident on radiographs. There have been reports of adult dogs with surgically confirmed FCP that had no or minimal radiographic evidence of osteoarthritis. It is possible that 1 or more of the dogs in the control group could have had elbow dysplasia with minimal osteoarthritis, but because they had normal CT features, it would not have changed the diagnostic interpretation.

Analysis of our results revealed that observers had significantly greater diagnostic certainty for normal elbow joints than for dysplastic elbow joints. This effect of elbow joint status (normal or dysplastic) was unexpected because it was anticipated that the CT characteristics would be detected with a high degree of certainty in dysplastic elbow joints. It is possible that observers formed an overall opinion that an elbow joint was normal or dysplastic from all available images in the film set. When an elbow joint was subjectively judged to be normal, then the diagnostic certainty for the lack of all CT characteristics was high; however, when an elbow joint was subjectively judged to be abnormal, the diagnostic certainty for evidence of CT characteristics was quite variable. The variability of the VAS scores again reflected the observer noise inherent in the decision-making process.

In general, diagnostic certainty for defects of the MCP and radial incisure was greatest for the transverse plane because this plane best displays the anatomy of those structures.23 However, diagnostic certainty for MCP fragments was greatest for the sagittal plane. This may have been attributable to partial volume averaging between the trochlea humeri and MCP, which can be mistaken for an FCP on transverse CT images. Image noise may also make it difficult to discriminate small, minimally displaced fragments, particularly those that are only visible in 1 slice. Therefore, in some elbow joints, small fragments may be more clearly discernable in the sagittal plane because there is no anatomic superimposition between the trochlea humeri and MCP.

Diagnostic certainty for evidence of MCP fissures (in situ fragments) was lower than expected. Similar to hypoattenuating subchondral defects, fissures were detected with greatest certainty by use of wide window settings. Diagnostic certainty for these somewhat high-contrast lesions was anticipated to be greatest for wide window settings because image noise would be minimized and less likely to obscure lesions. It could be assumed that when a subchondral defect or fissure was best identified at window width of 3,500 HUs, the lack of such perceptible defects in this window would therefore be associated with greater certainty for a normal MCP.

Small, ill-defined lesions can be obscured by the increased image noise inherent with high-contrast images. For that same reason, we discovered that many subchondral bone defects visible at window widths of 2,500 or 3,500 HUs were obscured at a window width of 1,500 HUs, which resulted in normal-appearing MCP subchondral bone. Therefore, caution should be used when evaluating elbow joints with a narrow window setting because potentially relevant subchondral defects may be obscured, which may lead to a misdiagnosis. This emphasizes the need to evaluate elbow joints with a wider window setting when assessing hypoattenuating subchondral defects or fissures.

We also discovered that CT may be too sensitive for detecting slight alterations of subchondral bone. For example, subtle changes in bone attenuation were accentuated in the widest display window, which cast doubt as to whether the subchondral bone was normal. In such instances, we found that the image for a window width of 3,500 HUs could be overinterpreted and could potentially contribute to a false-positive diagnosis. These findings contradict in vitro studies in which authors claim that as window width increases, the detectability of lesions decreases. However, some authors report that this effect is more pronounced for larger low-contrast lesions than for smaller high-contrast lesions. It is also believed by some authors that this effect is minimized for images obtained with a sharp reconstruction algorithm (which magnifies noise), rather than a smooth algorithm (which reduces noise). Because our images were obtained by use of a sharp algorithm, the increased image noise associated with the high-contrast display window likely accounted for the decreased conspicuity of subchondral defects. To the authors’ knowledge, observer performance for in vivo detection of osseous lesions has not been reported elsewhere; therefore, it is difficult to make comparisons between the results of our study and other in vitro studies.

Diagnostic certainty for evidence of subchondral sclerosis of the trochlea humeri was strongly affected by the window and plane. Compared with hypoattenuating defects of subchondral bone, which were most
visible for the window width of 3,500 HUs, subchondral sclerosis was most visible for the window width of 1,500 HUs. This is in accordance with studies in which investigators found that the ability to detect lower contrast lesions improves when they are displayed in a narrow window setting but decreases with increasing window width. Subchondral sclerosis will be accentuated in high-contrast images because of increased image noise, whereas sclerosis will appear diminished in low-contrast images. A narrow window setting will also accentuate normal subchondral bone and falsely mimic sclerosis. Alternatively, a wide window setting may diminish the appearance of sclerotic lesions to the point that subtle lesions may go undetected. Because of this, it is critically important that subchondral bone be evaluated with wide and narrow window settings to avoid misinterpretation.

The dorsal plane permits evaluation of the articulation between the trochlea humeri and MCP; thus, it was expected that abnormalities of the trochlea would be best displayed in this plane. It was assumed that diagnostic certainty for subchondral defects of the trochlea humeri would also be highest for the dorsal plane; however, diagnostic certainty was unexpectedly low. Interobserver variation in the evaluation of the humeral condyle was believed to account for this discrepancy. Diagnostic certainty for one of the observers was lower than expected, and this was possibly a result of the detection by that observer of additional subchondral defects or cyst-like lesions within the caudal portion of the condyle or epicondyle in some elbow joints. When these changes were evident, the observer stated that the diagnostic certainty for the defined characteristic was reduced. Despite the discrepancy, the authors consider the dorsal plane to be the most ideal for specifically evaluating the trochlea humeri for subchondral defects related to erosive lesions or osteochondritis dissecans.

Multiplanar image reformating is one of the primary advantages of CT, which allows an observer to evaluate anatomic relationships in alternative planes. Sagittal, dorsal, or oblique planes may reveal the extent of complex lesions that may be underestimated in transverse images. Images for the sagittal and dorsal planes allow evaluation of the entire humeroulnar and humeroradial joint. Our finding that joint incongruity was diagnosed with the highest confidence for the sagittal plane supports other studies on the use of CT in normal and dysplastic elbow joints. Actually, CT can provide only a gross estimation of congruity because articular cartilage is not visible in CT images. Regardless, measurements of elbow joint spaces on dorsal and sagittal reformatted images are accurate, and minor differences in limb positioning have a minimal effect on image reformating or measurement of joint spaces.

In the study reported here, the observers had difficulty discriminating focal MCP subchondral defects from MCP fissures. Based on the assumption that any hypoattenuating defect of the subchondral bone implies osteomalacia, cartilage fibrillation or chondromalacia (or both) could also be assumed and surgical exploration may be indicated. The clinical relevance of differentiating between focal subchondral defects and MCP fissures has yet to be determined because the decision for surgical exploration may be made solely on the basis of detecting abnormal subchondral bone of the MCP. Correlation between the CT characteristics and histologic findings is needed to fully determine the importance of these abnormalities. However, this is not practical in a clinical population. It may be possible to characterize isolated lesions of the MCP, but other lesions (such as radial incisure) within the elbow joint cannot be assessed without submission of the entire elbow joint for histologic evaluation, which would be unacceptable in a clinical population. Additional studies in which investigators use purpose-bred dogs with elbow dysplasia may be necessary to correlate CT characteristics with surgical and histologic findings and to determine their clinical importance.

In the study reported here, we determined that interobserver variation in interpretation of CT images could be quite high. Despite this, we found that the plane and window settings for CT images had significant effects on diagnostic certainty for CT characteristics of elbow dysplasia in dogs. We believe that this study represents a real-world scenario in which CT images may be evaluated and interpreted by multiple observers. For gross structural abnormalities of the MCP, radial incisure, and joint incongruity, diagnostic certainty was primarily influenced by the image plane, whereas alteration of subchondral bone density (hypoattenuating defects or sclerosis) was primarily influenced by window width. Window width was found to significantly affect diagnostic certainty for subchondral bone lesions; therefore, subchondral bone should be evaluated by use of both wide and narrow window settings and in multiple planes to prevent misinterpretation.

Several variables significantly affected diagnostic certainty and would be recommended when evaluating elbow joints for characteristics of dysplasia. These include use of the transverse plane at 3,500 HUs to detect hypoattenuating lesions of the MCP, such as subchondral defects or in situ fissures; the dorsal and transverse planes at 1,500 and 3,500 HUs to detect subchondral defects of the trochlea humeri and determine whether subchondral bone is normal or sclerotic; the transverse plane to detect irregularity or subchondral defects of the radial incisure; the transverse and sagittal planes to detect MCP fragments; and the sagittal plane to detect humerounlar, humeroradial, and radioular joint incongruity.

References


