ANALYSIS OF RISK FACTORS FOR ELBOW DYSPLASIA IN GIANT BREED DOGS.

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Abstract:

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Methods: Twenty-five giant breed puppies (Bernese mountain dogs, English mastiff, and Newfoundland) received bilateral elbow radiographs monthly from 2-6 months of age, bimonthly until radius/ulna physeal closure, followed 2 months by bilateral elbow computed tomography. Radiographic parameters measured included presence/absence of a separate center of ossification of the anconeal process (SCOAP), medial coronoid disease (MCD), ununited anconeal process, humeral osteochondrosis, elbow incongruity, as well as the length of the radius and ulna, radius-to-ulna ratio, and date of closure of the radial and ulnar physes.
Results: Fifteen dogs completed the study. Two Bernese Mountain dogs were diagnosed with MCD. Risk factors significantly associated with medial coronoid disease included dyssynchronous physeal closure and decreased radius-to-ulna ratio, detected between 8-11 months of age. SCOAP was present in 60% of the dogs, and was not a risk factor for development of elbow dysplasia.
Clinical significance: Transient, dyssynchronous growth of the radius and ulna may be a risk factor for development of MCD in Bernese Mountain dogs. Dyssynchronous physeal closure or decreased radius-to-ulna ratio prior to radiographic closure of the distal ulnar and radial physes warrants further study in Bernese Mountain dogs and other breeds subject to MCD development.

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Introduction

Elbow dysplasia (ED) is a common cause of progressive crippling osteoarthritis in dogs, and has been shown to have an increased prevalence in giant breeds.(1) Depending on the underlying abnormality and severity, age of onset for clinical signs can be young, with most dogs presenting at less than one year of age.(2, 3) Elbow dysplasia can be defined by multiple abnormalities present in the elbow, including medial coronoid disease (MCD), humeral osteochrondrosis (OC), ununited anconeal process (UAP), and elbow incongruity.(3, 4) Proposed mechanisms for the development of elbow dysplasia include joint incongruity, altered biomechanical forces across the elbow joint, altered endochondral ossification and osteonecrosis.(3, 5-7) Elbow joint incongruity is thought to be secondary to a length mismatch between the radius and ulna, with a short radius leading to MCD and a short ulna leading to UAP.(3, 6, 8, 9)

MCD is the most common form of elbow dysplasia in the dog and the exact etiopathogenesis remains unknown.(1, 10) Hypotheses for the pathogenesis of MCD include abnormal mechanical forces from elbow incongruity, abnormal endochondral ossification or osteonecrosis.(5, 9) However, there is a discrepancy between studies of radial-ulnar incongruity with some studies identifying no difference in radial-ulnar congruity in dogs with or without MCD, while others have found that radial-ulnar incongruity may correlate with the severity of MCD in some cases.(11, 12)

There are two main theories for the pathogenesis of UAP: failure of fusion of a separate center of ossification of the anconeal process (SCOAP) or dyssynchronous growth of the radius and ulna resulting in elbow incongruity and secondary UAP.(8, 13) When a SCOAP is present, a radio-lucent line is identified separating the anconeal process from the olecranon on radiographs in dogs between 10-13 weeks of age; with the expected time of fusion to the olecranon reported to occur at less than 20 weeks of age.(14) UAP is diagnosed when there is persistence of the lucency between the anconeal process and olecranon in dogs over 22-24 weeks of age, due to a failure of SCOAP closure.(4, 15) However, recent evidence suggests that most breeds of dog do not have a SCOAP.(15) Further, SCOAP have not been described in many of the breeds with the highest prevalence of UAP including the Bernese Mountain dog, Rottweiler, Mastiff, St. Bernard and Newfoundland. (1, 15, 16) Alternatively, UAP has been proposed to occur secondary to dyssynchronous growth between the radius and ulna, with secondary incongruency leading to altered biomechanical forces to the SCOAP resulting in UAP.(8) This theory is supported by the finding that ununited anconeal process is often seen with concurrent radial-ulnar incongruency.(17)

Incongruency of the elbow can occur in physiologic and pathologic forms, with the pathologic forms of elbow incongruency resulting from unequal growth between the radius and ulna or from abnormal development of an elliptical shape of the trochlear notch of the ulna.(6, 18) Incongruency of the elbow has been described as a step defect between the radius and ulna with a nonuniform joint space.(6) Diagnosis of incongruency in mild cases is difficult but severe radioulnar discrepencies can be identified using radiographs, computed tomography (CT) or arthroscopy. CT has been reported to be more accurate than radiographs and less dependent on patient positioning for the diagnosis of elbow incongruency.(6, 19)

The incidence of elbow dysplasia has declined in select populations of high risk breeds of dogs.(20) This is largely due to the efforts of groups such as the International Elbow Working Group. The goal of this group is to identify affected dogs and recommend removal from the breeding pool through grading elbow radiographs of 1-year-old dogs from 0 (normal) to 5 (severely affected).(21) While selective breeding using this method has successfully decreased the prevalence and severity of elbow dysplasia in many breeds of dog, unfortunately many dogs are bred before 1 year of age. A method of diagnosis of elbow dysplasia in young growing dogs is needed to remove affected dogs from the breeding pool, develop methods of early intervention in dogs at a high risk of elbow dysplasia, and to enable early owner education about the disease. The aim of the present study was to identify radiographic risk factors for development of elbow dysplasia in giant breed dogs less than 1 year of age. The null hypothesis was that there was no difference in any of the measured radiographic parameters that could differentiate individual giant breed dogs that develop elbow dysplasia from those that do not.

Material and methods

Animals: This prospective clinical study recruited twenty five giant breed puppies from breeders of Bernese mountain dog, English mastiff and Newfoundland dogs in XXX and XXX area. The XXX Institution Animal Care and Use Committee approved the study and written consent was obtained from all owners prior to enrollment.

Puppies that were found to have any clinical lameness, cardiopulmonary, hepatic or gastrointestinal abnormalities on initial physical examination were excluded. Puppies were initially recruited at 7-8 weeks of age and radiographed on a monthly basis until 6 months of age and then every other month until physeal closure. Bilateral CT examination of the elbows was performed 2 months after radiographic determination of physeal closure.

Radiography of the elbows: At each visit, an orthopedic examination was perfomed on each dog followed by bilateral 3-view elbow radiographs under an approved sedation protocol [dexmeditomidine 5 micrograms per kilogram (Pfizer Animal Health, New York, NY) and butorphanol 1 milligram per kilogram (Akorn, Inc, Decatur, IL), intravenously]. The radiographic study consisted of lateral, flexed lateral and extended craniocaudal elbow and antibrachium images acquired using digital CR radiographic equipment (Fuji Medical Systems U.S.A., Inc., Stamford, CT). Radiographs were centered on the elbow and collimated to include the carpus and as much of the humerus as possible. Each projection included a calibration marker to correct for any magnification during later measurements. The exposure settings used for the elbow radiographs ranged from 70 or 75 kVp and 0.64-1.0 mAs, and were typical settings for elbow radiographs in dogs of this size in our institution. Upon completion of the study, sedation of the dog was reversed with atipamazole [5 micrograms per kilogram given intramuscularly (Pfizer Animal Health, New York, NY)].

Computed tomography of the elbows: All computed tomography (CT) exams were performed 2 months following radiographic evidence of physeal closure of the radius and ulna using a 64–detector CT scanner (Aquillion 64, Toshiba America Medical systems, Inc., Tustin, CA, USA). All dogs were scanned in ventral recumbency from the distal phalanges to the shoulders with a tube voltage of 120 kVp, a tube current ranging from 350-400 mA, a helical pitch of 53, a pitch factor of 0.828, 0 degree tilt and a slice thickness of 0.5 mm. Thin collimated isovolumetric CT volume data were used to create transverse, dorsal and sagittal reconstructed images of the elbow and antebrachium with 2 mm slice thicknesses. Images were generated with both bone and soft tissue algorithms, and were viewed as bone (width 2700 HU, level 350 HU) or soft tissue window (width: 400 HU, level: 40 HU) images, respectively.

Evaluation of images: The radiographic and CT images were sent to a designated imaging server for off-line analysis. A DICOM viewer (eFilm, version 3.4.0, Merge Healthcare, Heartland, WI, USA) was used to view all imaging studies. Radiographs were evaluated independently by a veterinary student and a board certified radiologist. Each radiograph was assessed for the presence or absence of a SCOAP and, if present, the age at which radiographic closure of the SCOAP was first detected. The presence or absence UAP, FCP, OC, elbow osteoarthritis and physeal closure status of the radius and ulna were also recorded. Elbow incongruity was evaluated by measuring any step defect between the radius and ulna and recording the shape of the trochlear notch and humeroulnar joint space. The length of the radius and ulna were measured using an electronic caliper tool of the image viewing software, and the calibration marker was used to correct for magnification. The radius-to-ulna ratio was calculated with the formula: (length of radius in cm)/(length of the ulna in cm). The rate of change in bone length was calculated as: [(bone length on the current visit) - (bone length on the previous visit)]/(the time between visits in months).

CT images were evaluated for the presence or absence UAP, FCP, OC, elbow osteoarthritis, and elbow incongruity, with similar methods as described for the radiographic studies.

Statistical analysis: Statistical analyses were performed using commercially available software. (Graphpad Prism, Temecula, CA). Group differences between dogs with and without elbow dysplasia were determined for continuous data (Kruskal-Wallis test), and binomial data (Fisher's Exact test). Non-parametric data were reported as the median, ±SEM with 95% confidence intervals (95% CI). Significance was set at $P<0.05$.

Results

Subjects: A total of 25 dogs were recruited for this study (Table 1), of which 15 dogs completed the study. Reasons for dogs not completing the study included death of the owner (1 Newfoundland), owner attrition from the study (3 Newfoundland), and the owner moving from the area (6: 1 Bernese mountain dog, 5 Newfoundland). The Bernese mountain dogs were from three separate litters from different breeders. Litters included 1, 4, and 5 dogs. All nine Newfoundland puppies were from the same litter. The English mastiffs were from 3 different litters, two liters of two dogs each and one dog from a separate litter.

Elbow dysplasia: Based on radiographs, medial coronoid disease was suspected in 4 dogs, 3 Bernese mountain dogs and 1 English mastiff. The margination of the medial coronoid process was indistinct in two Bernese mountain dogs, which was unilateral in one dog and bilateral in the other (Figure 1, 3). Unilateral rounding of the medial coronoid process was present in 2 other dogs, a Bernese mountain dog and an English mastiff. In the English mastiff, the rounding of the medial coronoid process resolved at the radiographic visit at 10 months of age. No dog was diagnosed with humeral osteochondrosis or UAP on the basis of radiographs.

Based on the bilateral CT images of the elbows of the 15 dogs that completed study, 2 dogs of the original 4 with radiographic abnormalities of the medial coronoid process were diagnosed with MCD, 1 bilateral and 1 unilateral. These dogs were both Bernese mountain dogs with indistinct margination of the medial coronoid process detected on radiographs. The dog with radiographic evidence of bilateral MCD had bilateral MCD diagnosed using CT images and arthroscopy, and the dog with radiographic evidence of unilateral MCD was diagnosed with unilateral MCD using CT images and arthroscopy. In both dogs with MCD, fragmentation of the medial coronoid process was found (Figure 1). The 2 dogs with unilateral rounding of the medial coronoid process on radiographs had no evidence of medial coronoid disease on CT images. No dogs were diagnosed with humeral osteochondrosis or UAP based on CT images.

SCOAP: SCOAP were initially detected when dogs were between 12.9 and 14.9 weeks of age (median 13.9 weeks; Figure 2). Based on these data, the presence or absence of a SCOAP could be assessed in 20/25 dogs, including 9 Bernese mountain dogs, 5 Newfoundland dogs and 6 English mastiffs. A SCOAP was detected in 12 dogs, including 8/9 Bernese mountain dogs, 4/6 English mastiffs and 0/5 Newfoundland dogs. In all 12 dogs, the SCOAP were bilateral. Fusion of the SCOAP to the anconeal process was first detected at 16.7-22.3 weeks of age, with the median age of 18.6 weeks.

Of the 15 dogs that completed the study, none of the dogs with a SCOAP developed UAP or OC. One Bernese mountain dog with SCOAP developed bilateral MCD. Of the 8 dogs without a SCOAP, one Bernese mountain dog developed unilateral MCD and none of these dogs developed UAP or humeral osteochondrosis. Based on these data, the presence or absence of a SCOAP is not a risk factor for development of elbow dysplasia ($p = 0.37$ for MCD; $p = 1$ for UAP and OC).

Synchronicity of physeal closure: The synchronicity of closure of the physes for the radius and ulna could be assessed in 6 English mastiffs and 6 Bernese mountain dogs, but none of the Newfoundland dogs (due to attrition from the study). The closure of the distal ulna and distal radius occurred at the same radiographic visit for all dogs between 9.6 and 12.9 months of age except for two of the Bernese mountain dogs. Both of the Bernese mountain dogs with dyssynchronous closure of the physes developed MCD. In the dog with bilateral MCD, the proximal radial physis closed before the distal ulnar physis which closed before the distal radial physis (Figure 3). In the dog with unilateral MCD, the proximal radius and distal ulnar physes closed before the distal radial physis. Based on these data, disparate closure of the physes of the radius and ulna is a risk factor for development of medial coronoid disease ($P = 0.0095$), but not for development of UAP or humeral osteochondrosis ($P = 1.0$). In these 2 dogs, the dyssynchrony of physeal closure was first detected at 9.6 and 10.7 months of age, and in the dog with bilateral MCD persisted until at least 11.4 months of age.

Radius to ulna ratio: There was a small, yet significant decrease in the ratio of the length of the radius-to-ulna seen between the 2 dogs with MCD and the dogs without MCD (Table 2, Figure 4,

$p = 0.0005$). This indicates that dogs diagnosed with MCD had a mildly shorter radius than dogs not diagnosed with MCD. There was a significant difference in the ratio of radius-to-ulna length between the dogs diagnosed with MCD and Bernese mountain dogs ($p = 0.01$) and English mastiff dogs ($p = 0.001$) without MCD, however, there was no difference between English mastiff and Bernese mountain dogs without MCD ($p > 0.05$). The median radius-to-ulna ratio for Bernese mountain and English mastiff dogs without MCD was 0.84 and 0.85, respectively (Table 2). Only dogs with a radius-to-ulna ratio less than 0.835 between 240 and 300 days of age developed MCD. Further, the dog with unilateral MCD had a radius-to-ulna ratio less than 0.835 between 240 and 300 days in the dysplastic elbow but not in the non-dysplastic elbow. Analyses were not performed for Newfoundland dogs because none of these dogs completed the study.

Radius and ulna length measurements: The radius and ulna of the left and right were symmetric, and the difference in length of the left and right radius and ulna was minimal (radius: 0.1 ± 0.01 cm; ulna: 0.1 ± 0.02 cm). The length of the radius and ulna did not differ in dogs with or without MCD (radius: 0.13 ± 0.03 cm; ulna: 0.1 ± 0.03 cm; $p = 0.13$).

Elbow incongruity: The shape of the trochlear notch and humeroulnar joint space were normal in all of the dogs at all measured time points except for the dog with bilateral MCD. In this dog, there was no radiographic evidence of elbow incongruity until 7 months of age. Starting at this radiographic visit, the shape of the trochlear notch became flattened and sclerotic, the humeroulnar joint space became asymmetric, and there was a step defect of 2-3 mm between the head of the radius and the trochlear notch of the ulna. The changes to the shape of the trochlear notch and humeroulnar joint space did not progress after initial detection, the step defect on the right remained at 3 mm and the step defect on the left progressed from 2 mm to 3 mm. In the dog with unilateral MCD, the shape of the trochlear notch and humeral ulnar joint space were normal and no step defect was noted between the radial head and trochlear notch of the ulna.

Discussion

Two of the giant breed dogs in this study were diagnosed with elbow dysplasia secondary to medial coronoid disease (MCD) with fragmentation of the medial coronoid process of the ulna as documented on arthroscopy. Risk factors for development of medial coronoid disease in these 2 dogs were dyssynchronous closure of the physes of the radius and ulna detected between 287 at 321 of age and a radius-to-ulna ratio of less than 0.835 between 240 and 300 days of age. A separate center of ossification of the anconeal process (SCOAP) was not found to be a risk factor for development of medial coronoid disease, ununited anconeal process or osteochondrosis of the medial aspect of the humeral condyle. We reject the null hypothesis, and conclude that there are radiographic risks factors in giant breed dogs for development of elbow dysplasia, specifically MCD, which can be detected before 1 year of age. Due to the small number of dogs and breeds in this study, and the fact that only 2 dogs developed MCD, these results may not prove to be relevant in other breeds or inspection of larger groups of dogs.

There was a small but significant decrease in the radius-to-ulna ratio in the dogs that developed MCD. By comparing the radius-to-ulna of the forelimbs of dogs with medial coronoid disease to those without medial coronoid disease, there is no overlap between affected and unaffected dogs between 240 and 300 days of age. In fact, in the dog with unilateral MCD, there was a decrease in the affected limb compared to the unaffected limb in this time period. Further, only dogs with medial coronoid disease had radius-to-ulna ratios of less than 0.8. These data support the hypothesis that elbow incongruity with a short radius is a risk factor for MCD. Due to the small numbers of dogs in this study, a Type I statistical error cannot be ruled out. Further research is warranted to determine whether other breeds of dogs in a large population also develop these abnormalities in conjunction with MCD. None of the dogs developed UAP, therefore these data were unable to test the hypothesis that a short ulna relative to the radius would result in UAP. A radius-to-ulna step defect, humeroulnar joint incongruity and abnormality of the shape of the trochlear notch was seen in the dog with bilateral MCD but not in the dog with unilateral MCD. It is possible that a step defect, joint incongruity and changes and shape of the trochlear notch are seen in dogs with more severe MCD, or dogs with bilateral MCD, however there were not enough dogs present in the study with MCD to assess any spectrum of change.

Dyssynchronous closure of the physes of the radius and ulna was only noted in dogs with MCD. In these dogs, the physes of the ulna closed before the physes of the radius. Combined with the finding of a decreased radius-to-ulna ratio in affected dogs, this supports the hypothesis that the radius was transiently shortened in these dogs in relation to the ulna. This was likely because the ulna reached the length of skeletal maturity before the radius. During this short period of asymmetry between the radius and ulna, it is possible that there were altered stresses placed on the medial aspect of the elbow, and this may have predisposed these dogs to develop MCD. These data are supported by the findings that the radius-to-ulna ratio increased to the level seen in dogs not affected with MCD as they approached skeletal maturity. The transient nature of this radius-to-ulna ratio shortening may be the reason that some studies have described altered growth of the radius-to-ulna as a risk factor for elbow dysplasia while others do not.(11, 12)

A SCOAP was present bilaterally in 12 of the dogs, none of which developed an ununited anconeal process. This is the first study to report the presence of a SCOAP in Bernese mountain dogs or English mastiff dogs. Previous studies have reported the presence of a SCOAP in

German Shepard dogs, Greyhound, Pit Bull mix, Doberman Pinscher, Golden Retriever, and Labrador Retriever mix.(15, 22) In German Shepard and Greyhound dogs, fusion of a SCOAP to the anconeal process is reported to occur by 20 weeks of age. In the Bernese mountain dog and English mastiffs of this study, SCOAP fusion was noted between 16 and 23 weeks of age. Based on these data, we recommend that the expected date of fusion be increased to 23 weeks of age for giant breed dogs, that is dogs reaching greater than 35 kg body weight at physeal closure.

It is been hypothesized that the presence of a SCOAP is a risk factor for development of UAP. The canine breeds with the highest prevalence of UAP include the German Shepherd, Bernese Mountain dog, Rottweiler, Mastiff, St. Bernard and Newfoundland.(1, 16) In the present study, bilateral SCOAP were seen in 8 of 9 Bernese mountain dog and 4 of 6 English mastiff dogs and 0 of 5 Newfoundland dogs. None of the dogs with a SCOAP developed UAP. Combined with the data of a recent study, the data do not support the hypothesis that a SCOAP is a risk factor for development of UAP in medium, large or giant breed dogs.(15) These data are more indicative that the presence of a SCOAP is a variation of normal skeletal development.

The limitations of this study include the small sample size, with a total of 25 dogs enrolled in the study and only 15 completing the study. Due to the nature of prospective studies, ten dogs failed to complete the study and discontinued between 48 and 251 days of age. No Newfoundland puppies completed the study, and attrition most frequently occurred after 100 days of age. With these data we were able to evaluate for presence of a SCOAP, but not for synchronicity of radius/ulna physeal closure. Further studies with a larger sample size, and equal number of participants from each breed, and including dogs that are not direct siblings would be beneficial for evaluating the true prevalence of SCOAP in these grades.

In summary, risk factors for the development of elbow dysplasia secondary to MCD in Bernese mountain dogs found in the study were dyssynchronous closure of the physes of the radius and ulna and a decrease in the radius-to-ulna ratio. These findings may indicate at least one mechanism for the development of MCD in giant breed dogs. The presence of a SCOAP was not a risk factor for development of MCD, and may be a variation of normal in Bernese mountain dogs and English mastiffs. Further research is required in larger numbers of dogs and in other breeds affected by MCD and elbow dysplasia before applying the results of this study to clinical cases.

Figure legends

Figure 1: Craniocaudal and lateral radiographic projections, and transverse and sagittal plane CT images of the left elbow of a Bernese mountain dog with bilateral elbow dysplasia due to fragmentation of the medial coronoid process. On the radiographic images, the margins of the medial coronoid process are indistinct. On the CT images, a distinct triangular mineral fragment can be seen adjacent to the medial coronoid process, consistent with a diagnosis of left fragmented medial coronoid process.

Figure 2: Flexed lateral radiographs of the right elbow of a Bernese mountain dog with a SCOAP. At 9.4 weeks of age, no mineral opaque SCOAP is seen (black rimmed arrow). The SCOAP is first seen in this dog at the radiographic visit at 13.3 weeks of age (white arrow). Fusion of the SCOAP to the anconeal process is occurring at 18.3 weeks of age (white arrow). The SCOAP is fused to the anconeal process (black arrows) and a thin physeal scar noted at 23.3 weeks of age, with continued remodeling of the region of the SCOAP seen at the radiographic visit of 26.3 weeks of age. At 35.3 weeks of age, there is no radiographic evidence at this dog had had a SCOAP.

Figure 3: Craniocaudal and neutral lateral projections of the right elbow of the Bernese mountain dog with dyssynchronous physeal closure and bilateral MCD at 11.4 months of age. The open physes of the distal radius are indicated with white arrows, and the closed physes of the proximal radius and distal ulna are indicated with grey arrows. This is a right forelimb of the same dog as in Figure 1, and on the lateral projection, the medial coronoid process of the ulna is indistinct and blunted.

Figure 4: Ratio of the length of the radius to the length of the ulna with individual lines for each forelimb of each dog in the study. The radius/ulna ratio of dogs with MCD (Black line) was

lower than Bernese mountain dogs (light gray line) and English mastiff dogs (gray lines) without MCD. For the dog with unilateral MCD, the affected limb is depicted with a solid line and the unaffected limb is depicted with a dashed line. Between 240 and 300 days of age, all MCD affected forelimbs had a radius/ulna ratio of less than 0.835 with no of affected and unaffected forelimbs.

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Table 1. Subjects in the study by breed and gender, as well as the number of animal that completed the study, and the number of animals that did not complete the study and the age at of the final radiographic visit.

	Males	Females	Completed study	Partial study
Bernese Mountain Dog (10)	4	6	9	1 (2 m)
English Mastiff (6)	4	2	6	0
Newfoundland (9)	2	7	0	9: 4 at 2 m, 1 at 4 m, 1 at 5 m, 2 at 6 m, 1 at 8 m

Table 2. The radius-to-ulna ratios for the Bernese Mountain and English mastiff dogs without medial coronoid disease and with medial coronoid disease, including p values, SEM and 95% confidence intervals.

	Bernese Mountain	Bernese Mountain 250-300 d	English mastiff	English mastiff 250-300 d	MCD	MCD 250-300 d
R/U ratio	0.84 0	0.860	0.850	0.845	0.830*	0.830*
SEM	0.0018	0.0018	0.0015	0.0019	0.0038	0.026
95% CI	0.838, 0.845	0.854, 0.862	0.843, 0.849	0.842, 0.850	0.821, 0.837	0.822, 0.835

R/U ratio = the length of the radius divided by the length of the ulna. MCD = dogs with medial coronoid disease, EM = English mastiff dogs, BMD = Bernese Mountain dogs. * $p < 0.05$.

Figure 1: Craniocaudal and lateral radiographic projections, and transverse and sagittal plane CT images of the left elbow of a Bernese mountain dog with bilateral elbow dysplasia due to fragmentation of the medial coronoid process. On the radiographic images, the margins of the medial coronoid process are indistinct. On the CT images, a distinct triangular mineral fragment can be seen adjacent to the medial coronoid process, consistent with a diagnosis of left fragmented medial coronoid process.
84x104mm (300 x 300 DPI)

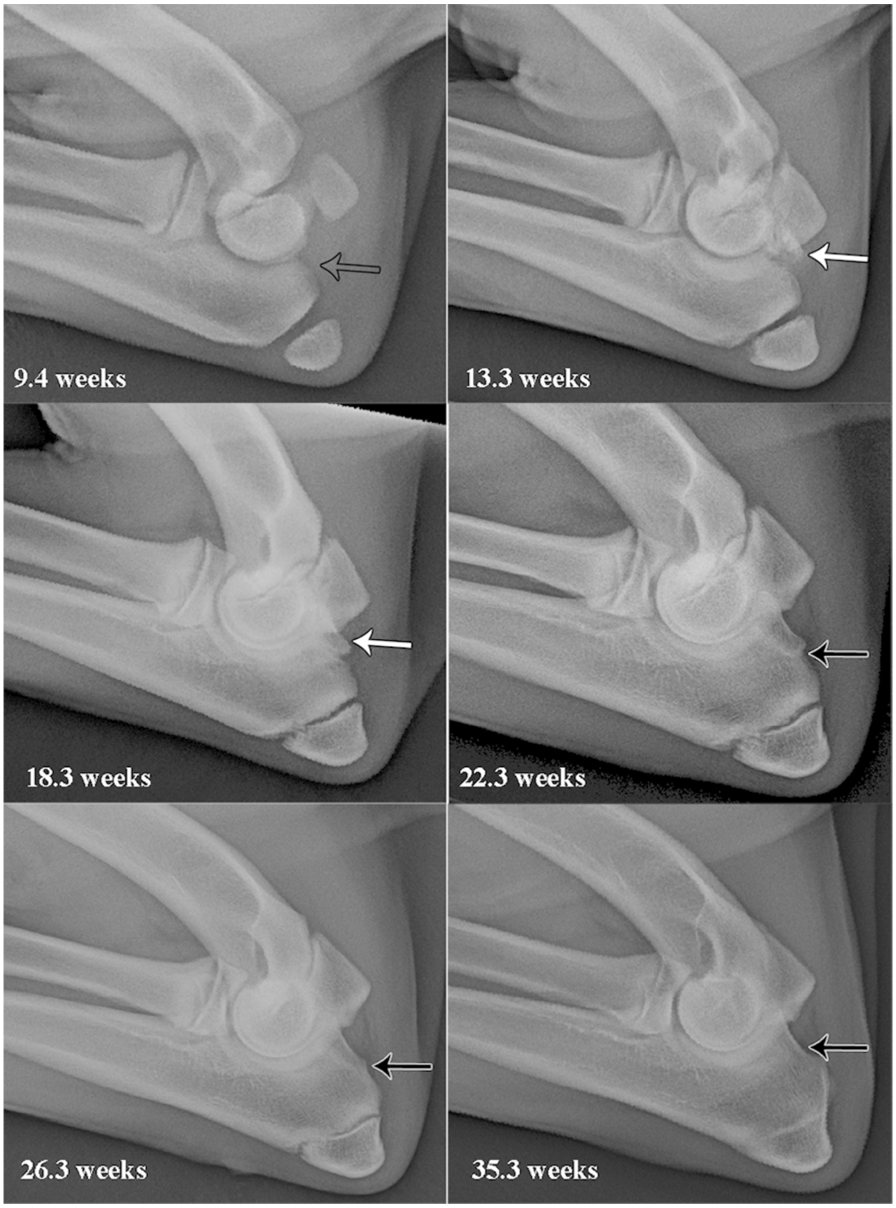

Figure 2: Flexed lateral radiographs of the right elbow of a Bernese mountain dog with a SCOAP. At 9.4 weeks of age, no mineral opaque SCOAP is seen (black rimmed arrow). The SCOAP is first seen in this dog at the radiographic visit at 13.3 weeks of age (white arrow). Fusion of the SCOAP to the anconeal process is occurring at 18.3 weeks of age (white arrow). The SCOAP is fused to the anconeal process (black arrows) and a thin physeal scar noted at 23.3 weeks of age, with continued remodeling of the region of the SCOAP seen at the radiographic visit of 26.3 weeks of age. At 35.3 weeks of age, there is no radiographic evidence at this dog had had a SCOAP.
84x114mm (300 x 300 DPI)

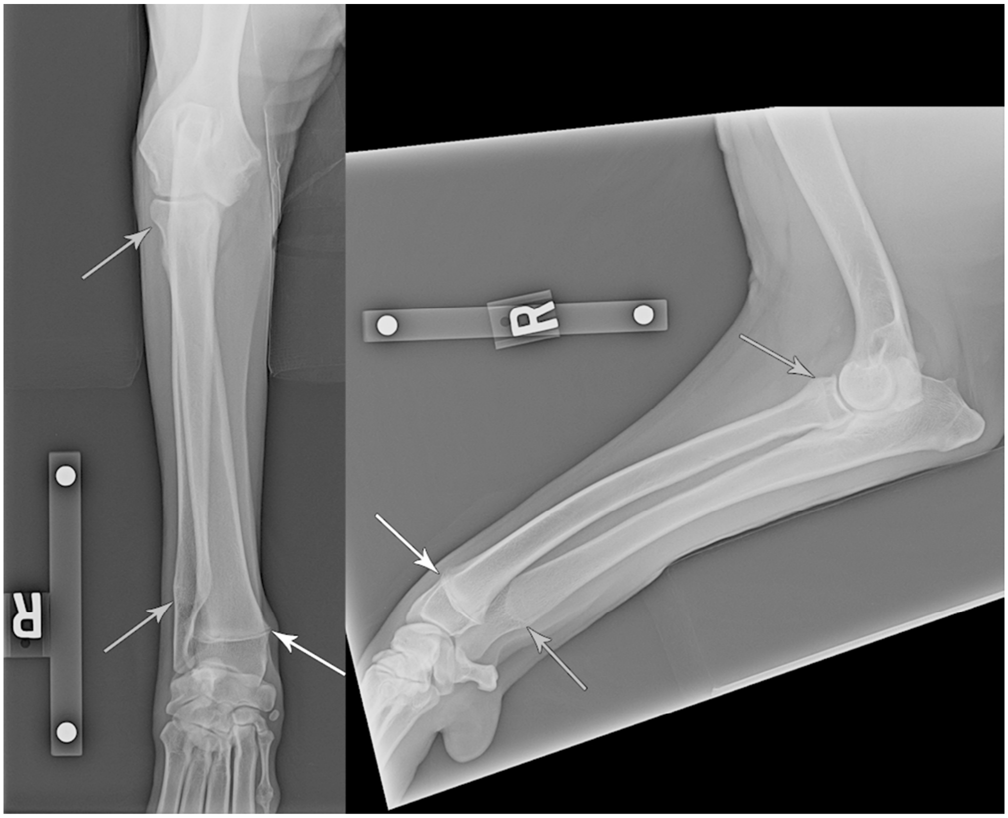

Figure 3: Craniocaudal and neutral lateral projections of the right elbow of the Bernese mountain dog with dyssynchronous physeal closure and bilateral MCD at 11.4 months of age. The open physes of the distal radius are indicated with white arrows, and the closed physes of the proximal radius and distal ulna are indicated with grey arrows. This is a right forelimb of the same dog as in Figure 1, and on the lateral projection, the medial coronoid process of the ulna is indistinct and blunted.
84x68mm (300 x 300 DPI)

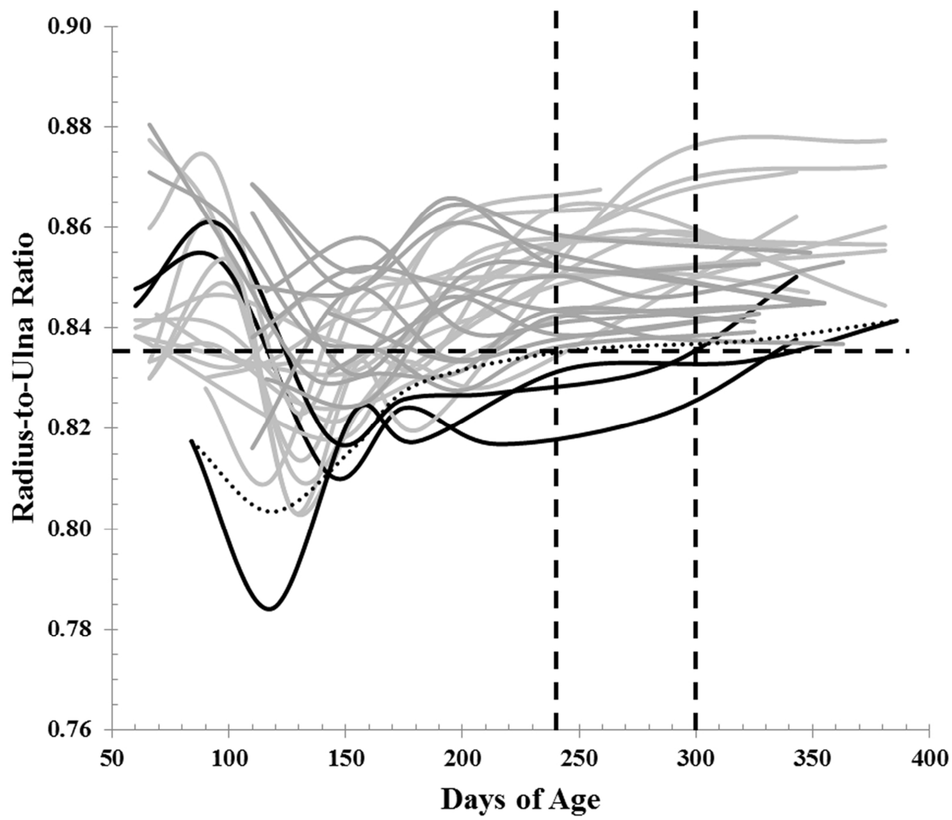

Figure 4: Ratio of the length of the radius to the length of the ulna with individual lines for each forelimb of each dog in the study. The radius/ulna ratio of dogs with MCD (Black line) was lower than Bernese mountain dogs (light gray line) and English mastiff dogs (gray lines) without MCD. For the dog with unilateral MCD, the affected limb is depicted with a solid line and the unaffected limb is depicted with a dashed line. Between 240 and 300 days of age, all MCD affected forelimbs had a radius/ulna ratio of less than 0.835 with no of affected and unaffected forelimbs.
71x60mm (600 x 600 DPI)