Comparison of the radius of curvature of the ulnar trochlear notch of Rottweilers and Greyhounds

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Objective—To compare radius of curvature along the ulnar trochlear notch of Rottweilers and Greyhounds to determine whether morphologic differences exist that may contribute to the cause and pathogenesis of fragmented coronoid process in Rottweilers.

Sample Population—Paired elbow joints from 13 Rottweilers and 14 Greyhounds.

Procedure—Elbow joints were radiographically scored on the basis of severity of osteoarthritic lesions. The articular contour of each ulnar trochlear notch was digitized. The radius of curvature at defined points along the ulnar trochlear notch was compared between breeds.

Results—Radius of curvature of the ulnar trochlear notch was not a constant function of arc length in either breed but had a consistent characteristic appearance in both breeds. Radius of curvature was greatest at each end of the ulnar trochlear notch and had 2 peaks in the midportion of the notch in both breeds. These peaks occurred farther distally in the notch and were larger in Rottweiler ulnae than Greyhound ulnae. A significant difference in mean radius of curvature was detected between breeds at these peaks. Greyhounds had significantly greater mean radius of curvature at the end of the medial coronoid process, compared with Rottweilers.

Conclusions and Clinical Relevance—Radius of curvature of the ulnar trochlear notch is a complex function of arc length in Rottweilers and Greyhounds. The waveform has a consistent characteristic appearance in both breeds. Although significant differences were identified between breeds, associations between these differences and cause or pathogenesis of fragmented coronoid process in Rottweilers were not apparent. (Am J Vet Res 2001; 62:968–973)

Fragmented coronoid process is the most commonly identified developmental orthopedic disease of the elbow joint in large-breed dogs.1,2 The cause and pathogenesis of fragmented coronoid process have yet to be elucidated. Fragmented coronoid process was initially thought to be a manifestation of osteochondrosis3; however, the histologic and ultrastructural appearance of the lesions is more consistent with mechanical failure of the cartilage and subchondral bone of the coronoid process and subsequent ineffective fibrous repair than with osteochondrosis.4,6

Grondalen and Grondalen1 speculated that osteochondral fissures or fractures may be the result of conformational abnormalities that place excessive loads on the developing medial coronoid process. Wind7 reported that elbow incongruity may be present in dogs with fragmented coronoid process. The normal radioulnar joint articulation is characterized by a smooth transition between the ulnar trochlear notch and the proximal articular surface of the radial head.8 Necropsies of dogs with fragmented coronoid process reveal that the mediocoronal process and distal edge of the ulnar trochlear notch are often positioned slightly proximal to the adjacent articular surface of the radial head.9,10 This incongruity is theorized to place excessive load on the developing medial coronoid process during weight-bearing and is implicated as the cause of fragmentation.11 Elbow incongruity is speculated to result from asynchronous growth between the radius and ulna, specifically radial growth lagging behind that of the ulna.12 Development of the ulnar trochlear notch is characterized by a smooth transition of the articular surface of the radial head.7,9 This incongruity is thought to be a manifestation of osteochondrosis14; however, the histologic and ultrastructural appearance of the lesions is more consistent with mechanical failure of the cartilage and subchondral bone of the coronoid process and subsequent ineffective fibrous repair than with osteochondrosis.16

Subjective differences in the anatomic conformation of the articular structures of the canine elbow have been described. Heavy-set breeds have a relatively large proximal ulna and a slightly larger, wider, less steeply sloping medial coronoid process, compared with those of coursing breeds.1 These anatomic differences may suggest an increase in the weight-bearing function of the ulna in heavy-set dogs.

Quantitative characterization of the morphologic features of the elbow joint would be useful to more accu-
rately define these observed conformational differences. Accurate evaluation of the radius of curvature of the ulnar trochlear notch has been difficult because of the anatomic complexity of the elbow joint. Recent advances in computer technology have led to the development of equipment and software programs capable of performing this task. It was our hypothesis that the radius of curvature of the ulnar trochlear notch of breeds of dogs with a high incidence of fragmented coronoid process would be different from that of the ulnar trochlear notch of breeds of dogs not typically affected with this condition. The purpose of the study reported here was to objectively compare the radius of curvature of the ulnar trochlear notch of the elbow joints of adult Rottweilers, a breed of dog with a high incidence of fragmented coronoid process, with that of adult Greyhounds, a breed of dog in which fragmented coronoid process has only been reported as a traumatic sequel to racing, to determine whether there are differences in the morphologic features of the ulnar trochlear notch that may contribute to the development of this condition.

**Materials and Methods**

**Elbow joints**—The forelimbs of 13 adult Rottweilers and 14 adult Greyhounds were harvested within 6 hours of euthanasia. Although complete signalment and historical information was not available for some of these dogs, none of the dogs were euthanatized for reasons related to elbow dysplasia. All limbs were initially stored at –20°C. The limbs were thawed to 20°C, the surrounding soft tissues were debrided from the limbs, and the elbow was disarticulated and visually evaluated for the presence of degenerative changes. All limbs were then fixed in neutral-buffered 10% formalin. Craniocaudal and lateral radiographs of each humerus, radius, and ulna were obtained with a digital radiographic system. The radiographic scoring system established by the International Elbow Working Group was used to grade the degree of osteoarthritic change (Appendix) by 1 investigator (SMN). This investigator was aware of breed of dog for each elbow, because obvious morphometric characteristics within both breeds made this impossible.

**Digitization**—The articular plane of the ulnar trochlear notch of each ulna was determined by use of a 3-dimensional digitizing instrument and accompanying software. This task was performed by a single operator (KEC) who was unaware of the radiographic score group of each elbow. The operator was aware of the breed of dog for each elbow, because obvious morphometric characteristics within both breeds made this impossible. The articular plane of the ulnar

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**Figure 1**—Photograph of the ulna of a dog. Notice reference points on the ulnar trochlear notch. A = Anconeal process. B = Approximate midpoint of the ulnar trochlear notch. C = Craniomedial tip of the medial coronoid process.

**Figure 2**—Schematic representation of reduction of digitized spatial data of the radius of curvature of the ulnar trochlear notch in Rottweilers and Greyhounds. A—Original digitized spatial data. B—Spatial data after coordinate rotation. C—Rotated data fit with sixth-order polynomial. Notice that this particular data set was rotated 45°, because through visual inspection, this rotation angle gave the best curve fit. D—Natural coordinate (s) begins at anconeal process and ends at medial coronoid process. E—Normalized natural coordinate (s*) constructed so that 0 ≤ s* ≤ 1. F—Radius of curvature versus the normalized distance along the notch.
trochlear notch was defined by use of 3 references points: the cranial tip of the anconeal process, the midpoint of the trochlear notch, and the crano-medial tip of the medial coronoid process (Fig 1). After this plane was defined, the intersection of the plane with the intact hyaline cartilage surface of the ulnar trochlear notch was digitized. The resulting series of data points was coincident with the articular surface and the defined articulation plane.

A 6-step reduction of the digitized spatial data was performed to allow radii of curvature comparisons between dog breeds at the same relative anatomic position along the trochlear notch (Fig 2). The original Cartesian x-y reference frame of each set of planar spatial data was translated so that the tip of the anconeal process (the first spatial data pair) was located at \((x_0, y_0) = (0, 0)\). The frame was successively rotated about the fixed origin while simultaneous sixth-order polynomial curve fits were performed on the rotated spatial data. The rotation that resulted in the highest regression correlation coefficient \((R^2)\) was selected as the frame in which to express the curve fit. Sixth-order fits resulted in no spurious noise for any of the data sets. Lower-order fits were investigated but were less satisfactory, especially in the middle portion of the notch; higher-order polynomial fits resulted in spurious noise. The radius of curvature \(\rho\) of each set was computed at each rotated spatial data pair \((x', y')\), using the formula

\[
\rho = \left[1 + \left(\frac{dy'}{dx'}\right)^2\right]^{3/2} / \left(\frac{d^2y'}{dx'^2}\right)
\]

where \(d\) is the derivative operator from the calculus.

A natural coordinate \(s\) was defined along the trochlear notch beginning at the first and ending at the last rotated spatial data pair. A natural coordinate value \(s_n\), beginning with \(s_0 = 0\), was determined for each pair from the equation

\[
s_n = s_{n+1} + (x_n - x_{n+1})^2 + (y_n - y_{n+1})^2;\quad n = 1, 2, 3, ..., N
\]

where the last term represents the distance between successive \((x', y')\) pairs and \(N\) is the number of \((x', y')\) pairs. A normalized natural coordinate \(s^*\) was constructed such that \(0 \leq s^* \leq 1\), \(s^* = 0\) at the tip of the anconeal process, and \(s^* = 1\) at the tip of the medial coronoid process. Finally, the radii of curvature were expressed as a function of the normalized natural coordinate for each data set.

### Results

All Rottweiler elbow joints had gross evidence of degenerative joint disease ranging from mild to severe. Four Rottweiler elbow joints were determined to be

<table>
<thead>
<tr>
<th>Breed</th>
<th>Normal</th>
<th>Mild arthrosis</th>
<th>Moderate arthrosis</th>
<th>Severe arthrosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greyhounds</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rottweilers without FCP</td>
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<td>13</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Rottweilers with FCP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
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FCP = Fragmented coronoid process.
*See Appendix for criteria for radiographic scores.

Figure 3—Sixth-order polynomial curves fit to raw planar articular contour data for the ulnar trochlear notch. In 2 Rottweiler elbows, representing the best fit for all elbow joints (top) and the worst fit for all elbow joints (bottom).
Radiographically normal. Four Rottweiler elbow joints had a gross lesion consistent with fragmented coronoid process; 1 elbow joint each in the mild and moderate osteoarthrosis groups, and 2 in the severe osteoarthrosis group. There was an even distribution of left and right Rottweiler elbows among the radiographic score groups. Neither gross nor radiographic evidence of degenerative joint disease was found in any of the Greyhound elbow joints (Table 1).

Radius of curvature data was best fit by use of a sixth-order polynomial function. This order function resulted in a mean $R^2$ value of 0.9960 (range, 0.9808 to 0.9988) for both breeds (Fig 3). Maximum observed error associated with curve fit for all curves (200 µm) was less than the accuracy of our digitizing instrument (230 µm). The Rottweiler ulna with the poorest polynomial curve fit had a step deformity in the articulation of the radius and ulna. At the medial margin of the radius, the articular surface of the radial head was situated proximal to the articular surface of the medial coronoid process. This incongruency may have affected our ability to accurately digitize the ulnar surface in this region.

Radius of curvature of the trochlear notch was not a constant function of arc length in either breed. The plot of radius of curvature as a function of length along the trochlear notch in both breeds had a consistent characteristic appearance. The radius was greatest at the ends of the curve corresponding to the anconeal and coronoid processes. The midportion of the curve had 2 peaks and 3 corresponding troughs in both breeds (Fig 4).

Within breed comparisons of right and left trochlear notch mean radius of curvature revealed no significant differences at any evaluation point in the Greyhounds. Comparison of right and left Rottweiler trochlear notches revealed significant differences in mean radius of curvature at 20, 25, 40, and 70% of ulnar trochlear length. Between breed comparisons of trochlear notch mean radius of curvature revealed significant differences at several locations along the curves. The mid-portion radius of curvature peaks occurred farther distally in the notch and was of greater magnitude in Rottweiler ulnae, compared with Greyhound ulnae. Corresponding significant differences in mean radius of curvature between breeds were seen at these peaks. Greyhound trochlear notches had significantly greater mean radius of curvature at the tip of the coronoid process, compared with Rottweiler trochlear notches (Fig 4). No other factors or interactions were found to be significant.

One Rottweiler ulna from the mild arthrosis group was excluded from statistical analysis, because it had a negative (convex) radius of curvature at the coronoid process. This ulna appeared to be grossly and radiographically similar to all other Rottweiler ulnae. The difference was attributed to a technical digitization error. The ulna was sectioned for histologic analysis and was unfortunately not available for redigitizing.

**Discussion**

Wind proposed that elbow joint incongruity and subsequent fragmentation of the medial coronoid process may result in part from ulnar trochlear notch dysplasia; the ulnar trochlear notch in dogs with elbow joint disease is slightly elliptic in shape, with an articular curvature of a radius that is too small to fully encompass the humeral trochlea. This hypothesis has not been fully examined because of difficulties in accurately measuring trochlear notch curvature. Our intent was to evaluate this hypothesis further, using current technology that would allow precise determination of trochlear notch radius of curvature.

Our data indicated that the radius of curvature waveform of the ulnar trochlear notch was a complex function of arc length in the 2 breeds we examined. We expected the radius of curvature to be a constant function of arc length throughout the trochlear notch (a flat radius of curvature waveform) because of the hinge-type conformation of this joint. Instead, the radius of curva-
turity was greatest at the ends of the notch and had 2 additional peaks in the midportion of the notch. This characteristic can be seen as 2 relatively flat spots along the trochlear notch contour (Fig 3). This finding was remarkably consistent within and between breeds, especially in the Greyhounds, as indicated by the small dispersion of the data. The functional reason for the trochlear notch having these morphologic characteristics was not apparent. We do not believe these findings are an artifact of data collection, because the definition of the digitization plane was precise, and the digitization methods were accurate. The radius of curvature waveform may reflect functional adaptations to maximize congruency within the small range of motion angles that develop during weight bearing while also allowing extremes of flexion and extension. Alternatively, this waveform may be necessary to allow congruent flexion and extension of the elbow joint at varying degrees of pronation and supination. Regardless, we do not believe that differences in prevalence of elbow joint dysplasia among breeds may be entirely explained by the ulnar trochlear notch simply being too closed or too open, as it has been hypothesized.

Significant differences in mean trochlear notch radius of curvature at isolated discrete points were seen between right and left elbow joints of Rottweilers. Similar differences were not seen in the Greyhound elbow joints. There is no data to support preferential use of a limb in symmetric gaits such as the trot,17,18 which could explain this finding in Rottweilers. We would have been less surprised to find right-left differences in the Greyhounds. Right-left differences in skeletal properties have been detected in racing Greyhounds, attributable to the counterclockwise racing direction; Greyhounds used in our study had been used for racing. Articular cartilage lesions cannot explain the differences between left and right Rottweiler ulnae, because there was no eburnation or loss of articular cartilage along the plane of digitization. There was an even distribution of left and right Rottweiler elbow joints among the radiographic score groups. The importance of this finding in Rottweilers is uncertain.

Significant differences between breeds in mean radius of curvature were seen at several points along the trochlear notch. Rottweilers had a significantly smaller mean radius of curvature at points corresponding with the medial coronoid process (95 and 100% of trochlear notch length), indicating a more closed notch in this area. Conceivably, this could place increased stress on the medial coronoid process, resulting in incongruity and subsequent degenerative changes. However, this study did not examine humero-ulnar congruity; so conclusions based on this finding should be made cautiously.

Significant differences in mean radius of curvature between breeds were also seen at both midportion waveform peaks. The Rottweiler waveform peaks were typically greater in magnitude and occurred farther distally along the trochlear notch. There are 3 possible interpretations of this finding with regard to the development of osteoarthritis: the difference is primary and unrelated to osteoarthritic changes; the difference is primary and contributes to the osteoarthritic changes; or the difference is secondary to the degenerative process. It is impossible to determine from the available data whether these differences are primary differences in joint morphologic features or secondary joint changes. All Rottweiler elbow joints had gross evidence of osteoarthritis, and an unaffected group of Rottweiler elbow joints was not available for comparison. As discussed earlier, the importance of these midportion peaks is uncertain, therefore, suggestion that the location and size of the peaks is a causative factor for osteoarthritis is speculative. If the differences are attributable to primary morphologic differences, causality cannot be confirmed by use of the present data.

It has been suggested that shape or geometric features of the articulating surfaces of a joint may contribute to the development of osteoarthritis.20-21 Bullough et al20 stated that there is a necessary physiologic incongruity in diarthrodial joints that facilitates the even distribution of load across the joint surfaces, maximizes joint stability, and maintains the nutrition of articular cartilage by facilitating the movement of synovial fluid into the articular cartilage. Age-related remodeling of joints results in altered load distribution with subsequent articular cartilage degeneration and development of osteoarthritis.26 It is unlikely that age-related remodeling of joints plays a role in the development of fragmented coronoid process, because this disease occurs in young dogs. Shepstone et al27 compared the morphologic features of the distal portion of the femur in human knee joints with and without eburnation of the articular cartilage. These authors found that there was a difference in the shape of femora with and without eburnation, but they could not conclude that any of the observed differences in shape are risk factors for the development of osteoarthritis in human knee joints.

The cause of fragmented coronoid process in Rottweilers cannot be explained by data of the study reported here. Our study examined only a single component of the elbow joint, the articular plane defined by the ulnar trochlear notch. This articular plane is not the same as, or parallel to, the sagittal plane defined by the cross-section of the humeral condyle with the smallest diameter. The task is a mechanical one, because the coronoid process is medial to the center of the humeral condyle, and it has been implied, although not biomechanically proven, that most of the weight-bearing forces in the elbow joint are transmitted from the humeral condyle to the radial head.28 This has been supported during mechanical evaluation of radial fracture repair models and in studies of articular contact areas within the elbow joint.7 Evolutionary adaptation of the distal limbs of cursorial vertebrates has resulted in a reduction of bone and muscle mass to maximize endurance and economy of effort. To compensate for the loss of structural support, the joints of these animals have been modified to function as hinges, allowing motion only in the line of travel through the development of interlocking splines and grooves in the joints.24 These anatomic modifications are easily identified within the canine elbow joint and lead to the conclusion that the primary role of the ulna is stabilization of the elbow joint, whereas that of the radius is weightbearing.
Joint congruity was not specifically examined in our study, and conclusions regarding congruity would be highly speculative. Stress placed on the medial coronoid process attributable to joint incongruity is likely to be dynamic, making precise in vitro measurements of articular surface congruity difficult. We have, however, identified significant morphologic differences between the ulnar trochlear notch of Greyhounds and Rottweilers, which warrants further investigation.

References


Appendix

Radiographic scoring system of the International Elbow Working Group

Normal (grade 0) — No radiographic evidence of osteophytes in the joint.
Mild arthrosis (grade 1) — Radiographic evidence of osteophytes (height, < 2 mm) found anywhere in the joint.
Moderate arthrosis (grade 2) — Radiographic evidence of osteophytes (height, 2 to 5 mm) found anywhere in the joint.
Severe arthrosis (grade 3) — Radiographic evidence of osteophytes (height, > 5 mm) found anywhere in the joint.