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Digital Radiographic Analysis of Optical Density of the Distal Segment of the Trochlear Notch of the Ulna in Labrador Retrievers with Fragmented Coronoid Process

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Abstract

The aim of the study was to find whether there is a difference in the optical density of the subtrochlear region of incisura trochlearis and in the region of processus coronoideus medialis ulnae in elbow joints with fragmented processus coronoideus and in healthy elbow joints of the Labrador retriever breed.

We evaluated digital radiographs of elbows (n = 26) with arthroscopically or arthrotomically proven FCP and digital radiographs of healthy elbows (n = 28). A template was made on radiographs in the JiveX program (Visus Technology Transfer) demarcating individual regions of interest (ROI) in which median optical density was measured. For normalisation of median optical density data of individual ROI, median optical density of the caudal ulnar cortex was used. Elbow joints with fragmented processus coronoideus had a lower mean median optical density in the distal part of incisura trochlearis compared to healthy elbow joints. The lowest median optical densities were found in the region of processus coronoideus medialis and in the distal part of the trochlear notch of the ulna in the region of processus coronoideus lateralis. The biggest difference in median optical densities between elbows with FCP and healthy elbows was found in regions distant from the articular surface.

In evaluation of the opacity of the trochlear notch of the ulna it is appropriate to assess the whole region of the proximal ulnar metaphysis from the articular surface to the caudal ulnar cortex.

Dog, elbow dysplasia, subtrochlear sclerosis, fragmented coronoid process

Fragmented processus coronoideus medialis (FCP) is the most frequently occurring developmental disease of the elbow in dogs (Wind and Packard 1986; Boulay 1998; La Fond et al. 2002; Meyer-Lindenberg et al. 2002; Gemmill et al. 2006). FCP occurs alone or less frequently in combination with OCD of the medial humeral condyle or UAP (Guthrie and Pidduck 1990; Meyer-Lindenberg et al. 2002; Rovesti et al. 2002; Meyer-Lindenberg 2006). It is a disease with breed predisposition. Large breeds of dogs are affected most frequently; FCP has been found even in small breeds of dogs and crossbreeds (Boulay 1998). Most often affected breeds include the Labrador retriever, Golden retriever, Rotweiler, Bernese mountain dog, Mastiff, German shepherd and Chow-chow (Boulay 1998; La Fond et al. 2002; Morgan et al. 2000; Bissenik et al. 2005).

Classification of elbow dysplasia (ED) as per protocol of the International Elbow Working Group (IEWG), classification of ED according to Lang et al. (1998) as well as classification of ED according to the Orthopaedic Foundation for Animals is based on evaluation of elbow joint congruity and the extent of osteoarthrotic changes. As one of the classification criteria these systems also use subjective evaluation of subchondral sclerosis and radio-opacity of the trochlear notch of the ulna. In dogs with FCP, subtrochlear sclerosis of ulnar metaphysis and the presence of periarticular osteophytes are much better indicators of the

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presence of FCP than radioulnar incongruity (Mason et al. 2002). Subjective evaluation of subchondral sclerosis consists of simple visual assessment of radio-opacity of the subchondral bone. Regions with higher radio-opacity (lower optical density) are evaluated as more sclerotic than less radio-opaque regions (with higher optical density). Subjective evaluation of radio-opacity by more examiners may therefore vary markedly, especially in a bilateral disease when comparison of radio-opacity of the trochlear ulnar notch and PCM with the contralateral extremity is impossible (Hornof et al. 2000). For measuring the extent of subchondral sclerosis a method has been developed which is, however, based on subjective evaluation of subchondral sclerosis (Smith et al. 2009). The aim of the study was to monitor optical density of the subtrochlear region of incisura trochlearis and the region of processus coronoideus medialis (PCM) of the ulna in elbows with FCP and in healthy elbows of the Labrador retriever breed using digital radiography and to find whether there is a difference in optical density of the subtrochlear region of the ulna between elbows with FCP and healthy elbows. Null hypothesis presumed no difference in optical density of the subtrochlear region of the ulna between elbows with FCP and healthy elbows. Alternative hypothesis presumed a difference in optical density of the subtrochlear region of the ulna between elbows with FCP and healthy elbows.

Materials and Methods

Inclusion criteria

The study included a total of 26 elbows of 16 dogs of the Labrador retriever, patients of the Department of Diagnostic Imaging and the Department of Surgery and Orthopaedics of the Small Animal Clinic, Faculty of Veterinary Medicine, University of Veterinary and Pharmaceutical Sciences Brno. The criterion for inclusion of elbows into the study was an arthrotomic or arthroscopic proof of FCP. The control group was formed by 28 healthy elbows of 14 dogs of the Labrador retriever. The criterion for inclusion into the control group was a negative finding regarding possible pathological changes during orthopaedic and radiological examination of the elbow. Orthopaedic examination indicating elbow disease included establishing a restricted extent of motion in the elbow joint, crepitation, swelling of the elbow joint, palpable joint effusion and pain during elbow handling. Radiological examination indicating elbow disease included subtrochlear sclerosis of the ulna and sclerosis of the base of processus coronoideus medialis (PCM), apparent fragmentation, rounding or blurred boundary of the cranial border of PCM, formation of osteophytes and enthesophytes and joint effusion. The control group did not include dogs that manifested elbow disease in the contralateral extremity or that concurrently showed any clinical or radiological signs of elbow dysplasia in the contralateral extremity.

Radiography

All radiographs were made under deep sedation induced by combination of medetomidine (10-20 µg/kg i.v.) and butorphanol (0.2 mg/kg i.v.), or in general intravenous anaesthesia (medetomidine 10-20 µg/kg i.v., butorphanol 0.2 mg/kg i.v., propophol 1 mg/kg). Radiographs of elbows were taken in mediolateral (ML) projection in the standing angle (approximately 120° semiflexion in the elbow joint) and in craniocaudal oblique projection (Cr15L-CdMO). Radiographs were made on the X-ray apparatus Proteus XR/a. The X-ray image was recorded in a digital form in DICOM format 1170 × 2370 px resolution (CR, Capsula XL, Fuji). All radiographs were made without the use of grid with the cassette placed immediately under the elbow joint.

Estimation of optical density

Digital analysis of optical density was performed in the JiveX program (Visus Technology Transfer). For evaluation of optical density of incisura trochlearis ulnae we used our own method. A template was made on the mediolateral radiograph of the elbow, consisting of a system of concentric circles and sectors. A circle was made that corresponded as closely as possible by its shape to the shape of the trochlear ulnar notch. Furthermore, another concentric circle was made that touched the cranial border of the caudal ulnar cortex. The third concentric circle copied the caudal border of the superposition of the trochlear ulnar notch with humeral condyles. The fourth and fifth concentric circles were placed at 1/3 and 2/3, respectively, of the distance between the circle copying the caudal border of humeral condyles and the circle copying the cranial border of the caudal ulnar cortex. Furthermore, sectors of 15° (± 1°) were made with the peak coming from the centre of concentric circles. First, a connecting line was made from the centre of concentric circles to the cranial border of processus coronoideus lateralis ulnae. From this line we made four 15° sectors in the caudal direction and two 15° sectors in the cranial direction of a total extent of 90 °. By intersection of the sectors and circles individual regions of interest (ROI) were delineated, marked 0°-15° A, 0°-15° B, 0°-15° C, 16°-30°A, 16°-30°B 16°-30°C, 31°-45°A, 31°-45°B, 31°-45°C, 46°-60°A, 46°-60°B, 46°-60°C, 61-75°A, 61-75°B ,61-75°C, 76-90°A, 76-90°B, 76-90°C. The cranial border of ROI 0°-15° A, 0°-15° B, 0°-15° C was demarcated by the cranial border of PCM. The region of interest of the cranial apex of PCM (ROI PCM) was demarcated only subjectively according to the assumed course of the cranial border of PCM (Plate XVII, Fig. 1). The region of interest of the humeral trochlea (ROI humerus) was demarcated by the circle corresponding as closely as possible by its shape to the shape of the humeral trochlea. In each ROI optical density of the radiograph was measured. Furthermore, three parallel lines were drawn intersecting the caudal ulnar cortex. The first line (A) ran parallel to the radial plateau. The second parallel line (B) intersected the cranial tip of processus anconeus ulnae. The third parallel line (C) intersected the caudal cortex of the ulna distally from the radial plateau at the same distance as that of lines A and B. The region of interest in the caudal cortical bone was delineated by the thickness of the cortical bone and the two parallel lines A and C. In thus demarcated ROI, median optical density was measured (Plate XVII, Fig. 2). In order to take into consideration the size of the elbow (or the size of the patient) and different expositions, median optical density in individual regions of interest was divided by the median optical density of the region of interest of the ulna. The result was the mean relative median optical density of individual regions of interest. We compared relative optical densities of ROI 0-90° of healthy elbows and elbows with FCP, and relative optical densities of corresponding regions of interest (ROI) in healthy and diseased elbows. In the control group of healthy elbows we observed correlation of the change of optical density of the caudal cortex of the ulna and the change of the optical density in the distal (ROI 31-45°A) and caudal part of incisura trochlearis (ROI 76-90°A).

Statistical analysis

For statistical analysis of the mean median optical density of individual ROI of the ulna of elbows with FCP and the control group Student's *t*-test was used. For finding correlation between the median optical density of the cortical bone of the ulna and the optical density of the selected region of incisura trochlearis regression analysis was used.

Results

The group of elbows with FCP included 26 elbow joints of 16 dogs (11 males and 5 females). Of these, 10 dogs manifested bilateral disease, 6 dogs were affected unilaterally. Their mean age was 16.1 months (SD ± 6.19) within the range of 6-24 months. The control group included 28 elbows of 14 dogs (8 females and 6 males). Their mean age was 12.7 months (SD ± 1.66) within the range of 10 to 15 months.

We found a high correlation between the median optical density of the caudal cortex of the ulna and the optical density of the distal part of the trochlear ulnar notch (ROI 31-45°A) with a correlation coefficient of $r = 0.96$, determination coefficient of $r^2 = 0.93$ and level of significance of $p = 4.2 \times 10^{-12}$ (Fig. 3). Likewise, we found a high correlation between the median optical density of the caudal cortex of the ulna and the caudal part of incisura trochlearis (ROI 76-90°A) with a correlation coefficient of $r = 0.93$, determination coefficient of $r^2 = 0.86$ and level of significance of $p = 4.79 \times 10^{-6}$ (Fig. 4).

We found a highly significant difference between the mean relative median optical density of incisura trochlearis ulnae of elbows with FCP and the control group of healthy elbows (Student's *t*-test, $p < 0.001$). The mean relative median optical density of the trochlear ulnar

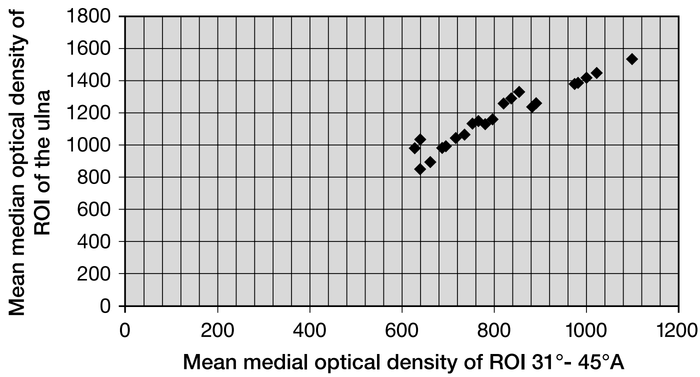

Fig. 3. Correlation between mean median optical density of the caudal cortex of the ulna and the mean median optical density of the distal part (ROI 31°-45°A) of incisura trochlearis

notch was lower in elbows with FCP than in elbows of the control group. Mean relative median optical densities of the distal segment of the trochlear notch of the ulna in healthy elbows and in elbows with FCP are presented in Table 1.

Mean values of relative median optical density of the trochlear notch of the ulna and the humeral trochlea of elbows with FCP and the control group of healthy elbows are presented in Fig. 5. In the region of cranial apex of PCM (p = 0.96) and in the caudal third of the caudal part of the trochlear notch of the ulna in the ROI 61°-75°C (p = 0.38), ROI 76°-90°C (p = 0.76) we found no significant difference between mean relative median optical densities in elbows with FCP and the control group. Significant differences (p < 0.05) between relative median optical densities in the control group and the group of elbows with FCP were found at the base of PCM in the ROI 0°-15°A (p = 0.031), ROI 0°-15°C (p = 0.02), ROI 16°-30°A (p = 0.029), ROI 16°-30°B (p = 0.015) and in the cranial third of the caudal segment of incisura trochlearis ROI

Table 1. Mean relative median optical densities of the distal segment of the trochlear notch of the ulna in healthy elbows and elbows with FCP

Elbows	Healthy elbows	FCP
n	28	26
Mean	0.815250	0.726675
Median	0.829679	0.714824
Minimum	0.687572	0.502853
Maximum	0.925103	0.937956
SD	0.069079	0.119508

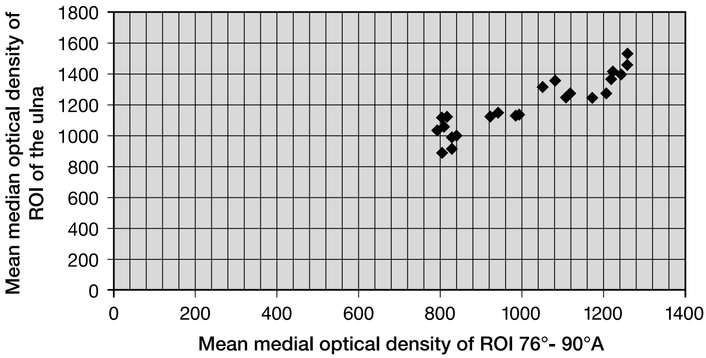

Fig 4. Correlation between the mean median optical density of the caudal cortex of the ulna and the mean median optical density of the caudal part (ROI 76°-90°A) of incisura trochlearis

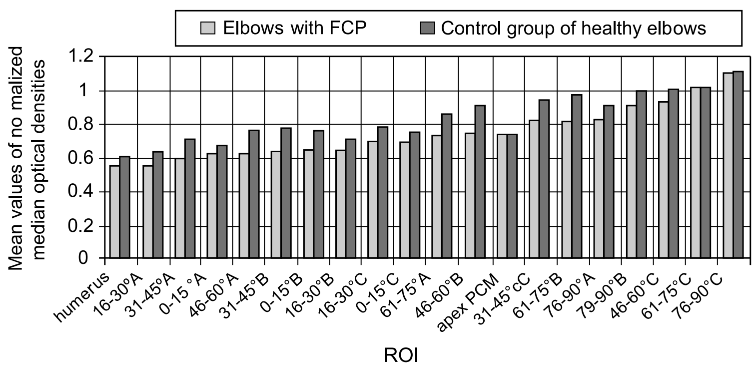

Fig 5. Mean values of normalized median optical density of incisura trochlearis of the ulna and humeral condyle of elbows with FCP and the control group of healthy elbows

76°-90°A (p = 0.027). Highly significant difference ($p < 0.01$) between relative median optical densities of the control group and the group of elbows with FCP was found along the trochlear ulnar notch in the ROI 0°-15°B ($p = 2.2 \times 10^{-7}$), ROI 16°-30°C ($p = 4.2 \times 10^{-4}$), ROI 31°-45°A ($p = 3.1 \times 10^{-3}$), ROI 31°-45°B ($p = 1.75 \times 10^{-5}$), ROI 31°-45°C ($p = 1.95 \times 10^{-5}$), ROI 46°-60°A ($p = 8.5 \times 10^{-4}$), ROI 46°-60°B (p = 0.0001), ROI 46°-60°C (p = 0.001), ROI 60°-75°A ($p = 5.6 \times 10^{-4}$), ROI 60°-75°B (p = 0.0004), ROI 76°-90°B ($p = 4.2 \times 10^{-3}$). We found no significant difference (p = 0.307) between mean relative median optical densities of the humeral trochlea of elbows with FCP and the control group. Fig. 6 (Plate XVIII) shows graphically the regions with significant differences between mean relative median optical densities of elbows with FCP and the control group of healthy elbows.

Discussion

Changes in optical density of the trochlear notch of the ulna may be best evaluated on ML neutral or ML flexion projection of the elbow in the distal part of the trochlear notch of the ulna (Wind 1986; Berry 1992; Hornof et al. 2000). For digital quantification of optical density in our study we used our own method derived from the method used in the study of Burton et al. (2007). By analysis of the obtained data in healthy elbows we found a very high correlation between the median optical density of the caudal cortex of the ulna and the median optical density of the selected segment of the distal and caudal part of the trochlear notch of the ulna. Similar results were obtained also by Burton et al. (2007), who found by a different method at various exposition values high correlation between the intensity of pixels of the caudal cortex of the ulna and the intensity of pixels of the selected regions of the trochlear notch of the ulna (r = 0.98). Correlation between the median optical density of the caudal cortex of the ulna and the median optical density of the selected segment of the trochlear ulnar notch was very high. These results therefore justified our using of optical density of the caudal cortex of the ulna for normalisation of the median optical density of the trochlear ulnar notch. Normalised median optical densities may then be compared even in radiographs with slightly different expositions.

The results of the study showed highly significant difference in the optical density of the trochlear notch of the ulna between the group of elbows with FCP and the control group of healthy elbow. In elbows with FCP we found lower optical density (increased radio-opacity) in the distal segment of the trochlear ulnar notch. These results are in agreement with the results of digital analysis of subchondral sclerosis of the trochlear ulnar notch in another study (Burton et al. 2007). They are also in agreement with the subjective evaluation of the opacity of the trochlear ulnar notch of elbows with FCP in other studies (Wind 1986; Berry 1992; Hornof et al. 2000).

Using fraction analysis of individual segments of the trochlear notch of the ulna the lowest mean median optical density (the most radio-opaque region) was found in healthy as well as diseased elbows in the region of PCM at the site of superposition with the head of the radius and in the region of the distal segment of the trochlear ulnar notch in the region of processus coronoideus lateralis in the proximity of articular surface. The results of our study correspond to the results of subjective evaluation of opacity of PCM and the trochlear notch of the ulna in other studies (Wind 1986; Hornof et al. 2000; Smith et al. 2009).

Although the lowest mean median optical densities were found at the base of PCM in the proximal third of the distal segment of the trochlear notch of the ulna, contrary to our expectations fraction analysis discovered the biggest differences in normalised median optical densities between elbows with FCP and healthy elbows in the control group in the medial and distal third of the trochlear ulnar notch, i.e. in regions more distant from the articular surface. Burton et al. (2007) reported the site with the biggest difference in pixel intensity was the proximal segment of the distal part of the trochlear ulnar notch in the region of the base of PCM. There may be several reasons leading to such discrepant results and they may be intercombined. The main cause is probably the difference in the method used. Although we have shown a high level of correlation between median optical density of the caudal ulnar cortex and the median optical density of the selected segment of the trochlear ulnar notch, the dependence curve need not have a linear form during the whole course, especially in the place of very high, or conversely, very low optical density. A certain problem may be posed by the relatively low number of elbows in our as well as in the previous study. The extent and size of osteophytes and subchondral sclerosis may be markedly different in elbows with FCP, and the representation of elbow joints with a varying extent of osteoarthrotic changes in our and the previous study may have affected the results of the study. In the region of the caudal third (cranially from the caudal cortex of the ulna) of the caudal part of the trochlear notch of the ulna we found no significant difference in mean median optical densities of elbows with FCP and the control group of healthy elbows. A probable cause of this phenomenon is the fact that the vertically directed articular surface of the caudal part of the trochlear ulnar notch is not a weight-bearing articular surface of the elbow and thus it is not exposed to abnormal load, and also the fact that it is distant enough from the insertion of the joint capsule. Likewise Burton et al. (2007) did not find in this part of the trochlear ulnar notch a significant change in pixel intensity between elbows with FCP and the control group of healthy elbows.

Using fraction analysis of mean median optical densities, significant difference was found in mean median optical densities of the base of PCM between healthy and diseased elbows. In elbows with FCP the mean median optical density of the base of PCM was lower (more sclerotic) than in healthy elbows, which corresponds to the subjective evaluation of radio-opacity of PCM in other studies (Wind 1986; Hornof et al. 2000; Berry 1992; Burton et al 2008). PCM in elbows with FCP is exposed to abnormal load and increased sclerosis of subchondral bone, thickening of trabecular bone and formation of periarticular osteophytes occur. Yet it is not possible to establish unambiguously from the results of our study to what extent PCM itself is involved in the change of optical density, and to what extent it is due to a change in optical density of the superposed head of the radius. In the region of the cranial apex of PCM we found no significant difference between elbows with FCP and the control group. The cranial apex of PCM in elbows with FCP is subjectively evaluated as hard to define and has a flattened, irregular, or rounded shape, or may be completely indistinct in ML projection (Hornof et al. 2000). There may be several reasons why we found no significant difference in optical densities of the cranial apex of PCM. Changes in optical density of a fragmented cranial apex of PCM vary considerably. The cranial apex of PCM may show both higher and lower radio-opacity. Fragmented apex of PCM may remain in the original position and continue to be nurtured via lig. anulare without any change in its density. The demarcation of the ROI of the cranial apex of PCM itself is burdened by certain error; especially in elbows with FCP the cranial border of PCM cannot be demarcated at all. The cranial apex of PCM has a negligible thickness compared to the head of the radius and in the total opacity of the ROI participates negligibly compared to the head of the radius.

We included in our study also the comparison of normalised median optical density of the humeral condyle of elbows with FCP and healthy elbows. Although the medial surface of the medial humeral condyle is a site of early osteoarthrotic changes (Morgan 2000), we found no significant difference in normalized median optical densities of humeral condyles. A probable cause of this finding is the fact that the size of enthesophytes on the medial humeral condyle is negligible, considering the total thickness of the humeral condyle. Likewise the zone of subchondral sclerosis on the medial humeral condyle is negligible considering the total surface of the humeral condyle.

Increased radio-opacity of the trochlear notch of the ulna in dysplastic elbows is probably due to subchondral sclerosis, thickening of bone trabecules and formation of periarticular osteophytes/enthesophytes along the medial border of the trochlear notch of the ulna (Burton et al. 2007). Articular surfaces respond to increased load by remodelling the subchondral bone which is manifested in radiographs by increased radio-opacity of the subchondral bone (Radin 1999; Samii et al. 2002). Increased radio-opacity of the trochlear notch of the ulna and PCM cannot be unequivocally explained merely by subchondral sclerosis and formation of periarticular osteophytes. In dogs with ED and FCP synovia is also multiplied and the joint capsule swollen. It cannot be unequivocally differentiated to what extent the absorption of X-rays is due only to bone structures and to what extent to the soft tissues. Considering the ratio of the thickness of bone structures and soft tissues, absorption of X-rays by soft tissues may be considered negligible in our study.

A weak point of this study lies mainly in the manual demarcation of the ROI. Demarcated ROI then do not contain always the same number of pixels. Considering the large surface of ROI and the measuring of mean optical density, it is possible to consider this fact as negligible with respect to the aim of the study. In dysplastic elbows with an elliptical shape of the trochlear notch of the ulna, cranial subluxation of humeral condyles occurs, and thus also of the centre of concentric circles. Therefore, the corresponding ROI of elbows with FCP and healthy elbows may not overlap completely. In evaluation of radio-opacity of the trochlear ulnar notch also the technique of radiograph production plays a role. On a markedly underexposed radiograph, changes caused by subchondral sclerosis can not be distinguished from the underexposition of the radiograph (Hornof et al. 2000). In contrast, Burton et al. (2008) found no significant difference in subjective evaluation of the opacity of the trochlear ulnar notch at six different expositions. Incorrect positioning with oblique imaging of humeral condyles leads to superposition of the medial part of the humeral condyle and the trochlear notch of the ulna. At the site of superposition, subchondral sclerosis is thus imitated even in a healthy elbow joint (Hornof et al. 2000).

The results of our study objectively confirm increased opacity of the subtrochlear region of ulnar metaphysis in elbows with FCP. The results of the study suggest that it is suitable to evaluate subtrochlear sclerosis as a sign of elbow dysplasia. The lowest optical densities (the most sclerotic regions) in elbows with FCP as well as healthy elbows were noted in the region of PCM and in the proximity of the articular surface of the distal segment of incisura trochlearis. The biggest differences in mean median optical densities were found in regions more distant from the articular surface. In evaluation of the opacity of the trochlear notch of the ulna it is appropriate to assess the whole region of the proximal ulnar metaphysis from the articular surface to the caudal ulnar cortex. An optimum solution for establishing the actual bone density is measuring the bone density using a bone densitometer with dual energy, or CT densitometry (Samii a kol. 2002).

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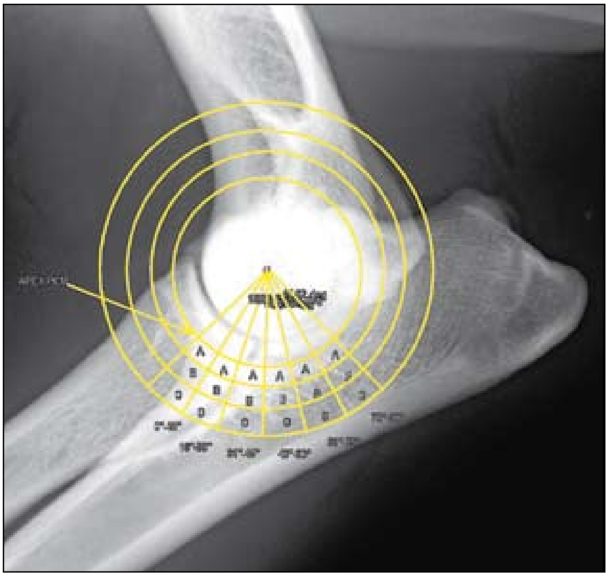

Fig. 1. Demarcation of individual regions of interest (ROI) on a radiograph of an elbow

Fig. 2. Demarcation of regions of interest (ROI) of caudal cortex of ulna

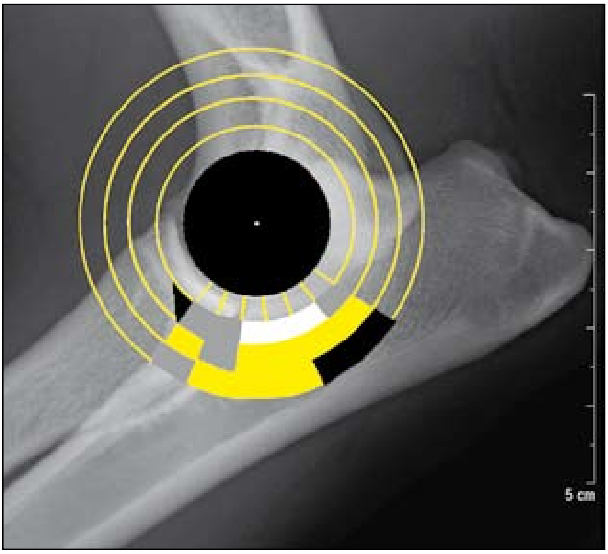

Fig. 6. Sites with the biggest difference in mean median optical densities of elbows with FCP and the control group of healthy elbows. Black $p > 0.05$, grey $p < 0.05$, white $p < 0.01$, yellow $p < 0.01$