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Summary

Objectives: To evaluate inter- and intraobserver reliability of the assessment of CT features commonly used in the identification and classification of medial coronoid process disease (MCPD) and to assess inter- and intraobserver variability in the identification of the percentage ulna sclerosis from single transverse CT images.

Methods: Eight observers, on two occasions, reviewed 84 standardised single transverse CT images acquired at the level of the apex of the medial coronoid process on two occasions. Observers assessed for: the presence of MCPD, coronoid process fragmentation, osteophytes, sclerosis grade, and sclerosis delineation with normal bone defined by the sclerometer. Cohen's kappa and Intraclass Correlation Coefficient were calculated.

Results: Interobserver agreement was fair to moderate for identification of CT changes consistent with MCPD, moderate to almost perfect for presence/absence of fragmentation, and moderate for osteophyte detection. Agreement was poor for sclerosis grading. Percentage sclerosis measured with a sclerometer had moderate to almost perfect inter- and intraobserver agreement.

Clinical Significance: These findings suggest that subjective assessment of CT images is less reliable and repeatable than more quantitative methods.

Keywords: medial coronoid disease, sclerosis, CT, agreement

Introduction

Canine elbow dysplasia (CED) is a common cause of forelimb lameness in young, large-breed dogs (Morgan *et al.* 1999, Farrow *et al.* 2014). The term CED collectively describes medial coronoid process disease (MCPD) including fragmented medial coronoid process (FMCP) (Grondalen *et al.* 1981, Fitzpatrick *et al.* 2009), ununited anconeal process (Carlson 1961), osteochondrosis of the humeral condyle (OCD) (Olsson 1983) and joint incongruity (International Elbow Working Group 2001). Of these, MCPD is the most prevalent lesion (Van Ryssen 1997, Meyer-Lindenberg *et al.* 2002, Lavrijsen *et al.* 2010).

Accurate assessment of changes affecting the medial coronoid process on radiographs are hampered by both superimposition of the radial head over the medial coronoid process and the presence of osteophytes. CT has been evaluated for the detection of FMCP, having a reported sensitivity of 71-88% compared to a sensitivity of 23.5% with radiographs (Moores *et al.* 2008, Carpenter *et al.* 1993). CT has also been demonstrated to be more sensitive than radiographs for the identification of MCPD (with a sensitivity of 86.7% and 56.7% respectively) (Carpenter *et al.* 1993). Subsequently, the use of computed tomography (CT) has become widespread in the assessment of elbow congruity and changes affecting the MCP (Haudiquet *et al.* 2002, Voorhout 1987, Klumpp *et al.* 2010, Lau *et al.* 2013, Lau *et al.* 2014). Cartilaginous changes and overt fragmentation of the MCP can be evaluated concurrently arthroscopically and it has been recommended that both diagnostic modalities should be combined for the most accurate assessment of medial coronoid disease (Moores *et al.* 2008).

Changes in subchondral bone density (Phillips *et al.* 2014) as well as detection of incongruity (Gemmill *et al.* 2005, Burton *et al.* 2013) can be appreciated with high accuracy from CT images. Subchondral bone density and sclerosis, represented on CT by increased attenuation and loss of trabecular pattern, is a commonly observed and non-specific finding that is observed in canine elbow affected by osteochondrosis, ununited anconeal process, incongruity or humeral intracondylar fissures. Furthermore, it has been reported to be an early indicator of MCPD (Hornoff *et al.* 2000). Qualitative assessment is included in the International Elbow Working Group (IEWG) grading system for elbow dysplasia (International Elbow Working Group 2001).

The most common changes affecting the canine MCP in case of elbow disease (including elbow dysplasia, MCPD, OCD, etc) include an abnormally shaped MCP and the presence of sclerosis (Reichle *et al.*, 2000). Other commonly reported abnormalities include the presence of osteophytes, distinct fragmentation, fissure and lucency. The presence or absence of some, or all of these features have more recently been used to culminate in a CT determined 'severity' grade of the condition (Kunst *et al.* 2014, Moores *et al.*, 2008). The assessment of these features is then used together with clinical findings and arthroscopy to evaluate dogs with MCPD. Moreover, the presence and degree of subchondral sclerosis affecting the medial coronoid process is frequently referred to in the literature (Olsson 1983, Reichle *et al.* 2000, Burton *et al.* 2008, Draffan *et al.* 2009, Fitzpatrick *et al.* 2009, Farrell *et al.* 2014) and a correlation between ulnar sclerosis and fragmentation of the coronoid process has been demonstrated (Burton *et al.* 2007). Reliability and repeatability of radiological assessment of ulnar trochlear notch sclerosis has been assessed in elbows with MCPD (Burton *et al.* 2008).

Despite a large number of publications discussing the multitude of CT features assessed when investigating and diagnosing cases of MCPD, no study has yet evaluated inter- and intraobserver reliability and repeatability of such assessment. Knowledge of inter- and intraobserver reliability is essential to allow appropriate interpretation of study results involving CT assessment of MCPD within and between institutions. In the future, features with the highest inter- and intraobserver reliability will be useful to allow a foundation for future research, with the aim of finally establishing the relationship between CT findings and clinical presentation.

The aims of this study were firstly to report a method of measuring sclerosis percentage of the MCP and ulna on CT, secondly to assess inter- and intraobserver reliability in interpreting the presence or absence of CT features consistent with MCPD from a standardised transverse image at the level of the medial coronoid process, and finally to establish if observers can repeatedly and reliably grade MCP sclerosis from the single transverse CT image.

Material and Methods

All elbow CT images acquired from dogs presenting to XXX between XXX and XXX were retrospectively retrieved from the image archive. Elbow images included both normal and abnormal elbows (affected by MCPD as confirmed by clinical findings, CT and arthroscopy).

Image acquisition

Images were acquired using a Siemens Emotion 16 slice helical scanner (Erlangen, Germany), with slice thickness of 0.6mm, pitch of 0.75, rotation time of 1 second and 130 kVp and 80 mAs. All images assessed were reconstructed on a sharp (B60) algorithm (Siemens). All dogs had been positioned in sternal recumbency, with the limb of interest extended, ensuring there was no supination or pronation of the elbow. For each elbow three dimensional multiplanar reconstruction (MPR) views were created using OsiriX (version 5.6 32-bit, Pixmeo, Geneva) open source DICOM viewer, permitting transverse, dorsal and sagittal images to be viewed concurrently. Repeatable slice alignment was achieved by aligning slices with the caudal cortex of the ulna in the sagittal view and lateral aspect of the ulna in the dorsal view (Fig 1). Once the alignment was complete, the sagittal view was used to center the image on the most cranial part of the proximal ulna, immediately distal to the humeral condyle resulting in a repeatable standardised transverse image through the apex of the MCP. The transverse plane was chosen as the medial coronoid process is best defined in this plane (Reichle 1999). A window width of 3500 HU as previously recommended (Tromblee *et al.* 2007) and window level of 700 HU were used. A single transverse image for each elbow was archived as a JPEG file.

Experiment 1: To assess inter- and intraobserver variability in the measurement of sclerosis percentage

Four board certified orthopaedic surgeons, two board certified radiologists, one diagnostic imaging resident and one surgical resident reviewed individually a single transverse CT image of the ulna at the level of the medial coronoid process from each elbow included in the study. All except one of the observers had been working together in the same institution for at least six months prior to the study.

Each observer was asked to draw a line on the transverse CT image representing where, if present, they considered the junction between the normal and the sclerotic trabecular bone pattern to be delineated. This measurement was made on each transverse CT image by the eight observers twice (separated by 4 weeks). A single observer (XX) then used a sclerometer to quantify, as a percentage, the position of the observer's line demarcating the transition between normal and sclerotic trabecular bone. The use of a sclerometer was firstly reported by Smith et al. (2009) who applied the technique to quantify ulna sclerosis on lateral radiographs of the elbow from dogs with MCPD. Here, we applied the instrument to transverse CT images of the ulna at the level of the MCP. The sclerometer (Fig 2A) was superimposed on the image with the cranial line of the sliding scale being aligned with the most cranial cortex of the medial coronoid process of the ulna and the caudal line intersecting the most caudal cortex of the ulna. The hinged sclerometer line was then aligned with the line drawn by the observers (Fig 2B). If sclerosis was not deemed present the score was recorded to be 0%. (Fig 3)

Experiment 2: To assess interobserver reliability to identify features used in the diagnosis of MCPD and sclerosis grade from transverse CT images

Each observers recorded whether they considered the ulna and medial coronoid process to be normal or abnormal, and they assessed images for the presence or absence of pre-determined variables (Table 1). Images were presented in a random sequence and observers did not communicate with each other. In addition to these binary variables, observers were requested to grade images using a four point ordinal grading scheme, with grade 0 representing a normal MCP and grade IV representing the MCP entirely sclerotic (Table 2).

Experiment 3: To assess intraobserver reliability to identify features used in the diagnosis of MCPD and sclerosis grade from transverse CT images

To assess intraobserver variability, each observer reviewed all CT images twice, with the same assessment criteria as in experiment 2, on occasions separated by at least four weeks. The order of the images presented to the observers was randomly assigned for the purpose of blinded image reading.

Statistics

Cohen's kappa (κ) for nominal data (experiment 2 and 3) and intraclass correlation coefficient ($ICC_{(2,1)}$) for numeral values (experiment 1) were calculated to evaluate inter- and intraobserver agreement between the eight observers, and for each category of observers: surgeons (including board certified and resident), diagnostic imagers (including board certified and resident), board certified orthopaedic surgeons, board certified diagnostic imagers, board certified (including diagnostic imagers and surgeons). Interpretation of the κ and the ICC value were based on Landis and Koch (1977) as shown in Table 3.

Results

84 transverse CT images were retrieved and included in the study. Mean age was 33 months (+/- 22 months) for the clinically unaffected dogs and 44 months (+/- 38 months) for the MCPD-affected dogs. Both normal and abnormal elbows (as confirmed by history, clinical examination, CT and arthroscopy findings) were included in the study. Breed and

disease status represented included Greyhound clinically unaffected, Labrador Retriever clinically unaffected and MCPD-affected Labrador Retriever.

Experiment 1

When assessing the sclerosis percentage, the interobserver agreement varied between moderate to almost perfect between groups. The intraobserver agreement was moderate to almost perfect (Table 4).

Experiment 2

Kappa analysis results are presented in Table 4. The κ value demonstrated that interobserver agreement for transverse CT images being representative of MCPD was fair between orthopaedic surgeons, board certified orthopaedic surgeons and moderate for board certified radiologists.

κ value demonstrated that the interobserver agreement for the presence or absence of FMCP was moderate among all observers but was almost perfect for board certified imagers. Interobserver agreement for the presence of osteophyte was moderate within all groups. Sclerosis grading had a poor interobserver agreement in all groups (Table 4).

Experiment 3

Assessment of intraobserver agreement for all images was moderate to almost perfect for MCPD, strong to almost perfect for FMCP and moderate to strong for osteophytes. The results for sclerosis grading were observer-dependent, varying between a fair and strong

intraobserver agreement. This was independent of the experience of the observer as there was no difference between residents and board certified individuals (Table 4).

Discussion

The results of this study demonstrate significant inconsistency both between and within observers and groups of observers in their ability to agree on the presence, absence or grading of features used in the diagnosis of MCPD and sclerosis grade from transverse CT images.

Agreement were similar in all groups except board certified imagers. The interobserver agreement of all features among board certified imagers was slightly better compare to the other groups but this was not statistically different ($p=0.73$).

The CT features interpreted from a single standardised transverse image with highest agreement was the presence of FMCP, followed by the presence of osteophyte and MCPD. A single human elbow CT has similarly evaluated inter- and intraobserver agreement with two observers for the presence of fragmentations and osteophytes within the elbow based on CT transverse images (Zubler *et al.* 2010). In this human study, interobserver agreement was almost perfect for the presence of fragmentation ($k=0.83$) and it was strong to almost perfect for the osteophyte detection ($k=0.67-0.8$), depending on their localisation within the elbow. Despite not suffering from the same disease process as dog detection of fragmentation in the human elbow CT images had a similar interobserver agreement to our finding in canine elbows with an interobserver agreement of 0.61-0.81 in our study. However, interobserver agreement for osteophytes detection in our study ($k=0.41-0.49$) was not as good as the human CT study.

In our study, sclerosis grade had the largest variation in k values (ranging from poor to strong). Our findings suggest that using an ordinal grading system for the severity of MCP sclerosis has poor interobserver and intraobserver reliability and repeatability. The use of such grading system is therefore of questionable benefit when comparing between different observers, studies, or institutions. Interestingly, Burton *et al.* (2008) reported a fair interobserver agreement and a moderate to strong intraobserver agreement when using a four-point ordinal grading scale to score sclerosis from Labrador Retriever elbows radiographs. These results were similar to our findings.

Use of a sclerometer was initially developed to allow quantitative measurement of ulnar notch sclerosis on canine medio-lateral elbow radiographs (Smith *et al.* 2009). Smith *et al.* (2009) demonstrated that diseased elbows had a mean sclerosis percentage score of 47% compared to dogs with clinically unaffected elbows, where the percentage was 0%. The use of the sclerometer resulted in good interobserver agreement. Application of the sclerometer to assess the sclerosis percentage on the single standardised transverse CT image resulted in moderate to almost perfect inter- and intraobserver agreement. The quantitative assessment of sclerosis significantly improved inter- and intraobserver agreement compared to the subjective grading system. It would be interesting in the future to determine if the improved reliability of using a quantitative method to assess the degree of sclerosis affecting the MCP and ulna would result in a better correlation between CT, clinical and arthroscopic findings in these cases.

Digital analysis and regional quantification of bone mineral opacity from elbow radiographs of dogs affected with MCPD has been reported to be useful in the quantification of sclerosis (Burton *et al.* 2007). Clinically, CT allows *in vivo*

quantification of bone density using the Hounsfield unit (HU) (Thrall, 2002). Improved accuracy of diagnosis of MCP disease may be possible when applying quantifiable and semi-quantifiable assessment methods of the degree of sclerosis (Burton *et al.* 2007, Draffan *et al.* 2009, Smith *et al.* 2009) affecting the ulnar trochlear notch and MCP in dogs (Draffan *et al.* 2009). Unfortunately methods of assessment of bone mineral density (regions of interest determination of HU, CT absorptiometry and dual-energy X-ray absorptiometry DEXA) are not readily available or utilised in clinical veterinary practice. Use of the sclerometer as applied in our study offers a simple, cheap and rapid method of quantifying the degree of ulna sclerosis based on the visual assessment of a standardised transverse CT image at the level of the medial coronoid process. In future the sclerometer can be applied as a standardised measuring device which may improve standardisation and reproducibility of method for future investigation of MCPD. Furthermore, the sclerosis percentage measured using this simple sclerometer technique could be compared to objective measurements of bone density by CT.

Limitations of the sclerometer discussed by Smith *et al.* (2009) included a difficulty in consistently defining the most caudal aspect of the radial head on radiographs (as rotation of the elbow can modify the landmark) and modification of the landmark position due to osteophyte superimposition. When applying the sclerometer to transverse CT images, no bone superimposition was present. The cranial and caudal borders of the ulna were easy to identify. A large number of osteophytes overlying the cranial aspect of the coronoid process could potentially influence the results as the cranial margin of the medial coronoid process becomes less delineated. This would also be expected to be the case with FMCP.

Draffan *et al.* (2009) evaluated trochlear notch sclerosis on radiographs using a percentage scale and a grading system and compared it with a CT grading of MCPD. In their study, as the grade of MCPD on CT increased, so did the grade of sclerosis on radiographs. However, the sclerosis percentage on radiographs did not increase as much as the sclerosis grade. Draffan *et al.* (2009) hypothesised that during evolution of MCPD, the sclerosis extent (percentage scale) might not increase significantly, but the severity of sclerosis (assessed by the sclerosis grade) might be more detectable. For this reason, it was recommended the use of both a percentage scale and a grading system to assess sclerosis on radiographs: severity and extent of sclerosis should be evaluated together. The same notion could be extrapolated to CT but no study has yet evaluated the correlation between the extent or severity of sclerosis with age or MCPD severity.

In the present study, the percentage sclerosis was measured along a line perpendicular to the long axis of the ulna. This measurement was simple, cheap and easy, and results in a good inter- and intraobserver agreement. However, we did not measure the depth of changes present in the canine elbow and how far the sclerosis limit was from the radial incisure. In the future, it will be interesting to develop a method to measure the depth of bone density changes and to correlate the percentage sclerosis along the long axis and the sclerosis depth with clinical presentation and arthroscopic features. The use of a region of interest to determine Hounsfield unit (HU) might be an option to measure precisely the depth of changes.

A limitation of our study was that observers assessed only a single transverse image of the ulna. This image was standardised between all elbow assessed. Previous studies evaluating both elbow incongruity (Burton *et al.* 2013, House *et al.* 2009, Gemmill *et al.*

2005) and sclerosis changes (Phillips *et al.* 2014, Samii *et al.* 2002) have employed single transverse CT images. We elected to use a standardised transverse CT image to measure the percentage ulnar sclerosis. One of the primary aims of this study was to present an easy method providing a quantitative measure of ulna sclerosis (i.e. percentage ulnar sclerosis), which in future studies can be compared between studies and also be correlated to severity of clinical disease. The use of a standardised and readily repeatable CT image was deemed most appropriate to achieve this. Assessment of sequential transverse slices and multiplanar evaluation would however permit a more global assessment of features such as fissures, fragmentation and the presence or absence of osteophytes affecting MCP and therefore, may affect the inter- and intraobserver reliability of these features.

A further limitation to our study is that all except one observer had worked in the same institution for at least six months. Interobserver relationship is important as the results do need to represent the generalized population. Among the board certified surgeons who took part in our study, training pertaining to interpretation of elbow CT had taken place in three separate institutions. The two board certified diagnostic imaging observers had undergone residency training in different institutions. We therefore considered that the results represent a broad range of individual observers with different training backgrounds.

In our study cross sectional images were taken from canine elbow CT scans acquired over 12 months period. Signalment, clinical and arthroscopic findings were not considered as the aim was determining inter- and intraobserver variability in assessment of CT images rather than the association between CT and clinical signs or arthroscopic

findings. In the future, it will be important to determine the specificity of sclerosis percentage measurement in the diagnosis of MCPD. Sclerosis percentage, with a moderate to almost perfect inter-and intraobserver agreement, should be assessed along with further indicators of MCPD such as presence of fragment or fissure, hypointense appearance of the apex of the MCP, appearance of radioincisive notch of the ulna and the presence or absence of elbow incongruity. It is clear that further studies need to be performed on all these factors using the entire CT study, not just looking at quantitative methods of sclerosis measurement. However, the results of our study suggest subjective grading systems may be less worthwhile.

It must be acknowledged here that the changes in bone density that occur in the region of the medial coronoid process and cranial aspect of the ulna at the level of the coronoid process are indeed complicated and the terminology used historically to subjectively describe the CT findings at times likely raises a number of questions. Previous CT studies investigating MCPD (Reichle *et al.* 2000, Moores *et al.* 2008) have reported that the most common abnormalities of the MCP include an abnormal shape of the MCP, and the presence of MCP sclerosis. Despite this, other publications have suggested that there is in fact a reduction in bone density within the MCP (Philips *et al.* 2015, Burton *et al.* 2010). When applying the sclerometer here we have measured the percentage of the ulna that has lost its normal trabecular appearance and cortico-medullary differentiation as demonstrated in figure 3. Defining this percentage, as we have done here, does indeed suggest an increase in bone density. However this may not be the case and assessment of actual bone density using a quantitative assessment such as regional HU would be necessary to confirm if sclerosis is deemed present.

In summary, this study demonstrates that features commonly assessed on transverse CT images of the elbow, including the presence or absence of MCPD and sclerosis grade, may have poor to moderate inter- and intraobserver agreement. The ability of observers

to agree on the sclerosis percentage was moderate to almost perfect. These results advocate the use of quantitative methods for sclerosis measurement in the computed tomographic assessment of MCPD although further CT study would need to be performed to better understand the clinical relevance of all these CT features.

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FIGURES AND TABLES

Fig 1 : 3D multiplanar reconstruction of CT elbow images showing the method used to produce the standardised transverse views of the ulna at the level of the apex of the MCP. Sagittal reconstruction (A), dorsal reconstruction (B) and transverse image (C)

Fig 2: Application of the Sclerometer

A: the sclerometer is superimposed on the elbow CT image with the cranial line (a) aligned with the most cranial cortex of the ulna and the caudal line (b) aligned with the most caudal cortex of the ulna.

B: the hinged sclerometer line (c) was then aligned with the line drawn by the observer (grey line) and the percentage can be read (red circle)

Fig 3: CT landmarks to measure sclerosis percentage (%sclerosis) and caudal Border of the Coronoid process (BoCo).

The black line was drawn by the observers to define sclerosis.

L: length of line between the most caudal and the most cranial aspect of the ulna ;

β : length between the most caudal aspect of the ulna and the black line drawn by the observer

The percentage sclerosis was defined as β/L

Table 1: Variables assessed by the observers for each CT transverse image

Table 2: Grading criteria for medial coronoid process sclerosis

Table 3: Interpretation of the Intraclass Correlation Coefficient and the Kappa by Landis & Koch²³

Table 4: Inter- and intraobserver agreement for MCPD, FMCP, osteophytes, sclerosis grade, %sclerosis. *Kappa, ICC values and agreement noted as poor (*), fair (**), moderate (***), strong (****) or almost perfect (*****)*

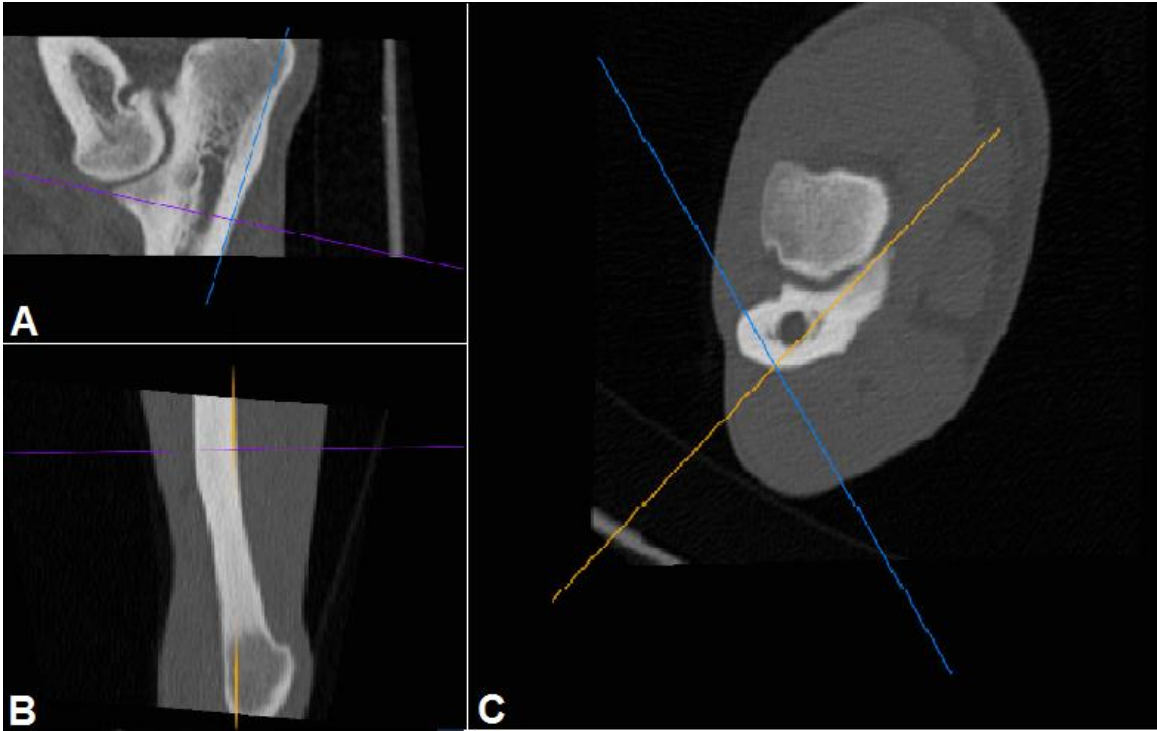


Figure 1

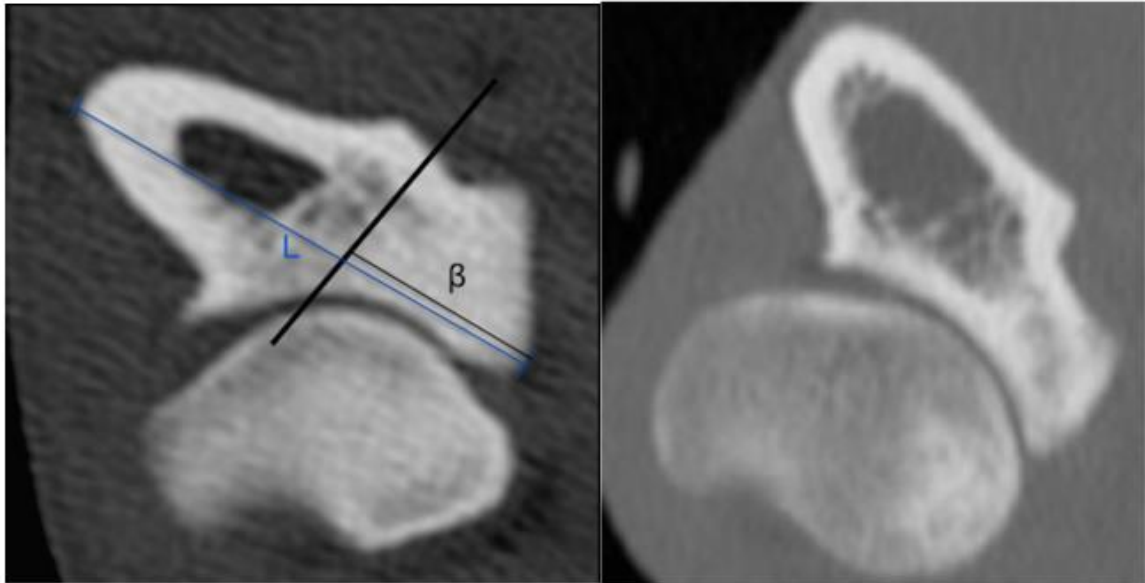


Figure 2

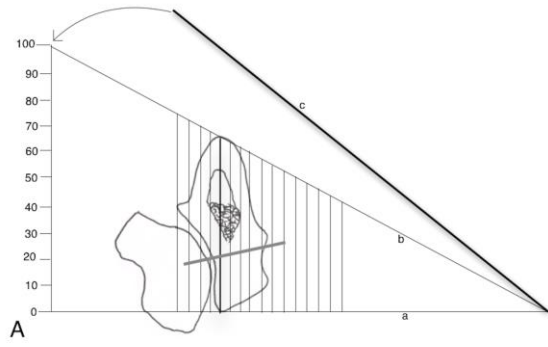


Figure 3A

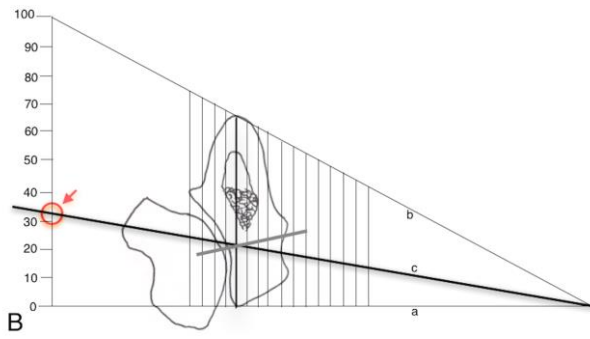


Figure 3B

Table 1: Variables assessed by the observers for each CT transverse image

MCP disease	Presence	-	Absence						
Fragmented coronoid process	Presence	-	Absence						
Osteophytes	Presence	-	Absence						
Coronoid sclerosis grade	0	-	1	-	2	-	3	-	4

Table 2: Grading criteria for medial coronoid process sclerosis

Grade 0	No sign of MCP sclerosis Even bone density
Grade 1	Slight MCP sclerosis Majority of MCP bone normal and even density
Grade 2	Sclerotic MCP Majority of MCP sclerotic rather than normal appearance
Grade 3	Sclerotic MCP All of MCP sclerotic rather than normal appearance sclerosis extending caudally into medullary cavity
Grade 4	Sclerotic MCP All MCP sclerotic rather than normal appearance Sclerosis extending caudally into medullary cavity of ulna Loss of large amount of medullary cavity du to sclerosis of ulna

Table 3: Interpretation of the Intraclass Correlation Coefficient and the Kappa by Landis & Koch²³

ICC values or Kappa values	interpretation
< 0.2	poor agreement
0.21-0.4	fair agreement
0.41-0.6	moderate agreement
0.61-0.8	strong agreement
> 0.8	almost perfect agreement

Table 4: Inter- and intraobserver agreement for MCPD, FMCP, osteophytes, sclerosis grade, and sclerosis percentage (%sclerosis).

Kappa, ICC values and agreement noted as poor (), fair (**), moderate (***), strong*

Assessed Features	Inter-observer agreement						Intra-observer agreement						
	Among all observers	Among board certified	Among imagers	Among surgeons	Among board certified imagers	Among board certified surgeon	Diagnostic imaging resident	Board certified Imager 1	Board certified Imager 2	Surgery resident	Board certified Surgeon 1	Board certified Surgeon 2	Board certified Surgeon 3
MCPD	0.2678 **	0.2950 **	0.5123 ***	0.2134 **	0.5038 ***	0.2815 **	0.7499 ****	0.6853 ****	0.7083 ****	0.5827 ***	0.8756 *****	0.5592 ***	0.3815 **
FMCP	0.6716 ****	0.6813 ****	0.7625 ****	0.6386 ****	0.8144 *****	0.6143 ****	0.7565 ****	0.7798 ****	0.7960 ****	0.9206 *****	0.8393 *****	0.6752 ****	0.7710 ****
Osteophytes	0.4816 ***	0.4823 ***	0.4667 ***	0.4996 ***	0.4183 ***	0.4840 ***	0.7035 ****	0.5884 ***	0.7381 ****	0.7959 ****	0.7857 ****	0.5819 ***	0.6227 ****
Sclerosis grade	0.1641 *	0.1458 *	0.1890 *	0.0997 *	0.1558 *	0.0752 *	0.4409 **	0.2763 *	0.6315 ****	0.3591 *	0.6195 ****	0.3294 *	0.2639 *
%Sclerosis	0.5483 ***	0.5961 ***	0.4520 ***	0.5031 ***	0.8237 *****	0.5250 ***	0.7548 ****	0.6232 ****	0.5973 ***	0.7708 ****	0.8735 *****	0.7334 ****	0.8088 ****

(****) or almost perfect (*****)