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# COMPARISON OF PLAIN RADIOGRAPHY AND COMPUTED TOMOGRAPHY FOR DETECTION OF ELBOW DYSPLASIA IN LABRADOR RETRIEVER

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# ABSTRACT

To our knowledge there has been no comprehensive direct comparison between the plain radiology and computed tomography (CT) for diagnosis of elbow dysplasia through the use of a grading score.

The first aim of the study was to clinically apply a comparative grid (proposed at the last IEWG meeting in 2016) to grade elbow dysplasia on CT similarly as is done on traditional radiology.

The second objective was to evaluate the concordance of the grading between the two imaging modalities at the age less than 12 months and over 12 months and to emphasise the differences observed between puppies and adult dogs.

Thirty-nine (39) Labrador Retriever (78 elbow joints) were included in the study, the dogs were own client dogs, asymptomatic, no one showed any sign of lameness nor other clinical problems.

At the age <12 months the concordance between plain radiology grading and CT grading was fair (K 0.33), the sensitivity of radiography to identify elbow dysplasia was 75% and specificity 100% (P<0.001). At the age >12months the concordance was fair too with K 0.23 and the sensitivity was 70% and specificity 98% (P<0.001).

A development of the disease has been noted between the evaluations at different ages. On plain radiography the grade of the disease remained invariable in 54 joints and developed a worse grade of disease in 19 joints and improved in 5 joints (P

0.004). On CT the grade of the disease remained invariable in 52 joints and showed a worse grade in 24 joints and improved in 2 joints (P 0.001).

Further studies including also other breeds might provide more information about the accurate use of a score grading on CT. The presence of false-negatives in our group of dogs and the fair agreement between the two modalities open a discussion about the exclusive use of radiographs in the screening program. As well a screening program to treat dogs at too young an age should be reassessed having regard to the disease progression, which, however is not related to any clinical symptoms.

# CHAPTER 1
# SCOPE AND AIM

Elbow incongruence (INC), ununited anconeal process (UAP), medial coronoid process disease (MCD), osteochondrosis/osteocondritis dissecans (OC) are the pathology included in the complex elbow dysplasia. Firstly, animal description, and anamnesis associated to clinical examination are necessary to make a diagnosis, but essentially and traditionally, radiology is used to confirm it. Nowadays, other more sophisticated imaging modalities as CT, MRI, nuclear scintigraphy, ultrasound and arthroscopy are also available (Cook C., 2009).

Plain radiology is the routine diagnostic imaging modality used for diagnosing canine elbow dysplasia. It is a method which provides an overview of the bone structures, of the joint space and of the surrounding soft tissue. The benefits and advantages of this diagnostic tool are multiple and include: the speed of handling images, the painless and non-invasiveness, does not require special preparation unless fasting to sedation, does not require recovery time and is relatively economic (Thrall D., 2013).

While radiology is quite accurate to diagnose UAP and OC/OCD, the certain diagnosis of MCD and elbow incongruity are difficult. For this purpose, computed tomography (CT) has been widely used. In fact, CT is a non-invasive imaging modality that makes use of computer processed combinations of x-ray images taken from different angles to produce cross-sectional images of anatomic structures. The advantages of CT over plain radiography of the elbow joint include: the increased of details, thus the anatomic structures can be evaluated without the superimposition of structures making easier the interpretation of the images, the reconstruction of the images in multiple planes making easier the overview of the complex elbow joint. Disadvantages include cost of equipment purchase, use, maintenance, and exposure of the patients to ionizing radiation (Cook C., 2009).

There are discordant opinions about the sensitivity and the specificity of conventional radiographic projections and of the CT in imaging the medial coronoid disease. Also questionable which is the "gold standard" modality to evaluate elbow dysplasia between the CT scan and arthroscopy.

The sensibility of traditional radiology is variable and has been estimated to range from 10 to 62 per cent and 96%, 98% (Lau S., 2013; Rau F.,2011; Villamonte-Chevalier A., 2015 (A)). On the other hand, CT sensitivity results in previous published studies of 88%, superior to plain film radiography, xeroradiography, linear tomography and arthrography in detecting MCD (Carpenter L., 1993). In a recent study that evaluate 180 elbow joints, the CT sensitivity was of 100% and the specificity of 93%; CT showed pathologic signs in one joint but no lesions were seen during arthroscopy. CT specificity of 84 %, 60.9 %, and 85 % was previously reported by different authors (Moores A., 2008; Rau F.,2011; Carpenter L.,1993). Instead, the radiographs specificity has been estimated between 40% and 64% (Rau F.,2011; Villamonte-Chevalier A., 2015 (A)).

In human medicine the arthroscopy is considered the "gold standard" technique to assess the elbow disorders; in Veterinary Medicine it has been considered by different authors as the best modality also, but there is not a full agreement. Indeed, recent studies affirmed that CT is the superior modality to assess MCD because arthroscopy cannot identify every fragment of the medial coronoid process, especially the nondisplaced fragments (Villamonte-Chevalier A., 2015 (A)). Otherwise more than one articles underline that the two modalities are complementary (Coppieters E.,2016; Moores A., 2008).

In our study, we assumed CT as the "gold standard" to evaluate the elbow joint, particularly for the medial compartment disorders and elbow dysplasia in general. We evaluated on radiographs and CT the elbow joints of Labrador Retriever dogs at the age less than 12 months and older than 12 months. The aims of the study were:

- to clinically apply a comparative grid (proposed at the last IEWG meeting in 2016) to grade elbow dysplasia on CT similarly as it is done on traditional radiology;
- to evaluate the concordance of the grading between the two modalities;
- to emphasise the differences observed between puppies and adult dogs.

# CHAPTER 2

# ELBOW JOINT ANATOMY

The elbow joint (*articulatio cubiti*) is a stable compound ginglymus, or hinge joint formed by the proximal end of the radius and ulna and the distal end of the humerus. It is a complex joint formed by the humeroradial joint (*articulatio humeroradialis*), the humeroulnar joint (*articulatio humeroulnaris*) and the proximal radioulnar joint (*articulatio radioulnaris proximalis*) freely communicates with the humeroradial and humeroulnar joints. A joint capsule is common to all three articular parts (Evans H., 2013) (Fig.1).

The humeroradial joint transmits most of the weight-bearing forces of the limb, the humeroulnar joint restricts the movement of the joint to a sagittal plane and the radioulnar joint permits the pronation and supination movements. In normal Labrador Retrievers the range of motion of the elbow joint has been reported to be in flexion 50 degrees and in extension 180 degrees measured with goniometry in awake dogs (Hady L., 2015).

## HUMERUS

The humerus is the bone of the brachium and is divided into head, neck, body and condyle. The distal articular surface forming the elbow joint is the condyle that is positioned cranially to the long axis of the shaft and shaped like an inclined cylinder. The humeral condyle develops as lateral and medial components that should fuse during development to form the single condyle. The smallest lateral area is the *capitulum humeri*, which articulates with the radial head, and the largest medially located is the *trochlea humeri*, which articulates with the trochlear notch of the ulna. Laterally and medially the humeral condyle has two prominence named respectively lateral epicondyle (*extensor epicondyle*) and medial epicondyle (*flexor epicondyle*) where different muscles of the forelimb attach.

On the caudal part of the humeral condyle there is a deep excavation called olecranon fossa (*fossa olecrani*) which communicates over the supratrochlear foramen with the radial fossa (*fossa radialis*) located cranially.

## ULNA

The ulna is the bone of the antebrachium with the radius. It is divided into two extremities (proximal and distal), a body and a shaft. The proximal ulna is the olecranon and is composed by the olecranon tuber, the anconeal process and the proximal part of the trochlear notch.

The ulna articulates with the humerus at the level of the trochlear notch (*incisura trochlearis*), also called *semilunar notch* due to its smooth, vertical and half-moon-shape with cranial concavity. The proximal end of the trochlear notch is the anconeal process that fits within the olecranon fossa of the humerus when the joint is extended; the distal end is called radial notch (*incisure radialis*) of the ulna that prolongs with the medial coronoid process (*processus coronoideus medialis*) and the lateral coronoid process (*processus coronoideus lateralis*). These processes increase the surface area of the cubit joint and reduce the range of motion to the sagittal plane. Furthermore, the base of the medial coronoid process articulates with the radial head and the humeral trochlea, extends into a midbody that diverges distally with caudocranial direction and mediodistally at the level of the apex.

## RADIUS

The radius is the main weight-bearing bone of the antebrachium and it is shorter than the ulna. It is divided into a head, a neck, a body and a trochlea distally. The head (*caput radii*) has irregularly oval outlining with a concave articular surface, the articular fovea (*fovea capitis radii*), that articulates with the *capitulum humeri* and the lateral part of the trochlea of the humerus. The more caudal aspect of the head is the articular circumference (*circumferentia articularis*) that is longer than corresponding radial notch of the ulna allowing the rotational movements.

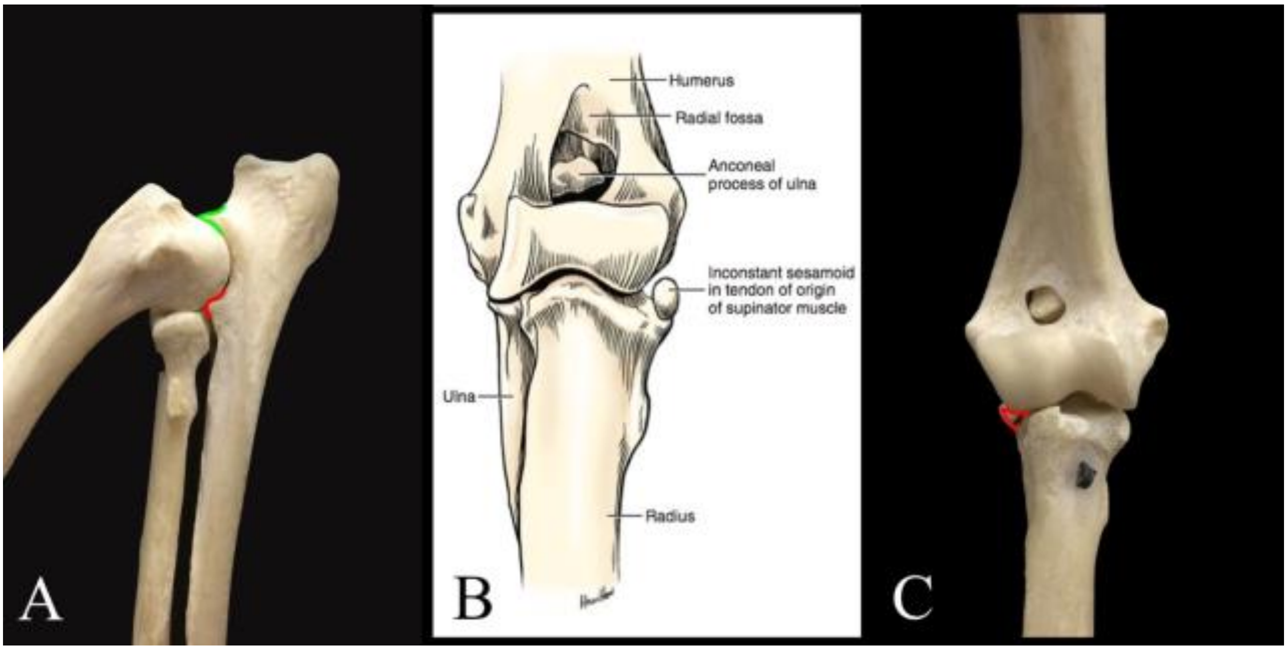


**Fig. 1 (A) Anatomical model of elbow joint, medial view; (B) Left elbow joint, cranial view (Miller's anatomy book); (C) Anatomical model of elbow joint, cranial view –in red the medial coronoid process, in green the anconeal process.**

## LIGAMENTS

The elbow is also supported by the addition of a number of ligaments, the most important being the collateral ligaments for joint stability (Fig. 2).

The lateral collateral ligament (*lig. collaterale cubiti laterale*) is the primary one involved in the stabilization of the elbow in supination at a standing angle of 135° of extension and may effect rotatory range of motion.

The medial collateral ligament (*lig. collaterale cubiti mediale*) is smaller than the lateral collateral ligament and is important secondary stabilizer for pronation.

The annular ligament of the radius (*lig. anulare radii*) is a thin band that runs transversely around the radius. In conjunction with the ulna, it forms a ring in which the articular circumference of the radius turns when the forearm is rotated.

The olecranon ligament (*lig. olecrani*) is an elastic ligament that passes between the craniomedial aspect of the olecranon to the medial border of the olecranon fossa.

The oblique ligament is a small but distinct band of fibres in the cranial aspect of the joint capsule (Evans H., 2013).

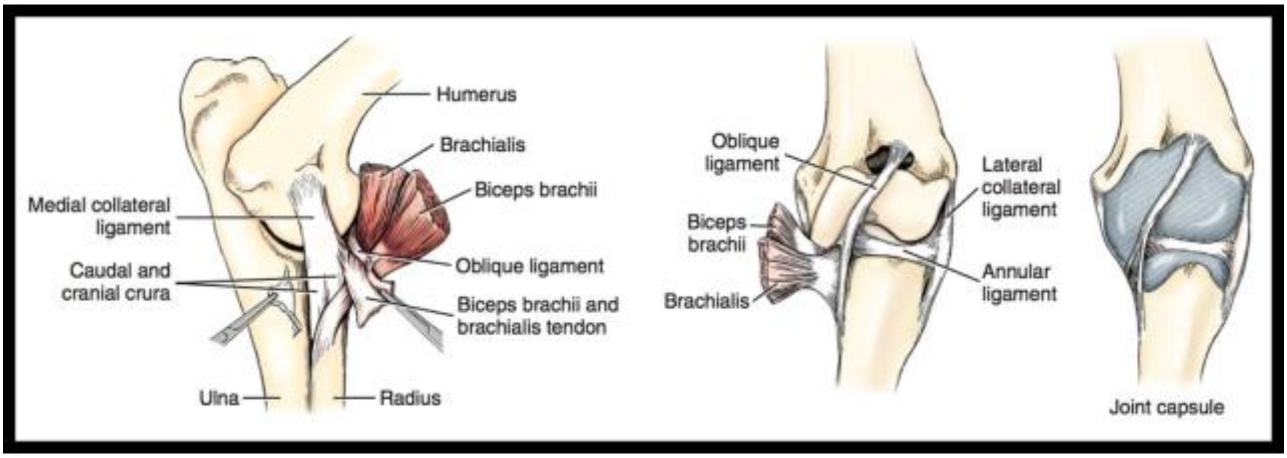


**Fig. 2 Ligament of the left elbow joint, cranial and medial view (Miller's anatomy book).**

## MUSCLES

The main muscle groups surrounding the elbow joint are the extensor and the flexor muscles. Respectively they lie caudally (*triceps brachii and anconeus*), cranially (*brachialis and biceps brachii*), laterally and distally (*the carpal and digital extensors*) and medially and distally (*carpal and digital flexors*) to the elbow. Also the extensor muscles of the carpus and digits originate directly or indirectly from the lateral epicondyle of the humerus (*extensor carpi radialis, common digital extensor, lateral digital extensor and extensor carpi ulnaris*). Most of the flexor muscles of the carpus and digits originate from the region of the medial epicondyle of the humerus (*flexor carpi radialis, deep digital flexor, superficial digital flexor and flexor carpi ulnaris*). The supinator muscle lies under the extensor carpi radialis and the lateral collateral ligament; a sesamoid bone, usually bilateral, was observed in 31% of the radiographs of 100 supinator tendons dissected from 50 of the dog (Wood A.,1985). The pronator teres lies cranial to the flexor carpi radialis and the medial collateral ligament lies between these two muscles (Evans H.,2013).

Immature skeleton shows different secondary ossification centres in the distal humerus and in the proximal radius and ulna, including the lateral and medial part of the humeral condyle which fuse at the age of 16 weeks. The anconeal process fuses before the 5 months of ages and it develops by apposition or by a separate ossification centre, or a combination of both. For the medial coronoid process, has been demonstrated that it has not an own ossification centre, separated between the base and the apex, developing exclusively by appositional ossification and is completed earlier in smaller than in larger dogs, respectively 16 weeks and up to 20 weeks. In particular, for the Labrador Retriever the age reported is 18 weeks. The age of fusion of the secondary ossification centres varies in dogs of different breeds, within litters, and quantity of calcium intake, but is not influenced by gender (Voorhout G., 1987; Breit S., 2004; Lau S., 2013; Hare W.,2002) (Table 1.).

| | | |
|---|---|---|
| Humerus | -Medial epicondyle | 6-8 months |
| | -Condyle to shaft | 6-8 months |
| | -Condyle lateral and medial | 16 weeks |
| Radius | -Proximal | 7-10months |
| | -Distal | 10-12 months |
| Ulna | -Anconeal process | < 5months |
| | -Olecranon tuberosity | 7-10 months |
| | -Distal | 9-12 months |

**Table 1. Age when the physeal closure occurs.**

# CHAPTER 3

# ELBOW DYSPLASIA: PATHOPHYSIOLOGY AND GENETIC ASPECT

The term “canine elbow dysplasia” (ED) was used for the first time in 1961 by Carlson to describe a certain anomaly of the elbow joint. The term dysplasia derived from Greek word *dys* meaning abnormal and *plassein* meaning to form and it has been considered a non-specific term denoting abnormal development of the elbow (Carlson W., 1961; Kirberger R., 1998; Lang J., 1998). Several studies researched a genetic base for the elbow dysplasia that seems to be inherited in different ways, in different breeds of dog, but should also be unrelated to the inherited aspect and for this reason, at the moment it makes unpredictable the results of genetic test.

The condition encompasses the clinical and radiographic manifestation of elbow incongruity (INC), ununited anconeal process (UAP), medial coronoid disease (MCD), osteochondritis dissecans (OCD) (Wind A., 1986; Olsson S., 1975; Lau S., 2015; Vaughan L., 1979).

Proposed mechanism for the development of the elbow dysplasia including various type of joint incongruity, altered endochondral ossification (osteochondrosis) and abnormal biomechanical force that can cause pathological consequence in the elbow joint. The main hypothesis suggests a genetic predisposition related to secondary risk factor which influence the occurrence of the disease (Michelsen J., 2013).

The secondary risk factors that can predisposed to the development of the disease are multiple: environmental, mainly small traumatic episodes and nutritional causes are strongly suggested. Moreover, a breed, age and gender predispositions are also well-known (Nap R., 1996).

Trauma is usually minimal and associated with hyperactivity or overweight dogs. When severe trauma occurs, consequent premature closure of a physis may markedly influence the adjacent joints: in this case the pathological condition that occurs is not included in the elbow dysplasia complex.

It has been reported that the over nutrition and rapid growth, a surplus of calcium, phosphorus and vitamin D can determinate an interference with the endochondral ossification (Tryfonidou M., 2003).

Breeds most commonly affected are the large and the giant dogs in particular the Rottweiler, Bernese Mountain Dog, Labrador and Golden Retriever and the German Shepherd dog, but it is also reported in small chondrodystrophic breeds such as French Bulldog (Narojek T., 2008). Certain breeds are more susceptible to a particular form of elbow dysplasia and more than one component may occur simultaneously like UAP and FCP or FCP and INC. For example, combined MCD and OCD are largely identified in Labrador Retriever, rather than UAP that is frequently identified in German Shepherd dogs (Meyer-Lindenberg A., 2006; Samoy Y., 2012).

The ED shows a prevalence of 17,7% in Labrador Retriever in UK and 70% in Bernese Mountain Dogs in Netherlands (Morgan J., 1999; Hazewinkel H., 1995).

The age at presentation varies between reports and compartments affected, but usually are immature dogs around 6 and 18 months of ages.

A gender predisposition is also reported and the males are affected about twice the rate of females, although in a study of risk analysis for fragmented coronoid process and elbow incongruity in Bernese Mountain Dogs, a sex predisposition was not found (Meyer-Lindberg A., 2006; Ubbink G., 1999).

Especially in Labrador Retrievers, it has been demonstrated having a strong correlation with the sex of the dogs, in fact the presentation of the osteoarthrosis is approximately twice more frequent in males than in female dogs, but not more severe (Lavrijsen I., 2012).

The consequence of the pathology is elbow arthrosis, which may be clinically unapparent or result in marked lameness (Hornof W., 2000). In fact, some dogs affected by elbow dysplasia never develop elbow osteoarthosis (Kunst C., 2014).

Following, each component of the canine elbow dysplasia will be described in more detail.

## 3.1 JOINT INCONGRUITY

Elbow incongruence is a term describing malalignment of the joint surfaces of the elbow. The consequence is an abnormal increased of pressure within the cubit joint that can lead to a trauma of different anatomical components. In the literature a physiological and either a pathological form of incongruity in human elbow joints as in dogs has been reported.(Samoy Y., 2006).

At least, there are three forms of pathological incongruity related to the development of the elbow dysplasia: a radioulnar incongruence (ulna is too short/radius is too short) a humeroulnar incongruence, a rotational incongruence.

The first type of the radioulnar incongruence is correlated to an asynchronous growth of the radius and ulna. The purposed aetiologies are various such as trauma of the growth plate, hypertrophic osteodystrophy or a persistent cartilage in the distal ulnar growth plate.

In case of ulna longer than radius and consequently a short radius, the weight that usually is loading on the radius, is transferred to the medial coronoid process of the ulna. There is a step formation at the level of the radial incisure associated to a proximal displacement of the medial coronoid process. This step or the chronic inflammation can create an avascular fragment of bone (Michelsen J., 2012; Preston C., 2000; Olsson E.,1993).

If the ulna is shorter than radius, there is a narrow joint space between the tip of the anconeal process and the humeral condyle, running to increased pressure on the anconeus, which leads to fragmentation or a non-union in case of a separate ossification centre.

The second type is the humeroulnar incongruity related to an abnormal shape of the trochlear notch of the ulna. In fact, the shape of the trochlear notch can be elliptic instead of having a normal circular shape and a mismatch between the curvatures of the trochlear notch and the humeral trochlea. This conformation leads to a caudal displacement of the ulna relative to the humeral condyle and an increased humeroulnar joint space. This abnormality increases the load placed on the medial coronoid process, eventually leading to its fragmentation.

Interesting is to see as in large breed dogs, the growth rate of the proximal part of the ulna should be quicker to be synchronised with the growth rate of the humeral condyle. If the growth of the proximal part of the ulna is disturbed, the size of the ulnar trochlear notch is too small to hold the humeral condyle.

A third type of incongruity that has been suggested, is a rotational incongruity involving shear forces across the lateral aspect of the medial coronoid process originating a compression of the medial coronoid against the radial head by the eccentric pull of the biceps brachialis muscle groups especially during the flexion: the result is a trauma on the radial notch (Fitzpatrick N., 2009 (B)) (Fig. 3).

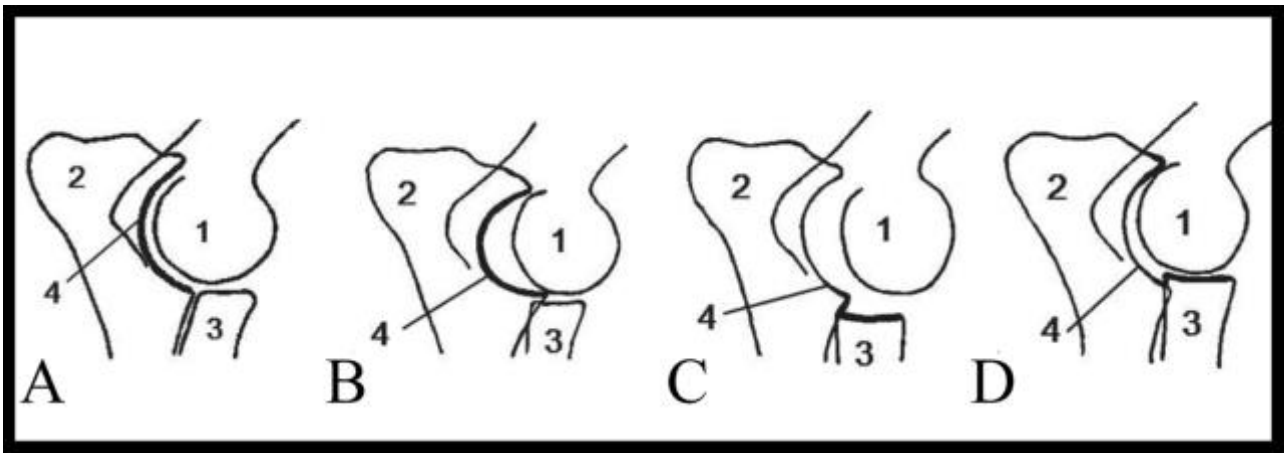


**Fig. 3 Schematic drawing. A) Congruent joint with parallel joint space with (1). humerus, (2) ulna, (3) radius, (4) trochlear notch of the ulna; B) Incongruent joint with elliptical shape of the trochlear notch instead of round; C) Incongruent joint with short radius; D) Incongruent joint with short ulna (Samoy Y., 2006).**

## 3.2 MEDIAL CORONOID DISEASE (MCD)

The medial coronoid process fragmentation (FCP) is a component of canine elbow dysplasia and it is the most common cause of lameness in young medium-large breeds of dog. Recently, the term medial coronoid disease (MCD) has been introduced, being more representative to describe the fissure and the fragmentation and pathologic changes of the articular cartilage and of the subchondral bone involving the medial coronoid process (Lau S., 2015).

In Labradors, the most frequent form of ED is the fragmented coronoid process, whereas OCD and elbow incongruity are diagnosed less frequently. Prevalence of the MCD is from 11 to 50% in Labrador Retrievers with thoracic lameness and 6% in Dutch Labrador Retrievers with a heritability 0.17 (Lavrijsen I., 2012). Other authors suggested that between 13% and 21% of Labradors can be affected by FCP, or from 17 to 21% of Labradors can present this form or other forms of elbow dysplasia (Ubbink G., 1999; Kirkberger R., 2007; Coopman F., 2008; Temwichitr J., 2009; Studdert V., 1991; Morgan J., 1999).

The age of presentation is between 6-18 months of age with the mean age at diagnosis of 13 months with clinical signs occurring as early as 4 months of age.

The incidence of bilateral disease is variable, it has been considered from 25% to 80%; for that reason, the evaluation of both forelimbs at the moment of the clinical examination is strongly suggested (Tobias K., 2013).

A genetic study in Labrador Retriever looking for a correlation between the presence of MCD and abnormal collagen genes, did not show any relevant results possibly due to the small number of dog considered, the complexity of the disease and small information of the canine DNA (Salg G., 2006).

The ethiopathogenesis regarding the development of the MCD has been well studied, but is still incompletely understood. Different hypotheses have been advanced like the radioulnar incongruity, trauma, inherited component, over nutrition, ischemia, trauma.

Olsson in 1993 proposed that the pathology should be related to a disturbance of the endochondral ossification, leading to an abnormal thickness of the cartilage. However, there were no evidence of osteochondrosis on histomorphometry of the medial coronoid process examined after subtotal coronoidectomy in 38 lame dogs with MCD (Danielson K., 2006). Instead, a lack of osteocytes and the presence of micro damages in the trabecular bone were reported, emphasizing as the subchondral bone is an important element in the development of the disease. On the other hand, the joint incongruity is also considered to play an important role in the pathogenesis of the disease. At least, all of the three forms of incongruity considered are possibly involved in the medial coronoid pathology.

Which type of incongruence is mainly involved in the development of the MCD is still contradictory, possibly due to different breed of dogs analysed in different studies and different diagnostic tools used. It is interesting to underline as a temporary radioulnar incongruence has also been found and it can be severe enough to determine a damage to the coronoid process.

When the fragmentation occurs, one or more fragments of bone may have fractured. The fragments often remain attached to the annular ligament, but also may project from the articular surface causing erosion of the adjacent medial humeral condyle called *kissing lesions* (Fitzpatrick N., 2009 (A)). These erosions may penetrate more or less the cartilage till the subchondral bone and extend from the apex to the body of the medial coronoid process. These lacerations are differentiated from OCD lesions because they are more lateral positioned and the surround cartilage is less thickened (Kirberger R., 2006).

As previous indicated, the result of the medial coronoid disease is the osteoarthrosis of the medial compartment of the cubit joint.

## 3.3 UNUNITED ANCONEAL PROCESS

Ununited anconeal process is a developmental disease of the cubit joint that is mainly affecting young dogs. German Shepherd dogs are the most representative breed with the highest incidence, but is also described in many large breed of dogs like St. Bernard, Labrador Retriever, Great Dane, Bernese Mountain Dog, Pointer and in chondrodystrophic breeds (Sjostrom L., 1998). In Labrador Retriever the ununited anconeal process is very seldom occurring (Meyer-Lindenberg A., 2006).

The pathogenesis of the ununion of the anconeal process is still partially unknown. It has a multifactorial aetiology and also a genetic predisposition has been shown. Several hypotheses have been proposed like a metabolic defect, nutritional deficiencies, trauma and hormonal disturbances (Sjostrom L., 1998).

At the base of this disorder, a failure of fusion of a separate centre of ossification of the anconeal process or dyssynchronous growth of the radius and ulna resulting in elbow incongruity and secondary ununited anconeal process has been suggested.

When a failure of fusion of a separate centre occurs, on radiographs a radiolucent line between the anconeus and olecranon persists over 22-24 weeks of age (Cook C., 2009). Most of the breed of dogs does not have a failure of the fusion (Frazho J., 2010).

In case of elbow incongruity, when the radius is longer than the ulna, the radial head can displace the humeral trochlea proximally relatively to the ulna and consequently there may be an overloads on the anconeal process. This could interfere with bony union of the anconeal process by 20–22 weeks of age in large dogs where there is a separate ossification centre, causing UAP (Michelsen J., 2013).

If the anconeal process is affected by disease the results are an instability of the joint with a successive inflammatory change due to the presence within the joint of free fragments of the anconeus process. Sometimes the non-union can be total or still have a connection with the olecranon through cartilaginous tissue (Tobias K., 2013).

## 3.4 OSTEOCHONDRITIS DISSECANS (OCD)

Osteochondrosis (OC) of the humeral condyle is a multifactorial and polygenic disorder with a heritability of 0.77 in Labrador Retrievers, although the genes involved are unknown (Padgett G., 1995). Diet, mechanical overload, endocrine and traumatic background are suggested as predisposing conditions.

OC is the result of the failure of the endochondral ossification caused by a delay endochondral ossification that results in a thickening of the articular cartilage and of the epiphysis. At this point a fragmentation of the cartilage associated with a partial or complete separation of the top layer of cartilage can occur to ineffective diffusion of nutrient from synovial fluid and transform OC in the progress form which is osteochondritis dissecans (OCD). The cartilage fragment may mineralise at a later stage and thus can be detectable on radiographs. Osteochondral flap can induce joint effusion, synovitis, subchondral edema, and degenerative joint disease that lead to pain and lameness. This pathology sometimes can be associated to lesions of the medial coronoid process and of the anconeal process in the elbow dysplasia complex (Chanoit G., 2010).

Clinical signs of OCD are first seen at 3-4 months of age, but average age of referral is 5-8 months (Hazewinkel H., 1995).

Summarising, heritability has been recognised for this polygenic condition that is elbow dysplasia and the correlation to secondary risk factors. A screening programme to select suitable breeding stock has been initiated in several countries and has decreased the incidence of the pathology.

# CHAPTER 4

# METHOD OF DIAGNOSIS OF THE ELBOW DYSPLASIA

In young dogs with lameness the diagnosis of elbow dysplasia is made from the animals' signalment, anamnesis, clinical evaluation and diagnostic imaging tools. More invasive, and sometimes useful to treat the pathology is considered arthroscopy. Some affected dogs may show stiffness, exercise intolerance, or non-specific mobility problems. If they are clinically lame, varying degrees of lameness may be exhibited or have an abnormal gait. Gait abnormality usually is present in dogs with bilateral disease, unless one elbow is worse than the other, making a unilateral lameness evident. The presentation may worsen over a period of weeks to months. It is usually worse after exercise and never completely resolves with rest. Furthermore, in case of bilateral pathology, the dogs may become unwilling to exercise for long periods or may even refuse to complete a walk. At physical examination, the limbs are usually rotated inward with elbows rotated outward. Joint effusion can be detected in the standing patient as a distended, fluid-filled pouch at the lateral aspect of the elbow joint associated or not to a muscle atrophy. Because of pain, dogs can demonstrate a flex and extend resistance showing discomfort to manipulation and having a decreased in range of motion in case of osteoarthritis. Many puppies with MCD are uncomfortable when digital pressure is applied directly over the medial coronoid process (Kirberger R., 1998; Vermote K., 2010; Palmer R., 2010).

A multitude of diagnostic imaging modalities has been used to diagnose canine elbow dysplasia, to assess the disease and the severity of presentation.

## 4.1 PLAIN RADIOGRAPHY

Plain radiography has been the first and standard imaging modality used to diagnose elbow dysplasia. These days, it still represents the imaging modality more used in the routine practise for the diagnosis. It has the advantage to be economical, readily accessible and performable with a low grade of sedation or anaesthesia to obtain optimal positioning (Kirberger R., 1998).

Traditional radiology can be used to diagnose the pathology by identifying the cause, and as a method of screening to identify dogs with and without this disorder (Heng H., 2015).

In 1989 the International Elbow Working Group (IEWG) was founded, constituted by veterinarians and breeders; it focuses on the study and prevention of the elbow dysplasia. Through annual meetings it gives an update on the news in the field of elbow dysplasia.

In 1994 IEWG proposed an international research protocol for the classification and a scoring system to evaluate the severity of ED based on the size of the osteophyte formations in specific areas of the cubit joint, as expression of osteoarthritis, and the presence of primary lesions like UAP, MCD, OCD, INC.

The standard views available to the full radiographic evaluation of the cubit joint are the following below (Boroffka S., 2015).

Radiographs are usually taken with the dog in lateral or sternal recumbency with the interested joint in contact with the cassette positioned on the table.

The dog lying in lateral recumbency is positioned for:

- The mediolateral extended **(ML extended)** projection. The angle between the humerus, radius and ulna is 120 degrees with the primary beam centred on the medial epicondyle. This view improves the evaluation of elbow incongruity, the presence of osteophyte formations on the cranial aspect of the joint and on the caudal surface of the lateral condylar ridge, the visualization of the medial coronoid process that is superimposed on the radial head.

- The mediolateral maximally flexed **(ML flexed)** projection. The angle between the humerus and radius and ulna is <45 degrees. The carpus should be not elevated for the correct lateral position of the elbow. The anconeal process is free-projected and osteophyte formations at this level are identified. Ununited anconeal process either the flexor enthesiopathy can be well appreciated (De Bakker E., 2013).

The dog is lying on sternal recumbency for:

- The craniolateral-caudomedial oblique pronated **(Cr15°LCdMO)** projection. The humerus, radius and ulna are positioned in a straight line and the limb pronated 15 degrees. The beam is centred on the joint. This projection enhanced the medial humeral condyle osteochondral defects, the elbow incongruity and the medial coronoid process is free-projected from other structures, increasing visibility.

- In the extended supinated mediolateral **(Cd75°MCrLO)** projection the joint is maximally extended and the limb is supinated about 15 degrees. The cranial edge of the medial coronoid process is better seen. In fact, the primary beam is possibly in line with the fragment edge and increases the possibilities of detecting a fragmented medial coronoid process.

- The craniocaudal projection **(CrCd)** is performed with the humerus, radius and ulna in a straight line. The primary beam is centred on the articular space distally to the medial epicondyle. It is improved the evaluation of the medial humeral condyle, particularly: osteochondral defects (kissing lesion), osteophytes on the medial humeral epicondyle and it allows to differentiate the sesamoid of the supinator longus tendon from a fragment of the coronoid process.

- The craniomedial-caudolateral oblique supinated **(Cr45°MCdLO)** with the forelimb supinated 45–50 degrees. This is not a typical radiograph performed for the diagnosis of ED but it is useful to evaluate the lateral humeral condyle and the sesamoid of the supinator longus tendon and the incomplete ossification of the humeral condyle.

- The distomedial-proximolateral oblique **(Di35°MPrLO)** the joint is flexed 90 degrees, the antebrachium elevated 35 degrees and the extremity supinated 40 degrees. This projection improves the visualization of the medial coronoid process (Haudiquet P., 2001).

Also microfocal radiography of the elbow has been described to diagnose elbow osteochondrosis, but some lesions were still not detectable and this is not a readily available technique (Guthrie S., 1991).

According to the screening program proposed by the IEWG a mediolateral flexed projection of each elbow is necessary for the evaluation of the status of the cubit joint and the orthogonal projection, the craniolateral-caudomedial projection pronated 15 degrees is highly recommended (Ondreka N., 2015; Hazewinkel H., 2015).

Considering specific anatomical regions of the elbow joint and the presence of osteophytes at this level, a scoring protocol to grade ED has been done.

The regions of interest are in the **ML flexed 45 degrees projection**: the proximal surface of the anconeal process, the cranial aspect of the radial head, the cranial edge of the medial coronoid process, the caudal surface of the lateral condylar ridge, sclerosis of the trochlear notch of the ulna at the base of the coronoid process; in the **craniolateral-caudomedial projection pronated 15 degrees** development osteophytes: on the medial surface of the medial epicondyle, at the medial edge of the medial coronoid process (Fig. 4).

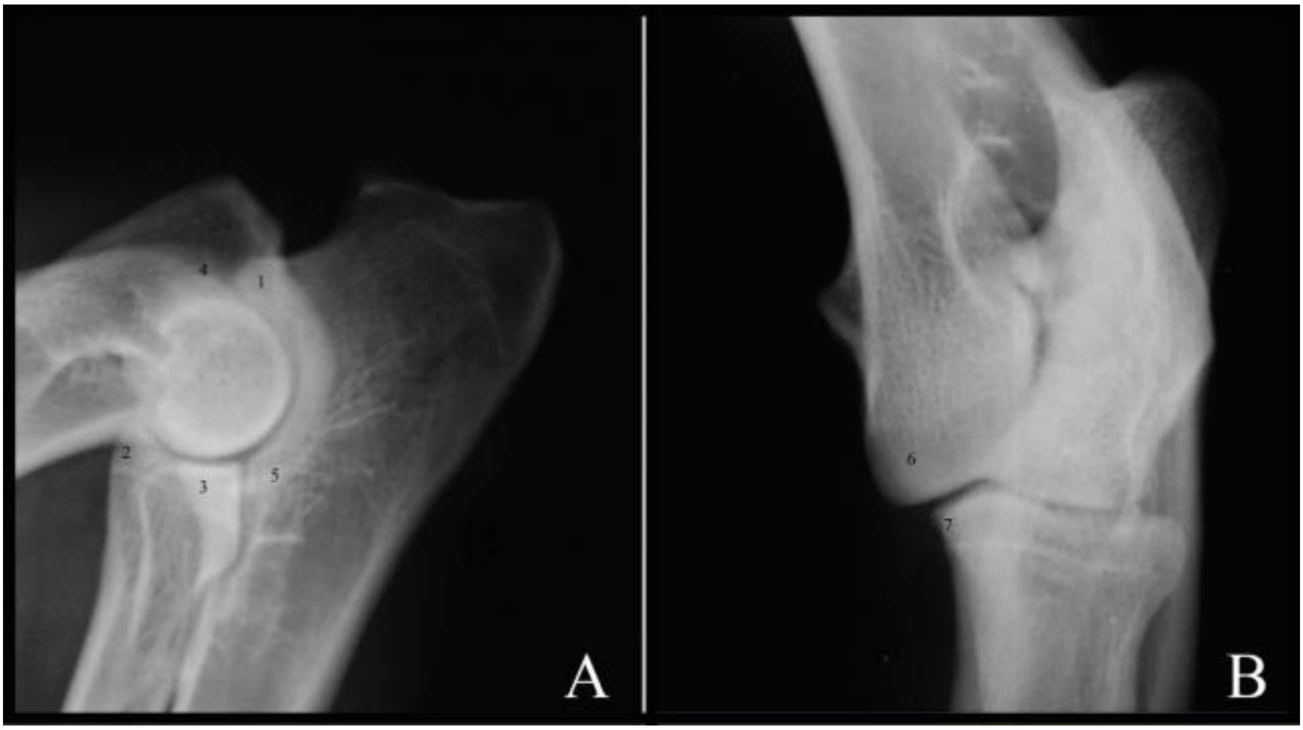


**Fig. 4 (A) ML flexed 45 degrees projection: (1) the proximal surface of the anconeal process, (2) the cranial aspect of the radial head, (3) the cranial edge of the medial coronoid process, (4) the caudal surface of the lateral condylar ridge, (5) sclerosis of the trochlear notch of the ulna at the base of the coronoid process; (B) (6) medial epicondyle, (7) the medial edge of the medial coronoid process.**

The arthrosis score used, categorized as normal (grade 0) the elbow without any sign of arthrosis or pathological changes, as mild (grade 1) when there are osteophytes less than 2 mm in height, as moderate (grade 2) when the osteophytes are 2-5 mm in height and severe (Grade 3) when the osteophyte formations are more than 5 mm. In the last update of 2010 either the sclerosis of the ulnar trochlear notch and the joint incongruity are contemplated. A suspicion of incongruence with a step formation of 3-5 mm between radius and ulna and/or clear sclerosis is considered as grade 2. A step formation larger than 5mm as sign of obvious incongruence is considered as grade 3 (Table 2.).

An additional borderline grade is allowed in some countries as Italy, Germany, France. It is a grade between the grade 0 and grade 1 assigned in case of minimal changes on the surface of the anconeal process and in case of increased sclerosis in the caudal aspect of the trochlear notch of the ulna at the level of the base of the medial coronoid process. This score has been used by the IEWG at the begin of the program and remove in 1997 from the international procedures. Moreover, in several countries the presence of a primary lesion such as UAP, FCP, OCD, or INC $\geq$ of 2 mm, automatically results in grade 3 and the suspicion of primary lesions scored in grade 2. On the other hand, in Scandinavia, UK and USA/Canada the scoring is based on the osteophyte formations and the UAP is the only one considered as primary lesion.

Several countries get they own screening program to diagnose elbow dysplasia with a minimum of one radiographic projection performed. Perhaps, in Italy such as in Finland a single mediolateral projection flexed 45 degrees is request and the orthogonal one, the craniolateral-caudomedial oblique pronated 15 degrees, is facultative, but recommended. In a study performed in 2013 by Lappalainen et al. to evaluate the accuracy of the Finnish protocol to diagnose ED in Labrador Retriever comparing to the computed tomography results they assumed that the agreement between the plain radiography with one ML view and computed tomography was good. Otherwise for small changes and for a full evaluation of the medial compartment including the OCD of the humeral condyle and kissing lesions related to the medial coronoid disease the additional Cr15°LCdMO should give more information. This might decrease the prevalence of MCD in Labradors with a grade 1 based on one projection that are included in the breeding program even though the pathology underdiagnosed (Lappalainen A., 2013; Pedrani G., 2009).

| **Plain Radiography** | | |
|---|---|---|
| **Grade 0** | Normal joint | Normal elbow without any sign of arthrosis or pathological changes |
| **Grade 1** | Mild osteoarthritis | -osteophytes <2mm in height or minor presence of sclerosis<br>- Radioulnar step of up to 2 |
| **Grade 2** | Moderate osteoarthritis | -osteophytes 2-5mm in height<br>-evident sclerosis of the ulnar trochlear notch at the base of the coronoid<br>- radioulnar step of 3-5 mm (suspicion of incongruence)<br>- indirect signs of UAP,FCP,OCD, |
| **Grade 3** | Severe osteoarthritis | -Osteophytes >5 mm<br>-Radioulnar step >5mm (obvious incongruence)<br>-Presence of UAP,FCP, OCD |

**Table 2. Grading score for elbow dysplasia on Plain Radiography.**

### 4.1.1 RADIOGRAPHIC DIAGNOSIS OF INCONGRUENCE

Elbow incongruence has been diagnosed conventionally with plain radiography. In a congruent elbow joint the articular space between the humerus, radius and ulna is seen as a continuous circular arch. In 1986 Wind described the main radiographic findings in a cubit joint affected by incongruity using the mediolateral extended and the craniocaudal projections, instead of the mediolateral flexed projection that was not considered convenient for the diagnosis of incongruity because the elbow joint was compressed. The reported radiographic features of an incongruent elbow joint were: a step formation between radius and ulna, an increased of the joint space, a cranial displacement of the humeral head and an elliptic shape of the ulnar trochlear notch instead of circular one (Wind A., 1986). Although in 2001 Collins and others, comparing the radius of curvature of the ulnar trochlear notch of Rottweilers and Greyhounds, showed as in dogs of different breed, one highly representative for FCP and the other not, there were not significant differences in degree of curvature in the predisposed breed (Collins K., 2001).

To measure the radioulnar step on radiographs three methods have been proposed. The first method measures the distance between radial plateau and the lateral coronoid process, the second method measures the distance between the circle adjacent to the radial head and the circle adjacent to the lateral coronoid process. The third method shows the size of the lateral and medial joint space.

To measure the cranial displacement of humerus and an abnormality in the shape of the trochlear notch of the ulna on radiographs three methods have been shown. The first technique measures the size of the joint based on the diameter of the humeral condyle. The second one measures the shape of the trochlear notch, based on the angle between the anconeal process, the centre of the notch and the lateral coronoid process. The third method measures the cranial displacement of humerus, by comparison of the surface of the humeral condyle within the notch and the total surface of the humeral condyle (Samoy Y., 2006) (Fig. 5).

Initially Wind (1986) asserted that the position of the joint could not influence the degree of incongruity, but later Murphy and Mason (1998-2002) affirmed the opposite, valuing the radiology not as much as sensitive for the diagnosis of incongruence due to the superimposition of structures and the effects of positioning. In fact, the pronation and supination can mimic a step formation between the radius and ulna and the angle of projection either can modify the evaluation (Wind A., 1986; Samoy Y., 2006; Murphy S.,1998; Mason D., 2002). Murphy and others (1998) compared six radiographic projections, three mediolateral 45-90-135° and three craniocaudal. The craniocaudal projections alone were considered non diagnostic for the incongruity because allowed only the visualization of the humeroradial joint (Murphy S., 1998).

In 2005, Blond and others confirmed Murphy's study which indicated the mediolateral view with the elbow flexed 90 degrees like the best view to diagnose the joint incongruity with the highest specificity. Instead the lowest specificity was shown with an angle of 135 degrees, possibly due to a physiologic incongruence of the humeroulnar joint at this angle that has been reported in normal dogs presenting a poor contact between the medial aspect of the anconeal process and the central portion of the ulnar trochlear notch.

The sensitivity and specificity of radiographic detection of incongruity is directly related to the severity of the pathology, more reliable with a radioulnar step of 2 mm or more (Blond L., 2005; Preston C., 2000) (Fig. 6).

For humeroulnar incongruity a method was proposed to quantify the degree of humeroulnar incongruity in Labrador Retrievers with and without MCD, and to study correlation between humeroulnar and radioulnar incongruity. They suggested the use of a subluxation index which supported the presence of the pathology in dogs with MCD (Proks P., 2011).

Because of that, other more advanced modalities are necessary to a more accurate diagnosis; computed tomography and arthroscopy are more reliable to identify elbow incongruity, mainly for the prognosis of the elbow dysplasia.

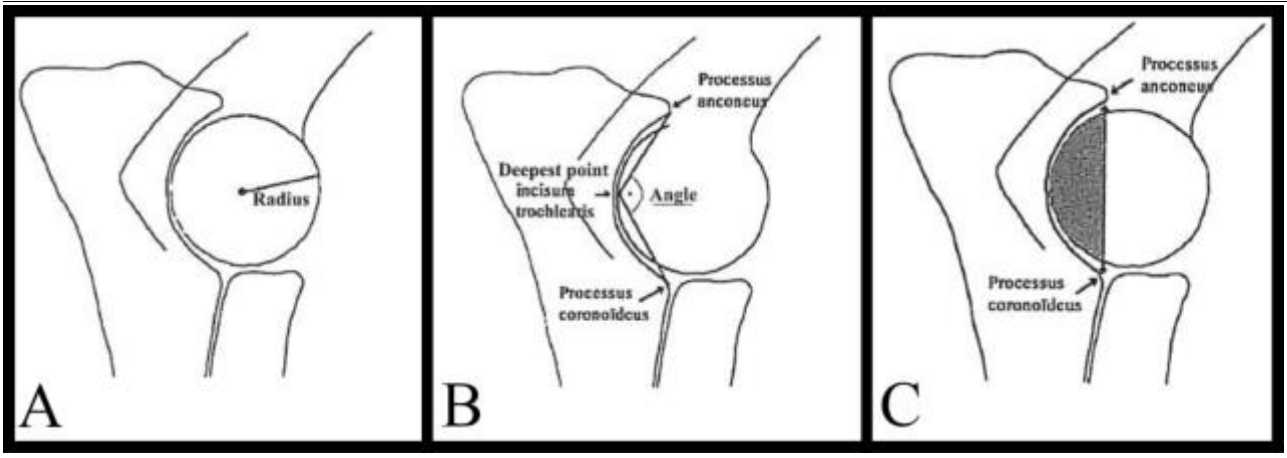


**Fig. 5 Schematic drawing. Measurement of cranial displacement of humerus and an abnormality in the shape of the trochlear notch of the ulna. (A) To measure the size of the joint based on the diameter of the humeral condyle. (B) To measure the shape of the trochlear notch, based on the angle between the anconeal process, the centre of the notch and the lateral coronoid process. (C) To measure the cranial displacement of humerus, by comparison of the surface of the humeral condyle within the notch and the total surface of the humeral condyle (Samoy Y, 2006).**


**Fig. 6 (A) ML projection (B) CrCd projection of the elbow joint with severe incongruent joint with step formation >2mm (↕).**

## 4.1.2 RADIOGRAPHIC DIAGNOSIS OF MCD

In case of forelimb lameness when the cubit joint is involved, plain radiography, associated with collection of animals' signalment, anamnesis and clinical visit, is still the most common imaging tool used in the routine practice, for the diagnosis of suspected MCD (Smith H., 2009).

In 1995 Miyabayashi in a radiographic study of the medial coronoid process in dogs reported that the Cr15°LCdMO was the best projection to visualize the medial coronoid process avoiding the summation with the proximal aspect of the radius and ulna. This finding was confirmed by Wosar and other in 1999 in a radiographic evaluation of dogs with possible fragmented coronoid process. Moreover, in 2001 Haudiquet and others suggested the distomedial-proximolateral oblique projections for the detection of coronoid fragmentation. However, the sensitivity of these conventional radiographic projections to visualize the medial coronoid process is variable and has been valued to range from 10 % to 62 % making challenge using only this modality (Smith H., 2009).

By 6 months of age, the medial coronoid process should be completely ossified, clearly visible, and come to a well-defined point as it meets the articular surface of the humerus. In the mediolateral flexed view is seen as a triangular shaped shadow summates on the caudal aspect of the radial head. In the craniocaudal projections, the medial coronoid process is a distinct, triangular process, extending from the proximomedial aspect of the ulna. If the medial coronoid process is ill-defined, it has a blurred edge, rather showing a rounded or flattened shape or cortical irregularity with proliferations, the coronoid disease is strongly suspected (Hornof W., 2000; Cook C.,

2009) (Fig. 7(A)).

The fragmentation of the medial coronoid process is better seen when the primary beam is parallel to the plane of the defect. If it is minimally displaced or the defect is located along the radial notch of the ulna parallel to the head of the radius should be difficult to reliable the detection of fragmentation. For that reason, in case of persistent lameness in young dogs that are radiographically normal at 6-7 months of ages, it is necessary to repeat the examination 6-8 weeks later. Mainly the degenerative changes related to the medial coronoid disease can indicate the pathology, and these include the formation of periarticular osteophytes on the dorsal aspect of the anconeus (70%), on the cranial aspect of the radial head (37%), and on the humeral epicondyle (56%) (Fitzpatrick N., 2009) Fig. 7(B)). Radiographic signs of incongruity are also reported associated to medial coronoid disease that can also be a cause of the pathology. Another early indicator of MCD is considered the sclerosis of the ulnar trochlear notch. The best projection to appreciate the sclerosis is the mediolateral flexed and the interesting area is on the distal aspect of the trochlear notch at the base of the coronoid process, avoiding at this level the summation with the radius. If in the projection the elbow is rotated the humerus radiopacity can be summated to the one of the notch, miming a sclerosis. The increased opacity is created by the combination of the increased bone density with the summation of periarticular osteophytes along the base of the ulnar trochlear notch. The evaluation is usually subjective and the comparison with the contralateral forelimb is useful to appreciate the difference in case one elbow joint get the pathology and the other is non-affected, but often the pathology is bilateral. Also a digital analysis of ulnar trochlear notch sclerosis in Labrador Retriever using a quantitative analysis of film density on digitised radiographs has been purposed (Burton N., 2007) (Fig 8).

In case of MCD the medial humeral condyle is often involved, in fact erosive lesion at this level are frequently associated to affection of the medial coronoid process. These erosions of the cartilage are called “kissing lesions” and seem to be more commonly seen in old dogs but have also been described in young dogs (<1 year). Radiographic findings associated to these lesions vary from mild edema or partial thickness of the cartilage to abrasions or fibrillation. Usually linear abrasion tracts extend to the subchondral bone of the trochlea and in advanced cases, these linear tracts interdigitate with similar, mirror image tracts on the trochlear notch. The subchondral bone adjacent to the lesion can become sclerotic and can be associated or not to the formation of osteophytes. In some cases, collapse of the medial compartment is visible on the craniocaudal radiographic projection which suggests the presence of cartilage erosions. Although in some cases clear radiographic signs of pathology are absent, arthroscopy may demonstrate extensive erosions (Coppieters E., 2015; Vermote K., 2010) (Fig. 9).

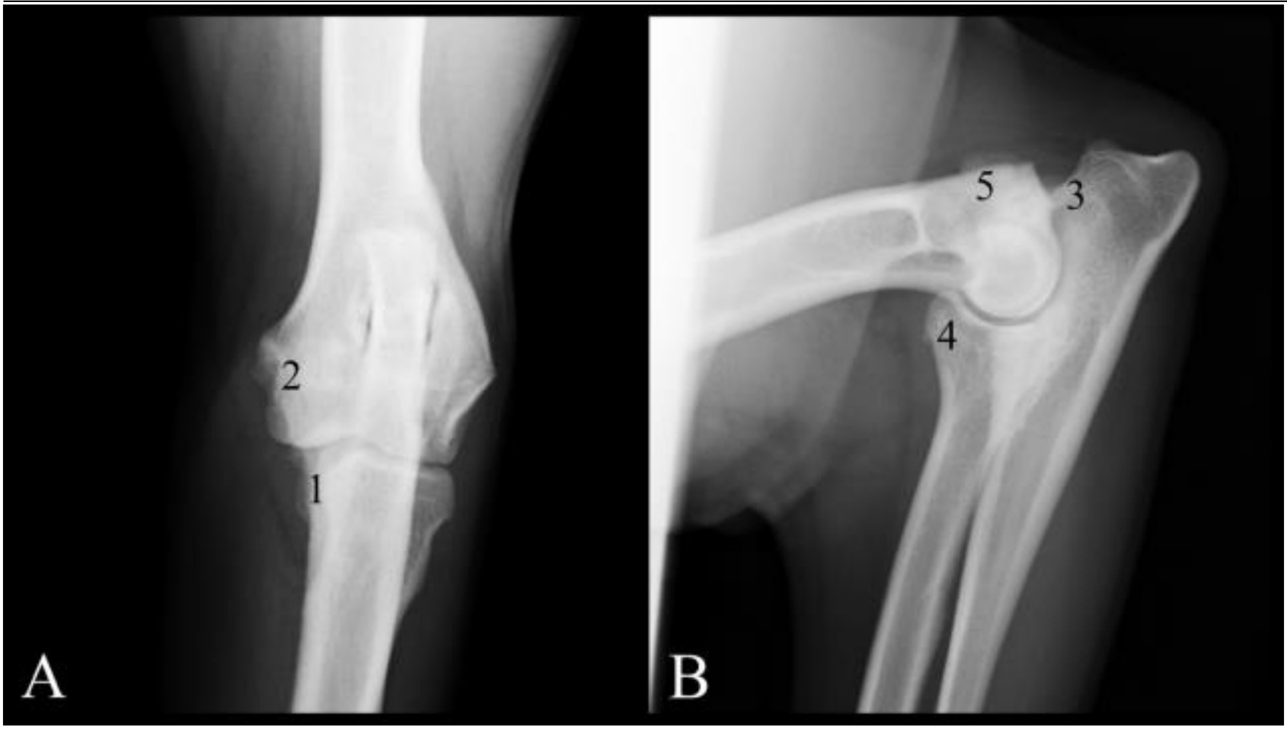


**Fig. 7 (A) Cr15°LCdMO projection of the left elbow joint osteophytes formation on the medial aspect of the medial coronoid process (1) and humeral medial epicondyle (2). (B) ML projection of the left elbow joint (3) osteophytes on the dorsal aspect of the anconeus, (4) on the cranial aspect of the radial head, (5) on the humeral medial epicondyle.**


**Fig. 8 ML projection of the left elbow joint: (*) sclerosis of the trochlear notch of the ulna.**

**Fig. 9 ML projection of the left elbow joint: kissing lesion (black arrowhead).**

## 4.1.3 RADIOGRAPHIC DIAGNOSIS OF UAP

The anconeal process has a separate ossification center. The radiolucent line between the anconeus and the olecranon is normally seen until 20-22 weeks (< of 5 months). After this time the presence of this gap is related to ununited anconeal process (Cook C., 2009)

The best view for UAP diagnosis is the flexed mediolateral projection, avoiding the summation with the physis of the medial humeral epicondyle: in case of UAP, a gap between the anconeal process and olecranon is visible (Fig. 10). In fact, the growth plate of the medial humeral condyle in the extended mediolateral projection can be confused for ununited anconeal process.

On radiographs the shape of the anconeal process is asymmetric, with the lateral side higher than the medial side. This anatomical variation can cause an opacity dorsally on the anconeal process, which is considered an osteophyte in Nordic countries. When the projections are oblique this finding can be emphasized (Lappalainen A., 2014).

**Fig. 10 Flexed ML projection of the right elbow joint: ununion of the anconeal process (white arrow).**

## 4.1.4 RADIOGRAPHIC DIAGNOSIS OF OCD

Osteochondritis dissecans is commonly seen in the medial humeral condyle. The projection more sensitive to diagnose OCD lesions is the comparing Cr15°LCdMO view showing a sensitivity of 57% in a comparative study between five different radiographic projections for the diagnosis of the osteochondritis dissecans. Also the CrCd had a good result with 56% of sensitivity. Instead the ML, flexed ML, and Di35M-PrLO views had low diagnostic value for detection of OCD lesions with a sensitivity respectively of 7%, 10%, 4% (Chanoit G., 2010). On radiographs the OCD lesion is observed as a radiolucent, irregular, flattening or a radiolucent defect of the subchondral bone of the distal aspect of the articular surface of the medial epicondyle. The surrounding bone has increased radiopacity, becoming sclerotic. Sometimes these lesions can be confused with the "kissing lesions" that are erosions of the cartilage related to the medial coronoid disease. In some cases, kissing lesions can be distinguished from OCD because the surrounded bone is less sclerotic than in OCD lesions and are more lateral located. Moreover, with the kissing lesions occasionally has been observed a radiolucency or sclerosis in the adjacent radius or ulna (Cook C.,2009) (Fig. 11).

**Fig. 11 Cr15°LCdMO projection of the right elbow joint -OCD lesion (black arrowhead).**

## 4.2 COMPUTED TOMOGRAPHY

Computed tomography is a non-invasive imaging modality that makes use of computer processed combinations of x-ray images taken from different angles to produce cross-sectional images of anatomic structures. Indeed, unlike the plain radiography that is a two-dimensional modality, with the creation of thin slices, the CT allows a three-dimensional view avoiding the issue of the superimposition. In computer tomography the system can represent different tissues based on the physical, biochemical characteristics showing on the display, different shades of gray. Disadvantages include a requirement for sedation or general anaesthesia, cost of equipment purchase, use, and maintenance, and exposure of the patients to ionizing radiation (Cook C., 2009).

The advantages of CT over plain radiography of the elbow joint include: the increased of details: in fact, the anatomic structures can be evaluated without the superimposition of structures making easier the interpretation of the images, there is the possibility to reconstruct the images in multiple planes making easier the overview of the complex elbow joint. CT provides complete imaging of articular subchondral bone but not articular cartilage.

The appropriate window settings and the correct planar images are necessary to evaluate properly the elbow joint. Essential to detect lesions on computed tomography is the experience of the evaluators and the CT display used to read the images (Thrall D., 2013; Tromblee T., 2007; De Rycke L., 2002; Cook C., 2009). The biggest limitation of the computed tomography of the elbow joint is the lack of single protocol. In fact, multiple protocols have been suggested in different publications to perform the examination.

For the position of the dogs several studies suggest different decubitus to perform the scan of the elbow joint. Some authors report to have positioned the dogs in left lateral recumbency on the computed tomographic scanning table with the elbow joints parallel and extended cranially. The heads of the dogs were pulled back to the lateral side to scan both elbow joints in the gantry. In another study the dogs were positioned in sternal recumbency using a trough like-support, with the forelimbs parallel and extended cranially (De Rycke L., 2002; Tromblee T., 2007; House M., 2009). Also a dorsal recumbency with the head and neck displaced laterally and caudally and the elbows positioned at an angle of 135 degrees to simulate normal weight-bearing position has been purposed.

Tromblee and others (2007) purposed the following procedure: the anatomic scan margins are the top of the olecranon and at least 2-3 cm distal to the radial head. The thickness of the slices should be from 0,5 mm to 2 mm with an overlapping slice index of 0.5 to 1mm for reconstructing imaging planes. The images can be acquired in transverse plane and reformatted in sagittal and dorsal planes. For each plane the window widths (WW) that should be used goes from 1500 Hounsfield Units (HU) to have a high contrasted images to 2500-3000 HU to have a medium and a low-contrast. Using a window width of 1500 HU and 2500 HU the window level (WL) used can be 300 HU and with a WW of 3500, the WL can be of 500 HU. The optimal voltage (kVp) is from 100 to 130 and the current (mAs) 100-200.

Transverse, sagittal and dorsal planes at 3500 HU and 1500 HU are the best to visualized abnormalities of the radial incisure of the ulna, trochlear defects, the appearance of the subchondral bone, fragments, elbow incongruity. It is important to underline that non-mineralized cartilaginous fragments which are visible with magnetic resonance, can be missed in CT images. Moreover, transverse plane at 3500 HU makes easiest the identification of hypoattenuating areas (Tromblee T., 2007; Reichle J., 1999) (Fig. 12).

At the last IEWG (2016) Ondreka and others proposed a grid for grading the elbow dysplasia based on CT findings.

If the grade is 0 on plain radiography which is a normal elbow joint without any sign of osteoarthritis or other signs of pathology (incongruity, subtrochlear sclerosis, primary lesions) on CT there are no features of elbow dysplasia. If the grade is 1 (mild osteoarthritis) the CT findings are the presence of osteophytes <2 mm in high, step formation between the radius and ulna up to 2 mm, irregularity or hypoattenuated area at the level of the radial incisure. In grade 2 based on radiographs (moderate osteoarthritis) CT findings are the presence of osteophytes of 2-5 mm, radioulnar step between 2-5 mm. Grade 3 (severe osteoarthritis) associated to presence of osteophytes of >5 mm in high, a step formation of 5 mm between the radius and ulna and the presence of any primary lesions as UAP, FCP, OCD (Ondreka N., 2016) (Table 3.).

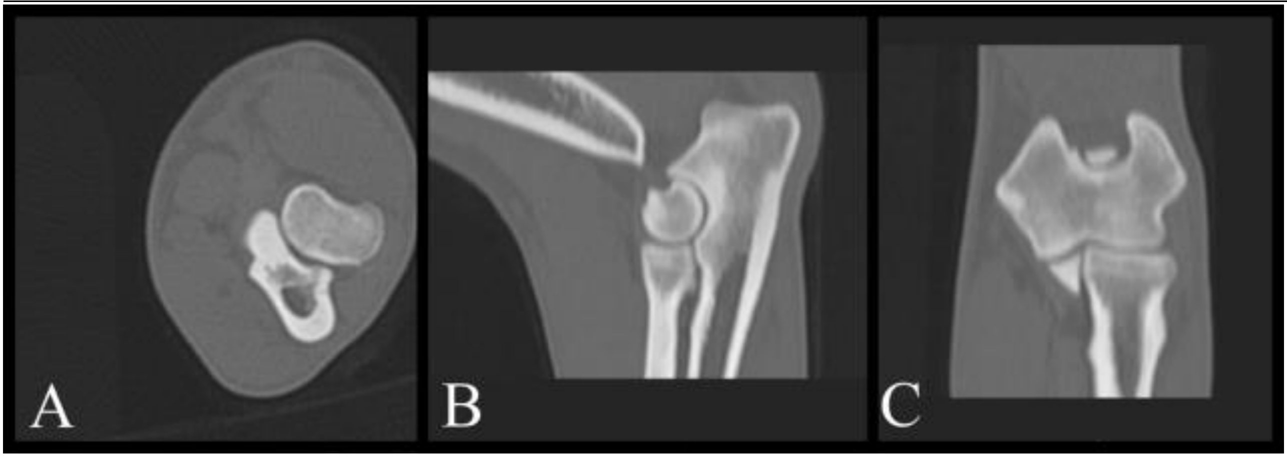


**Fig. 12 Right elbow joint MPR reconstruction (A) transverse plane (B) sagittal plane (C) dorsal plane.**

| Computed Tomography | | |
|---|---|---|
| **Grade 0** | Normal joint | Normal elbow joint, No evidence of incongruity, sclerosis or arthrosis |
| **Grade 1** | Mild osteoarthritis | -Osteophytes < 2 mm high<br>-Radioulnar step of up to 2 mm<br>-Minor sclerosis at the base of the coronoid process<br>-Obvious irregularity/cystic lesions of the radioulnar incisure in combination with other findings |
| **Grade 2** | Moderate osteoarthritis | -Osteophytes of 2-5 mm high<br>-Obvious sclerosis at the base of coronoid.<br>-Radioulnar step of > 2-5 mm (suspect incongruence) |
| **Grade 3** | Severe osteoarthritis | -Osteophytes of > 5 mm high<br>-Radioulnar step > 5 mm (obvious incongruence)<br>-Presence of UAP, FCP, OCD |

**Table. 3 Grading score for elbow dysplasia on Computed Tomography.**

### *4.2.1 CT DIAGNOSIS OF ELBOW INCONGRUITY*

Computed tomography has been the non-invasive modality most extensively used in veterinary medicine to assess incongruity of the cubit joint. Due to the importance of this component of canine elbow dysplasia, considered also a causative factor of development of the pathology, many studies have been performed. Mainly because radiographic detection and quantification of elbow incongruity is more challenging, less accurate and subjective than the CT-scan showing a higher degree of objectivity and greater sensitivity and specificity than plain radiography. In fact, CT through the use of proper image data reformatting and quantitative analytic methods to define the structural relationship between the radial and ulnar articular surfaces, decreases the errors associated with subjective assessment (Kramer A., 2006).

In 2005, in *a vitro* model the authors induced mechanically the radioulnar incongruence in canine cadaveric forelimbs suggesting the CT as a good imaging modality for the diagnosis of incongruity (Holsworth I., 2005). One of the main issue related to this imaging tool is represented to the absence of a single protocol to detect the elbow incongruity. In fact, many protocols have been suggested for the diagnosis and in one study in non-affected dogs was underlined that the position of the elbow is considered a crucial point. Different positioning has been evaluated: with the elbow in supination or pronation or in neutral position, with the joint extended and a standing angle of 135 degrees or 160 degrees.

Pronation had an effect on RUI (radioulnar incongruence), resulting in elevation of the apex of the medial coronoid process with the opposite effect noted with supination.

On joint extension and a standing angle of 160, there was a cranial translation of the ulna, increasing the space between the radius and ulna at the ulnar incisure (Wagner K., 2007).

Besides, many planes have been studied and the most reliable reconstruction plane was the mid-coronoid oblique plane, because it allows the most accurate measurement of radioulnar congruence (Holsworth I., 2005). Also a 3-D measurement technique capable of evaluating the canine radioulnar congruence has been proposed and appears to be less influenced by the positioning than 2D analysis (House M., 2009).

The radioulnar incongruity (RUI) has been considered a potential cause of medial coronoid disease and of cartilage damage, but there are many conflicting evidence in the literature regarding the presence of this abnormality and its significance in dogs with medial compartment disease of the elbow (Wind A., 1986). This is related to the absence of elbow incongruity that has been sometimes noted in association of FCP at the time of diagnosis.

Based on CT findings, Gemmill and others (2005) assumed the hypothesis that joint incongruity at the apex of coronoid process was associated with FCP, but not in each dog included in the examination (Gemmill T., 2005). Instead, Kramer and others (2006) measuring the RUI at the base, mid region and apex of the coronoid process, they did not find significant difference in RUI of the mid region and apex of the medial coronoid process between dysplastic and normal cubit joints. They assumed that RUI would have a significant influence in the pathophysiology of medial compartment disease in the dog, but it might be transient during skeletal growth and did not show at the time of diagnosis of disease. This temporary nature of the pathology open a discussion about the utility of the use of ulnar or radial osteotomies to restore the normal alignment between articular surfaces in dogs with diagnosed MCD (Kramer A., 2006).

## *4.2.2 CT DIAGNOSIS OF MEDIAL COMPARTMENT DISEASE*

Computed tomography has been considered the "gold standard" for identifying medial coronoid disease (Tobias K., 2013). CT has been suggested as the more accurate technique for detecting primary MCD lesions compared with plain film radiography, xeroradiography, linear tomography and arthrography (Carpenter L., 1993). However, a previous study that compared CT with arthroscopy found that the results can be contradictory. There were significant associations between the two modalities, but absence of lesions on CT does not preclude elbow dysplasia comparably, the absence of arthroscopic abnormalities does not preclude the disease (Moores A., 2008). In a recent study the authors showed that CT, rather than arthroscopy, could be the main technique used to assess MCD lesions of the canine elbow joint, based on the high sensitivity and specificity, underlining that arthroscopy cannot identify every fragment, especially the non-displaced fragments of the medial coronoid process (Villamonte-Chevalier A., 2015 (A)). One of the vantage of CT on arthroscopy is the possibility to assess the subchondral bone, including the presence of sclerosis, microcracks, necrosis, cyst-like lesions and fragmentation, mainly in case of integrity of the articular cartilage. Although the main disadvantage of CT is the inability to evaluate the cartilage status and sometimes it is hard to recognize the fragments when they are in situ or minimally displaced (Tobias K., 2013; Lau S., 2015). The abnormalities of the medial coronoid process on CT include: abnormal shape, hypoattenuated areas, sclerosis of the medial portion, irregularity or hypoattenuated areas at the level of the incisura radialis, fissure, fragment, osteophyte formations (Reichle J., 2000) (Fig. 13).

Labrador Retriever is the breed most frequently affected by fragmentation of the medial coronoid process (Lavrijsen I., 2012). Lau and others, comparing radiology, computed tomography and arthroscopy in Labrador Retrievers with medial coronoid disease reported a high incidence of subtrochlear sclerosis at the intramedullary bone cavity at the trochlear notch mainly in Labrador Retrievers less than 12 months of age and they quantified this sclerosis. Measuring the region of interest (ROI) at the ulnar subtrochlear bone area, the mean CT attenuation in the ROI was 972.7±147.5 HU (range, 741–1189 HU) in the patient group affected by MCD and 587.2 ± 102.4 (range, 463–739 HU) in the healthy group (Lau S., 2015). In other studies, it was not found a correlation between the sclerosis of the medial coronoid process and sclerosis of the humeral trochlea with the fragmentation of the medial coronoid process. They assumed that these differences were related to the subjective evaluation of sclerosis, with a large inter-observer variation between different studies (Moores A., 2008; Groth A., 2009).

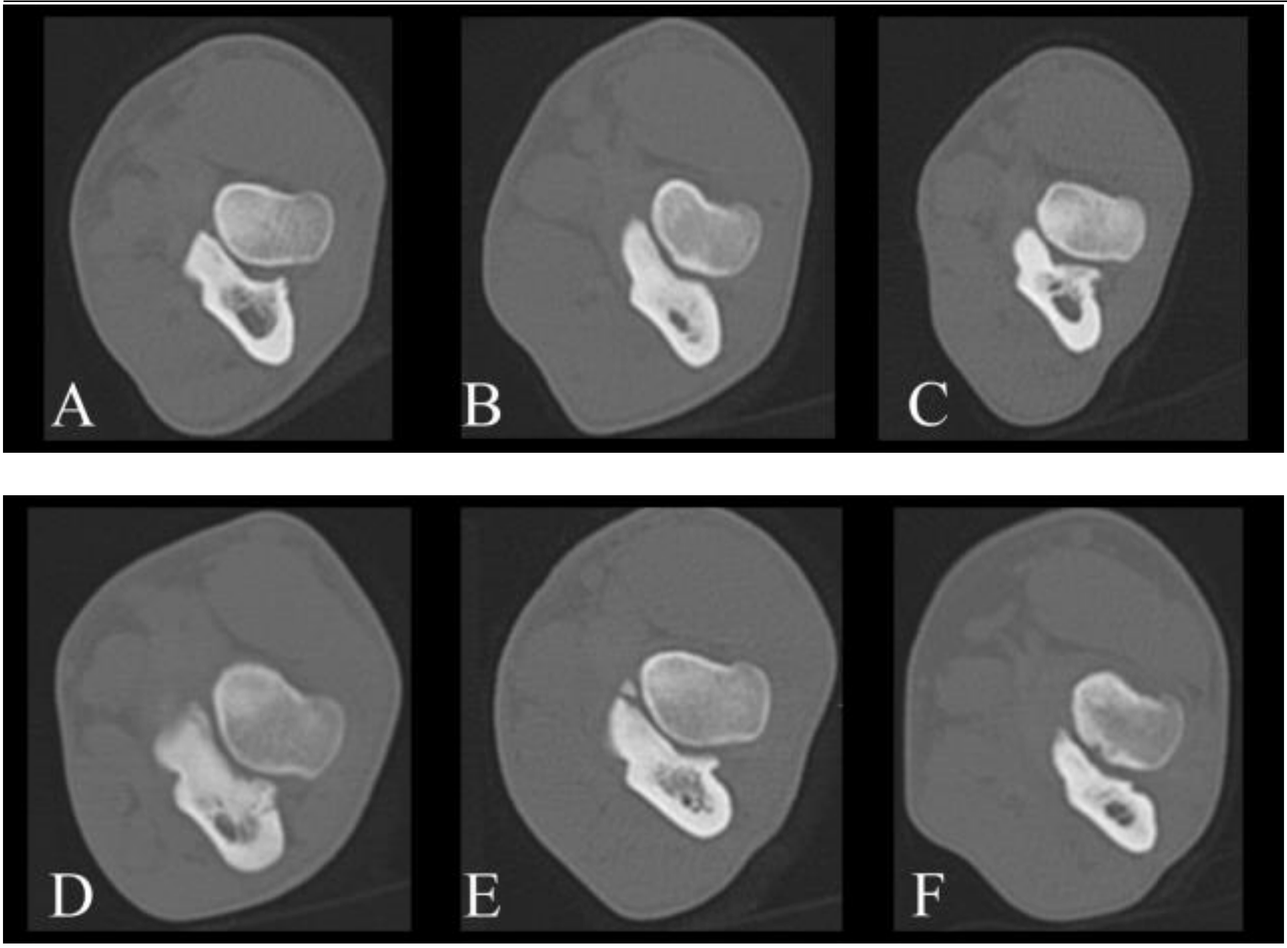


**Fig. 13 Medial coronoid disease (A) hypoattenuated areas, (B) sclerosis of the medial portion, (C) irregularity at the level of the incisura radialis, (D) fissure, (E) fragment, (F) osteophyte formation.**

### *4.2.3 CT DIAGNOSIS OF UAP*

Ununited anconeal process can be identified on computed tomography, but this modality is not considered the first option due to the easy identification of this pathology on plain radiography. On sagittal plane the UAP appears as a complete or uncomplete hypoattenuating line between the anconeal process and the olecranon. The CT can be a useful tool for the surgeon to evaluate the position of the fragment respect to the olecranon (Cook C., 2009) (Fig. 14).

**Fig. 14 Sagittal plane -ununited anconeal process on CT. Hypoattenuating line between the anconeal process and the olecranon (black arrowhead).**

### *4.2.4 CT DIAGNOSIS OSTEOCHONDRITIS DISSECANS*

In human medicine, CT has been used for diagnosis of osteochondritis dissecans associated to intraarticular fragments (Miller T., 1999).

The lesions related to osteochondritis dissecans of the humeral condyle are generally diagnosed with radiology. OCD lesions are best identified on a sagittal or dorsal plane reformatted images as a lucency (hypodensity) or flattening of the medial aspect of the humeral condyle with surrounding subchondral bone sclerosis (Reikle J., 2000). It is difficult to know whether these lesions are primary osteochondrosis (OC) or osteochondritis dissecans (OCD) lesions, or eroded wear lesions secondary to an opposing FMCP (kissing lesions) (Reikle J., 1999).

## 4.3 COMPUTED TOMOGRAPIC ARTHROGRAPHY

Computed tomographic (CT) arthrography has been studied for the detection of thin cartilage lesions and definition of the stability of osteochondral fragments in the human elbow (Shahabpour A., 2008).

In human medicine, comparing CT arthrography and MRI arthrography has been shown that CT may be superior to MRI due to better spatial resolution, superior detection of small calcific bodies, and low-price of the modality (Holland P., 1994). Computed tomographic arthrography in veterinary medicine has been proposed as imaging diagnostic modality to assess the joint space, particularly for the evaluation of the articular cartilage. The results of this *in vitro* study in normal elbow joints suggest that CT arthrography can delineate the articular cartilage. Although the cartilage thickness is measured slightly more than showed with histomorphometric methods. Moreover, this diagnostic tool provides a superior measurement precision that image planes nevertheless the contrast medium concentration and the anatomical area (Gendler A., 2015). Further studies, also in canine elbows affected by elbow dysplasia should be performed to test the modality.

## 4.4 MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging is a diagnostic modality that provides similar advantages of computed tomography for diagnosis of elbow dysplasia, but also allows the access to the status of the articular cartilage, cartilage–bone interfaces, and bone marrow lesions. The main limitations of MRI include expense, availability. Furthermore, due to the small size of the elbow joint and the complex conformtion, there is a potential lack of distinction between the cartilage of the humerus and cartilage of the radius and ulna. For these reasons, MRI arthrography (MRA), using gadolinium-DTPA, has been recommended for canine elbow imaging. Also thin contiguous slices must be acquired to determine small details.

Though the minimum slice thickness may be limited, depending on the sequence, with conventional spin-echo T1-weighted or T2-weighted sequences, slices cannot be less than 2 mm thick or the signal-to-noise ratio becomes too low to be of diagnostic value. For this reason, three-dimensional Fourier transformation (3DFT) allows the use of very thin slices without compromising signal-to-noise ratio and it is recommended to scan the elbow joint.

Use of a small circular orbital coil is suggested for diagnosis of elbow dysplasia to get improved signal-to-noise ratio. All MRI planes, dorsal, sagittal, and axial/transverse, are potentially useful for diagnosis of pathology (Snaps F., 1998; Snaps F., 1999; Cook C., 2009).

### *4.4.1 MRI FOR DIAGNOSIS OF ELBOW INCONGRUITY*

Magnetic resonance for diagnosis of elbow incongruity has been considered studying the relationship between the ulnar trochlear notch and the humeral trochlea and at various locations, underlining differences between large, small and chondrodysplastic breeds. In large-breed dogs, there was a smaller articular space at the level of the anconeal process and a larger joint space at the center of the ulnar trochlear notch that may not have the capability to compensate for incongruity between the radius and ulna (Janach K., 2006; Cook C., 2009).

### *4.4.2 MRI FOR DIAGNOSIS OF MCD*

For the diagnosis of fragmented medial coronoid process in the canine elbow joint, Snaps and others (1999) showed the possible MRI appearance of the medial coronoid process affected by pathology. Three different types of MRI abnormality of the medial coronoid process, based on surgery results, have been described. They identified a displaced fragment, a non-displaced mineralized fragment and non-mineralized fragment. MRI showed an accuracy of 95.5% to diagnose fragmentation in comparison to a 77% of radiographic accuracy. It was also higher than CT accuracy because on computed tomography examination, an abnormal medial coronoid process was not always detected, especially when the fragment was cartilaginous. In MRI studies, the displaced fragments had a low-intensity signal. Contrary, the cartilaginous appeared relatively hyperintense (Snaps F., 1999).

### *4.4.3 MRI FOR DIAGNOSIS OF UAP*

On T2-weighted image, ununited anconeal process has been described in MRI as a hyperintense gap between the anconeal process and the proximal aspect of the ulna on sagittal plane (Reichle J., 1999; Cook C., 2009).

### *4.4.4 MRI FOR DIAGNOSIS OF OCD*

Osteochodral lesions are best evaluated in dorsal and sagittal planes. A thickening of the articular cartilage of the medial aspect of the humeral condyle or a flattening of the condylar surface can be observed. Also cartilage erosions or irregular areas are often associated with subchondral bone lesions. Minimal articular cartilage lesions without involvement of the subchondral bone may be difficult to identify due to the low possibility to distinguish the thin opposing articular cartilage surfaces in this region (Cook C., 2009).

## 4.5 ULTRASONOGRAPHY

Ultrasonography is a real-time non-invasive diagnostic imaging technique widely used in the musculoskeletal disorders and, less commonly, to assess the bone and cartilage disturbs (Cook C., 2009). In fact, bone and cartilage are more deeply located, making difficult the penetration of echoes, also the high acoustic impedance of the bone, that is denser than soft tissues, makes challenging the definition of the architecture. The intact subchondral bone interface is represented by a hyperechoic line with a strong acoustic shadow and the cartilage is visible as an anechoic thin layer of uniform thickness with hyperechoic interface (Vandevelde B., 2006). Several ultrasonographic studies of the elbow joint have been reported. To assess the canine elbow a high frequency transducer (18MHz) is recommended. In the normal canine elbow, the lateral and medial humeral epicondyles, the humeroradial and humeroulnar joints, anconeal process, the radial head and medial coronoid process are identified. The lateral and medial humeral epicondyles appear as a hyperechoic line with distal acoustic shadowing. The lateral epicondyle is more rounded than the medial epicondyle. The humeroradial and humeroulnar joints spaces are identified as hypoechoic regions between the hyperechoic interfaces of bone. The anconeal process is visualized as a distinct hyperechoic line. The medial coronoid process is evident as a hyperechoic angular line with acoustic shadowing; it extends approximately $5.3 \pm 0.1$ mm into the joint. Its base is 1 to 2 mm in length, merged with the ulnar diaphysis. The medial coronoid process is more easily seen after the intra-articular injection of saline or iohexol, as its borders are so surrounded by anechoic fluid. The subchondral bone of the head of the radius is represented as a hyperechoic line (Villamonte-Chevalier A., 2015 (B); Knox V., 2003). If the medial coronoid process is fragmented the surface is often irregular with proliferation or distinct fragmentation. If the medial coronoid process is affected by a disturb of endochondral ossification, the echogenicity changes becoming less hyperechoic as in normal bone, closer to the echogenicity of the fibrous or soft tissues. In case of UAP an irregularity or interruption in the cortical proximal bone margin of the anconeal process can be seen. Instead, the OC lesions are difficult to be evaluated due to the typical location that cannot be reached ultrasonographically. The elbow joint incongruity has not been evaluated by ultrasound and would likely be difficult to investigate for these same reasons. Osteophyte formations or abnormal bone can be visible as irregular, hyperechoic lines lying from the cortical bone (Cook C., 2009).

## 4.6 NUCLEAR SCINTIGRAPHY

Nuclear scintigraphy has been used in veterinary medicine to localize the origin of the lameness or to identify early small changes in the elbow joint. The technique offers the major advantage of increased sensitivity over standard radiographic imaging, in fact it is very sensitive to localize and quantify dynamic bone change, before changes are demonstrable by radiography. The disadvantages include: low specificity, results should be interpreted with clinical examinations and other investigations, the equipment is expensive and requires a dedicated room and it is necessary an authorization to receive and dispose of radioactive substances with personnel trained in radiation handling and safety. After scintigraphy, the patients and any biologic waste must be isolated, the time varying depending on country and state regulations (Cook C., 2009).

The radiopharmaceutical commonly used for the examination of the joint is the $^{99m}$Technetium diphosphonates. This is the radionuclide Technetium -99m which emits gamma rays of the energy 140 KeV and has a half-life of 6 h to which is attached a diphosphonate. The most commonly used are methylene diphosphate (MDP) and hydroxymethylene diphosphate (HDP). The detector can be a probe based system, or a gamma camera which consists of a sodium iodide crystal, which when exposed to gamma rays produces light flashes which are detected by a photomultiplier tube behind the crystal. This then emits an electrical pulse which is monitored by electronic counting circuitry. For the elbow scintigraphy the dog is positioned in sternal recumbency on the table lined up with a horizontal fixed gamma camera and both forelimbs are located on top of the camera. There are three phases of a bone scan: a vascular phase (few second), a soft tissue phase when the tracer is still within the vascular compartment (20 min after injection) a static bone phase image (2 hours after injection). In the bone phase, the radiopharmaceuticals used are combined with the hydroxyapatite of the bone especially in the areas where the vascularization is increased for any reason. Due to the small size of the elbow joint, it is often possible to see an increased radiopharmaceutical uptake involving the whole joint. Sometimes it is also possible to observe a focal uptake in the anconeal process region in case of UAP, rather than in the distal aspect of the medial humeral condyle affected by OCD or at the base of the medial coronoid process in case of MCD (Schwarz T., 2004).

## 4.7 ARTHROSCOPY

Arthroscopy is a minimal invasive surgical procedure on a joint in which an examination and sometimes a treatment of damage is performed using an arthroscope. In human medicine, arthroscopy is considered the “gold standard” for evaluating joint cartilage lesions (Figueroa D., 2007). In veterinary medicine, it has been considered the “gold standard” for assessing medial coronoid disease because articular surfaces can be evaluated directly and cartilage lesions can be detected. Moreover, it offers a short convalescence and an optimum functional result, but it does not prevent the development of secondary OA. A recent study suggests the CT as “gold standard” for diagnosis of MCD based on the high sensitivity and specificity of computed tomography on arthroscopy. In fact, arthroscopy cannot identify every fragment, especially the non-displaced fragments of the medial coronoid process. (Moores A., 2008; Villamonte-Chevalier A., 2015 (A); Fitzpatrick N., 2009).

Arthroscopic evaluation of the elbow joint needs a general anaesthesia with the dog positioned in dorsal recumbency with a sandbag under the affected elbow. A 2.7 mm arthroscope may be used in large breed dogs, but a 1.9 mm is considered superior. A lateral recumbent position can also be used with a 2.4 mm arthroscope (Tobias K., 2013; Villamonte-Chevalier A., 2015 (A)).

The cartilage lesions are graded based on Modified Outerbridge Scoring System: grade 0 represents a normal appearance of the cartilage; grade 1 when chondromalacia is present associated to softening and swelling of the cartilage; in grade 2 is observed a partial thickness fibrillation and fissuring of the cartilage; in grade 3 deep ulcerations are seen that do not reach the subchondral bone; in grade 4 there is a full thickness cartilage fissuring with exposure of the subchondral bone; in grade 5 eburnated subchondral bone is observed (Table. 4).

| **Modified Outerbridge Scoring System** | |
|---|---|
| **Grade 0** | Normal appearance of the cartilage |
| **Grade 1** | Chondromalacia associated to softening and swelling of the cartilage |
| **Grade 2** | Partial thickness fibrillation and fissuring of the cartilage |
| **Grade 3** | Deep ulcerations that do not reach the subchondral bone |
| **Grade 4** | Full thickness cartilage fissuring with exposure of the subchondral bone |
| **Grade 5** | Eburnated subchondral bone |

**Table. 4 Modified Outerbridge Scoring System**

In dogs affected by MCD, synovitis can be observed during arthroscopy revealing: an increased frequency of visible blood vessels and increased distension or tortuosity of vessels, a loss of colour of the synovial layer and, another frequent finding, the fimbriation of the synovial surface with large numbers of fine villous protrusions and increased plication of the synovium that did not disappear with capsular distension during arthroscopy. Also displaced fragments, fragments in situ, osteochondromalacia are reported (Lau S., 2015; Schulz K., 2003; Fitzpatrick N., 2009).

Fitzpatrick and others (2009) suggested a grading system for integrity of the medial coronoid process based on arthroscopy. Grade intact is representative of a coronoid process, without any sign of fissuring or fragmentation and without any movement of the medial aspect of the coronoid process during probing, but also associated to cartilage damage (Modified Outerbridge scores 1–5 may be present); grade fissure is localized full-thickness cartilage fissure, but medial aspect of the coronoid process remains in situ during examination; grade fragmentation is associated to free osteochondral body with corresponding loss of medial coronoid process or a fragment that is easily manipulated upon probe palpation (Fitzpatrick N., 2009) (Table. 5).

| **MCP Grade** | |
|---|---|
| **Intact** | -No signs of fissuring or fragmentation; no movement of the medial aspect of the coronoid process during probing<br><br>-Cartilage damage, modified Outerbridge scores 1–5 may be present. |
| **Fissure** | -Localized full-thickness cartilage fissure, but medial aspect of the coronoid process remains in situ during probing |
| **Fragmentation** | -Free osteochondral body with corresponding loss of MCP or<br><br>-Freely manipulated upon probe palpation. |

**Table. 5 Grading System for integrity of the medial aspect of the Coronoid Process.**

The damage of the medial humeral condyle is often associated to MCD. The 'kissing lesions' are cartilage erosions of the medial humeral condyle associated to a fragmented coronoid process, suggesting that the injury of the condyle is determined by roughness from the coronoid disease. Similar appearance of the cartilage is seen in joints affected by OCD of the medial humeral condyle. Kissing lesions and OCD lesions can be both present in the same elbow joint.

The OCD lesions are characterised by a flap of articular cartilage, usually partially attached to the medial humeral condyle, but can be also free within the joint space. Sometimes the cartilage fragment can still be attached to the subchondral bone and the subchondral bone defect can be detectable only after probing.

Arthroscopy has been proposed either for diagnosis of elbow incongruity in a *vitro model*. Although the evaluation of a step formation between the radius and ulna during arthroscopy should be done carefully, inserting an arthroscope inevitably causes joint distortion and it is highly operator dependent. Common arthroscopic findings observed in incongruent joints are: fragmentation of the medial coronoid process, fleece-like formations on the radial head, irregular surface in the center of the ulnar trochlear notch, cartilage defects of the medial humeral condyle and the humeroulnar and humeroradial joint space.

These cartilage lesions are associated to severe incongruity most likely as a result of an altered pressure distribution within the joint (Samoy Y. 2012; Bennett D., 1981; Eljack H., 2015).

# CHAPTER 5

# SCREENING PROGRAM OF ELBOW DYSPLASIA IN ITALY

A screening scheme to reduce the incidence of elbow dysplasia has been introduced by the IEWG. It is made available on internet and it is in use in many countries. Only few conditions are prescribed for screening: the dog should be mature, minimum 12 months of age and at least one radiograph (mediolateral flexed view) of good quality has to be available for evaluating.

In Italy, in 2009 with the cooperation between the Ministry of Agricultural Policy and the Italian Kennel Club, ENCI (Ente Nazionale Della Cinofilia Italiana), the official guidelines for screening elbow dysplasia in dog have been drawn up, in accordance with the rules of the Federation Cynologique Internationale (FCI).

A group of expert and certificated veterinarians can perform the elbow joint radiographic examination and make a preliminary judgment. Following, the radiographs are sent to official veterinary centers designated by the ENCI for the final judgment in 30 days.

ENCI also acknowledge those certifications of ED which meet the FCI requirements from other countries.

The projection for evaluating is the mediolateral view flexed 45 degrees and it is recommended, but is not mandatory the craniolateral-caudomedial oblique pronated 15 degrees'.

The minimum age for elbow dysplasia is 12 months for any breed (Decreto Ministeriale n°19878, 2015).

The grading as described above is based on the arthrosis score categorized as normal (grade 0) the elbow without any sign of arthrosis or pathological changes; as “border line” (BL) when minimal pathological changes are present but they are not so pronounced to award a grade 1; as mild (grade 1) when there are osteophytes less than 2mm in height; as moderate (grade 2) when the osteophytes are 2-5mm in height; severe (Grade 3) when the osteophyte formations are more than 5 mm. In the last update of 2010 either the sclerosis of the ulnar trochlear notch and the joint incongruity are contemplated. A suspicion of incongruence with a step formation of 3-5 mm between radius and ulna and /or clear sclerosis is considered as grade 2. A step formation larger than 5mm as sign of obvious incongruence is considered as grade 3.

In Italy the “border line” grade was added when German shepherds, in 2006, encountered issues in competitions in Germany because were graded as 1 even though minimal changes are shown. For this breed are allowed to reproduction only grade 0, BL or 1 (PedraniG., 2009).

# CHAPTER 6

# TREATMENT OF ELBOW DYSPLASIA

Ideal goal of any treatment for elbow dysplasia should be to remove pain, to stop the progression of the disease and to prevent degenerative joint disease. There are multiple therapeutic approaches to treat the pathology and is still unclear which might be the best choice between surgical and conservative treatment regimes. For these reasons the selected therapy is related to own experience, although some elaborated algorithms have been suggested to help the decision.

Non-surgical treatments are sometimes recommended for dogs that are affected by subtle pathology, and in dogs having no evidence of current elbow incongruity or to decrease the elbow pain and maintain the mobility. The keystones of non-surgical treatment are body weight management, physiotherapy, exercise modification, medication as painkillers or intra-articular injection of autogenous substances (plasma-derived, fat-derived) (Fitzpatrick N., 2009; Vannini R., 2015).

The surgical treatment depends on pathology.

*REMOVAL OF THE FRAGMENT*

In case of FMCP, with arthroscopic approach, the fragment can be removed. Otherwise it may freely move within the articular space causing synovitis, thickness of the joint capsule osteoarthritis and consequently producing pain.

*SUBTOTAL CORONOID OSTECTOMY*

Another method available is the subtotal coronoid ostectomy that removes mostly of the medial coronoid process. In fact, it has been demonstrated that the whole subchondral bone can be involved by micro cracks in case of coronoid disease, generating pain.

*BICEPS ULNAR TENDON RELEASE*

The biceps ulnar tendon release has been proposed as a treatment in case of MCD associated to small fragments, synovitis and pain. Recently the biceps brachialis complex has been suggested as the cause of rotational incongruence that should be at the base of the fragmentation of the coronoid process. The surgery is performed to avoid that during the contraction of the muscle complex is generated a compressive force leading the radial head into the radial incisure of the ulna.

*DISTAL ULNA OSTEOTOMY*

In young dogs affected by radioulnar incongruence, younger than 6-8 months the distal ulna osteotomy is preferred. It is a partial osteotomy and at this age, the interosseous ligament still allows the shift of the ulna in relationship to the radius.

*DYNAMIC PROXIMAL ULNA OSTEOTOMY*

For the joint incongruity, also a dynamic proximal ulna osteotomy is possible. It is an oblique osteotomy of the proximal ulna which should release the pressure on the joint. It is performed in growing young dog, but they can have a severe pain at least till the osteotomy does not heal.

*PROXIMAL ABDUCTING ULNAR OSTEOTOMY*

When the entire medial compartment is involved, the complex medial coronoid disease and erosion of the medial humeral condyle can evolve in a collapse of the medial aspect of the elbow joint. With the proximal adducting ulnar osteotomy, a slight abduction of the ulna of about 4 to 6 degrees is created. The result is an unloading of the medial compartment alleviating pain and lameness. This procedure includes the proximal osteotomy of the ulna associated to a plate fixation that create a modification of the forelimb alignment.

*SLIDING HUMERAL OSTEOTOMY*

To unload the medial compartment and shift the weight-bearing to the lateral compartment a sliding humeral osteotomy has been proposed. A humeral transverse osteotomy is performed and the bones fixed with a special step plate fixation that keeps the distal humerus in a medially shifted position.

## *CANINE UNICOMPARTMENTAL ELBOW SYSTEM*

In old dogs with medial coronoid disease a small prosthesis can be placed in the medial compartment, used to reduce friction between bearing surfaces, decreasing the pain.

## *ELBOW PROSTHESIS*

A total elbow replacement with a prosthesis has been proposed, but not yet taken off due to the cost and difficulty to implement.

# CHAPTER 7

# EXPERIMENTAL

Between 2013 and 2016, thirty-nine healthy Labrador Retrievers, twenty-two males and seventeen females were referred to the University of Parma Hospital from the same breeding for screening elbow dysplasia. The same dogs were evaluated at less than 12 months of age (range of age 120-220 days) and when they were older than 12 months (range of age 370-550 days). The dogs were raised on a diet of commercial dog food and they lived half of the time indoor and half outdoor. Signalment and history were recorded for any dog followed by physical and orthopaedic examination. At the clinical examination inspection at the walk, trot and palpation of the joint to define the range of motion and pain reaction were considered. None reported history of lameness or sign of pain at the elbow joint. Once the dogs were scheduled for plain radiographs, CT of the elbow joints was performed, but CT findings had no effect on the radiographic evaluation.

## RADIOGRAPHIC ASSESSMENT

Dogs were sedated using the association of 150 µg/kg medetomidine and 0.1 mg/kg butorphanol administered intramuscularly. Two radiographic projections the 45° flexed medio-lateral and the craniolateral-caudomedial oblique pronated 15 degrees were obtained of all elbow joints. Radiographs were evaluated by one radiologist diplomate ECVDI, one board certified radiologist and a Phd student. The observers were blinded to the identity of the patient and results of the CT findings were evaluated randomly and in consensus with the radiographic images of each patient as paired sets (left and right elbows).

Radiographs were evaluated systematically for elbow dysplasia according to the guidelines of the IEWG. Grade 0 was the normal elbow without any sign of arthrosis or pathological changes, grade 1 when there were osteophytes less than 2mm in height or minor presence of sclerosis; grade 2 when the osteophytes were 2-5mm in height, and/or evident sclerosis of the ulnar trochlear notch at the base of the coronoid, and/or suspicion of incongruence with a step formation of 3-5 mm between radius and ulna and /or indirect signs of UAP,FCP,OCD, grade 3 when the osteophyte formations were more than 5 mm and/or a step formation larger than 5mm as sign of obvious incongruence and/or presence of UAP, FCP, OCD.

## COMPUTED TOMOGRAPHY ASSESSMENT

Dogs after radiographic study were positioned on the table in sternal recumbency using a trough like-support. The heads of the dogs were pulled back to the lateral side to scan both elbow joints in the gantry with the forelimbs parallel and extended cranially. Each elbow joint was scanned in transverse and reformatted in sagittal and in dorsal planes. Transverse images were obtained from the upper point of the olecranon to 2 cm distal to the radial head perpendicularly to the forelimb in 1mm thick slices with 110kV, 90mA, and 1second tube rotation time. For each plane reconstructed, the display window widths (WW) used was 1500 and the displayed level (WL) was 300 HU, and 3500 WW at the level (WL) of 500. This setting is the same reported in other studies (Tromblee T., 2007).

CT studies were evaluated in consensus by two board certified radiologist and a Phd student unaware of the signalment, and the radiographic findings.

A grading score similar to that used for interpreting radiographs has been followed according to the grid proposed at the last IEWG meeting in 2016. Grade 0 was a normal elbow joint without evidence of incongruity, sclerosis, arthrosis; grade 1 in case of osteophyte formations <2mm high, obvious irregularity or cyst like lesions at the radioulnar incisure, and or incongruence <2mm; grade 2 was considered in relation to the presence of osteophytes between 2-5mm high or a radioulnar step between 2-5mm; grade 3 associated to osteophytes >5mm high or obvious presence of primary lesions (FCP, UAP, OCD, INC >5mm) (Ondreka N., 2016) (Table. 6).

| | Plain Radiology | Computed tomography |
|---|---|---|
| **Grade 0** | -Normal elbow without any sign of arthrosis or pathological changes | -Normal elbow joint, No evidence of incongruity, sclerosis or arthrosis |
| **Grade 1** | -Osteophytes <2mm in height or minor presence of sclerosis<br>-Radioulnar step of up to 2 | -Osteophytes < 2 mm high<br>-Radioulnar step of up to 2 mm<br>-Minor sclerosis at the base of the coronoid process<br>-Obvious irregularity/cystic lesions of the radioulnar incisure in combination with other findings |
| **Grade 2** | -Osteophytes 2-5mm in height<br>-Evident sclerosis of the ulnar trochlear notch at the base of the coronoid<br>-Radioulnar step of 3-5 mm (suspicion of incongruence)<br>-Indirect signs of UAP,FCP,OCD | -Osteophytes of 2-5 mm high<br>-Obvious sclerosis at the base of coronoid<br>-Radioulnar step of > 2-5 mm (suspect incongruence) |
| **Grade 3** | -Osteophytes >5 mm<br>-Radioulnar step >5mm (obvious incongruence)<br>-Presence of UAP,FCP, OCD | -Osteophytes of > 5 mm high<br>-Radioulnar step > 5 mm (obvious incongruence)<br>-Presence of UAP, FCP, OCD |

**Table. 6 Comparison of the grading score between Plain Radiology and Computed Tomography.**

## STATISTICAL ANALYSIS

Statistical software IBM SPSS 22.0 for MacOS was used for analysis. The development of the osteoarthritis on radiographs and on CT was compared by Wilcoxon signed ranks test, calculating exact P values. P values <.05 were considered statistically significant. Fischer's exact test in table analysis was applied to test the significance of any association between radiographic and CT signs of ED. Kappa statistics were used to assess agreement between grading and elbow dysplasia status based on CT. Agreement with kappa value was interpreted as follows: <0=less than chance, 0.01-0.20=slight, 0.21-0.40=fair, 0.41-0.50=moderate, 0.61-0.80=substantial, 0.81-0.99=almost perfect (Viera A., 2005). The sets would differ only if their kappa coefficients differ (=combined kappa is statistically significant).

## RESULTS

Thirty-nine Labrador Retrievers, twenty-two males and seventeen females were included in the study. The age ranged was from 120-220 days (median 170) at the first time and 370-550 days (median 460). On orthopaedic examination, none of dogs were found to be lame.

For the study 78 elbow joints were evaluated separately and based upon literature, and considering that is strongly recommended to allow to reproduction dogs with elbow joints grading 0 and 1, we assessed positive to elbow dysplasia the elbows with 2-3 grades of pathology as in radiographs as in computed tomography (Malm S., 2008).

On plain radiography at the age less than 12 months 46 joints were of grade 0.20 joints were of grade 1.12 were of grade 2 and none was of grade 3. Twelve elbow joints were considered positive to elbow dysplasia scoring 2.

At the age over 12 months 40 elbow joints were of grade 0.18 joints were of grade 1, 17 joints were of grade 2 and 3 joints were of grade 3. Twenty joints were considered positive to elbow dysplasia, 17 of grade 2 and 3 of grade 3 (Table. 7 and Fig. 16).

| 78 Elbow joints | Grade0 | Grade 1 | Grade 2 (+) | Grade 3 (+) |
|---|---|---|---|---|
| RX <12M | 46 | 20 | 12 | 0 |
| RX >12M | 40 | 18 | 17 | 3 |

**Table. 7 Result for radiographic assessment for 78 elbow joints at <12months and >12 months.**

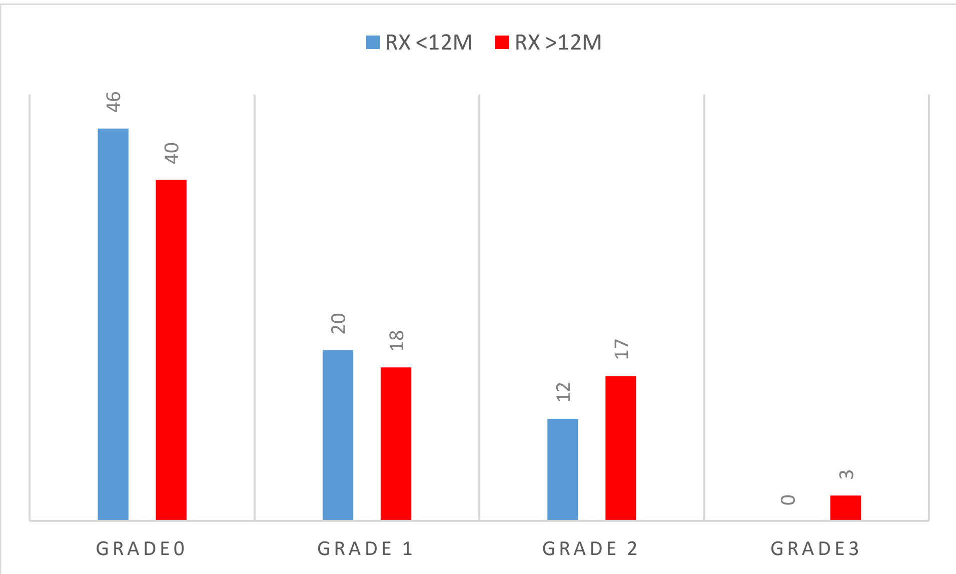


**Fig. 16 Result for radiographic assessment for 78 elbow joints at <12months and >12 months**

On CT assessment at the age less than 12 months 46 elbow joints were graded 0.16, joints were graded 1.7, joints were graded 2 and 9 joints were graded 9. Sixteen joints were positive to elbow dysplasia, 7 scoring 2 and 9 scoring 3.

Over 12 months of age 35 joints were grade 0.16 joints remained grade 1. 4, joints were graded 2. 23, joints were of grade 3. Twenty-seven elbow joints were positive to elbow dysplasia, 4 with grade 2 and 23 with grade 3 (Table 8. and Fig. 17).

| 78 Elbow joints | Grade0 | Grade 1 | Grade 2 (+) | Grade3 (+) |
|---|---|---|---|---|
| CT <12M | 46 | 16 | 7 | 9 |
| CT >12M | 35 | 16 | 4 | 23 |

**Table. 8 Result for CT assessment for 78 elbow joints at <12months and >12 months**

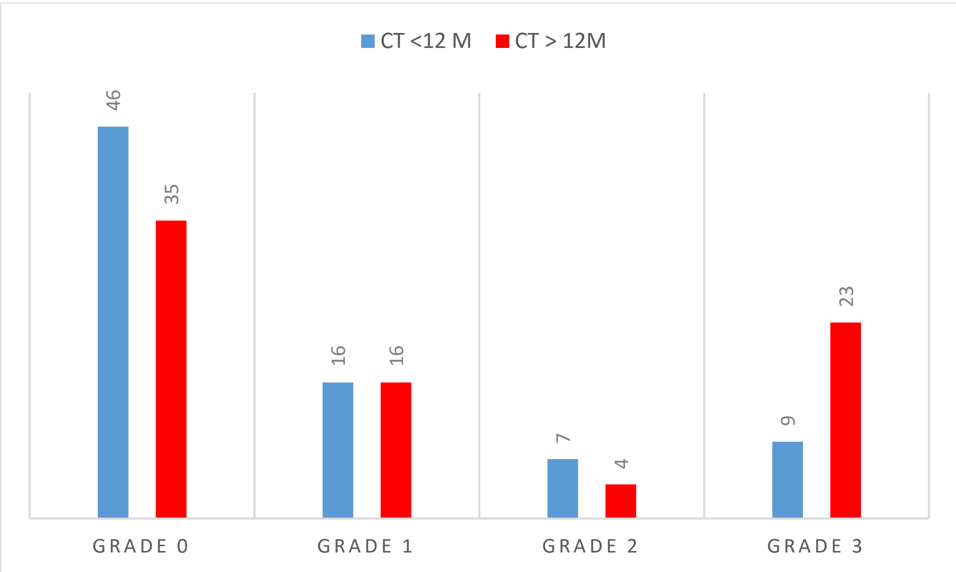


**Fig. 17 Result for radiographic assessment for 78 elbow joints at <12months and >12 months**

Comparing radiographic findings of the same dog at the age less than 12 months and over 12 months: 36 joints judged 0 remain grade 0; 7 joints assessed 0 became grade 1; 2 of grade 0 became grade 2; 4 joints of grade 1 became grade 0; 10 graded 1 remain grade 1; 7 grade 1 became grade 2; 1 grade 2 became grade 1; 8 grade 2 remained grade 2; 3 of grade 2 became grade 3. The grade of the disease remained invariable in 54 joints and developed a worse grade of disease in 19 joints and improved in 5 joints (P 0.004) (Table. 9).

| | ***RX > 12M*** | | | |
|---|---|---|---|---|
| | ***Grade0*** | ***Grade1*** | ***Grade2*** | ***Grade3*** |
| ***Rx < 12M*** | | | | |
| ***Grade0*** | 36 | 7 | 2 | 0 |
| ***Grade1*** | 4 | 10 | 7 | 0 |
| ***Grade2*** | 0 | 1 | 8 | 3 |
| ***Grade3*** | 0 | 0 | 0 | 0 |

**Table. 9 Results pf radiographs at <12 and > 12 months.**

Comparing CT findings at less than 12 months and over 12 months: 33 joints remained grade 0; 7 of grade 0 became grade 1; 1 of grade 0 became 2; 6 joints of grade 0 became grade 3; 1 graded 1 became grade 0; 9 joints graded 1 remained grade 1; 2 joints of grade 1 became grade 2; 3 joints graded 1 became grade 3; 1 joint graded 2 became 1; 1 joint of grade 2 remained grade 2; 5 joints graded 2 became grade 3; 9 joints of grade 3 remained grade 3. The grade of disease worsened in 24 elbow joints and improved in 2 (P 0.001) (Table 10.).

| | ***CT >12M*** | | | |
|---|---|---|---|---|
| | ***Grade0*** | ***Grade1*** | ***Grade2*** | ***Grade3*** |
| ***CT <12M*** | | | | |
| ***Grade0*** | 33 | 7 | 1 | 6 |
| ***Grade1*** | 1 | 9 | 2 | 3 |
| ***Grade2*** | 0 | 1 | 1 | 5 |
| ***Grade3*** | 0 | 0 | 0 | 9 |

**Table 10. Results of radiographs at <12 and > 12 months.**

Comparing radiographic and CT findings at less than 12 months: 35 joints of grade 0 were confirmed grade 0; 8 joints of grade 0 were graded 1; 2 joints of grade 0 were graded 2; 11 joints judged 1 were graded 0; 8 joints assessed 1 were confirmed grade 1; 1 joint of grade 1 was graded 2; 1 of grade 1 was graded 3; 4 joints evaluated 2 were confirmed grade 4; 8 joints of grade 2 were scored 3. There was an agreement in 47 elbow joints, the scoring and elbow dysplasia status based on CT was fair (K 0.33). The radiological grading was in agreement in 47 elbow joints and in disagreement with the CT ranking in 31 elbow joints, 20 that shown a lower grade and 11 had higher score. Assuming that are not allowed to breeding the rate 2 and 3 the sensitivity of the grading was 75% and specificity 100% (P<0.001). Four joints were false negative, two were graded 0 on radiographs and 2 on CT, one graded 1 it was graded 2 and one ranked 1 was grade 3 (Table. 11).

| **78 elbow joints <12M** | **COMPUTED TOMOGRAPHY** | | | |
|---|---|---|---|---|
| | **Grade0** | **Grade1** | **Grade2 (+)** | **Grade3(+)** |
| **Rx** | | | | |
| **Grade 0** | 35 | 8 | 2 | - |
| **Grade 1** | 11 | 8 | 1 | 1 |
| **Grade 2** | - | - | 4 | 8 |
| **Grade3** | - | - | - | - |

**Table 11. Comparison of plain radiography and CT at the age < 12 months.**

Comparing radiographic and CT findings at the age over than 12 months: 27 joints of grade 0 were confirmed grade 0; 10 joints assessed 0 were graded 1; 2 joints of grade 0 were scored 2; 1 joint of grade 0 that was graded 3; 7 joints of grade 1 were graded 0; 6 joints of grade 1 were confirmed grade 1; 3 joints of grade 1 were graded 3; 1 joint of grade 2 was graded 0; 16 joints of grade 2 were graded 3; 3 joints scored 3 were confirmed grade 3. The agreement between grading and elbow dysplasia status based on CT was fair (K 0.23). The radiological grading was in disagreement with the CT grading in 42 elbow joints, 34 showed a lower grade and eight had higher score. Assuming that are not allowed to breeding the rate 2 and 3 the sensitivity of the grading was 70% and specificity 98% ($P<0.001$).

Eight joints were false negative, two were graded 0 on radiographs and 2 on CT, one graded 0 it was graded 3, 2 of grade 1 were graded 2 and three assessed 1 were classified 3. One joint was a false-positive assessed as rate 2 on radiographs and 0 on CT (Table. 12).

| **78 elbow joints >12M** | **COMPUTED TOMOGRAPHY** | | | |
|---|---|---|---|---|
| | **Grade 0** | **Grade 1** | **Grade 2 (+)** | **Grade 3 (+)** |
| **Rx** | | | | |
| **Grade 0** | 27 | 10 | 2 | 1 |
| **Grade 1** | 7 | 6 | 2 | 3 |
| **Grade 2** | 1 | - | - | 16 |
| **Grade 3** | - | - | - | 3 |

**Table 12. Comparison of plain radiography and CT at the age > 12 months.**

## DISCUSSION

In our study, a homogeneous sample of dogs was considered. The selected breed was Labrador Retriever, well known to be highly representative for elbow dysplasia.

The first objective of our study has been to compare the radiographic and CT findings through the use of a scoring system. To our knowledge there has been no comprehensive direct comparison between the two modalities for diagnosis of elbow dysplasia through the use of a grading score. We assumed CT as the "gold standard" modality for detection of elbow dysplasia. Based on this we adapted the scoring grid proposed at the 30th annual meeting of IEWG (2016) to evaluate the grade of disease on CT in dogs of both ages less than 12 months and over 12 months. In parallel, radiographs have been independently assessed following the IEWG guidelines to assign the grade of disease. Grade 0 was given to normal elbow joints without any sign of disease, grade 1 was related to minor changes and the grade 2-3 in case of disease more developed. The overall grade is used internationally as the basis for breeding advice. Ideally dogs with 'normal' (grade 0) elbows or grade 1 should be chosen and at least dogs with 2 or 3 arthrosis should not be used for breeding.

At the age less than 12 months, comparing radiographic and CT findings, the radiological ranking was in disagreement with the CT grading in 31 elbow joints, 20 showed a lower rate and 11 got higher grading. It is important to underline that 4 of these 20 elbow joints were false-negative judged on traditional radiology as grade 0-1 and 2-3 on CT, this means that these dogs should not be used for reproduction as stated above. Eleven dogs that were grade 1 on radiographs were evaluated 0 on CT. The reason of the dissimilarity was the minimal sclerosis of the ulnar trochlear notch that was seen on radiographs and it was not associated to pathological changes at the medial coronoid process and possibly related to the system that we used to assess the subtrochlear sclerosis. In fact, to assigne a positive sclerosis value on CT we used both subjective and objective evaluation, but for the final score we approved the objective method proposed by Lau et al, considering normal the dogs with a mean CT attenuation under the 739 HU (Lau S., 2015). On the other hand, based on the results and development of the disease we do not totally agree with this cut-off value, on account of the fact that 4 of these elbows grade 0 on CT based on sclerosis and normal coronoid process at the evaluation >12 months showed a grade 3 of pathology. This can indicate an underestimation of the subtrochlear sclerosis using the objective method that was subjectively in agreement with radiographs.

At the age over 12months, the radiological grading was in disagreement with the CT one in 42 elbow joints, 34 showed a lower grade and eight had higher grade. In particular, nine of these elbow joints were false-negative and 1 was a false positive considering grade 2-3 as cut-off. The false-positive was valued as grade 2, because of obvious sclerosis on radiographs and it was perfectly normal on CT. Ten joints were graded 0 on radiographs and of grade 1 on CT due to the presence of osteophyte formations less than 2mm in high on the medial coronoid process. Indeed, 16 joints were of grade 2 and established grade 3 on CT due to obvious fragmentation of the medial coronoid process. This finding is clearly related to the superiority of the CT to reveal fragments or fissures of the medial coronoid process, that sometimes can be suspected on radiology but not confirmed. However this is not strictly relevant to the breeding purposes.

Using radiographs for the diagnosis of elbow dysplasia in Labrador Retriever, is sensitive and specific in both ages. We had a higher sensitivity (75%) and a higher specificity (100%) in dogs younger than one year. In dogs over 12 months of age the sensitivity of plain radiology decreased showing a 70% for sensitivity and a specificity of 98%. In previous studies the sensibility of radiology has been reported to be variable and has been estimated to range from 10 to 62 per cent and 96%, 98% in other studies (Lau S., 2013; Rau F., 2011,Villamonte-Chevalier A., 2015 (A)). Instead, the radiographs specificity has been estimated between 40% and 64% (Rau F., 2011; Villamonte-Chevalier A., 2015 (A)).

With regard the presence of false- negatives in our group of dogs, a question about using only radiography in the screening program is also open and suggests a deeper investigation especially if we considered the number of dogs allowed to breeding otherwise excluded.

The second aim of the study has been to compare the development of the elbow dysplasia, especially of the osteoarthritis progression in dogs applying the scoring system described above. The results of plain radiology and of computed tomography have been processed separately, although both revealed a worsening of the condition. On plain radiology the grade of disease worsened in 19 joints and improve in 5 joints (P 0.004). Four of the five joints that improved passed from grade 1 to grade 0 and one from grade 2 to grade 1. These elbow joints were scored with a higher grade based on sclerosis that showed a lower degree at the second evaluation.

Comparing CT findings at both ages, there was an agreement in 52 elbow joints, and a disagreement in 26 joints. Two of the 26 had a negative rank and 24 a positive one (P 0.001). One of the two joints that was graded 2, showing obvious subchondral bone sclerosis of the ulnar trochlear notch at the base of the coronoid associated to osteophyte on the medial coronoid process <2mm, was graded 1 at the second examination because of the decreased of the sclerosis of the trochlear notch and unchanged size of the osteophyte. The other one passed from grade 1 to grade 0 because of decreased of the subchondral bone sclerosis.

We found a significant development of the disease with both modalities, though CT a larger number of affected joints were identified that is mainly related to the possibility of this modality to offer an overview of the anatomic structures.

Despite the development of the disease, that has been demonstrated by imaging tools, there were no clinical signs of pathology neither at younger age neither at adult age. The absence of clinical signs related to pathology has been previously reported in the literature, but our findings open a discussion on the use of a screening program at too young an age to treat the dogs.

The main limitations in the present study were the relatively small number of dogs and the absence of arthroscopic confirmation of the status of the joints assessed as free of dysplasia on imaging. The dogs participating in our study were clinically normal thus arthroscopy was not performed. Instead, CT was used as the “gold standard”, although some lesions might not be visible with CT (Moores A. 2008, Groth A., 2009). A further study including also other breeds of dog can provide more information about the use of a grading score on CT similarly as it is available on radiology. Also a comparative study correlating plain radiography and computed tomography to arthroscopy should be interesting.

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