Aus der Klinik für kleine Haustiere

des Fachbereichs Veterinärmedizin

der Freien Universität Berlin

# Radius-Ulna Fracture and Post-Traumatic Radius-Ulna Synostosis in Dogs

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*To my beloved parents for their invaluable love, support and consulting*

แด่ บิดาและมารดา ผู้เป็นดั่งพระพรหมและบูรพาจารย์ของลูก

# Contents

# Abbreviations

| | |
|---|---|
| ACA | angular correction axis |
| AO | arbeitsgemeinschaft für osteosynthesefragen |
| ASIF | association for the study of internal fixation |
| BCS | bicortical screw |
| CORA | the center of rotation of angulation |
| DCP | dynamic compression plate |
| DCRA | the distal caudal radial angle |
| Dr. | doctor |
| e.g. | for example |
| ESF | external skeleton fixation |
| *et. al.* | and other |
| etc. | et cetera |
| FPA | the frontal plane alignment |
| IM | intramedullary |
| kg | kilogram |
| K-wire | kirschner wire |
| LDRA | the lateral distal radial angle |
| MCS | monocortical screw |
| mm. | millimeter |
| mo. | month |
| MPRA | the medial proximal radial angle |
| NCP | non-contact plate |
| PCRA | the proximal cranial radial angle |

| | |
|---|---|
| SD | standard deviation |
| SPA | the sagittal plane alignment |
| *spp*. | species |
| y | year |
| ° | degree |

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# Chapter I Introduction

Fractures of radius and ulna occur frequently in small animals. The incidence of fractures in this region varies from 8.5 to 30 percent in dogs [22, 37, 44, 49, 51, 53, 57, 61]. Because radius and ulna are paired bones, the management of canine radius and ulna fractures is difficult and known for its high complication rate [27, 29, 44, 45]. The occurrence of complications during the process of bone healing depends on several factors such as age of the patient, the body weight of the patient, the activity of the patient, the type of fracture, the area and the number of fracture lines, the type of surgical management (the bone approaching techniques, fracture fixation systems, etc) and several more [12,34,35]. Complications that frequently occur include osteomyelitis, delayed union, nonunion, malunion, premature physeal closure, and fracture associated sarcoma [35]. Toy and miniature breeds are known for their high risk of complicated fracture healing due to nonunion or delayed union [9, 26, 29, 45, 68, 71, 81]. These complications occur especially when the fracture area is located on the distal third of the radius and ulna. In small dogs, decreased intraosseous vascular density at the distal diaphyseal-metaphyseal junction leads to reduced vascularity and therefore reduced conditions for optimal bone healing [81].

Innovative osteosynthesis methods e.g. double hook plate, mini T-plate, tubular external skeletal fixator or circular external skeletal fixator are the focus of many research studies [27, 29, 45, 68, 69, 74]. Several modern techniques to activate function of bone healing include bone graft, the use of bone morphogenetic proteins or the use of shock waves are also mentioned in many journals [37, 44, 51, 53, 57, 61]. However the function and the movement of forearm (the center of rotation of angulation of elbow and carpal joints, supination and pronation of forearm), the complications of bone healing e.g. malunion, radial malalignment, and post traumatic radius ulna synostosis are not well documented. All of these themes require further investigations especially post traumatic radius ulna synostosis.

The term "Synostosis" is defined as the ossification of the connective tissue to fuse two neighbor bones together[83]. Synostosis of the radius and the ulna can be classified as congenital form and post-traumatic form. Medical literature reports the congenital radius and ulna synostosis to appear rarely and it usually occurs at the proximal part of the radius and ulna [4, 83]. In contrast, post-traumatic radius-ulna synostosis may occur at any part between the radius and ulna along the length of interosseous membrane [2, 6, 7, 21, 30, 38, 43, 52, 65]. In humans, there are numerous and intensive studies about the radius and ulna synostosis. The most common cause of posttraumatic synostosis was identified as the operatively treated forearm fracture[6, 38, 65]. Human patients with a high activity level, comminuted fracture, open fracture, severe soft tissue trauma, hematoma formation between radius and ulna, injury of the interosseous membrane or patients with skull injury appear more likely to develop synostosis [83]. The ossification or callus formation of synostosis will result from the spontaneous bone healing after the traumatic bone fracture. Several predisposing conditions such as inadequate reduction of the radius or ulna fracture, or transfixation of the both bones with pins or screws during internal fixation before skeletal maturity were suspected. Synostosis impairs the motion between these two adjacent bones and may encounter the growing of the radius or ulna bone which results subsequently in growth deformities[43]. Synostosis is associated with significant functional impairment of the carpal joint such as pronation and supination as well as elbow joint incongruence[2, 4, 21]. In veterinary medicine, there is a lack of information about the incidence and the predisposing cause of canine radius-ulna synostosis, as the reported number of cases is insufficient [21, 43, 67]. Further studies including the incidences and predisposing causes of this complication, the correlation between the occurring of this complication and the presenting of lameness and function of the leg in fractured patients are required.

This dissertation is based on four studies:

**Study I: Retrospective study**

**Characteristics, complications, and outcome of canine radius-ulna fractures in 188 cases (1999 to 2009)**

The objectives of this study were:

1. To describe characteristics, complications, and outcomes of canine radius and ulna fractures treated at the Small Animal Clinic, Freie Universität Berlin, Berlin, Germany between 1999 to 2009
2. To compare various bone fixation methods used for canine radius and ulna fractures treatment
3. To describe the measurement of the center of rotation of angulation (CORA) system on the radiographs to identify the canine antebrachial angular deformities after radius and ulna bone healing
4. To evaluate factors that are related to the outcome of canine radius and ulna fracture treatments

**Study II: Retrospective study**

**Incidence and correlation factors of post-traumatic radius and ulna synostosis in dogs: 24 cases (1999-2009)**

The objectives of this study were:

1. To document the incidence of post-traumatic canine radius and ulna synostosis
2. To identify the most frequent location of post-traumatic canine synostosis formation
3. To identify correlation factors of post-traumatic canine radius and ulna synostosis
4. To measure the center of rotation of angulation at elbow joint and carpal joint in dogs after radius ulna fracture healing with and without synostosis formation.

**Study III: Experimental study**

**Measurement of pronation and supination in cadaveric dogs with surgical intervention to simulation of radius and ulna synostosis**

The objective of this study was:

1. To determine the physiologic range of motion of canine cadaveric forelimbs performing pronation and supination with and without synostosis between the radius and the ulna.

**Study IV: Case report**

**Outcome of treatments of post traumatic canine radius and ulna synostosis in four dogs including 2- year follow- up**

The objectives of this study were:

1. To identify the outcome of canine radius and ulna synostosis treatment
2. To describe the surgical procedure of bony bridge resection between radius and ulna and the recurrence of canine synostosis formation
3. To identify the causes related to the results of treatment

# Chapter II Literature review

## II.1 Anatomy and function of the canine forelimb

Canines are quadruped animals. The limbs of dogs in standing position are perpendicular to the vertebral column (Figure II-1). The canine forelimb is connected to the trunk by muscular structures [19, 39, 71]. These strong muscular structures enable the motion of the canine forelimb.

Figure II-1 A dog in standing position. Its limbs are perpendicular to the vertebral column.

The canine thoracic forelimb can be categorized into five regions[19, 39, 71] (Figure II-2):

a. The scapular region is the region that connects the lateral surface of the trunk to the forelimb. The skeletal bone of the scapular region is called scapula. The scapula provides several structures for the attachment of extrinsic and intrinsic muscles. The scapula is held in place by those strong muscles as they establish a non-conventional articulation of the scapula with the trunk[19, 39, 71].
b. The brachium (arm) is the region between the shoulder joint and the elbow joint. The skeleton bone of the brachium region is called humerus[19, 39, 71]. The

humerus is a long bone of the forelimb. The proximal humerus, articulates with the supraglenoid cavity of the scapula, establishing the shoulder joint[16, 54]. The distal humerus articulates with the radius and ulna, establishing the elbow joint [28, 54].

c. The antebrachium (forearm) is the region between the elbow and the carpal joint. The skeleton bones of the forearm are radius and ulna [2, 9, 21, 43, 44, 51]. The radius is the weight bearing bone; therefore the ulna is smaller and thinner than the radius.
d. The carpus (wrist) is the region between forearm (antebrachium) and forepaw (manus)[54]. The carpus includes seven bones which are arranged into two rows, one proximal and one distal row [39, 40].
e. *The manus (forepaw)* is the region between carpus and ground. The manus includes nineteen bones[19, 39, 71].

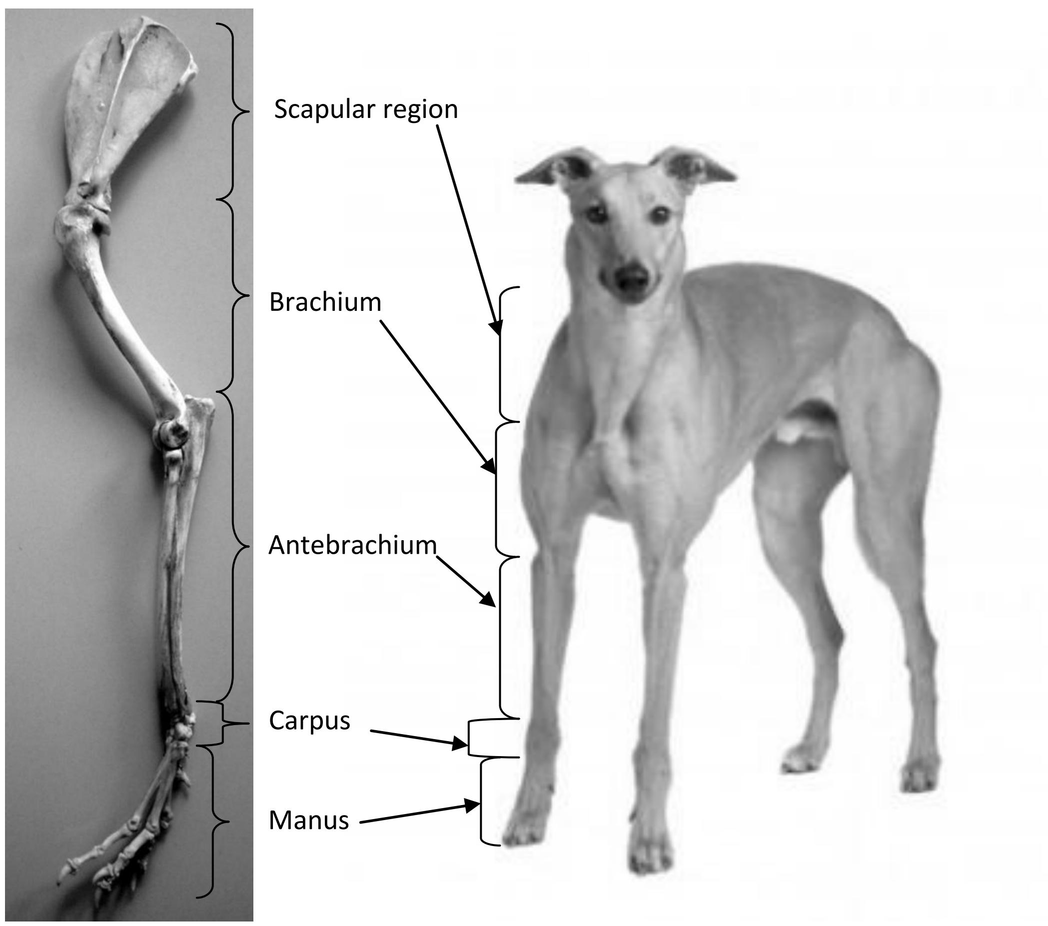


Figure II-2 Regions of canine thoracic limb

### II.1.1 Canine Forearm (antebrachium)

**Anatomy of the radius and the ulna in mature dogs**

The radius is the major weight bearing bone of the canine forearm [2, 9, 19, 21, 39, 43, 44, 51, 71]. The proximal part of the radius is characterized by its oval and concave shaped head [19, 39, 71]. The annular ligament surrounds the head of the radius and contributes to the formation of the elbow joint with the humerus [19, 39, 50, 54, 71]. The metaphyseal area of the radius is slightly tapered and finalizes in a flattened diaphysis [2, 9, 19, 21, 39, 43, 44, 51, 71]. The radial diaphysis is shaped uniform: flattened cranial caudally and slightly curved as it shifts from a lateral position at the elbow to a medial position at the carpus. The radial distal metaphysis is enlarged and blended to the epiphysis[2, 9, 19, 21, 39, 43, 44, 51, 71] (Figure II-3). The distal radial epiphysis is characterized by its concave articular surface which is congruent to the radial carpal bone. A medial distal radial prominence, called the processus styloideus, supports as proximal attachment of the medial collateral ligament at the antebrachiocarpal joint [40].

The proximal part of the ulna is characterized by a large bony process, called olecranon [28]. The olecranon is the insertion area of the triceps muscles. The proximal surface of the ulna articular surface, the trochlear notch/semilunar notch, articulates with the medial condylus of the humerus. The proximal trochlear notch is provided by the processus anconeus, while the distal trochlear notch is provided by the processus coronoideus [19, 39, 71]. The ulna tapers below the articular surface and curves cranially, while the diaphysis of the ulna continues to taper along its length. The ulna originates medially at the elbow joint and ends laterally at the carpal joint [19, 39, 71] (Figure II-3). The distal processus of the ulna, the processus styloideus, serves as the proximal attachment of the lateral collateral ligament of the antebrachiocarpal joint [40].

The medullary cavity of the radius is uniform in its size. Its medial-lateral diameter is larger than its cranial-caudal diameter. The maximal width of the medullary cavity of ulna is located at the proximal part and is tapered along its entire length. In small dogs, the medullary cavity of the ulna can be very small or non-existing [9, 81].

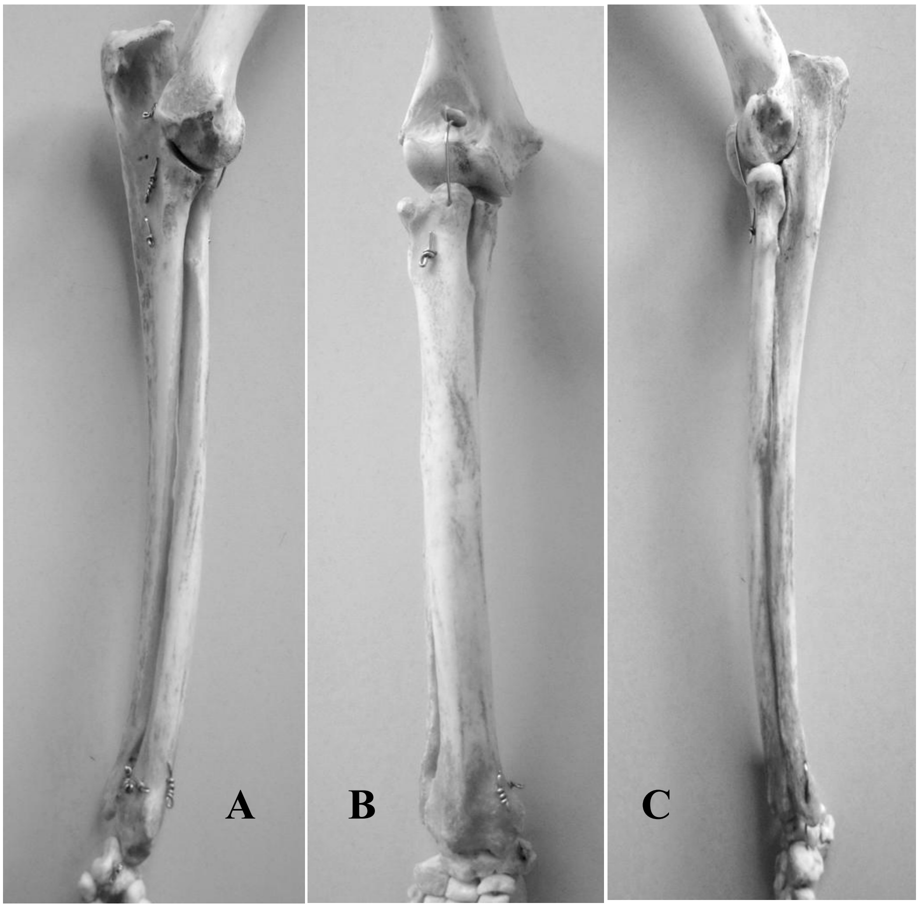


Figure II-3 Radius and ulna bones of the dog. Figure A displays medial appearence, figure B displays dorso-ventral appearence, and figure C displays lateral appearance

**Anatomy of the radius and the ulna in immature dogs**

In immature dogs, the ulna is composed of four epiphyseal regions which are the olecranon, the anconeal process, the coronoid process, and the distal ulna epiphysis [19, 39, 71] (Figure II-4). The olecranon epiphysis is shaped triangular and located at the caudal proximal extent of the olecranon [19, 39, 71]. This epiphyseal plate is responsible for approximately 15% of the ulna lengthening. Premature closure may result is ulna shortening, elbow incongruity, and elbow joint deformity [43, 48, 67, 80].

The anconeal process of the ulna is a triangular or “beak”-shaped. This region is responsible for forming the proximal extent of the trochlear notch. Its interface with the ulna is vertical, and can be fractured easily in dogs at young age [19, 39, 71].

The coronoid process of the ulna is a small epiphysis which contributes to the distal extension of the trochlear notch [19, 39, 71]. Its growth plate is vertical. A fracture in this region or an improper fusion of the growth plate can lead to joint instability [44, 45,48].

The distal ulna epiphysis is a large bony processus forming the processus styloideus of the ulna [19, 39, 71]. This growth plate is responsible for approximately 85% of the ulna length [19, 39, 71]. Its outline is V- shaped. The epiphysis located at the concave area of V-shaped and the metaphysis is characterized by its convex area of V- shaped. Premature closure of this growth plate may lead to ulna shortening, ulna bowing, or proximal ulna subluxation [80].

The radius is equipped with two epiphyses: the proximal and the distal epiphysis [19, 39, 71] (FigureII-4). The proximal epiphysis forms the radial head. The contact surface between the radial epiphysis and the radial metaphysis is slightly convex on the metaphysis and slightly concave on the epiphysis. This growth plate is responsible for approximately 30% of radial length [19, 39, 71]. Premature growth plate closure may lead to a shortened radius or ventral subluxation of the radial head [80].

The distal radial epiphysis forms the distal articular surface and the processus styloideus of the radius [19, 39, 71]. The surface between the metaphysis and epiphysis is convex on the metaphyseal side and concave on the epiphyseal side. This growth plate is responsible for approximately 70% of radial length [19, 39, 71]. Premature closure of the growth plate may lead to radial shortening, radial bowing, or ventral subluxation of the radial head causing elbow incongruence [48, 67]. Asymmetric closure of this growth plate can occur and results in radial shortening and bending toward the side of closure [48].

**Blood supply of the radial and ulna diaphyses**

In mature dogs, the major blood supply of the bone is provided by diaphyseal arteries. These arteries enter the radius through the nutrient foramen on the caudal surface of the proximal third of the radial diaphysis [81]. Additionally, the diaphyseal arteries have a separate nutrient artery that enters the ulna on its cranial surface of the proximal third of the ulna diaphysis. Both nutrient arteries are branches of the palmar interosseous artery [81]. Immature dogs may have another source of diaphyseal blood supply provided from vessels of the pronator quadrates muscle which is attached to the radius and the ulna on their medial surface [81].


Figure II-4 Radiographs of radius and ulna in a dog. Figure A displays bones of an immature dog: the epiphyseal plates are not closed. Figure B displays bones of a mature dog: the epiphyseal plates are closed. The radius is equipped with two epiphyses: proximal (a) and distal (b). The ulna is equipped with four epiphyses: the olecranon (c), the processus anconeus (d), the processus coronoideus (e), and the distal ulnar epiphysis (f).

**Articulations of radius and ulna bone**

The antebrachial part of the canine forelimb is based on two major bones (the radius and the ulna) and it is composed of six joints [19, 39, 71] (Figure II-5):

- Brachioantebrachial joint (elbow joint)
- Proximal radioulnar joint
- Distal radioulnar joint
- Antebrachiocarpal joint

- Middle carpal joint
- Carpometacarpal joint

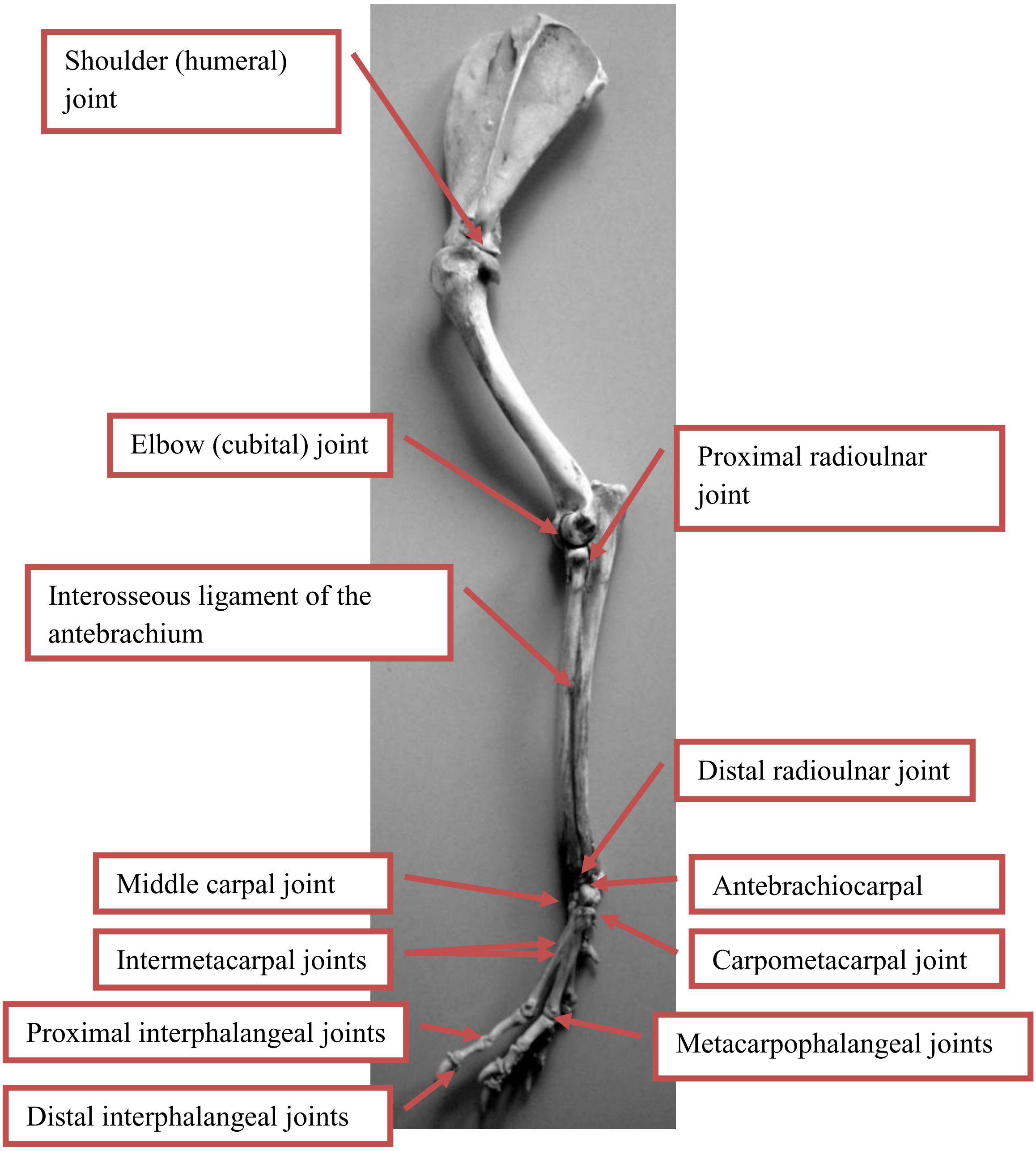


Figure II-5 Articulations of the canine forelimb

The antebrachium is one of the most important regions of the dog, as it is highly involved in the movement and the function of the forelimb [19, 39, 71]. The radius and ulna do not unite each other to form an articulation [19, 39, 71]. The space between radius and ulna is called interosseous space[82]. The interosseous space is a roughly rectangular space that separates the radius and the ulna through their entire length by the antebrachial interosseous membrane, a ligament and muscle which controls the movement between radius and ulna [82] (Figure II-6).

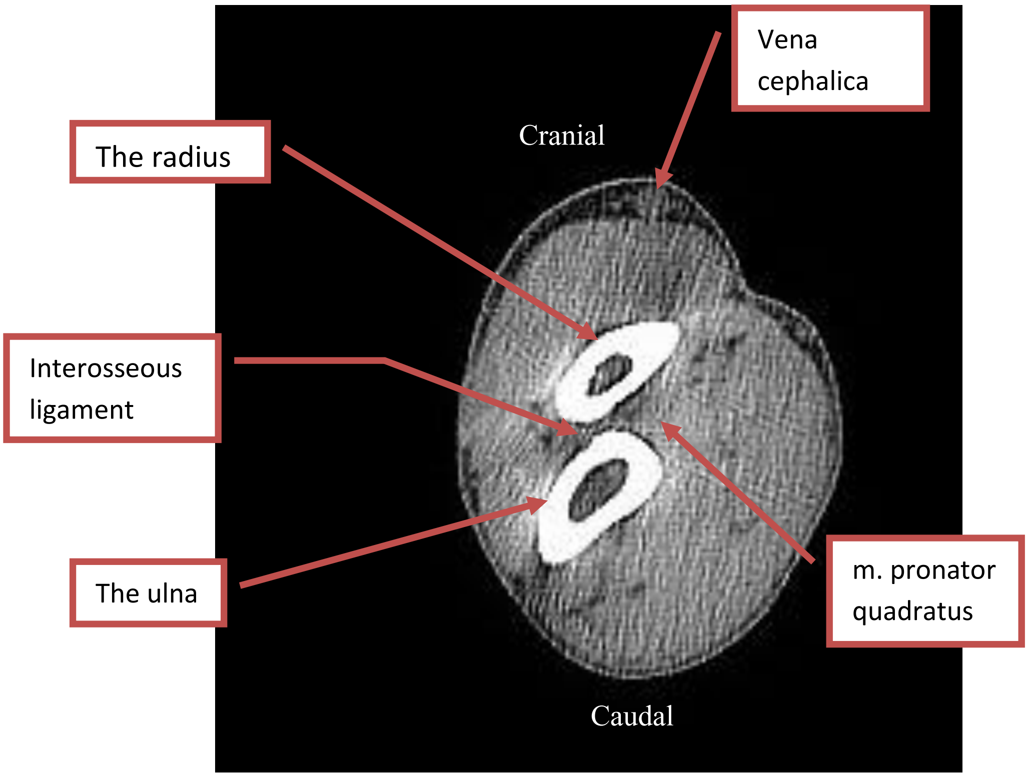


Figure II-6 Computer tomography scan in the transverse plane through the canine forelimb.

Canine antebrachium are connected with these joints: brachioantebrachial (elbow joint), radioulnar joints, and carpal joints. Brachioantebrachial (elbow joint) is a ginglymus joint composed with a small gliding component to fulfill its predominant motions in flexion and extension. This joint allows also for minimal rotation of the limb e.g., allowing the dog to supinate the paw. Radioulnar joints are separated into two structures: the proximal radioulnar joint and distal radioulnar joint. The motions of the radioulnar joints contribute to the limited degree of rotation [50, 54, 66] which is a characteristic of the canine thoracic limb. Carpal joints are composed of three main joints: the antebrachiocarpal joint, the middle carpal joint and the carpometacarpal joints. These individual carpal joints act as ginglymus joint. Thus, the main actions of those joints are extension-flexion in combination with, limited gliding movement [19, 39, 71].

### II.1.2 Function and movement of the antebrachium in dogs

The movement of the canine antebrachium is controlled by muscles, ligaments and nerves. The main functions of the forearm are: supination, pronation, elbow flexion, elbow extension, carpal flexion, and carpal extension [19, 39, 71].

a. Supination is defined as the dorsolateral rotation of the forelimb. The palmar surface of the paw turns up. This movement enables the dog to clean its paw or to remove a foreign body out of the ventral paw. This function is mainly controlled by the brachioradialis muscle and the supinator muscle [50, 54, 66] (Figure II-7B).
b. Pronation is defined as ventromedial rotation of the forelimb. The palmar surface of the paw turns down and enables the dog to stand. This movement is controlled by the pronator teres muscle and the pronator quadrates muscle [50, 54, 66] (Figure II-7C).
c. Elbow flexion is defined as the action to decrease the angle of the elbow joint. This movement is controlled by the bicep brachii muscle, the brachialis muscle, the extensor carpi radialis muscle, and the pronator teres muscle [50, 54, 66].
d. Elbow extension is defined as the action to increase the angle of the elbow joint. This movement is controlled by the triceps brachii muscle, the anconeous muscle, and the tensor fasciae antebrachii muscle [50, 54, 66].
e. Carpal flexion is defined as the action to decrease the angle of the carpal joint. This movement is controlled by the ulnaris lateralis muscle, the flexor carpi ulnaris muscle, the flexor carpi radialis muscle, and the deep digital flexor muscle [50, 54, 66].
f. Carpal extension is defined as the action to decrease the angle of the carpal joint. This movement is controlled by the extensor carpi radialis muscle, and the lateral digital extensor muscle [50, 54, 66].

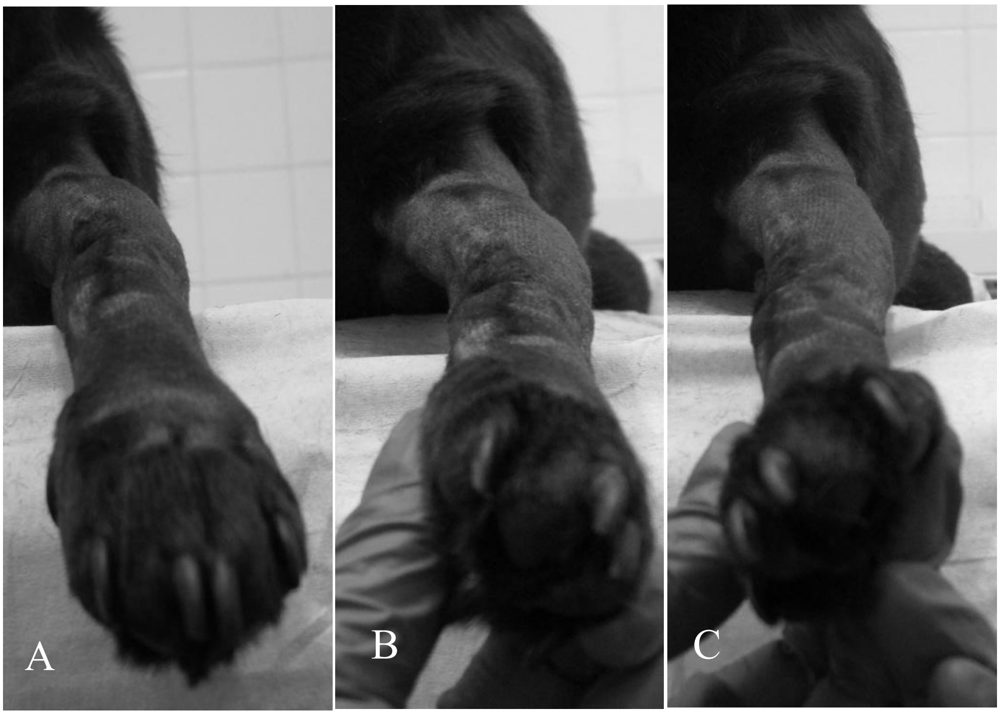


Figure II-7 Pronation and supination of the canine forelimb. Figure A displays the neutral position: The forelimb and the palmar surface of the carpus and metacarpus are held in neutral extension and flat against an examination surface. Figure B displays supination (everting the paw). Supination is measured by holding the palmar surface of the paw upward. Figure C displays pronation (inversion of paw). Pronation is measured by holding the palmar surface of the paw downward.

## II.2 Goniometry and measurement of joint function

The term "goniometry" originated from the Greek words *gōnia* (angle) and *metron* (measure). Therefore, goniometry describes the measurement of angles. Especially in medical literature, this term is used when measurements of joint angles and its movement are performed. In order to evaluate the joint function, measurements of joint motion are very important. These measurements are used not only in orthopedic examination, but also in assessing the outcome and success of physiotherapy. In veterinary medicine, goniometry is adapted since several years [15, 16, 50, 54, 66]. The angles of joints motions can be measured in the standing position of the canine forelimb, in its flexion or extension position and can be used on several joints such as the shoulder, the elbow, the carpal, the stifle and the hip joints [15, 16, 50, 54, 66].

The device used to perform goniometry is called goniometer. For medical use, goniometers are mostly made of a transparent plastic (Figure II-8). Reference angles of maximum flexion and extension of the canine forelimb have been reported for the Labrador retriever[36] and has proven goniometer to be a practicable, reliable and valid tool in the dog [15, 16, 50, 54, 66]. Using goniometer can avoid the risk of anesthesia which must perform in animal when computer tomography scan is running. The reference ranges of maximal pronation and supination have been published for healthy dogs and cats[54, 66]. The physiologic range of joint motion that were determined for the carpal joint and the elbow joint are shown in Table II-1.

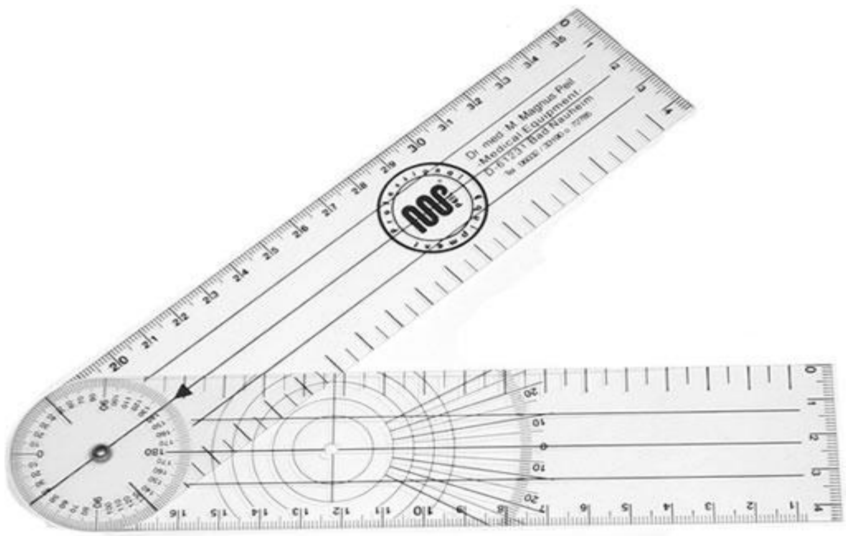

Figure II-8 Goniometer

Table II-1 Physiologic ranges of joint motion of the canine forelimb

| Joint | Joint motion | Range of motion (degrees) | | |
|---|---|---|---|---|
| | | Newton *et. al.* (1985)[54] | Roos *et.al* (1992)[66] | Jaegger *et. al.* (2002)[36] |
| Elbow | Flexion | 20-40 | | 36 ±2 |
| | Extension | 160-170 | | 165 ±2 |
| Radioulna | Pronation | 40-50 | 18-32 | |
| | Supination | 80-90 | 46-50 | |
| Carpus | Flexion | 20-35 | | 32 ±2 |
| | Hyperextension | 190-200 | | 196 ±2 |

## II.3 Canine radius and ulna fractures

Various types of radius and ulna fractures (green stick fracture, transverse fracture, oblique fracture, spiral fracture, and comminuted fracture) can be seen involving either both bones or one single bone [10, 11, 12, 37, 44, 51, 53, 57]. Shaft fractures of the radius and ulna can occur at all levels, however fractures of the distal third of the radius and/or the ulna are the most common[45]. The midshaft and the distal third of the radius and the ulna usually fracture as a unit[78]. Fractures located at the proximal third of the bones are typically independent fractures [28]. Fractures of these bones may be complete or incomplete and the level of the fracture site may be the same level in both bones or in different positions. The development of angulation and rotation at the fracture site can result in many complications i.e. malunion, delayed union, nonunion, and subsequent growth deformity [34, 35, 44,59]. Those complications usually are caused by fractures in the distal third of the radius /ulna, which have been related to insufficient blood supply in this region and the bone physeal plate is located in this area[5, 77, 81]. The surgeon should always be aware of those known complications. The risk of complication should be communicated to the owner intensively.

The majority of dogs diagnosed with radius and ulna fractures will not bear any weight on the affected limb [44, 51, 53, 57]. Occasionally, animals diagnosed with greenstick fractures or non-displaced epiphyseal injuries may still walk with that affected limb [44, 51, 53, 57]. However, most forelimb fractures are displaced and unstable at the time of presentation. A physical examination is necessary to determine the level of the fracture. Due to the minimal soft tissue covering of the radius and the ulna, open fractures occur easily [44, 51, 53, 57]. Two plane radiographs can be used to investigate the extent of the fracture and to assess the appropriate treatment and prognosis [37, 61].

The age of the patient is relevant for choosing the treatment techniques as well as for determining the prognosis [37, 44, 51, 53, 57]. Additionally, the size of the dog seems to be very important for the prognosis [9, 10, 11, 12, 14, 22, 29, 34, 35, 37, 44, 45]. In small breeds and toy breeds, improper fracture healing is seen more often, probably as a result of diminished surface contact of the fragment ends [45]. Fracture of small breeds and toy breeds require a precise reposition of the bone fragment and strong stabilization of the fixation technique in order to achieve satisfactory bone union [29, 45, 68]. In large breed dogs, an anatomical reposition of the fractured bone is less important [44]. In dog weighing more than 15 kg, reposition of the shaft more than 50% to the physiologic position of the diameter of the bone is usually sufficient to achieve satisfactory bone union [44, 51, 53]. The stability of the fracture in large breed dogs can be achieved with a limited amount of bone contact which is usually sufficient to provide adequate callus formation and secondary bone healing. In small breed dogs, a limited amount of reposition of fractured fragment would provide very little stability and may result in delayed union or nonunion. Fractures in immature dogs with open physes may heal faster and more completely than those in dogs with closed physes, especially if a bone gap is present at the fracture line [37]. Therefore, the proper treatment and the healing pattern of canine radial and ulna fracture have to be selected individually. Approximated duration of clinical canine radius and ulna bone union by using different of osteosynthesis are shown in Table II-2. The combination of age and bodyweight of the patient is an important factor and needs to be determined [44].

Table II-2 Approximately duration of clinical bone union after radius and ulna fracture in dogs (Lappin *et. al.* 1983) [44]

| Age of animal (years) | Repaired with External Skeletal Fixation | Repaired with Bone Plates | Repaired with Pins | Repaired with Casts and Splints |
|---|---|---|---|---|
| 0-0.5 | 1.5 mo (n= 2) | 3.5 mo (n=2) | No data | 1.08 mo (n=12) |
| 0.6-1 | 5.75 mo (n= 2) | 1 mo (n=2) | 3 mo (n=2) | 1.5 mo (n=10) |
| 1.1-2 | 2.08 mo (n= 5) | 6.5 mo (n=2) | 5 mo (n=1) | 1.5 mo (n=3) |
| >2 | 2.25 mo (n= 4) | 2.75 mo (n=8) | No data | 1.62 mo (n=4) |

### II.3.1 Fracture of the proximal radius

Fractures of the proximal radius are uncommon and very rare as this region is protected by the physiological structures of the canine elbow joint and the surrounding muscles [44, 51, 53]. Fractures at this location can mainly be seen at the physeal plate of immature dogs [44, 51, 53].

### Preoperative consideration

The proximal radius or the radial head is very important because it is the major weight bearing bone of the elbow joint [44, 51, 53]. The gold standard of fixation techniques used in this area has to ensure primary bone fracture healing without callus formation [44, 51, 53]. Only primary bone fracture healing prevents secondary arthritis and elbow joint stiffness [28, 30,37]. A lesion accompanied with severe chronic arthritis and damage of the artricular surface should be treated with specific procedures [28, 30,37]. In small breed dogs, the resection of the radial head and the transplant of autogeneous fat graft are recommended [37]. In large breed dogs, performance of elbow arthrodesis or insertion of elbow prosthesis is required [37].

### Surgical approaches and fixation techniques

Usually, the lateral approach is performed to correct proximal radius fractures [37]. The anatomical landmarks of the skin incision are the lateral epicondyle of the humerus and the craniolateral rim of the proximal third of the radius. The surgeon should palpate the lateral aspect of the radial head underneath the extensor muscle of the antebrachium. The radial nerve deep underneath the musculus extensor carpi radialis should be prevented from trauma by using the retractor. Collateral radial vessels must be ligated in order to enable dissection between the extensor carpi radialis and the common digital extensor muscle. The origin of the common digital extensor muscle may be incised and retracted, and the insertion of the supinator muscle must be elevated from the radius, to optimize exposure of the radial head. Comminuted fractures of the proximal radius may necessitate both, the medial and lateral approach to the elbow joint [37].

Cross pins using the Kirschner wire (K-wire) are commonly used to correct proximal physeal fracture of the radius[37, 44, 51]. Simple fractures at the radial head can be stabilized using a lag screw and/or K-wires. Complex fractures require stable implantation. In those cases, the application of a neutralization plate or a buttress plate should be performed. Small bone fragments where reposition is impossible should be removed to prevent needless callus formation [37, 44, 51]. Bone plates commonly used in veterinary medicine in this area are miniplates (1.5 or 2.0 mm) and T-plates (2.7 or 3.5 mm) [10, 37].

## Prognosis and results

The prognosis and the outcome of the treatments of proximal canine radius fractures are depending on the fracture type, the degree of soft tissue trauma and the quality of the repairing techniques used. The comminuted fracture requires a supporting soft bandage for two to six weeks depending on the healing process investigated by radiographs [37, 44, 51]. The most common complications of proximal radial fractures are osteoarthritis and growth disturbances in immature dogs [80]. Growth disturbances result due to a premature closure of the physeal plate causing shortening of the radius and subsequently elbow incongruence[80].

### II.3.2 Fracture of the radial diaphysis

Fractures of the canine radius occur most often at the diaphysis [45, 61, 68, 69]. These fractures are usually located on the middle and distal third of the diaphysis [45, 61, 68, 69]. Because of the minimal amount of soft tissue covering the radius in this area and also due to a low blood supply of this area, delayed unions and nonunions are common complications[81].

## Preoperative considerations

Usually, canine radius and ulna fractures require surgical fixation of the radius as the radius is the major weight-bearing bone [2, 9, 19, 21, 39, 43, 44, 51, 71]. The fixation and stabilization of both bones (radius and ulna) is recommended in giant breed dogs with comminuted fractures or fractures including damage of the processus styloideus ulnae [51]. Because of the limited amount of bone marrow in the radius, especially in toy breeds, the intramedullary pin technique cannot be recommended [9]. Moreover, pins can also interfere with the movement and function of the carpal joint which leads subsequently to arthritis [51]. The use of bone plates and screws is common[45, 68, 69]. The cranial or medial aspect of the radius is the surface most commonly used for the application of the bone plates and screws [45, 69]. External cooptation such as casts and splints with close reduction of the fractured bone can be used in young and medium sized dogs with non-complicated fractures [51]. The approach of the fracture ends after close reposition must obtain more than 50% of the bone diameter without the angulation formation [51]. The use of casts and splint should be avoided in large breed dogs or in dogs with a very high activity level as this fixation method is not able to stabilize the fracture bone in those cases. In toy breeds, many studies reported the use of casts and splints and the high incidence of nonunion in this fractured region [44,49,53,57,68]. External skeleton fixation (ESF) is another technique that is recommended for radius and ulna fractures [11,27]. The advantage of this technique can be seen especially in highly comminuted fractures and in open fracture with severe trauma of the surrounding soft tissue or severely soft tissue loss[11,27,29]. Several patterns of ESF can be applied to canine radius and ulna fracture. Unilateral-uniplanar (type I-a) and cranially applied unilateral-biplanar (type I-b) configuration may provide more comfort to the patient than the use of bilateral (type II) ESF [11,27,29].

**Surgical approaches**

The surgical approach to the radial diaphysis can be performed from craniomedial or craniolateral [10,37,69]. Traditionally, if fractures occur at the radial shaft, the craniomedial approach is used [10,37,69]. However, fractures located at the proximal part of the radial diaphysis are treated by using the lateral approach between the extensor carpi radialis and the common digital extensor muscle [51]. The craniolateral approach provides not only a better view to the fractured site, it enables the exposure of both radius and ulna [51]. For distal radial diaphyseal fractures, a cranial approach is considered to be the appropriate technique [68] .

**Stabilizing transverse and short oblique fractures**

Transverse fractures of the radial diaphysis are usually treated by using the bone plate attached to the cranial aspect of the radius via a craniomedial approach[45,68,69]. The plate is initially contoured for optimized contact to the cranial surface of the radius. The slightly over bent technique is called “pre-stress” [10,51]. It ensures the optimal contact of the bone plate at the far cortical surface of the fractured bone and is reached when the axial compression is applied. By applying improper or without pre-stress of the bone plate, bone gaps may result in the far cortex. The use of lag screws is another technique that can aid to fixate the bone fragments across the fracture line [51]. Lag screw is used especially in short oblique fractures following the application of neutralization bone plate at the cranial aspect of the radius.

Bone plates can also be applied to the medial aspect of the radius [69]. However, providing the optimized contours of the plate at this location is more complicated than applying the plate to the cranial aspect. If the fracture line is located at the distal end, contouring of the plate has to be in line with the cranial bow of the radial diaphysis [51]. The application of the plate on the medial bone is in advantages compared to the application of the plate at the cranial bone [69]. This technique allows a greater amount of screw surface to purchase the radius because of the thicker mediolateral radial bone diameter. This technique requires a smaller size of the bone plate in the medial aspect which normally has a closer spacing of the screw holes[69]. The use of a smaller bone plate beneficial and enables more screws to be placed in an individual bone fragment. In addition, placing the plate on the medial aspect can avoid trauma of the extensor tendons covering the distal part of the cranial radius[69].

The decision of placing the bone plate between the cranial or the medial bone surface depends on the surgeon preference because both of techniques result in the same axial stiffness [10, 69]. There are also other techniques that may be used in dogs with transverse or short oblique diaphyseal fractures of the radius and ulna such as ESF techniques [11, 29].

**Stabilizing long oblique and reducible comminuted fractures**

There are several techniques that can be applied to long oblique and reducible comminuted canine radius and ulna fractures [10, 11, 29, 37, 44, 45, 51, 53, 57, 62, 68, 69]. Long oblique fractures of the radial diaphysis are usually initially immobilized with multiple lag screws followed by the application of a neutralization plate [37]. Lag screws should be inserted in orthogonal direction to the bone plate [37, 51] (i.e. lag screws are applied in a mediolateral plane while the plate is applied cranially or lag screws are placed in a craniocaudal plane while the plate is applied medially).

The external skeleton fixation (ESF) is a good technique to apply in long oblique fractures located at the shaft of the radius [11, 62]. For enhanced stabilization of the fracture line, ESF can be used in combination with multiple cerclage wires [37]. Unilateral uniplane (type I-a) ESF with threaded pins should be applied from the craniomedial aspect [11, 37]. At least three pins should be inserted into each fractured fragment [11, 62]. If a stronger stabilization is needed, a second frame can be added to the craniolateral aspect, called the unilateral-biplaner (type I-b) ESF model [11]. Especially in immature dogs, it is very important to put the fixation pin in a safe distance from the physeal plate to prevent growth disturbances [37]. In those patients, drilling the pin through both radius and ulna, would lead to developmental deformities of the forelimb [80].

External cooptation techniques are not recommended in this type of radius and ulna fractures unless the ulna is still intact [37]. The goals of biological osteosynthesis are to achieve physiologic length and alignment of the fractured bone, without any disturbance of the fracture environment, and to provide a mechanical stability leading to bone healing [37]. In large breed dogs and active dogs, an additional stabilization technique may be required [51]. Placing intramedullary pin into the ulna or applying a second bone plate to the ulna is an effective supplementary technique [37, 51]. The plate attached to the ulna is commonly applied to the caudal surface of the bone and the diameter of the plate should be smaller than the diameter of the bone plate placed on the radius [10].

**Stabilizing non-reducible comminuted fractures**

Recommendation of the ideal treatment of highly comminuted fractures changed a lot in the past decade. Manipulations of intermediated bone fragments can often disturb the vitalization of smaller bone fragments causing bone sequestration, delayed union and nonunion[45, 68, 69].

Currently, modern techniques referring to a biological approach of fracture repair are recommended [37]. The goals of fracture repair are to achieve normal length of the injured limb segment, to restore the natural bone alignment and also to provide a mechanical environment which leads to bone union [37]. The intermediate bone fragment should be left in the fracture area to act as natural bone graft [10, 37]. The function of the implant is to provide a bridge between the two major bone fragments located proximal and distal from the fracture line [10, 37]. Bone plates and ESF are the only implant systems that are recommended to be applied in highly comminuted fractures of the radius diaphysis [10, 11, 37, 51]. Radiographs of the intact contralateral limb are important to estimate the ideal radial length and the natural alignment of the bone [37].

An “open-but-do-not-touch” technique is recommended when plate fixation is applied to the patient [37]. The goal of bridging plate repair needs at least three screws in each proximal and distal radial segment [10, 37]. Plate holes located in the fractured region are generally left empty [10, 37, 51]. Alternative procedures for protecting weakening of the plate caused by empty screw holes are the use of small intramedullary pins in the ulna or the application of plate to the caudal surface of the ulna or using the lengthening plate [37]. Cancellous bone graft is another technique promoting bone healing [37, 51]. After cancellous bone graft material has been collected and placed at the fracture region, the soft tissue should be closed rapidly to protect the bone graft vitality and to avoid the bacterial contamination [37].

ESF is the preferred implant for treating non-reducible comminuted canine radius fractures [11, 62]. The advantage of the ESF is the easy insertion of the pin due to the minimal amount of muscle tissue covering in this region [11, 62]. Additional, the closed fracture reduction can be performed with the hanging limb technique preserving regional blood supply [37]. The rigidity and stability of ESF can be adjusted depending on the stage of bone healing and the fixation frame can easily be removed after the clinical bone union has been obtained [13, 37].

The rigidity and stability of ESF should be revised approximately six weeks after surgery [11, 23, 27, 62]. Evaluation of the blood supply to the fracture area stimulating the callus maturation and the remodeling stage of the bone healing should be performed [81].

The use of Type III ESF is more often required in non-reducible comminuted fractures at the radius as it provides a very strong frame and ensures a better security at the pin-clamp-rod interfaces than other ESF techniques [37].

### Prognosis and results

Prognosis of the bone healing depends on the type of the fracture and also on the severity of the soft tissue trauma [37]. Moreover, the prognosis is also depending on the performance of the chosen osteosynthesis method which is applied to the patient [10, 11, 12, 13]. Improper management such as using instrumentation that enables fracture fragment rotation or movement, as well as early implant removing is commonly seen [37].

If suitable treatment and implantation was performed, complications are seen very infrequent especially complications of the diaphyseal fracture of radius and ulna [12, 23, 34, 35, 51]. Nonunion or delayed union can occur in small breed dogs or toy breed dogs because of their characteristic anatomy of the radius and ulna [45]. The distal part of the radius and the ulna in small dogs is characterized by an insufficient blood supply and low muscle protection [45, 81]. The combination of these anatomical characteristics results in reduced support of the healing process of the bone[81]. Treatment of non healing fractures requires resection of the bone fragments in combination with the application of bone plates and screws with or without cancellous bone graft transplantation [37]. In immature dogs, angular limb deformation or growth disturbance may occur especially if the trauma affected the distal ulna or the radial growth plate [80].

Post traumatic synostosis (the fusion of the radius and the ulna by the bony bridge) can be an unwanted result of the healing process [2, 6, 7, 30, 38, 52, 65, 72, 73, 83, 84]. This complication can interfere with the length of the bone in immature dogs and cause angular limb deformities similar to those seen after premature closure of the physeal plate [2, 80]. In mature dogs, synostosis may be based on several etiologies which, in contrast to humans, are not well documented [2]. Synostosis causes malfunction of pronation and supination in the affected limb [83, 85]. The ability of pronation and supination of the forearm is important to the animal and enables its grooming activity, capture of prey, self-defence and removal of foreign bodies underneath the paw [78].

### II.3.3 Fracture of distal radius and processus styloideus radii

This region of the canine radius and ulna is the most commonly fractured region [37, 44, 51]. Injuries located in this region are most often open fracture because of the low amount of soft tissue covering the distal aspect of the bone [9, 76, 78].

#### Preoperative considerations

In immature patients with fractures of the distal radius and the processus styloideus radii, growth plate disturbances should always be considered [37]. Early closed reposition should be attempted [37]. In case of stable fractures such as green stick fractures or non-dislocated fractures, external cooptation for three to four weeks can successfully be obtained [37, 51, 53]. Unstable and dislocated physeal plate fractures require an open reposition in combination with an internal fixation [37].

Avulsion fracture of the processus styloideus radii causes instability of the antebrachiocarpal joint [19, 40]. The processus styloideus radii is the region of attachment of the collateral ligament [19, 39, 40, 71]. The collateral ligament is the ligament that supports and enables joint stability [19, 39, 40, 71]. Concurrent fracture of the processus styloideus ulnae is commonly seen [19, 39, 40, 71]. Thus, subluxation or luxation of the antebrachiocarpal joint is a typical complication following these injuries [37]. Open reposition and internal fixation are recommended to treat the fracture of the processus styloideus radii and processus styloideus ulnae [37].

**Surgical approaches**

In order to perform surgery of fractures of the radial physeal plate or the radial metaphysic, the cranial approach is recommended [10, 37]. Fractures of the processus styloideus radii can be approached from a medial or lateral skin incision directed to the bone prominence [37].

The cranial incision of the distal radius can be performed using several landmarks: the proximal margin is defined as the junction of the cephalic and accessory cephalic veins while the distal margin should be located at the mid-metacarpus[37]. The incision of the deep fascia shall be performed between the tendon of the extensor carpi radialis and the common digital extensor muscle. To fully expose the distal diaphysis, an incision of the musculus abductor pollicis longus close to its distal insertion and its retraction to the proximal and lateral position need to be performed [37].

**Surgical treatment of the processus styloideus fractures.**

The most common fixation method used to treat fractures of the processus styloideus radii and ulnae is the tension band wire fixation [37, 44, 51]. Two small K-wires are driven parallel through the styloideus radii fragment. A small diameter wire (0.8 or 1 mm) should be used to create a figure eight fixation to the K-wires [37]. Using larger diameters of wire is risky, as disruption of the bone may occur when the K-wire are tightened [37].

The repair technique for treating the fracture of the processus styloideus ulnae is similar to the fixation method described above [37]. The only difference is the recommended use of a single k-wire [37]. If the fragment of the styloideus fracture is large, a lag screw may be applied [37, 44, 51, 53]. After the performed surgery, a soft bandage such as a modified Robert Jones bandage should protect and support the joint for approximately four to six weeks [37, 44, 51, 53].

**Surgical treatment distal radial physis fractures**

In immature dogs, fractures of the distal radial physis usually occur in both radius and ulna through the distal growth plate [37, 53]. Two K-wires can be applied to secure the epiphyseal segment to the proximal part [37]. In theory, those two K-wires should be placed perpendicular to the physis and parallel to each other [37]. Alternatively, one k-wire can be driven from the processus styloideus radii across the fracture and anchored into the lateral cortex of the radius [37]. The second wire can be driven from the processus styloideus ulnae, into the radial physis, across the fracture line, and anchored into the medial cortex of the radius. The ends of the K-wires should be bent over the processus styloideus ulnae to prevent migration and to facilitate removal [37, 54]. After surgery, soft bandages should be applied to support joint function for one to two weeks [37, 44, 51, 53]. This type of fracture occurs frequently in immature dogs [37]. The healing process in those dogs is rapid; its duration takes approximately four weeks [37]. The implant should be removed immediately after the fracture is healed [13].

**Surgical treatment of distal radial fractures in mature patients**

This type of fracture challenges many surgeons because of the small bone fragment at the distal part of fracture. The small fragment causes a limited area to attach the bone implant. A six holes veterinary mini T-plate (small fragment plate) with two or three 1.5 or 2.0 mm screws is the implant most suitable for very small patients. In small and medium dogs, larger bone screws (2.7 or 3.5 mm) can be applied to fix the short segment [37].

For large breed dogs, several bone implants are available such as double hook plates (3.5 mm) or T-plates (4.5 mm) [37]. An articular fracture of the distal radius needs perfect reposition in combination with powerful and effective osteosynthesis to minimize the risk of secondary osteoarthritis [12, 23, 35].

### Prognosis and results

In many cases, bone healing may be successful, but the injuries in the affected region may lead to secondary problems such as growth deformities in immature dogs or secondary arthritis in mature dogs [12, 23, 35, 80]. Surgeons should always consider those complications. A frequently follow-up after the fracture repair is recommended [12, 37]. Early detection and properly treatment of possible complications will minimize the damage [37]. In immature dogs suffering from injuries of the growth plate, internal fixation should be removed as soon as the fracture is healed (approximately after three to four weeks) [13, 37].

To prevent the occurrence of degenerative osteoarthritis, careful anatomical bone reposition and stabilization of the fragments with internal fixation methods are recommended [37]. Due to the small part of the distal bone fragment, a small sized implant and only few screws can be applied [10, 45, 59, 68]. The external cooptation can support joint function and assist the internal fixation [37].

Nonunion occurs frequently in toy breeds [34]. An appropriate selection of the fixation method, accurate fracture reduction, and eventually cancellous bone grafts are necessary to prevent nonunions especially in those canine breeds [37].

## II.3.4 Fractures of the ulna

### Preoperative considerations

Many ulna fractures result from road traffic accidents [37]. Polytrauma accompanied with complications of cardiovascular and pulmonary systems are of major concern[37, 57]. Radiographic examination of the thoracic cavity should be performed, at least two plane radiographs are necessary to interpretation the lesions [37]. If open fractures are present, bacterial cultures of deep tissue swabs should be obtained [79], and appropriate wound care initiated. Pain management control is also very important and should be concerned [37].

### Surgical approaches

Radius and ulna are united by the interosseous ligament and the intraosseous membrane[26, 47]. The annular ligament is attached to the lateral and medial part of the radial notch of the ulna [19, 39, 40, 71]. This ligament forms a ring around the radius allowing close contact between the radius and ulna as well as rotation of the radius during pronation and supination [19, 39, 40, 71].

There are three surgical approaches to the ulna: an approach to the olecranon[28], an approach to the trochlear notch and the proximal shaft, and an approach to the distal shaft and the processus styloideus [37].

The olecranon is approached by a curved lateral incision from the humeral epicondyle to the shaft of the olecranon. The subcutaneous fascia is incised with the skin, incision of the periosteum is performed between the olecranon and the anconeous muscle, elevation of the anconeous muscle exposes the lateral surface of olecranon.

The trochlear notch and the proximal shaft are approached by a caudal skin incision performed slightly medial to the olecranon. The anconeous and the musculus flexor carpi ulnaris are elevated following a periosteal incision. The incision is continued distally through the fascia between the ulna and the musculus ulnaris lateralis. Medial retraction of the flexor and lateral retraction of the extensor carpi ulnaris muscles expose the ulna and permit opening of the elbow joint by incision in the joint capsule at the level of the medial processus coronoideus and the radial head [37].

To approach the midshaft, the distal shaft, and the processus styloideus ulnae, the skin incision is made on the lateral surface of the bone [37, 51, 57]. After incision of the subcutaneous tissue, the antebrachial fascia is incised between the ulnaris lateralis muscle and the lateral digital extensor muscle. The bone is exposed by retraction of these muscles.

## Olecranon fractures

There are three types of olecranon fractures that are commonly seen [37]. The most frequent type is a simple fracture through the semilunar notch of the elbow [37]. The second most frequent type is the comminuted fracture of the olecranon. This type of facture is occasionally complicated by a fracture of the processus anconeus [37]. The less frequent type of olecranon fracture is a chip or avulsion fracture at the proximal end of the olecranon. The typical fracture at the olecranon is characterized by a strongly avulsion force from the triceps muscle which is attached to the end of the olecranon [37]. This avulsion force causes failure of an internal fixation method and leads to nonunion or fibrous union[28].

Intramedullary pins are tightly fit into the olecranon bone and can be used to stabilize a simple fracture [28]. However, high avulsion forces originating from the triceps muscle over the fulcrum can result in pin breakage before the healing process of the olecranon fracture is completed [37]. This type of complication can be prevented by compressing the fracture fragment to the olecranon by the tension band wire technique [28]. This method is a standard method for treating olecranon fractures [28].

Chips or avulsion fractures of the proximal olecranon can be stabilized with lag screws [37, 51, 57]. Comminuted fractures of the olecranon required the use of bone plates and screws at the lateral surface of the ulna [10, 37]. In case of complications associated with the fracture of the processus anconeus, reattachments of the processus anconeus to the olecranon should be performed using lag screws [37]. Furthermore, excision of the small fragments of the processus anconeus can be performed [37, 51, 57].

### Monteggia fractures

Monteggia fractures are fractures of the ulna with anterior dislocation of the radial head. This type of injury is very rare. One publication showed only 5 cases presented in small animal clinic during a 10 year period [53]. Anterior dislocation of the radial head occurs when the annular ligament ruptures and the ulna is fractured distal to the elbow. In the healthy dog, the annular ligament connects the radial head to the proximal ulna. The ulna shaft is firmly attached to the radius by the interosseous ligament and consequently moves with this ligament in an anterior direction .

The reduction of the radial head can easily be performed by repositioning of the fractured ulna, due to the strong connection of both radius and ulna which provided by the interosseous membrane[19, 39, 71], radial head is spontaneously moved into correct position [53]. The fracture of the ulna itself can be repaired by using the bone plate and screw technique or intramedullary pins in combination with tension band wires [51, 53].

### Prognosis and results

The prognosis of ulna fractures is usually very good [51, 53]. Even fractures associated with the articular surface of the elbow joint, treated with rigid internal fixation and accurate anatomical reduction of the bone fragments usually results in a good outcome [37]. However, joint stiffness is a common postoperative complication. Postoperative physiotherapy is recommended in patients with delayed weight bearing problems [50].

## II.4 Common complications of radius and ulna fractures

The goal of surgical fracture repair is the establishment of a rigid fixation method and the correct alignment of the fractured bone [37, 51, 53]. These actions allow for both timely and maximized return to function of the affected area[37, 51, 53]. The specific injury, species and breed conformation, age of the patient, general health status of the patient, concomitant disease processes, nutrition status of the patient, and concurrent medications influence the healing process [23, 34, 35, 59]. However, those factors are not the only parameters influencing the outcome. The selected method of bone repair and the surgical technique also play an important role in the outcome of fracture management [23, 34, 35, 59]. For this reason it is very important that the clinician is aware of possible inherent complications of fracture repair and takes action to prevent them. The most important complications of radius and ulna fractures include osteomyelitis, nonunion, delayed union, malunion, premature physeal closure, fracture associated sarcoma, synostosis, implant failure, and re-fracture after implant removal [23, 34, 35, 59]. The complication rates of canine radius and ulna fracture are show in Table II-3.

Table II-3 Complication rates of canine radius and ulna fracture

| Complications | Hunt *et.al.* (1980)[34] | Lappin *et.al.* (1983)[44] | Haas *et. al.* (2003)[29] |
|---|---|---|---|
| Osteomyelitis | 0.08 % (4/45) | 0.05% (5/98) | 0% (0/14) |
| Nonunion | 0.04 % (2/45) | 0.11% (11/98) | 0% (0/14) |
| Delayed union | No data | 0.06% (6/98) | 7.14% (1/14) |
| Malunion and Angulation | 0.02% (1/45) | 0.11% (11/98) | 7.14% (1/14) |
| Premature physeal closure | 0.17% (8/45) | 0.06% (6/98) | 0% (0/14) |
| Fracture-associated sarcoma | No data | No data | 0% (0/14) |
| Synostosis | No data | No data | 14.29% (2/14) |
| Implant failure | 0.48% (22/45) | 0.06% (6/98) | 0% (0/14) |
| Re-fracture after implant removal | 0.04% (2/45) | 0% (0/98) | 7.14% (1/14) |

### II.4.1 Osteomyelitis

Osteomyelitis is defined as local or generalized inflammation of the bone, resulting from infectious agents such as bacteria, fungi, or occasionally viruses [12, 17, 23, 28, 34, 35, 59, 78](Figure II-9). Etiology agents may originate via hematogenous or exogeneous (post traumatic origin) routes [35]. Exogenous routes include infections that extend from the surrounding soft tissue, usually as a result of excessive trauma [35]. Direct infection is believed to be the most common route of open fractures [12, 17, 23, 28, 34, 35, 59, 78].

Exogenous osteomyelitis is most often seen in open fractures but may also be caused iatrogenic during surgery [12, 35, 59]. Young, male, mid- to large-breed dogs are most commonly affected by osteomyelitis, but this is more likely associated with the predisposition of traumatic fractures of those dogs rather than with osteomyelitis [35]. The infection may be seen in suppurative form or nonsuppurative form, with the suppurative form being the common presentation. Nonsuppurative infections are usually caused by metalosis or granulomatous organisms [35]. Suppurative infections are usually initiated by bacteria, but fungal, viral, protozoal, and even parasitic infections have been reported. *Staphylococcus species* are the most common organisms cultured from affected bones (60% of all osteomyelitis caused by bacteria[17]). *Staphylococcus intermedius* are the most common, although other gram –

positive organisms are occasionally involved [17]. Gram-negative organisms have also been cultured including *Escherichia coli, Pseudomonas, Proteus* and *Klebsiella species* [17, 35].

Usually, bones are equipped with defend mechanisms to prevent infection and colonization from bacteria[35]. Osteomyelitis is not only caused by contamination with bacteria but also requires colonization of those bacteria into the bone[35]. Thus osteomyelitis occurs when physiologic mechanisms of bone protection fail. Defense mechanisms of the bone can be reduced by several factors such as tissue ischemia from vascular disturbance, bacterial inoculation, fracture instability or foreign material implantation. Tissue trauma (accidentally and surgically) and the following vascular compromise can be considered for all these factors that predispose bone to infection[59]. Therefore, the importance of tissue damage in the development of posttraumatic osteomyelitis cannot be overestimated [53, 59].

The primary mechanism of biomaterial-centered sepsis is based on microbial colonization of biomaterials and adjacent damage tissue. This type of microbial colonization is called “biofilm” and considered to be the most important factor associated with implant-associated chronic infection[53]. All biofilm is constructed with biomaterial surfaces and cover adsorbed macromolecules from the local tissue environment (often referred as a “conditioning film”). Microorganisms adhere to the conditioning film but a bare biomaterial surface can rarely be seen. Initial adhesion of the microorganisms is reversible and depends on the physical and chemical characteristics of the cell surface of the microorganism, the biomaterial surface, and the local extracellular fluid which provided by the local environment. Biofilm is composed of three components: the offending microbe, the glycocalyx produced by the microbe, and the host biomaterial surface. Biofilms protect bacteria from the action of antibiotics, impede the cellular phagocytosis mechanism, inhibit the invasion of antibodies into a lesion, and alter B- and T- cell responses. In conclusion, the existence of biofilms is contradicted to the management of bone infection [12, 53].

Dogs with acute osteomyelitis are commonly presented with clinical signs of tissue swelling and localized pain [12, 23, 34, 35, 59]. This group of patients is often fevered with various clinical signs of systemic disease including lethargy and inappetence [12]. Dogs with chronic osteomyelitis are commonly presented with localized clinical signs including draining tracts of exudate and lameness [12, 23, 34, 35, 59].

Physical examination and radiographic examination are important to diagnosis osteomyelitis in affected dogs [12]. In case of acute osteomyelitis, radiographic findings may include soft tissue swelling, periosteal bone proliferation, bone resorption and increased medullary density[12, 23, 34, 35, 59]. In chronic osteomyelitis, radiographic examinations may provide information including implant failure or nonviable bone fragments (sequestra) [12, 53]. Correct diagnosis of osteomyelitis is based on a positive microbiological culture from a sample collected from the fractured region, sequestra, local necrotic tissue, or implant [53].

The use of antibiotics solemnly will not eradicate the osteomyelitis[17]. Therefore, accurate treatment requires improvement of the hygiene at the local bone environment (i.e. removal of infected tissue, drainage of the affected area)[53]. Acute posttraumatic osteomyelitis commonly occurs within two to five days following the initial trauma[12, 53]. The post traumatic treatment must be aggressive in order to prevent the infection from developing into a chronic problem [12, 53]. The treatment includes drainage, debridement, systemic antimicrobial agents, rigid stabilization of the fracture, and some type of delayed closure. Initial antimicrobial therapy should be directed against the most common bacteria (penicillinase producing *Staphylococcus spp.*) until the result of bacterial culture and drug sensitivity from the direct bone culture can be obtained [17]. The antimicrobial agents should be applied intravenously injection for a minimum of three to five days followed by oral therapy for a minimum of four weeks. In many cases, antibiotic therapy needs to be continued for another four weeks[79].

The primary cause of chronic posttraumatic osteomyelitis is commonly identified to originate from tissue ischemia [12, 53, 59]. Therapy based on antibiotic drugs solemnly is less likely to be successful. Effective therapy includes improved the environmental condition by debridement, removal of possible bone sequestra, removal of necrotic tissue and foreign materials including bone implants, and biofilms [12, 53, 59]. Old implants should be removed and new rigid stabilization of the bone should be performed [23, 59]. Continuously antimicrobial therapy for six to eight weeks is recommended [17, 79]. The choice of antibiotic should be based on the results of the microbiologic culture and the drug sensitivity test [79]. In some cases, treatment with correct identified antibiotics may fail due to the inability of the antibiotic chemical to enter the site of infection[53]. The hindered penetration of the antibiotics may result from the presence of the biofilms, bone sequestra or ischemic tissue [12, 53].

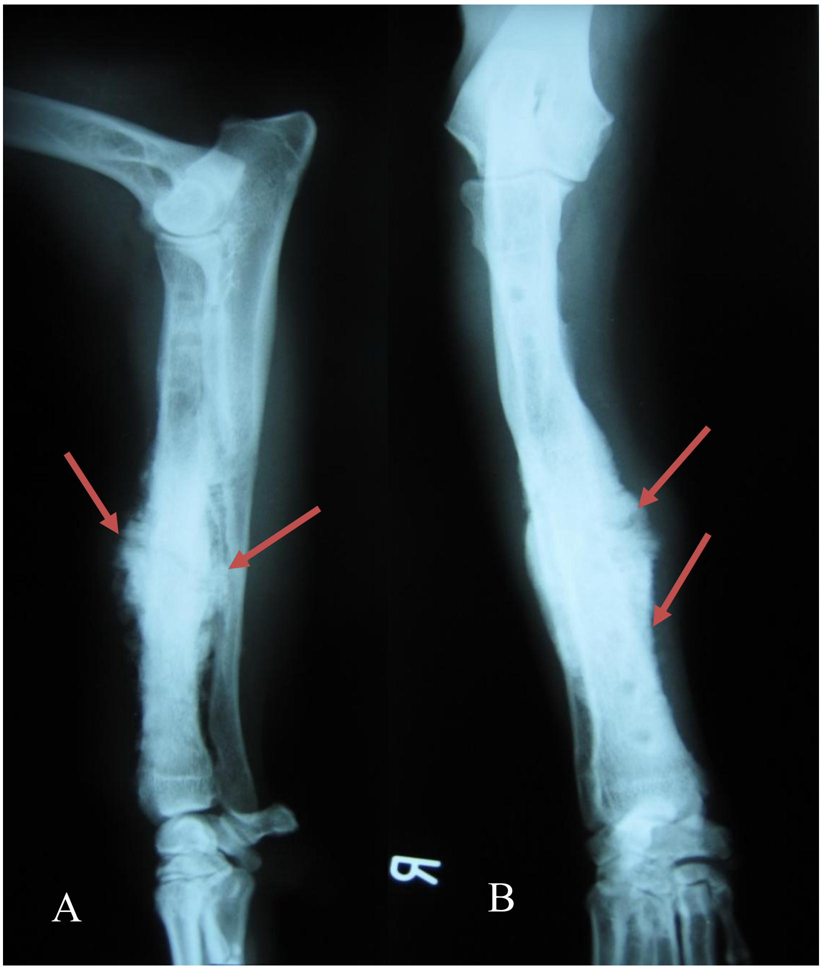


Figure II-9 Radiographs of canine radius and ulna with osteomyelitis. The radiographs identify a transverse fracture of the canine radius and ulna diaphysis located at the right forelimb. Previously, an osteosynthesis technique including the use of bone plate and screws was performed. After the dog was presented with clinical signs of bone infection, the implants were removed. Figure A displayed the lateral radiographic view. Figure B displayed the antero-posterier radiographic view. Both figures present periosteal proliferation and the occurrence of a bone sequestrum (red arrows).

### II.4.2 Nonunion, Delayed Union and Malunion

Fracture healing and the duration until bone union is finalized depends on a number of factors including age of the patient, general health status of the patient, preexisting diseases of the patient, nutrition of the individual patient, location and configuration of the specific fracture, time between the onset of fracture to the time of initial treatment, the risk of infection, associated soft tissue damage, and the type and stability of the selected fixation method [12, 53]. Therefore, there is no fixed time frame by which fractures should be healed [53]. However, if a fracture does not appear to be healed in the time expected, delayed union or nonunion must be considered [12, 44, 53]. It is important to recognize signs of non-healing or inappropriate healing [53]. Actions to correct the underlying problem must be taken immediately as the success in therapy is strongly correlated to the duration of this complication [12].

#### Nonunion

Nonunion is defined as a failure of a fractured bone to unite including a fracture in which all signs of repair have evidently been discontinued[12, 23, 34, 55, 59, 63]. Nonunion may result from chronic delayed union which is generally caused by the same processes. Nonunion can be viable (hypertrophic or hypervascular) or nonviable (atrophic or avascular) [53]. Viable nonunions can be characterized as hypertrophic, slightly hypertrophic, or oligotrophic. Additionally, nonunions can be classified based on callus formation: with callus formation (hypertrophic nonunion and moderately hypertrophic viable nonunion) and without callus formation (viable oligotrophic nonunion and non-viable nonunions) [53].

Affected dog are usually presented with continuing lameness and a non-weight bearing fractured limb [12, 23, 34, 55, 59, 63]. Clinical signs include painless muscle atrophy and joint stiffness [12, 34]. The movement of fractured fragments may be possible [12]. Nonunion can occur concurrently with an infection [12, 34]. Frequent radiographic examination should be performed to detect nonunions as soon as possible [12]. Nonunions shows no evidence of progressive fracture healing over a period of several months [35]. The callus will not bridge the fractured fragments of the bone, the fragments may be displaced. In radiographs, sequestra may be identified in opaque regions [12, 35].

Surgical intervention is required to create a new environment supporting the optimized bone healing process[12]. Loose implants, sequestra and necrotic tissue must be removed [12, 35, 37]. Stabilization of the fracture with appropriate instruments should be applied [37]. Adding the cancellous bone graft may be required [35, 37].

**Delayed union**

Delayed union is defined as a fracture that does not healed within the expected time frame [12, 35, 37]. Eighty percent of delayed unions are caused by an inappropriate surgical technique[12, 34]. Delayed union are most commonly caused by fracture instability and inadequate blood supply, but may also be caused by an infection of the bone (osteomyelitis) [12, 35]. Inadequate blood supply of the fractured site can be caused by severe accidental trauma, surgically disruption of the vessel or instability of the fracture site [35]. Areas with inadequate soft tissue coverage such as the antebrachium may also be equipped with a poor blood supply[81]. Therefore, it is very important to manipulate muscles and soft tissue gently when approaching the bone. Preserving the blood supply of fractures is of highest priority. The distal radius and ulna are the most common sites of delayed union[29, 70]. These locations are predisposed for both poor soft tissue coverage and limited blood supply. The distal third of the radius and ulna is a common fracture site. Clinical signs of delayed union include pain, instability of the fracture site, reluctance of the dog to bear weight on the fractured limb, and muscle atrophy [12, 34, 35, 37].

Factors associated with the development of delayed union may also be classified as follows [35, 37]:

- **Primary trauma** including kinetic trauma, excessive damage to the vascular supply, and increases the likelihood of delayed union due to necrosis and infection. Contamination of the fracture area due to traffic accidents is an inherent complication. An open wound with necrotic tissue may easily be contaminated with antibiotic resistant pathogens in the hospital.
- **Transportation of the patient** from the place of the accident to the clinic can worsen the injury. The movement of bone fragments when moving the patient may compress vital structures, such as the spinal cord. Long oblique or spiral fractures are characterized by sharp and spiky bone ends able to penetrate the skin leading to open fractures.

- **Systemic diseased** patients suffering from polytrauma such as pneumothorax, hemothorax, hemoabdomen, or ruptured internal organs are emergency cases. Concurrent diseases unrelated to the trauma such as metabolic diseases (hyperparathyroidism, hyperadrenocorticism, diabetes mellitus, hyper- and hypo thyroidism, growth hormone deficiency, renal disease, hepatobiliary disease and intestinal malabsorption) have been described as potential cause of delayed fracture healing. Neoplastic conditions and nutritional impairment such as calcium and phosphorus imbalance or vitamin deficiency are also related with disturbances of bone production. Some medication is known to interfere with bone healing such as corticosteroids, anticonvulsants and anti-neoplastic agents[29, 70].
- **Fracture management** it is another important factor surgeons should keep in mind. Optimized blood supply of the bone fragments improve rapid bone healing and improve resistance to bacterial infection. Minimized fragment manipulation improves the bone vascularity. The experience and skills of the surgeon also plays an important role.
- **Postoperative care** requires good communication between the surgeon and the owner of the affected animal. The owner should understand the postoperative care management and should follow the advice of the veterinarian when the dog stays at home.

Serial examinations of the patient should be performed postoperatively in order to evaluate the progression of fracture healing [12, 37]. It is important to perform both a clinical and radiographic evaluation of the affected limb [12, 37]. Delayed union should be suspected if the limb is more painful or used less compared to the last examination [35]. Radiographic examination should be scheduled to document the progression of fracture healing and to confirm the stability of the bone implant [12, 37]. A reasonable protocol might include radiographs immediately post surgery, radiographs after 7-10 days confirming implant stability, radiographs after 25-30 days to evaluate healing progression, and radiographs after two months to confirm complete fracture healing [37]. The radiographic appearances of a delayed union are similar to those of the expected healing process. However, progression of bone healing still occurs but at later time points [37].

Early surgical intervention soon after detection of an existing healing complication is related to successful outcome and a lower cost of treatment [12]. In general, the treatment of delayed unions requires adaptation of the originally technique that was performed rather than switching to a different method [12]. However, an additional external cooptation in patient with clinical sign of delayed union can be applied [34]. Surgical intervention with internal implantation is preferred and will result in a higher success rate [12]. Autogeneous bone graft may be applied to stimulate the healing process, especially in case of implant loosening or implant facture [37]. To stimulate bone healing after the application of external fixators, dynamization techniques or destabilization techniques should be performed at the optimal time[13, 23, 27, 29].

## Malunion

Malunion is defined as a faulty union of the fractured bone and results in non-anatomic formation[12, 34]. Malunion can result in angular limb deformity, limb shortening, gait abnormalities, and degenerative joint disease[1, 8, 60, 62, 74]. Premature weight bearing soon after fracture repair, inadequate fixation of the fracture, or an untreated or improperly treated fracture can cause malunion. The non-anatomic fracture healing results in unphysiologic weight bearing of the limb. This may result in disturbed limb function, deterioration of joint cartilage and subsequently lead to degenerative joint diseases[1, 75]. Malunion may result in deformities of any shape or location. However, angular limb deformities such as carpal or tarsal vulgus or varus and radius curvus are seen most common[2, 18, 48]. Several techniques improve the diagnosis of the limb deformity. These techniques include center of rotation of angulations measurements which is commonly used in human and veterinary medicine[8, 24, 25]. This technique detects the degree of bone angulation and therefore is of important value for the surgeon when achieving normal alignment of the limb. The aims of malunion surgery include anatomic alignment, restoration of the function, and the prevention of future degenerative changes of the affected joints. Restoring alignment to the bone is usually uncomplicated but may occasionally be complicated in chronic malunions or in cases when the natural shape of the bone is deformed from callus formation, remodeling or osteomyelitis.

Diagnosis of malunion can be based on radiographs. Additionally, the extent of varus, valgus, and rotational deformation as well as shortening of the leg can be determined by comparing the affected leg to the non-fractured limb. Radiographs should be performed in two planes (lateral view and antero-posterier view) at least. In both planes, the center of rotation of angulation technique can be applied[18, 48]. The performance of this technique is described in this dissertation, section II.5.

Corrective osteotomies are recommended in patients with malunion and subsequently functional impairment of the limb[43, 60, 62, 74]. In some patients with minor angular deformities, treatment is not required. Preoperative planning should include the calculation of the angulation of osteotomy. A dome-shaped osteotomy can be useful in animals with one plane deformity. Complex deformities require the use of circular external fixators called “ilizarov”. Ilizarov correct not only the angulation of the limb but also increase the length of the bone.

**II.4.3 Premature physeal closure**

Premature physeal closure can occur in immature dogs and results after fractures of the growth plate or the damages of the physis area[37]. The discontinuing growth of the pair bones and angular limb deformities especially those located in the forearm can result in a variety of effects. Therefore, it is important to recognize premature physeal closure as soon as possible [12]. Iatrogenic physeal damage should be prevented by gentle tissue manipulation, selection of suitable treatment, and early intervention after diagnosis [34]. The physeal area is characterized by its high cell to matrix ratio (hypertrophic zone), resulting in the weakest part of the physis [37]. Therefore, fractures in this area occur frequently in immature patients [37]. The surgeon should be aware of further physeal damage and not reduce the blood supply of this area [12]. Implants crossing the growth plate should be placed perpendicular to the physis allowing continuing growth of the bone [37]. If premature closure of the physeal plate has already occurred, aims of surgery are the restoration of the physiologic alignment and joint congruity while allowing the unaffected bones to continue physiologic growth [12]. In animals younger than five to six months of age, these aims are usually accomplished by performing an osteotomy or ostectomy of the affected bone [62]. Ulna osteotomies are commonly performed in premature distal ulna physis closure to restore elbow congruity [24, 62]. Occasionally, complex surgeries are required to restore length and angulation [24]. In mature animals or in immature animals with little growth remaining (usually animals older than seven months of age) both osteotomy and angular limb deformity correction is required[24].

### II.4.4 Fracture-associated sarcomas

Fracture-associated sarcomas are primary bone tumors located at a previous fracture site. Although fracture-associated sarcomas occur rarely, early diagnosis is important for the outcome of treatment in the affected animals[3, 14, 31, 37]. The predominant types of tumor affecting fractures are osteosarcomas. Other tumors including undifferentiated sarcomas, fibrosarcomas, and malignant mesenchyomas may be seen. Spontaneous bone tumors and fracture associated osteosarcomas can be differentiated based on location of the lesion [37]. Spontaneous osteosarcomas are mainly located at the metaphysis of long bones, while fracture-associated sarcomas can be identified all along the diaphysis of long bones at the sites of previous fractures. Fracture-associated sarcomas are commonly associated with the history of trauma, but the impact of trauma in tumor aetiology remains unclear. It has been hypothesized that the fluctuated mechanisms of osteodegeneration and osteogenesis promoting fracture healing may not be able to decrease its activity after bone healing has been accomplished, thus creating a population of tumor cells at the fracture site [37]. Another theory is based on the persistent irritation of tissue at the fracture area which may activate tumor cells that are already present in those fracture sites [34, 35,37]. The tissue irritation may be caused from the presence of implants [34]. However, fracture associated sarcomas appear to correlate with the previous fracture site rather than with the location of the implants [35]. Therefore fracture-associated sarcomas seem more likely to be related to trauma and the fracture healing process than to the use of implants. However, possible carcinogenous effects of implants have been discussed [14, 37]. In an experimental study in rats the incidence of orthopedic implants was related to the malignancy stage of the tumor [37]. Malignancies were associated with the use of implant material containing a high content of cobalt, chromium, and nickel[37].

The development of fracture associated sarcomas has also been associated with other postoperative complications including infection, delayed union, implant loosening, and draining tracts [31]. Other factors have also been discussed for the development of fracture associated sarcomas [13, 31]. Those factor include the use of dissimilar metals at the fracture site, corrosion of the metal implant, remodeled fracture healing, concomitant soft tissue damage, osteomyelitis, and any pathologic condition associated with increased bone turnover, especially bone infarcts, irradiation, nutritional osteodystrophy, chronic subclinical bacterial proliferation, and cortical bone allografts [13,31].

### II.4.5 Synostosis

Synostosis is defined as abnormal osseous union between two adjacent bones. Synostosis can occur in any pair bone such as radius-ulna, tibia-fibula, between two ribs, between two metacarpal bones, and between two metatarsal bones[83]. Synostosis can be caused by particular problems involving growth deformities[2, 43]. The predominant clinical problems related to synostosis are located in growing forelimbs, as each of the growth plates in the radius and ulna is responsible for a different percentage of total growth. A synchronous growth of radius and ulna is required for the physiologic development of the forelimbs. Thus, synostosis will impair the movement of the ulna shaft that occurs with normal longitudinal growth. The following problems such as humero-ulnar subluxation, shortening forelimb, angular deformity and antebrachio-carpal joint alteration (carpal valgus or carpal varus) will occur. It has been suggested that limb deformities may occur due to strong pull of the distal ulna growth plate on the distal radial physis which stimulates additional growth.

Synostosis between the radius and the ulna can be categorized into two forms: congenital and posttraumatic. Congenital synostosis can rarely be seen in dogs and cats. This condition is caused by a failure of segmentation between the radius and ulna in the embryo. Posttraumatic radius ulna synostosis (Figure II-10) differs from the congenital form by not only a different cause but also in treatment and prognosis. The traumatic form can occur at any location between the radius and the ulna along the length of the interosseous membrane. In human medicine, synostosis has been studied intensively and the incidence, etiology and the treatment of synostosis is well documented. However, only few studies in synostosis in veterinary medicine exist to date.

The etiology of posttraumatic synostosis between the radius and the ulna in humans is related to the occurrence of a surgical treated forearm fracture. Patients with a high activity level, comminuted fractures, and open fractures appear to be more likely subject of this complication[43]. Monteggia fractures and proximal forearm fractures also appear to have a higher incidence of synostosis. The use of bone graft and the protrusion of bone screws through the bone cortex also increase the incidence of synostosis. Additionally, radio-ulna synostosis is described as a consequence of soft-tissue injury, reconstructive procedures, hematoma formation between the radius and ulna, or injury of the interosseous membrane. In one study, patients with closed head injuries (skull, cranial trauma) appear to be more prone to this complication than patients without head trauma, presumably for the same reason that they develop heterotopic ossification[83].

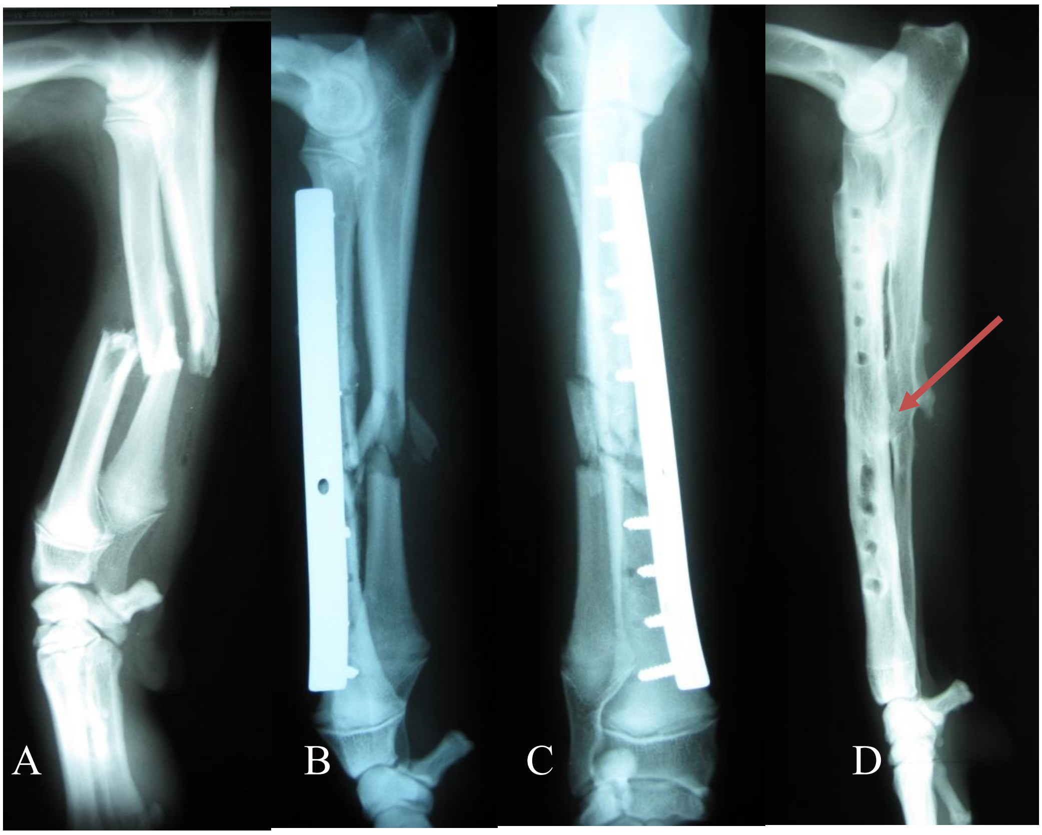


Figure II- 10 The formation of post traumatic radius and ulna synostosis in an eight month-old, mixed breed dog. Figure A displays a lateral radiographic view of fractures at midshaft of canine radius and ulna. Figure B and C display radiographic views of the same dog in figure A, two days later, postoperative (lateral and antero-posterier views, respectively). Bone plate and screws were applied to the fractured radius. Figure D displayed a lateral radiographic view after the removal of bone plate and screws (14 months later after the radiographs in figure A was performed). The formation of synostosis (red arrow) locates at the middle third of the radius and the ulna can be seen.

Indications for surgical treatment of synostosis between the radius and the ulna remain controversial. Indications are related to the clinical signs of the patient and the degree of forearm deformation. The individual examination must be assessed. Surgery should be performed following the appropriate workup including at least two orthogonal radiographic views (antero-posterier view and lateral view). The main purpose of the surgical intervention is the excision of the bony bridge between radius and ulna. However the unpredictable results and the recurrence of syostosis formation can occur. Careful dissection with minimal periosteal disruption prevents further stimulation of bone and may limit the recurrence. The interposition of a variety of materials following resection of the bony bridge, including the use of muscle, silicone rubber sheets, fat, fascia, and cellophane have been reported in order to prevent the reformation of synostosis. However, the outcome of using interposition materials was with varying degree of success[7, 30, 72, 73, 84]. Also, result of a study using low-dose radiation to prevent heterotopic ossification after reconstructive procedures on the hip in human medicine has influenced the treatment of synostosis. Low dose radiation application after resection of osseous synostosis in the antebrachium has been performed[83]. Some reports have proven the successful use of either non-steroid anti-inflammatory medication or radiation therapy to prevent the recurrence of heterotopic bone. However risk factors impeding an optimum outcome have also been mentioned. These factors include the location of the synostosis, the extent of the synostosis, the severity of the initial injury, and the timing of the operative resection.

### II.4.6 Implant failure

The major cause of implant failure is the technical errors[32]. The technical errors include undersized or oversized implant selection, improper number of implants, inadequate and improper screw or pin fixation, malpositioned plates or screw, and poor plating contouring [23, 59]. Improper implant selection may result in an implant inadequate to counteract the disruptive forces at the fracture site. The use of inappropriate bone implants such as the use of undersized implant and improper screws (Figure II-11) results implant failure. Improper application may also result in an inability to counteract the disruption forces (similar to an improper choice of implant) or it may initiate a series of events that adversely affects fracture healing. Bone plates should be applied to the proper site of the bone, guided by the principles of AO/ASIF system, which preserve the fracture from affecting force (e.g. bending, rotational, compression). The number of bone screws or pins inserted at each site of the fractured segment is also important. The use of at least three screws or pins in each proximal and distal bone segment is recommended [23, 59].

The competition between the successful fracture healing and the continuously implant-bone composite failing due to disruptive forces is always a challenge [34]. Mechanical and biological reasons may be responsible for failure of the implant-bone composite [37]. Mechanical reasons for failure include implant fatigue after burdening the patient weight for several weeks [37]. Biological reasons for implant failure occur when the time period required for fracture healing takes longer than the lifetime of the chosen fixation [37].

Clinical signs of acute pain at the fractured limb or a sudden decrease of function of the fractured limb are most commonly seen in patients with implant failure [12, 23, 59]. Radiographs are the most effective diagnostic tool that can be used to confirm implant failure. Failure of an implant does not always require surgical intervention [12]. If the process of fracture healing can continue without any disturbance, the intervention is unnecessary. When treating fractures with implant failure, surgeons need to consider the cause of the failure. The treatment plan should be considered for its mechanical and biological intervention. A rigid implant should be applied in cases of mechanical implant failure. Adapting the biological environment of the fractured area such as the removal of necrotic tissue, the improvement of the blood supply or the application of a bone graft may be necessary to activate the healing process [37].

Figure II- 11 The implant failure resulted from undersized of bone plate selection on fractured ulna and utilized of monocortical screws which failed to support the load of bone forces in a mature, large breed dog. This figure displays a lateral radiographic view of canine radius and ulna fractures. Each bone plate was applied on both radius and ulna. The bone plate that was applied to the ulna is broken (red arrow) due to the plate on ulna is too small and too short for this dog. Using of bicortical screws might improved the anchorage of screws on the fractured bone. The application of improper implant selection is one of the technical errors which lead to implant failure.

### II.4.7 Re-fracture after implant removal

The pathophysiology of re-fractures of the bone after implant removal remains unclear [12, 34, 35, 37]. In human medicine, the incidence of re-fractures ranges between 1.2 to 22 % [37, 42]. Suspected factors involved in the cause of re-fractures are the occurrence of complex fracture types (comminuted fracture, displacement of bone fragment), implants characteristics, early removal of the implants, and the lack of protection of the healed bone following implant removal[13, 37]. In veterinary medicine, the incidence of re-fractures after implant removal has not been documented to date [34, 35]. One possible reason for a lack of this kind of study in veterinary medicine might be the fact that the removal of the bone implants after fracture healing is not performed routinely in veterinary orthopedics [12, 59].

After the implant removal, the affected limb must immediately be able to burden the bodyweight of the patient [12, 13]. A sudden increase of the load bearing force may result in high stress at the fracture line and may cause a re-fracture [12, 13]. The rigid plate fixation associated with concurrent bone loss was investigated in several studies[34, 35, 44, 59]. A reduction in cortical density and an increased porosity post fixation has been shown to be associated with the risk of re-fractures. Empty screw holes after the removing of screws are the predominant location of re-fractures. External cooptation such as soft bandages should be applied to the patient after the removing of the implant. Restricted exercise of the patient must be guaranteed to prevent excessive weight load to the fracture site. The prevention of re-fractures is very important and the best method of treatment.

## II.5 Center of rotation of angulations measurement in the dog

The center of rotation of angulation (CORA) methodology has been well described and is established for the use in deformity planning and correction in people over many years. The CORA system was developed by, a human orthopedic surgeon, Dr. Paley, D.[37]. The CORA methodology requires the understanding of the anatomy of the affected bone including its mechanical axes and the relationship of these axes to the adjacent joints. When bones are in abnormal angulation, the bone's axes are also abnormal. The axial angles can be used to localize and quantify bone deformities, and identify the affected bone[24, 25]. Recently, veterinarians adapted this method for the use in dogs [18, 24, 25]. The CORA methodology is accomplished by an axis drawn along the long bone and two joint reference lines drawn across the joint at defined anatomic landmarks. These axes can be used as reference angles for the proximal and distal joint of each long bone. There are two axes defined for each bone: the anatomical axis and the mechanical axis. The anatomic axis is drawn from the center of the proximal end of the bone to the center of its distal end. The mechanical axis is drawn from the center of the proximal joint to the center of the distal joint. In bones such as radius and tibia the mechanical axis and the anatomical axis are identical, while in other bones such as femur, the axes are different. The intersection between the joint reference line and the bone axis determine the joint reference angle [18, 24, 25].

In forelimbs, physiological alignment of the radius can be determined in the frontal plane by determining joint orientation lines for both elbow joint and carpal joint from an anteroposterior radiographic view. Two sets of anatomic reference points can be determined for each joint (the elbow and the carpal joint) which will result in two reference joint lines. In the elbow, the orientation line can be drawn in one of two manners: the first manner is drawn from the proximo-lateral most aspect of the radial head to the proximo-medial aspect of the medial coronoid process and the second manner is drawn from the distal-most aspect of the humeral condylar capitulum to the trochlea (Figure II-12). In the carpal joint, the joint orientation line can be drawn along the articular face of the distal radius. This line connects the outer lateral aspect of the distal radius to the lateral aspect of the processus styloideus radii (Figure II-13). The anatomic axis of the radius in the frontal view was defined as the straight mid-diaphyseal line determined at points 25%, 50%, and 75% along the length of the radius (Figure II- 16B). Joint orientation angles for both elbow and carpal joint were defined, by measuring the angles from intersecting anatomic axis and joint orientation lines yielding the medial proximal radial angle (MPRA) at the elbow joint and the lateral distal radial angle (LDRA) at the carpal joint (Figure II-16).The absolute difference between MPRA and LDRA can be calculated and defined as the physiologic angle of frontal plane alignment (FPA).

From lateral radiographic view, sagittal radial orientation was assessed by determining the reference joint lines of the elbow joint and the carpal joint. The reference joint line of the elbow joint can be drawn by connecting the most proximal area of the caudal and cranial aspects of the radial head. In the carpal joint, the reference joint line can be drawn between the most distal areas on the caudal and cranial aspects of the radial articular surface (Figure II-14&15). Because the physiologic shape of the canine radius is bowed cranial (procurvatum), the saggital radial anatomic axis must also be followed as the natural curve of this bone. This curved axis can be divided into two straight mid-diaphyseal lines, one line for the proximal radius and another line for distal radius (Figure II- 16A). The straight mid-diaphyseal lines can be completed by dividing the radius into proximal and distal segments. Mid-diaphyseal points can be determined at the proximal and distal thirds of each segment and then the axes lines were drawn. The joint orientation angles were determined by measuring the angles from intersecting anatomic axes and joint lines yielding the proximal cranial radial angle (PCRA) at elbow joint and the distal caudal radial angle (DCRA) at the carpal joint (Figure II-16A). Because the radius does not present a single anatomic axis in its sagittal radiographic view, the angle of physiological sagittal plane alignment (SPA) was calculated from the angular difference between elbow and carpal joint lines. Reference ranges of physiologic FPA and SPA can be obtained from several studies[46, 74].

Fox *et. al.* (2006)[24] documented physiologic canine radial axes. MPRA was 85.3 ± 3.5˚ and LDRA was 86.7 ± 2.9˚. Mean FPA calculated from the absolute difference between MPRA and LDRA was 2.7 ± 2.7˚ (range, 0-8˚). From the sagittal radiographic view of physiologic canine radius, PCRA was 90.5 ± 4.0˚ and DCRA was 78.3 ± 4.8˚. Mean SPA or angle of natural procurvatum of the canine radius was 25.2 ± 8.2˚ (range, 8-35˚).

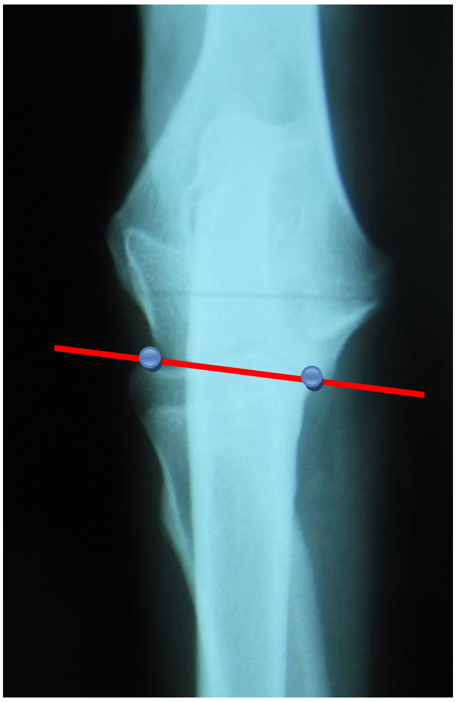

Figure II-12 The orientation line of canine elbow joint in the antero-posterier radiographic view. This figure displays the frontal view of the canine elbow joint radiograph. The orientation line (red line) was drawn from the most proximolateral aspect of the radial head to the proximomedial aspect of the medial coronoid process.

Figure II-13 The orientation line of canine carpal joint in the the antero-posterier radiographic view. This figure displays the frontal view of the canine carpal joint radiograph. The orientation line (red line) was drawn from lateral distal radial articular face to the medial articular face, ignoring the processus styloideus radii.

Figure II-14 The orientation line of canine elbow joint in the lateral radiographic view. This figure displays the sagittal view of the canine elbow joint radiograph. The orientation line (red line) was drawn from the cranial to the caudal aspect of the radial head.

Figure II-15 The orientation line of canine carpal joint in the lateral radiographic view. This figure displays the sagittal view of the canine carpal joint radiograph. The orientation line (red line) was drawn from the cranial to the caudal aspect of the distal radial articular surface.

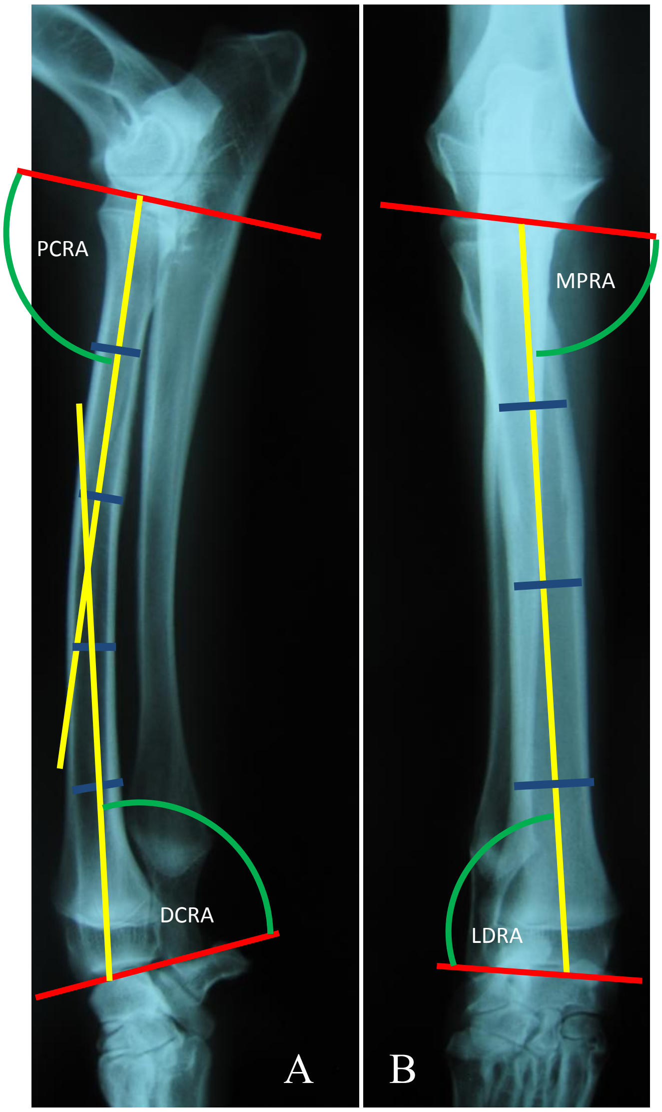


Figure II-16 Applied the center of rotation of angulation (CORA) methodology in the canine radius and ulna. Figure A displays a lateral radiographic view of the canine radius and ulna. The proximal cranial radial angle (PCRA) and the distal caudal radial angle (DCRA) are identified. Figure B displays an antero- posterior radiographic view of the canine radius and ulna. The medial proximal radial angle (MPRA) and the lateral distal radial angle (LDRA) are identified.

### II.5.1 Using the Center of Rotation of Angulation Methodology to correct radial deformities in dogs

Surgical correction of angular limb deformities and limb malalignment are commonly performed in small animal orthopedic surgery[43, 60, 74]. A unified system applicable to deformities in all long bones was not available in veterinary medicine for many years. Recently, the Center of Rotation of Angulation (CORA) methodology has been described for its use in planning surgery of deformities and correction of malalignment of the limb in humans and the result was satisfactory. Then, several veterinarians have adapted this CORA system for its use in dogs.

Furthermore, canine breed specific joint reference angles have been developed and can be used to aid planning of surgery deformity correction. Using breed specific reference ranges, the magnitude and location of multi-planar deformities can be quantified in frontal, sagittal, and transverse planes. If there are no breed specific reference values available, the physiologic opposite limb can be utilized to obtain joint reference angles for the individual patient (Figure II-17A). If both limbs are affected, the mean joint reference angles from the literature can be used. The joint reference angles are used to construct anatomic axes for proximal and distal bone segments (Figure II-17B&C). The CORA is located at the intersection of these anatomic axes, and its magnitude can be measured at this intersection (Figure II-17D). In most deformed limbs, CORA is uniapical in both the frontal and sagittal planes; however multiapical deformities can be seen. Generally, canine forelimbs, residual postoperative procurvatum deformities are more tolerable than valgus-varus deformities. For this reason, surgical correction is typically undertaken at the location of the deformity in the frontal plane[24]. Several surgical methods i.e. closing wedge, opening wedge, or radial osteotomy can be performed. Each of those methods has its advantages and disadvantages; for instance, the opening wedge increases limb length but it reduces bone stability, while the closing wedge provides a more stable construct but it can extend only limited limb length. The radial osteotomy can be performed in area next to joints, as the osteotomy location and angular correction axis (ACA) must not be the same locations. After performing radial osteotomy, limb stabilization can be achieved by using bone plates and screws, linear external fixation, or circular external fixation methods.

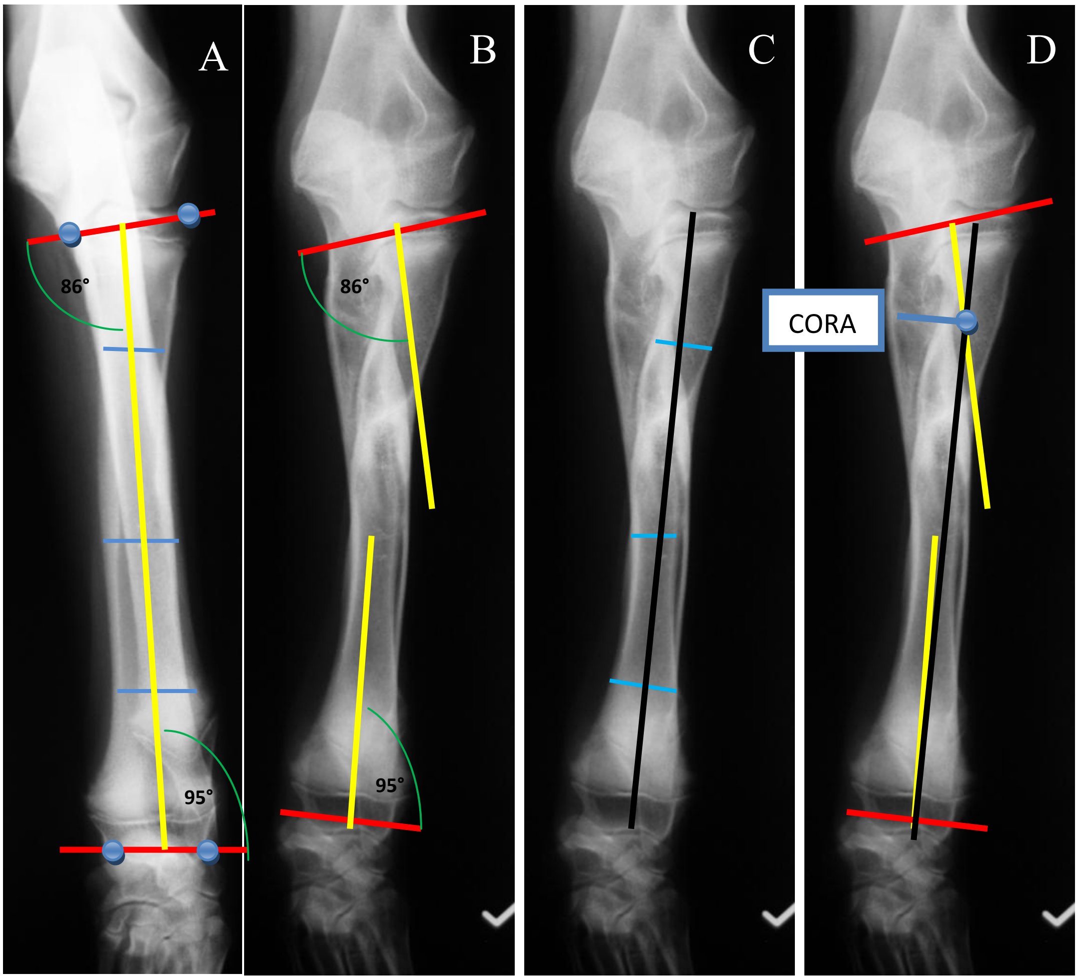


Figure II-17 Preoperative planning for a uniapical forelimb deformity in a dog. Frontal planes alignment determined by the CORA methodology is shown. Figure A displays a radiograph of normal canine radius and ulna (right side forelimb) in the frontal plane, the Medial Proximal Radial Angle (MPRA) and the Lateral Distal Radial Angle (LDRA) have been determined as a physiological reference angles. Figure B displays a radiograph from abnormal forelimb (left side) in the same dog in figure A. The reference values of Medial Proximal Radial angle (MPRA) and the Lateral Distal Radial Angle (LDRA) from the normal limb are used to determine the joint reference axes. Figure C displays frontal plane radial anatomic axis of abnormal forelimb (left side). Figure D displays the intersection of references axes and anatomical axis resulting in the center of rotation of angulation (CORA).

# Chapter III Materials and Methods

## Study I: Retrospective study

## Characteristics, complications, and outcome of canine radius-ulna fractures in 188 cases (1999 to 2009)

### Data collection

Medical records and radiographs of dogs suffering from fractures of radius and/or ulna admitted to the Small Animal Clinic, Freie Universität Berlin, Berlin, Germany between 1999 and 2009 were retrospectively reviewed.

Patient data included breed, age at treatment, gender, and bodyweight. Fracture information included site of the affected forelimb (right, left), duration from the onset of clinical signs to presentation and surgery, causes of the fracture (road traffic accident, biting injury, falling or jumping from a high place, unknown cause), character of the fracture (open or closed fracture), type of the fracture (green stick fracture, transverse fracture, oblique fracture, spiral fracture, reducible comminuted fracture, or non-reducible comminuted fracture), positions of the fracture line (proximal, middle and distal third of radius and ulna), surgical procedure and implantations, educational level and experience of the surgeon (professor, board certified surgeon, resident, clinician, doctoral student), presence of postoperative complications (evidence of bacterial infection, implant failure, re-fracture after removed implant, synostosis, malunion, non-union, delayed union, fracture related bone sarcomas), duration of bone healing, outcome of treatment (successful, amputation, arthrodeses, lost of follow-up), number of revision surgeries. The outcome of treatment in this study was defined as successful when the radiographic bone union was detected and the normal activity with full weight bearing to mild intermittent lameness of the affected limb was show.

## Statistical analysis

Descriptive statistics were calculated. Continuous data were expressed as median values and ranges. Categorical data were expressed as frequencies. Standard t-test and Pearson correlation were performed to determine the correlation of successful operation and required revision operation. A p-value of $< 0.05$ was accepted as being statistically significant.

## Study II: Retrospective study

## Incidence and correlation factors of post-traumatic radius and ulna synostosis in dogs: 24 cases (1999-2009)

### Data collection

This retrospective study includes clinical data of 2 groups of dogs were treated at the Small Animal Clinic, Freie Universität Berlin, Berlin, Germany during 1999 to 2009. The first group, the same group of the dogs in study I, was dogs with radial and ulna fractures caused by trauma (road traffic accident, biting injury, falling or jumping from high place, etc.). The second group, this group of dogs was not included in the study I, was dogs suffering from antebrachial growth deformities and received surgical operations to correct forelimb deformities. The medical records and radiographs associated with the radius and ulna regions were reviewed and patients with post-traumatic radius and ulna synostosis were identified.

Data from the medical records and radiographs included: signalment, body weight, curvature of the physioogic radius and ulna bone (straight short leg, straight long leg, and bow leg), causes of the fracture (road traffic accident, biting injury, falling or jumping from a high place, pathologic fracture, osteotomy to correct antebrachial deformities, and unknown cause), duration from the onset of clinical signs to surgery day, character of the fracture (open or closed fracture), types of the fracture (green stick fracture, transverse fracture, oblique fracture, spiral fracture, reducible comminuted fracture, or non-reducible comminuted fracture), severity of tissue trauma, positions of the fracture line on radius and ulna (proximal third, midshaft, and distal third), position of synostosis formation, osteosynthesis methods (bone plate and screw, external skeleton fixation, cast, pin, etc ), education and experience level of surgeon (professor, board certified surgeon, residence, clinician, and doctoral student), complications of bone healing (such as infection, instrument failure, synostosis, shortening of fractured leg, arthrodeses, re-fracture, fracture related bone sarcomas, malalignment, malunion, non-union, bone lysis, and lost of follow-up), number of revision surgeries, duration of bone healing (from the day of osteosynthesis to the day of implant removal), and the rotation of joint angulation which measured by the center of rotation and angulation (CORA) techniques from two plane radiographs (lateral view and antero-posterier view).

The joint orientation angles which measured by CORA techniques included identification of the medial proximal radial angle (MPRA), the lateral distal radial angle (LDRA), the proximal cranial radial angle (PCRA) and the distal radial angle (DCRA). The angular difference between MPRA and LDRA was determined and defined as the angle of frontal plane alignment (FPA). The angular difference between elbow (PCRA) and carpal (DCRA) joints was also determined and called the angle of sagittal plane alignment (SPA). To avoid the effect of implantation shadows on the angulation measurements, post-operative joint orientation angles were measured only in dogs that implant removal had been performed.

Anamnesis and the clinical signs of synostosis were recorded. Conservative treatments and surgical treatments were identified. The success of the therapy was mentioned by surgeon and/or the owner such as improved the supination and pronation, no lameness or intermittent lameness of the affected limb in the computer data system and recurrence of synostosis were also recorded.

### Statistical analysis

All statistical analyses were performed using computer software (SPSS Inc. Released 2008. SPSS Statistics for Windows, Version 17.0. Chicago: SPSS Inc). Descriptive statistic (mean, standard deviation, minimum, maximum) were calculated for continuous data. Standard t-test was performed to compare means of two groups. Pearson correlation was used to identify the correlation between synostosis formation and all of the other collected parameters. P-values< 0.05 were considered significant.

## Study III: Experimental study

## Measurement of pronation and supination in cadaveric dogs with surgical intervention to simulation of radius and ulna synostosis

### Selection of the cadaveric dogs

Seven fresh cadaveric of mature dogs (age between > 10 month-old to 12 year-old) with no specific breed were selected from donation of cadaveric dogs at the Small Animal Clinic, Freie Universität Berlin, Berlin, Germany. Inclusion criteria required the cause of death not to be related with musculoskeletal diseases and dog should not have any history of radius and/or ulna fracture. Both forelimbs were used for preparation. Hairs that covered the forelimbs were shaved to promote correct measurement of joint motion (Figure III-1). Two planes radiographs (lateral view and antero-posterier view) of both forelimbs were produced in order to scan the shape of radius and ulna and also to scan these bones for the occurrence of possible lesions. If any lesion of the forelimb could be observed, the according cadaver was excluded from the study.

Figure III-1 Shaved forelimbs of a cadaver dog. After hair shaving, the cadaver was placed at the ventral recumbency position. This preparation was performed before the measurement of pronation and supination.

**Measurement of pronation and supination techniques**

Pronation and supination angles of fourteen forelimbs from seven cadaveric dogs were measured before and after surgery. Two landmarks were assigned by a 20 gauge 1½ inch injection needle at the proximal and distal of forearm (Figure III-2A). The proximal landmark was placed at the elbow joint, the needle was punctured parallel to the long axis of humerus. The distal landmark was placed between the metacarpal III and IV bone. The starting position was determined on the palmar surfaces of the forelimb while the carpus and metacarpus were held in neutral extension flat against the examination surface. Figure III-2B shows the superimposition of two needles at the proximal and distal landmarks defining zero degree.

Supination is defined as inversion of the paw. The cadavers were placed in ventral recumbency position. Both forelimbs were extended. The measurements were performed in each leg. The forearm was laid flat against an examination table and perpendicular with the humerus. The paw was twisted in the anterior direction (faced up). The degree of supination was measured by determining the distance from the proximal needle to the distal needle (Figure III-3).

Pronation is defined as evertion of the paw. The cadavers were placed in ventral recumbency position. Both of forelimbs were extended. The measurements were performed in each leg. The forearm was laid flat against an examination table and perpendicular with the humerus. The paw was twisted in the posterior direction (faced down). The degree of pronation was measured by determining the distance from the proximal needle to the distal needle (Figure III-4).

After pre-operative measurements were performed, simulation of synostosis between radius and ulna was created by using surgical intervention. Post-operative measurements of pronation and supination of canine forelimbs were performed using the same procedure described above.

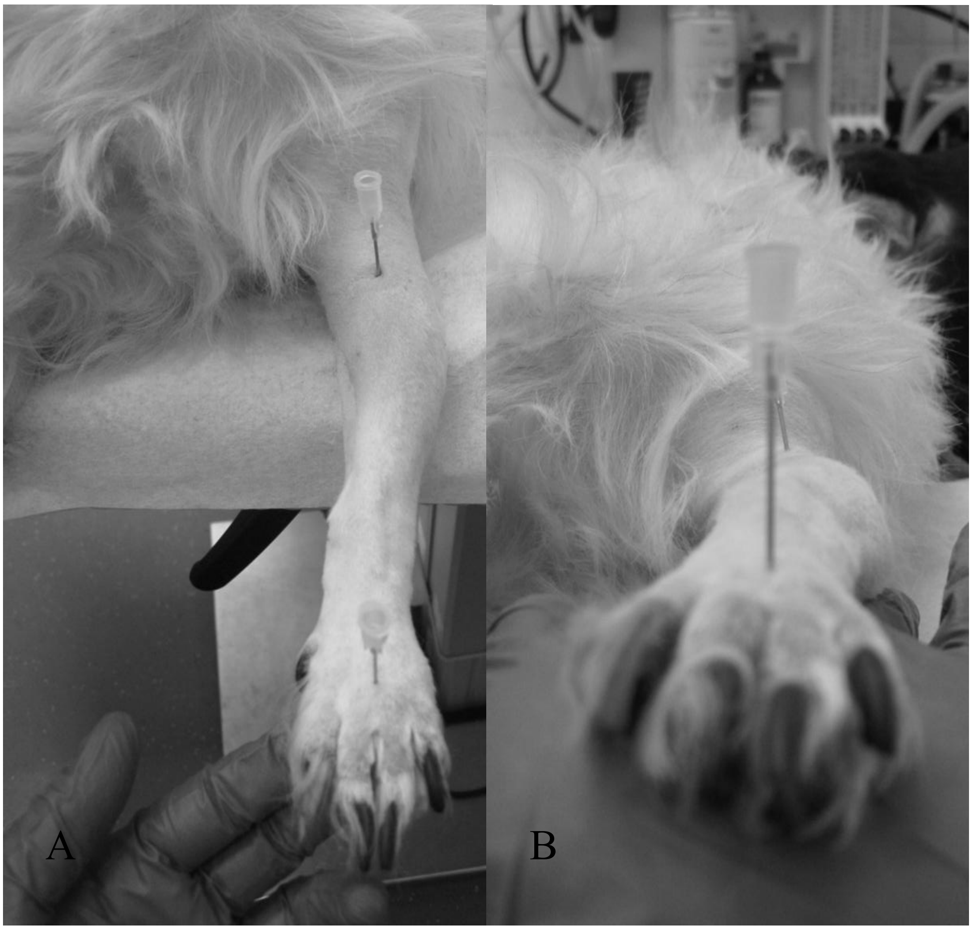


Figure III-2A and B The zero starting positions of the forearm in a cadaveric dog. Both figures display two of 20 gauge 1 ½ inch needles that were punctured to mark the zero starting positions. The proximal needle was placed on the elbow joint and is parallel to the long axis of the humerus. The distal needle was placed perpendicular to the paw between metacarpal III and IV.

**The surgical intervention to simulate synostosis between radius and ulna in cadaveric dogs**

After pronation and supination measurements in all of forelimbs were done. Surgical simulation of synostosis formation between radius and ulna in cadaver dogs was subsequently performed. The area of synostosis simulation was randomly chosen (proximal, middle and distal).

A craniomedial approach to the radius was performed followed by simulation of synostosis on the proximal, medial or distal position. One to two cortical screws were used to penetrate the radius and ulna and fix them together. The size of the screw was selected depending on the body weight of the cadaveric dog. Closure of soft tissues and skin were performed in a routine manner. Postoperative radiographs were done in two planes; lateral view and anteroposterior view. The position of the screw was reviewed (Figure III-5).

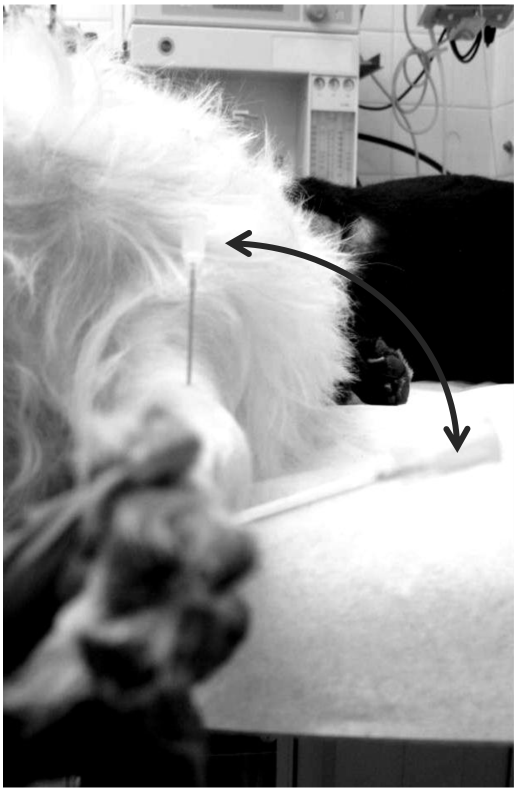

Figure III-3 Measuring of supination on left forelimb in a cadaveric dog. Supination (inversion paw) is performed by measuring the angle between two needles (black line). The proximal needle was placed on the elbow joint and is parallel to the long axis of the humerus. The distal needle was placed perpendicular to the paw between metacarpal III and IV

Figure III-4 Measuring of pronation on left forelimb in a cadaveric dog. Pronation (evert paw) is performed by measuring the angle between two needles (black line). The proximal needle was placed on the elbow joint and is parallel to the long axis of the humerus. The distal needle was placed perpendicular to the paw between metacarpal III and IV


Figure III-5 The standard radiographs in two planes of a cadaveric dog after surgery to simulate the synostosis between radius and ulna. Figure A and Figure B display the lateral and antero-posterier radiographic views of canine radius and ulna in a cadaveric dog (respectively). Two orthopedic bone screws were place at the middle part of radius and ulna to simulate the synostosis.

**Statistical analysis**

All statistical analyses were performed using computer software (SPSS Inc. Released 2008. SPSS Statistics for Windows, Version 17.0. Chicago: SPSS Inc). Descriptive statistic (mean, standard deviation, minimum, maximum) was applied when appropriate. Standard t-test was used to compare the data of 2 groups (pre-operative and post-operative measurements). P-values< 0.05 were considered significant.

## Study IV: Case report

## Outcome of treatments of post traumatic canine radius and ulna synostosis in four dogs including 2- year follow-up

### Inclusion criteria

Patients with radius and ulna synostosis after surgery or trauma were identified by radiographic examination. The medical records included documentation over a 2 year period. Several methods to treat synostosis were used: conservative, medical, physiotherapy and/or operative treatment. The success of the therapy which mentioned by surgeon and the owner such as improved the supination and pronation, no lameness or intermittent lameness or reduction grade of lameness of the affected limb in the computer data system and recurrence of synostosis were also recorded.

### Surgical techniques to correct synostosis between radius and ulna

In order to approach the localization of synostosis between radius and ulna, skin incision was performed from the lateral surface of the ulna to the level of synstosis formation. After incising the subcutaneous tissue, the ulna bone was exhibited. The excision of synostosis was performed by using an osteotome and accompanied by removal of two to three centimeters of ulna. In order to stop bleeding especially of the ulna incision surface, electrocautery was used. No interpositional materials such as fat graft, silicone or muscle were used to replace the empty space. The surgical wound was closed in a routine manner. Minimal postoperative immobilization of the operated limb was needed. Post-operative radiographs were performed to control the evidence of recurrence of the synostosis.

# Chapter IV Results

## Study I: Retrospective study

## Characteristics, complications, and outcome of canine radius-ulna fractures in 188 cases (1999 to 2009)

Medical records of Small Animal Clinic, Freie Universität Berlin, Berlin, Germany from the years 1999 to 2009 were reviewed. One hundred and eighty-eight cases of radius ulna fractures in 179 dogs were identified. In eight dogs, both forelimbs were fractured. In 85 dogs, only the left forelimb was fractured and in 87 dogs, only the right forelimb was fractured. Fifty-three breeds were represented (Table IV-1). Large mixed breeds (bodyweight higher than 25 kg) were more likely to be affected than others. This group of dogs was represented in 26 of 188 cases (13.83%). German shepherd breed was the second most common breed affected (17 of 188 cases; 9.04%). The third most common patient population were small mixed breeds (bodyweight lower than 10 kg), Yorkshire terriers and medium mixed breeds (body weight between 10 to 25 kg) were represented in 12 of 188 cases; (6.38%) each. Mean body weight of all affected dogs was 19.02 ± 13.34 kg. The study population included 95 males (75 intact, 20 neutered) and 84 females (71 intact and 13 neutered). The age of patients at the time of treatment varied from 1 to 173 month (Table IV-2). The median age was 21 month (1.75 years).

The causes of the traumatic fracture of the radius and/or ulna were identified as road traffic accidents (65/188 cases; 34.57%), falling or jumping from high places (24/188 cases; 12.76%), bite injuries (13/188 cases; 6.91%), others trauma causes (e.g., dog was kicked by horse, dog was hit by the owner) (33/188 cases; 17.55%). No information in the database or unknown causes were obtained in some cases (50/188 cases; 26.59%). The duration from onset of fracture to the day of surgery varied from one day to 90 days (Figure IV-1). Mean time of fracture onset to the day of operation was one day.

In 159 of 188 cases, radiographic information of the affected limb was available. The radiographs of 29 cases were loss from the archive. Fractured of radius and Ulna in those group of dogs was identified by the record of the clinician in the computer data system. Therefore, type of fracture was diagnosed only in 159 cases based on radiographs (Figure IV-2). Off all fractures, 51.57% (82/159 cases) were classified as transverse fracture, 23.90% (38/159 cases) were classified as oblique fracture, 14.46% (23/159 cases) were classified as comminuted reducible fracture, 4.40% (7/159 cases) were classified as comminuted non reducible fracture, 3.77% (6/159 cases) were classified as spiral fracture, and 1.89% (3/159 cases) were classified as green stick fracture. Twenty-nine of 188 forelimbs (15.42%) were accompanied with an open wound fracture.

In the majority of patients, both radius and ulna were fractured (143/188 cases; 76.06%). In 19 of 188 cases (10.10%), only the ulna was fractured, and in 26 of 188 cases (13.83%), only the radius was fractured. The location of the fracture line was classified for one of the three areas: the proximal third, the middle third, or the distal third. A summary of the localization of the fracture is shown in figure IV-3. The predominant number of fractures was localized at distal third of radius. The osteosynthesis applied to the radius and/or ulna fractures were bone plates and screws, external skeleton fixations, intramedullary pins, and external cooptations (Table IV-3). Some of the patients were applied to more than one osteosynthesis method due to their instability of the fracture, or the failure of first method chosen.

Table IV-1 Breed distribution of dogs with fracture of the radius and/or ulna (n= 188 cases)

| Small breed (<10 kg) | | Medium breed (10-25 kg) | | Large breed (> 25kg) | |
|---|---|---|---|---|---|
| breed | n | breed | n | breed | n |
| Small mix | 12 | Medium mix | 12 | Large mix | 26 |
| Yorkshire terrier | 12 | Kromfohrländer | 2 | German shepherd | 17 |
| Italian greyhound | 11 | Beagle | 1 | Siberian husky | 5 |
| Cairn terrier | 10 | Shar pei | 1 | Large müsterländer | 4 |
| Chihuahua | 7 | Brittany | 1 | Golden retriever | 4 |
| Sheltie | 5 | | | Labrador retriever | 3 |
| Jack russell terrier | 4 | | | Doberman pinscher | 3 |
| Miniature pinscher | 3 | | | Weimaraner | 2 |
| Poodle | 3 | | | Deutsch drahthaar | 2 |
| Pug | 3 | | | Bearded collie | 2 |
| West highland white terrier | 1 | | | Irish setter | 2 |
| Cavalier king charles spaniel | 1 | | | Briard | 2 |
| Bedlington terrier | 1 | | | Saint bernard | 2 |
| Maltese | 1 | | | Rhodesian ridge back | 2 |
| Whippet | 1 | | | Airedale terrier | 2 |
| Dachshund | 1 | | | Great dane | 1 |
| Papillion | 1 | | | Afghan hound | 1 |
| | | | | Rottweiler | 1 |
| | | | | Kangal | 1 |
| | | | | Flat coated retriever | 1 |
| | | | | Hovawart | 1 |
| | | | | Leonberger | 1 |
| | | | | English setter | 1 |
| | | | | Kuvasz | 1 |
| | | | | French spaniel | 1 |
| | | | | German longhaired pointer | 1 |
| | | | | American staffordshire terrier | 1 |
| | | | | Galgo español | 1 |
| | | | | Belgian shepherd dog | 1 |
| | | | | Greater swiss mountain dog | 1 |
| | | | | Alaska malamute | 1 |
| Total | 77 | | 17 | | 94 |
| % | (40.96) | | (9.04) | | (50%) |

Table IV-2 Age of dogs with fractured radius and/or ulna at the time of treatment (n=188 cases)

| Age at the time of treatment | n | % |
|---|---|---|
| 1 - 6 months | 31 | 16.49 |
| 7 - 12 months | 36 | 19.15 |
| 1.1 – 2 years | 37 | 19.68 |
| 2.1 - 3 years | 15 | 7.98 |
| 3.1 - 4 years | 13 | 6.91 |
| 4.1 - 5 years | 11 | 5.85 |
| 5.1 - 6 years | 13 | 6.91 |
| 6.1 - 7 years | 4 | 2.13 |
| 7.1 – 8 years | 8 | 4.25 |
| >8.1 years | 12 | 6.38 |
| Unknown | 8 | 4.25 |
| Total | 188 | 100 |

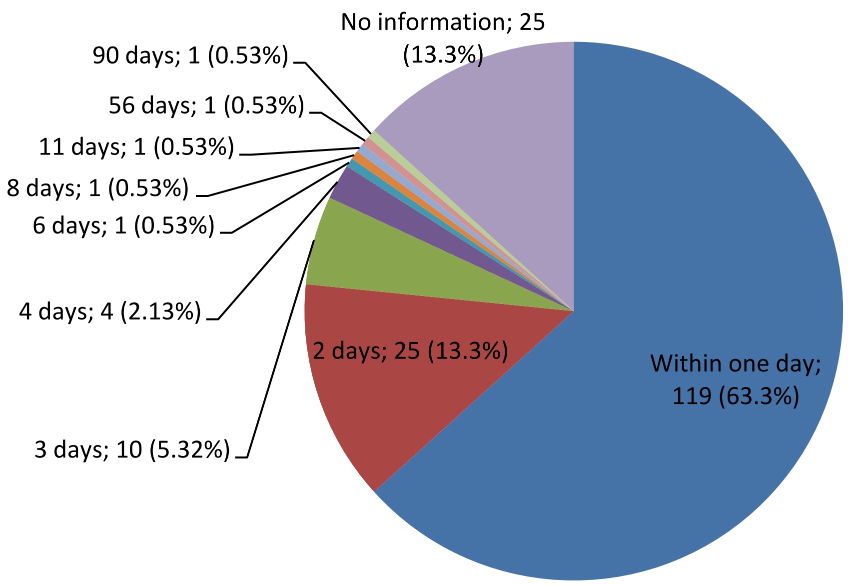


Figure IV-1 Duration of fracture onset until the surgery day of dogs with fractured radius and/or ulna (n=188 cases).

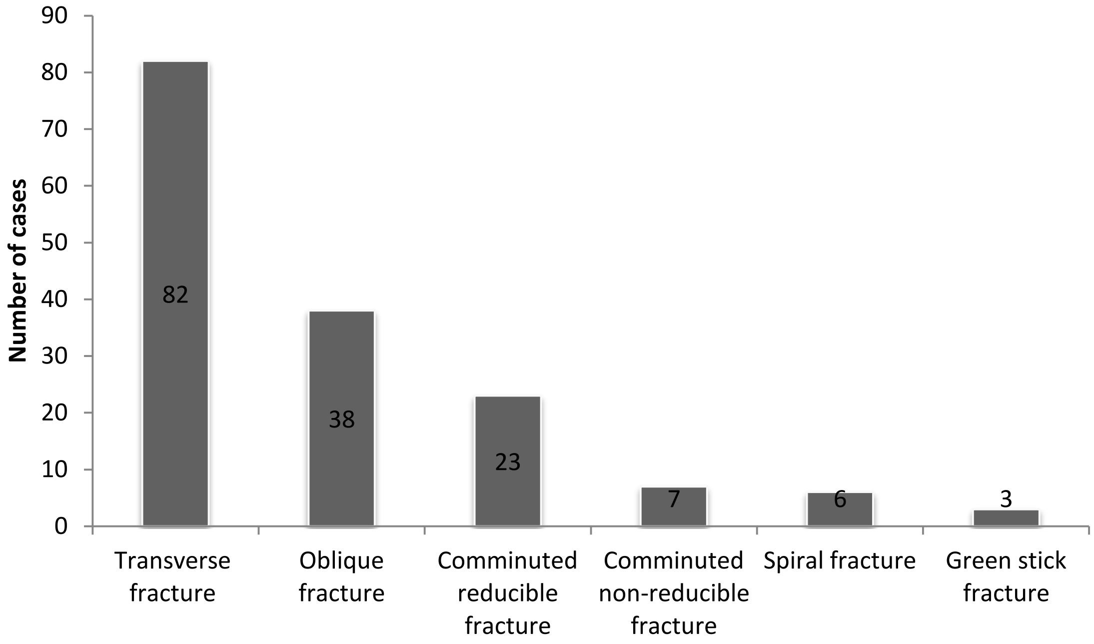


Figure IV-2 Classification of canine radius and/or ulna fracture type (n= 159 cases)

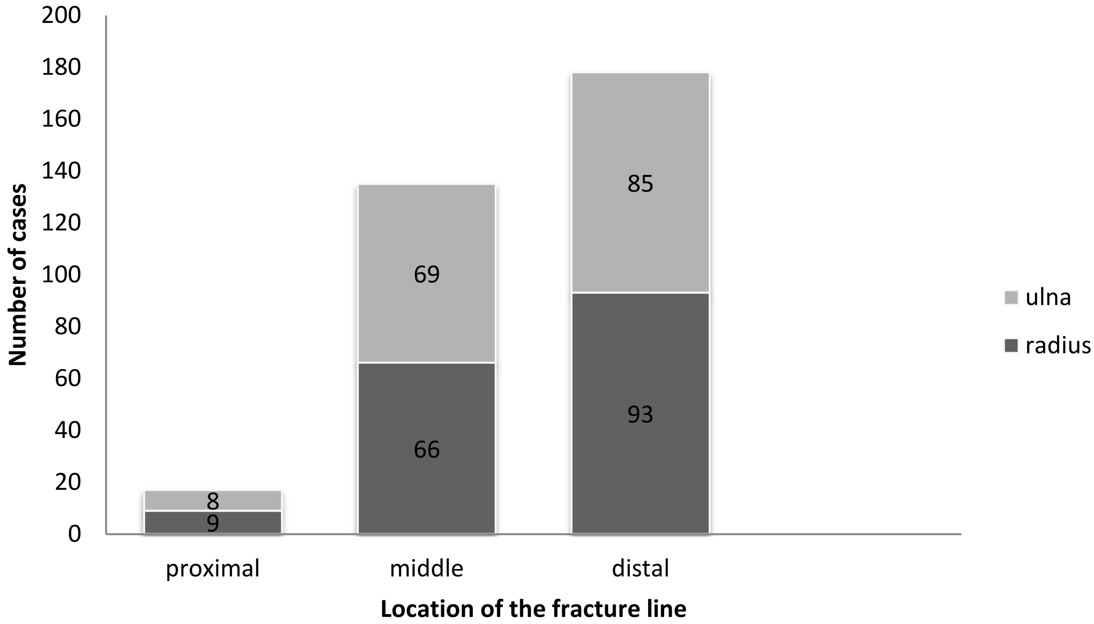


Figure IV-3 Column graph of the localization of the canine radius/ulna fractures. Data was evaluated from 188 cases. Most of the patients were presented with fractured both of radius and ulna (143 cases, 76.06%). Only radius was fractured in 26 cases (13.83%), and in 19 cases (10.10%), only the ulna was fractured

Table IV-3 Osteosynthesis methods that were applied to canine radius and/or ulna fractures (n=188 cases).

| Fixation method | n | % |
|---|---|---|
| Bone plate and screw | 135 | 71.8 |
| External skeleton fixation (ESF) | 21 | 11.2 |
| Bone plate and screw & cast | 7 | 3.7 |
| Pin | 5 | 2.7 |
| Bone plate & ESF | 5 | 2.7 |
| Bone plate and screw & pin | 4 | 2.1 |
| ESF & pin | 3 | 1.6 |
| Cast | 3 | 1.6 |
| Bone plate & ESF & cast | 2 | 1.1 |
| Pin & cast | 2 | 1.1 |
| ESF & cast | 1 | 0.5 |
| Total | 188 | 100 |

## Outcome

The successful outcome of the surgery in this study was defined when radiographic union was identified and/or the implants were removed after the bone union without the presenting of re-fracture. The duration of bone healing in the successful animal was calculated from the day of the first operation to the day of the implant removal. In 116 of 188 cases (61.70%), implant removal was performed at the Small Animal Clinic, Freie Universität Berlin. In 72 of 188 cases (38.30%), the records of implant removal were not found in our computer data system. However, in 14 of those 72 cases (19.44 %), radiographic bone union was show at the last day of follow up. In this study, the mean duration of bone healing was 108.11 ± 77.91 days (range: 24 days to 480 days). Table IV-4 shows the duration of bone healing classified by osteosynthesis method.

Revision surgery was performed in 20 cases (10.64%). Of 188 cases, 14 cases (7.4%) underwent one revision surgery. Two revision surgeries were performed in 3 cases (1.6%). Three, four and five revision surgeries were performed in one case (0.5%) each. The performance of revision surgery was significantly correlated with the presence of an open wound fracture ($R = 0.176$, $p < 0.05$), a bite injury fracture ($R = 0.232$, $p < 0.01$), a street accident fracture ($R = 0.154$, $p < 0.05$) and complications caused by bacterial infection ($R = 0.411$, $p < 0.01$). Breed, sex, age of treatment, types of fracture, location of the fracture line, osteosynthesis methods, and educational level and experience of the surgeon did not correlate significantly with the occurrence of revision surgery ($p > 0.05$).

Complications of radius and/or ulna fracture healing identified in this study included presenting signs of bacterial infection, implant failure, post-traumatic synostosis, shortening of the effected leg, re-fracture of the bone after removed bone fixation, non healing bone, bone lysis, and antebrachiocarpal joint instability (Table IV-5).

The center of rotation of angulations method was used in the affected limbs after the removal of the bone implant (Table IV-6) to identify the occurrence of the malunion, radial torsion and antebrachial growth disturbance of the fractured radius and/or ulna in canine patients. The increased number of revision surgery was related to a reduced lateral distal radial angle (LDRA) after fracture healing ($p < 0.05$). The reducing of the lateral distal radial angle is the characteristic for an abnormal outward of forearm which called "canine carpal valgus" (Figure IV-4).

Table IV-4 Duration of bone healing (days) identified for each method of osteosynthesis

| Fixation methods | cast | IM pin | plate & cast | ESF & cast | plate & ESF & cast | plate & screw | ESF | plate & ESF | ESF & IM pin | plate & IM pin |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean ± SD (day) | 40 | 73 ± 26.74 | 76.8 ± 26.78 | 95 | 109 | 115.15 ± 66.89 | 141.44 ± 38.87 | 171.6 ± 174.33 | 204.5 ± 116.92 | 216 |
| n | 1 | 4 | 5 | 1 | 1 | 79 | 16 | 5 | 3 | 1 |

Table IV-5 Complications of radius and/or ulna fractures in dogs (n=188 cases)

| Complications | Cases (%) |
|---|---|
| Presence signs of bacterial infection | 20/188 (10.6%) |
| Post-traumatic synostosis | 18/188 (9.6%) |
| Implant failure | 9/188 (4.8%) |
| Shortening of forelimbs | 3/188 (1.6%) |
| Re-fracture of the bone after implant removal | 3/188 (1.6%) |
| Non-healing/ non-union | 3/188 (1.6%) |
| Antebrachiocarpal joint instability | 2/188 (1.1%) |
| Bone lysis after 5 times revision surgery suspected of bone tumors lead to forelimb amputation | 1/188 (0.5%) |

Table IV-6 Center of rotation of angulation measurements were performed after the removal of the bone implant. In the lateral radiographic view of the canine radius and ulna, the proximal cranial radial angle (PCRA), the distal caudal radial angle (DCRA), and the angle of normal sagittal plane alignment (SPA) were identified. In the antero-posterior radiographic view, the medial proximal radial angle (MPRA), the lateral distal radial angle (LDRA), and the normal angle of frontal plane alignment (FPA) were identified.

| | Minimum | Maximum | Mean ± SD | Normal canine radial axes (Fox *et.al.* 2006)[24] |
|---|---|---|---|---|
| PCRA | 77.0 | 103.0 | 89.92 ± 4.29 | 90.5 ± 4.0 |
| DCRA | 61.0 | 100.5 | 76.83 ± 7.14 | 78.3 ± 4.8 |
| SPA | -15.0 | 34.0 | 13.09 ± 8.73 | 25.2 ± 8.2 |
| MPRA | 72.0 | 91.5 | 82.26 ± 3.60 | 85.3 ± 3.5 |
| LDRA | 71.0 | 100.0 | 81.99 ± 5.59 | 86.7 ± 2.9 |
| FPA | -14.5 | 14.0 | 0.27 ± 6.65 | 2.7 ± 2.7 |

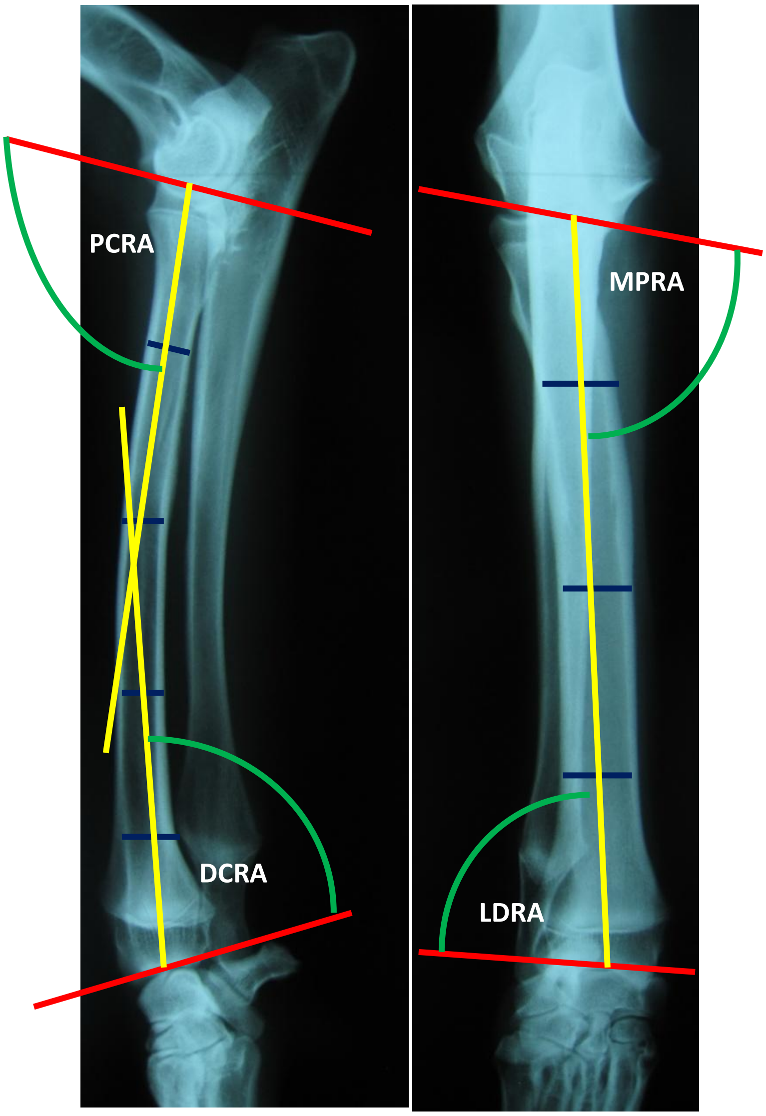


Figure IV-4 Center of rotation of angulation (CORA) measurement of the canine radius and ulna. In the lateral radiographic view, the proximal cranial radial angle (PCRA) and the distal caudal radial angle (DCRA) can be evaluated. In the antero- posterior radiographic view, the medial proximal radial angle (MPRA) and the lateral distal radial angle (LDRA) can be evaluated.

## Study II: Retrospective study

## Incidence and correlation factors of post-traumatic radius and ulna synostosis in dogs: 24 cases (1999-2009)

221 canine radius and/or ulna fractures which caused from traumatic fracture and osteotomy to correct forelimb deformities in 213 patients received orthopedic surgical treatment at the Small Animal Clinic, Freie Universität Berlin, Berlin, Germany during 1999 to 2009 were admitted to this study. In 24 cases (10.86%), radiographic diagnosis of post traumatic radius and ulna synostosis was showed after the surgical treatment. Synostosis formation located along the length of interosseous membrane, between radius and ulna (Figure IV-5). In all cases, synostosis formation was located at the fracture site (100%). Additionally, two cases (8.33 %) were presented with synostosis formation in the area where penetration of the surgical bone screw through the ulna occurred. The distal third of the radius was the area where synostosis formation was located most frequent (n= 13 cases; 50%). The middle (n=9 cases; 34.61%) and proximal third (n=4 cases; 15.38%) of radius and ulna were also affected by synostosis formation. Nineteen canine breeds were included in this study (Table IV-7). Large-sized dogs (n= 17, 70.83%) were the most common breed ($P=0.025$) affected by radius and ulna synostosis. However, synostosis occurred in small (n=4, 16.67%) and medium (n=3, 12.5%) sized dogs as well. Body weight (BW) was significantly positive correlated with post traumatic radius and ulna synostosis ($p= 0.03$, $R= 0.17$). The mean BW of dogs with synostosis was 25.40 ± 12.79 kg (range: 6 to 57 kg).

Age was significantly correlated with synostosis formation ($P< 0.05$). Young dogs (age < 2 years old) are more likely to be affected by synostosis formation than others. Mean age of affected dogs was 21.34 ± 21.75 months (range: 4 months to 8.58 years) (Table IV-8). Gender distribution included 12 intact males (50%), 3 intact females (12.5%), 5 neutered males (20.83%) and 4 neutered females (16.67%). The distributions of synostosis formation with causes of the fracture are shown in table IV – 9. The osteosynthesis methods (Table IV-10), the duration from the day of fracture onset to the day of surgery, educational level and experience of the surgeon, the positions of the fracture lines, the presence of an open wound fracture, the type of fracture (Table IV-10), and the duration of bone healing were not significantly correlated with synostosis formation ($p > 0.05$). In four cases presented with the open wound fracture; three of them suffered from bite injuries and one of them suffered from road traffic accidental trauma. The presenting sign of bacterial infection were highly positive correlated with synostosis formation ($p=0.013$, $R= 0.167$).

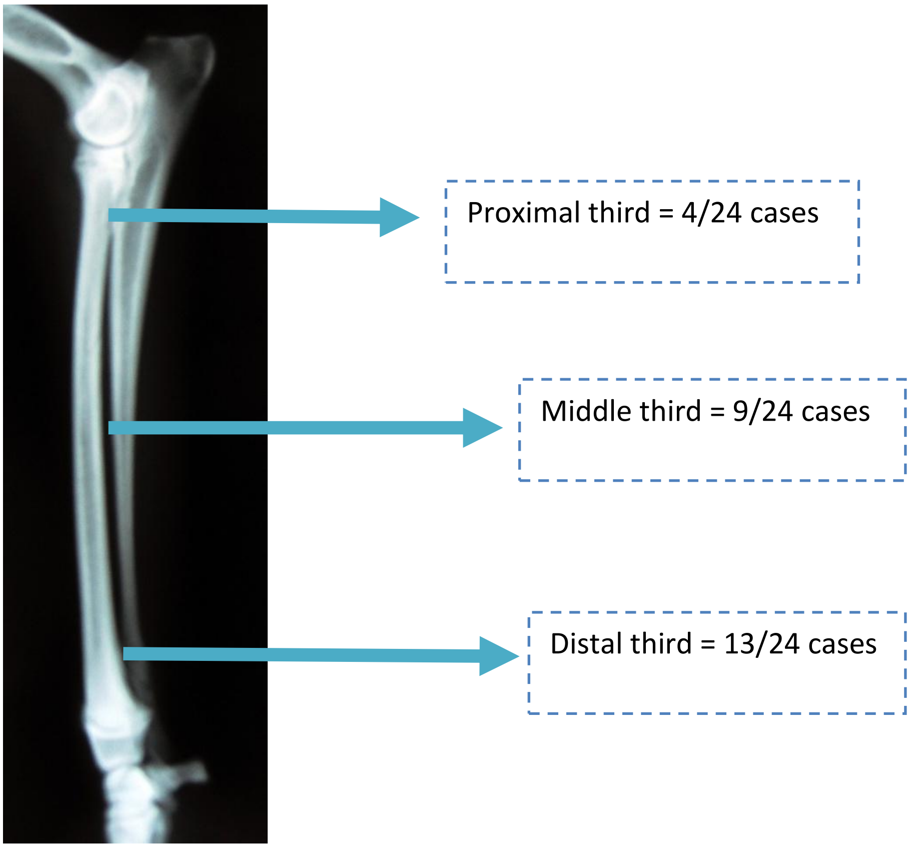


Figure IV-5 the localization of post traumatic canine radius and ulna synostosis formation in 24 cases. In all cases, synostosis formation was located at the fracture site. Additionally, in two cases (8.33 %) were presented with synostosis formation in the area where penetration of the surgical bone screw through the ulna occurred. The distal third of the radius was the area where synostosis formation was located most frequent (n= 13 cases; 50%). The middle (n=9 cases; 34.61%) and proximal third (n=4 cases; 15.38%) of radius and ulna were also affected by synostosis formation.

Table IV-7 Breed distribution of dogs identified with radius and ulna synostosis (n=24)

| Small breed (<10kg) | | Middle breed (10-25 kg) | | Large breed (>25 kg) | |
|---|---|---|---|---|---|
| Breed | n | Breed | n | Breed | n |
| Cairn terrier | 2 | Middle mix | 1 | Golden retriever | 3 |
| Sheltie | 1 | Beagle | 1 | Large mix | 2 |
| Italian greyhound | 1 | Whippet | 1 | Labrador retriever | 2 |
| | | | | Greyhound | 1 |
| | | | | Newfoundland | 1 |
| | | | | German shepherd | 1 |
| | | | | Belgian shepherd | 1 |
| | | | | Border collie | 1 |
| | | | | Hovawart | 1 |
| | | | | Munsterländer | 1 |
| | | | | Bernese mountain dog | 1 |
| | | | | English setter | 1 |
| | | | | Siberian husky | 1 |
| Total | 4 (16.67%) | | 3(12.5%) | | 17 (70.83%) |

Table IV-8 Age distribution of dogs suffering from radius and ulna synostosis at the day of radius ulna fracture (n=24)

| Age | n | % |
|---|---|---|
| 1 - 6 months | 2 | 8.33 |
| 7 - 12 months | 6 | 25 |
| 1.1 – 2 years | 11 | 45.83 |
| 2.1 - 3 years | 1 | 4.17 |
| 3.1 - 4 years | 1 | 4.17 |
| 4.1 - 5 years | 0 | 0 |
| 5.1 - 6 years | 1 | 4.17 |
| 6.1 - 7 years | 0 | 0 |
| 7.2 – 8 years | 0 | 0 |
| >8.1 years | 1 | 4.17 |
| Unknown | 1 | 4.17 |

Two plane radiographs were performed after removal of the bone implant. The joint orientation was determined using the CORA techniques (Table IV-11). In 20 of 24 cases, bone implant removal was performed at the Small Animal Clinic, Freie Universität Berlin, Berlin, Germany. The lateral distal radial angle (LDRA) and the angle of frontal plane alignment (FPA) were significantly correlated with post traumatic canine radius and ulna synostosis formation ($p < 0.025$). The formation of synostosis was positive correlated with LDRA ($R = 0.216$) but negative correlated with FPA ($R = -0.216$). Therefore, synostosis formation was significantly related to an increased LDRA and a decreased FPA. Implant failure was identified in one dog (the acrylic bar of the ESF was fractured) which leaded to instability of the antebrachiocarpal joint. In this dog, carpal joint arthrodesis was performed.

Only 5 of 221 radius and/or ulna fractures (2.26%) underwent surgery in order to correct synostosis formation. The decision to perform either conservative treatment or surgical treatment was chosen by the suggestion of the surgeon and the agreement of the owner. The clinical signs of patients that received surgical treatment included chronic lameness and ineffective conservative treatment. The duration from the first surgery to correct the radius and/or ulna fracture until surgery to correct synostosis varied from 2 months to 6 years. Eighty percent (n=4) of these patients did not show any sign of lameness until at least one year after the surgery to remove the bony bridge between radius and ulna. Recurrence of post traumatic canine radius ulna synostosis occurred in one case after the surgical treatment.

Table IV-9 Causes of radius and/or ulna fracture in dogs with post traumatic synostosis (n=24)

| Accidental trauma | Bite injuries | Corrected osteotomies | Unknown | Total |
|---|---|---|---|---|
| 15 (62.5%) | 3 (12.5%) | 5 (20.83%) | 1 (4.17%) | 24 (100%) |

Table IV-10 Osteosynthesis methods and type of fractures in 24 dogs with post traumatic radius and ulna synostosis

| Case | Implants | Types of Fracture | |
|---|---|---|---|
| **1** | ESF & IM pin | Comminuted | |
| **2** | ESF & IM pin | Transverse | |
| **3** | 3.5mm plate and screw | Transverse | |
| **4** | 3.5 mm plate and screw | Oblique | |
| **5** | ESF type II | Transverse | |
| **6** | 3.5 mm DCP | Oblique | |
| **7** | 3.5 mm DCP | Transverse | |
| **8** | 3.5 mm DCP | Oblique | |
| **9** | 4.5 mm NCP | Transverse | |
| **10** | 3.5 mm NCP with MCS | R:Transverse | U:Comminuted |
| **11** | 3.5 mm NCP with MCS | R:Spiral | U: Transverse |
| **12** | 3.5 mm NCP with MCS | R: Transverse | U:Oblique |
| **13** | 3.5 mm T-plate | R:Transverse | U:Comminuted |
| **14** | ESF | Transverse | |
| **15** | 2 mm T-plate | R:Transverse | U:Oblique |
| **16** | 3.5 mm NCP with MCS | Transverse | |
| **17** | 1st : 2.7 mm NCP<br>2nd: reconstruction plate | Transverse | |
| **18** | ESF & IM pin | Oblique | |
| **19** | 3.5 mm NCP | Transverse | |
| **20** | Plate & screw | No information | |
| **21** | 3.5 mm T-plate | Transverse | |
| **22** | 1st :IM pin<br>2nd: 2.7 mm DCP | Transverse | |
| **23** | No Implant | Ulna ostectomy | |
| **24** | No implant | Ulna ostectomy | |

DCP = dynamic compression plate; NCP = non-contact plate; MCS = monocortical screw; ESF = external skeleton fixation; R = radius; U = ulna

Table IV-11 Post-operative joint orientation in dogs with post-traumatic radius and ulna synostosis.

| Parameters | Synostosis dogs (n=20) | | | Non-synostosis dogs (n= 88) |
|---|---|---|---|---|
| | Mean ± SD | Minimum | Maximum | Mean ± SD |
| The proximal cranial radial angle (PCRA) | 90.77 ± 5.15 | 77.5 | 103.0 | 89.26 ± 5.09 |
| The distal radial angle (DCRA) | 74.37 ± 6.43 | 62.0 | 86.0 | 76.01 ± 8.76 |
| The angle of sagittal plane alignment (SPA) | 16.40 ± 7.29 | 6.0 | 34.0 | 13.24 ± 10.23 |
| The medial proximal radial angle (MPRA) | 80.67 ± 5.89 | 67.0 | 90.0 | 80.85 ± 6.40 |
| The lateral distal radial angle (LDRA) | 83.87 ± 6.16[a] | 76.0 | 95.5 | 79.37 ± 8.34[b] |
| The angle of frontal plane alignment (FPA) | -3.20 ± 10.53[c] | -28.0 | 10.0 | 1.48 ± 7.73[d] |

[a]&[b]; [c]&[d] were statistically different (t-test; P=0.025)

## Study III: Experimental study

### Measurement of pronation and supination in cadaveric dogs with surgical intervention to simulation of radius and ulna synostosis

The ranges of motions of the radius and ulna were measured by one investigator. Results were obtained by using two methods: using direct goniometer and evaluation from photographs. The results from both methods were not significantly different. Significantly difference was detected in measurements before and after surgical simulation of radius and ulna synostosis. After surgery, the motion of supination was significantly increased ($p < 0.01$) while the motion of pronation was significantly decreased ($p < 0.05$) (Table IV-12).

Table IV-12 Results of supination and pronation before and after surgical simulation of synostosis formation between radius and ulna in cadaveric dogs (n=14 limbs)

| No. | Supination (degree) | | Pronation (degree) | |
|---|---|---|---|---|
| | before surgery | after surgery | before surgery | after surgery |
| 1 | 50 | 60 | 20 | 20 |
| 2 | 75 | 75 | 45 | 35 |
| 3 | 72 | 75 | 55 | 35 |
| 4 | 70 | 83 | 70 | 40 |
| 5 | 62 | 65 | 45 | 40 |
| 6 | 71 | 95 | 55 | 65 |
| 7 | 70 | 60 | 55 | 45 |
| 8 | 55 | 80 | 40 | 45 |
| 9 | 85 | 100 | 25 | 25 |
| 10 | 75 | 95 | 40 | 40 |
| 11 | 75 | 87 | 37 | 30 |
| 12 | 82 | 89 | 48 | 21 |
| 13 | 75 | 100 | 35 | 30 |
| 14 | 77 | 79 | 44 | 30 |
| Mean ± SD | 71 ± 9.60 | 81.64 ± 13.66 | 43.86 ± 12.88 | 35.78 ± 11.64 |

## Study IV: Case report

## Outcome of treatments of post traumatic canine radius and ulna synostosis in four dogs including 2- year follow-up

The clinical data of patients enrolled in this study are shown in Table IV-13.

Table IV-13 Clinical data of patients enrolled in study IV

| Case no. | Breed | Age at first presentation | Age at time of surgery | Cause of trauma at radius ulna | Radiographic finding | Method of synostosis treatment |
|---|---|---|---|---|---|---|
| 1 | Labrador mix | 1y 3 mo. | 1st:1y 3 mo. 2nd:3y 6 mo. | Previous fracture of radius and ulna | Complete synostosis formation at the middle third of radius and ulna. Malunion (recurvatum) | Synostosis excision and ulna ostectomy |
| 2 | Italian-Greyhound | 5 mo. | No surgery to resection synostosis | Multiple surgeries to correct radius ulna fracture | Synostosis formation at the proximal and middle third of radius and ulna. | Physiotherapy and restricted activity |
| 3 | Hovawart | 4 mo. | 1st:4 mo. 2nd:6 mo. | Previous fracture of radius and ulna | Complete synostosis formation of the proximal to middle third of radius and ulna. Elbow malformation | Ulna ostectomy and corrected osteotomy |
| 4 | Giant schnauzer | 6 y 2 mo. | 9 y 11 mo. | Unknown | Complete synostosis formation at the distal third of radius and ulna. Proliferative periosteal reaction was presented at the metaphysis of radius and ulna. | Conservative treatment for a period of four years followed by synostosis excision and ulna ostectomy |

**Case 1**

A female Labrador-mix breed dog originated from the animal shelter suffered from progressive pain of the right forelimb. The dog was presented to the Small Animal Clinic in April 2009 at the age of 15 month. A physical examination was performed and two plane radiographs of the right forelimb were taken. Synostosis at the middle shaft of radius and ulna and malunion (recurvatum) of the radius and ulna were diagnosed based on the radiographic findings (Figure IV-6A). The dog underwent surgical resection. Ulna ostectomy (around two centimeters) was performed without replacement of any interpositional materials. Immediately after surgery radiographs were taken in order to document the result of the surgery. In these radiographs, one centimeter remnant of the proximal section of synostosis was visible (Figure IV-6B). However, the passive range of movement determined under general anesthesia was improved. An external cooptation was placed to the affected leg and remained for two months in order to support the weight burden and to maintain the alignment of affected leg. The dog did not exhibit any clinical signs of lameness up to 14 months after this operation.

Two years after the first surgical resection of radius and ulna synostosis, the clinical signs of the dog were recurrence: pain at the right forelimb and reluctance to move. Analgesic treatment, joint supporting nutrition as well as restricted movement were encouraged for five weeks but not effective. Base on radiographs, the dog was diagnosed with recurrence of synostosis at the ulna, proximal from the lesion treated two years ago (Figure IV-7A). The revision surgery was performed. Synostosis was removed by excising the remaining bony bridge. Creating multiple holes between radius and ulna directly on the synostosis site was performed by using a small orthopedic burr. Then, electrocautary was used to stop bleeding at the bony surface (Figure IV 7B). The external cooptation was applied for one month on the effected leg.

During the eight months follow-up period, no evidence of recurrent synostosis was detected.

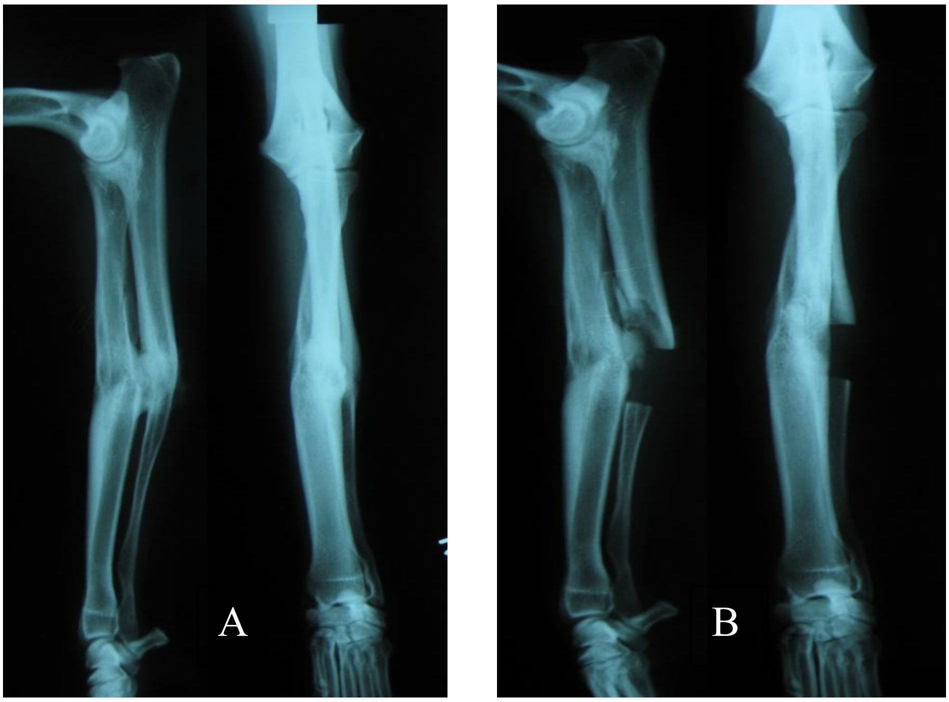


Figure IV- 6 Canine radius and ulna synostosis in the dog described in case 1. Figure A displays two planes radiographs of forearm before surgery, the formation of synostosis between the midshaft of radius and ulna can be identified. Figure B displays two planes radiographs of forearm after surgery, the resection of 2 cm ulna and the bony bridge between radius and ulna were performed.

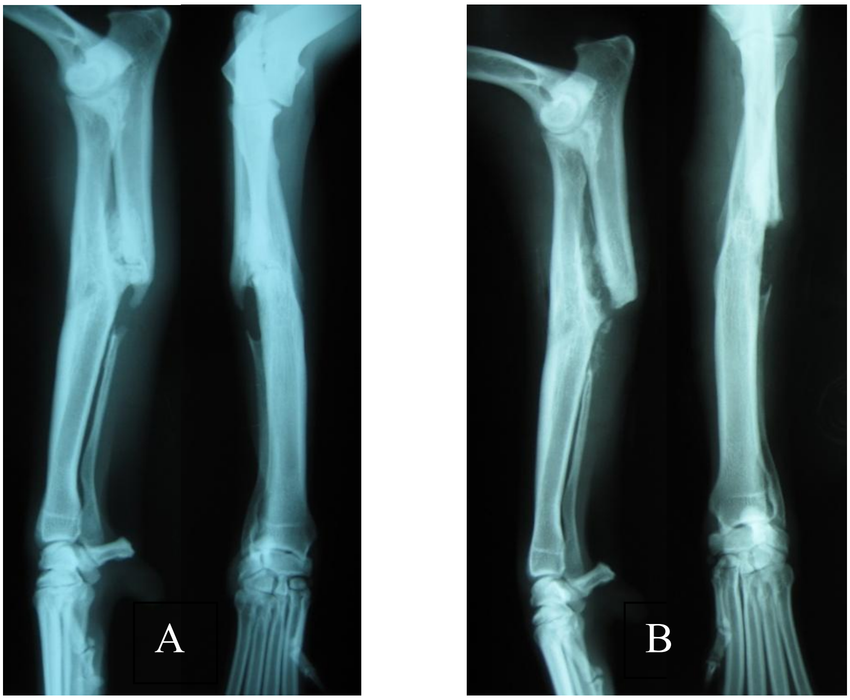


Figure IV-7 Recurrence of synostosis formation of radius and ulna in the dog described in case 1. Figure A displays two planes radiographs, the recurrence of synostosis can be identified. Figure B displays post-operative radiographs of canine radius and ulna after revision surgery to remove the remaining of synostosis.

**Case 2**

An Italian-greyhound, five month of age, fractured his right radius and ulna after jumping down from the bed of the owner in September 2009. The dog underwent surgery, a dorsal approach to radius and ulna was performed. A 2.7 mm non-contact bone plate with seven screw holes was applied to this patient. In the radiographs performed after surgery, penetration of a bone screw at the proximal part of the radius into the interosseous membrane to the ulna was documented (Figure IV-8). Ten days later, implant failure with malalignment and malangulation of the fractured leg was detected (Figure IV-9A). Revision surgery was performed. The non contact plate was removed and replaced with a 2.7 mm reconstructive plate with twelve screw holes (Figure IV-9B).

Forty-five days later, a dynamization technique was performed by removing some of bone screws. The entire bone implant was removed 134 days after the first surgery. The radiographs taken at this day shows synostosis formation at the proximal part of radius and ulna which was the traumatized area of interosseous membrane from the bone screw, and the middle part of the radius ulna which was the fracture line (Figure IV-10). Ten days after surgery, the dog showed signs of decreased range of motion at the carpal joint. Physiotherapy was recommended to the owner. Three months later, the dog did not exhibit clinical signs of lameness, the movement at the carpal joint was gradually improved.

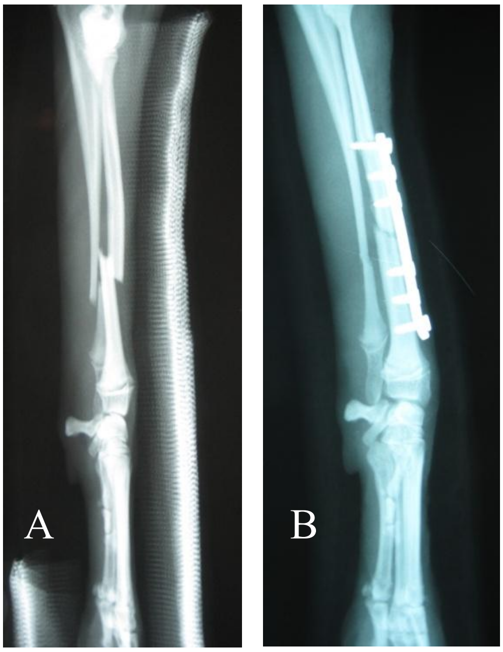


Figure IV-8 Radiographs of fractured radius and ulna in the dog described in case 2. Figure A displays the lateral radiographic views of fractured forelimb before surgery. Transverse fracture at midshaft of radius and ulna was identified. Cast was applied to support the affected forelimb. Figure B displays the lateral radiographic views of fractured forelimb after surgery. A 2.7 mm non-contact plate with seven bone screws was placed at cranial surface of the radius.

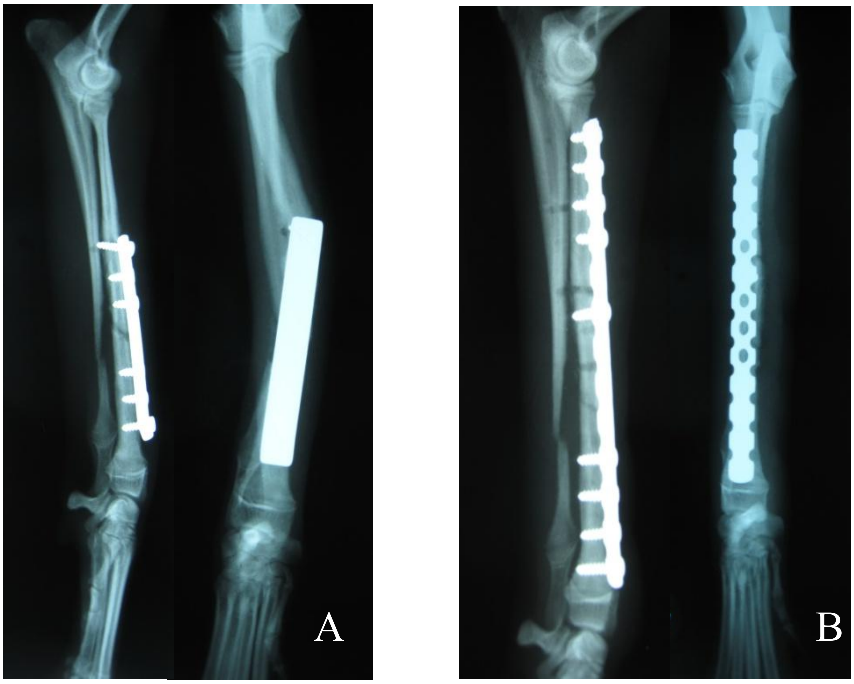


Figure IV-9 Radiographs of fractured radius and ulna with implant failure in the dog described in case 2. Figure A displays an affected forelimb which fixed with non contact plate and screws. Implant failure with malalignment of the fractured leg can be identified. Figure B displays radiographs of the same leg with figure A after revision surgery. Non contact plate was removed and replaced by a 2.7 mm reconstructive plate with nine bone screws.

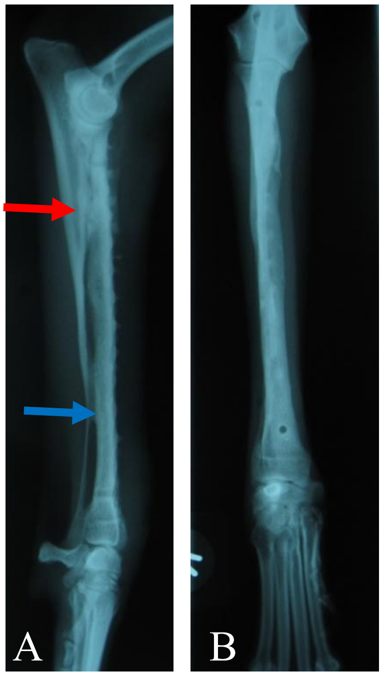


Figure IV-10 Radiographs of an affected forelimb in the dog described in case 2 after removal of bone implant. Figure A displays the lateral radiographic view and figure B displays the antero-posterier radiographic view. The synostosis formation is present at two locations: the proximal (red arrow) and medial (blue arrow) areas of radius and ulna.

**Case 3**

A Hovawart dog, four month of age, originated from the animal shelter and was referred to the Small Animal Clinic, Freie Berlin Universität on February 2009. This dog suffered from lameness of the left forelimb. The cause of lameness was identified as growth disturbances in combination with an elbow joint incongruence and subsequently shortening of the leg. Most likely, the cause of growth disturbance in dog was due to an unknown trauma at the radius and ulna region which had healed spontaneously. Radiographic examination was performed from both forelimbs (Figure IV-11). Formation of synostosis at the proximal to middle part between radius and ulna at the left forelimb was identified. The growth plates were not closed at that time. Malformation of the left elbow joint was detected. Surgical treatment with antebrachial corrected osteotomy was performed. The proximal ulna was approached from caudolateral. Ulna ostectomy (two centimeters) was performed to enable elongation of the radius in the affected leg. In order to stabilize the ulna, two intramedullary pins were used (Figure IV-12).

Fifty-three days after surgery, the dog still suffered from carpus valgus of the left forelimb. Revision osteotomy was performed. The surgery included the removal of two intramedullary pins at the proximal ulna and osteotomy at the distal third of radius and ulna. Malangulation of the bone was corrected and stabilized by using the external skeleton fixator (Figure IV-13). Thirty-eight days later after the revision surgery, the external skeleton fixator was removed. The radiographs of both forelimbs are shown in figure IV-14.

At the age of nine month, 80% of the physiological limb lengthening was noted and an increasing length of the ipsilateral humerus was seen. The physiologic elbow shape improved but pathologic carpal valgus and radius curvus were slightly presented.

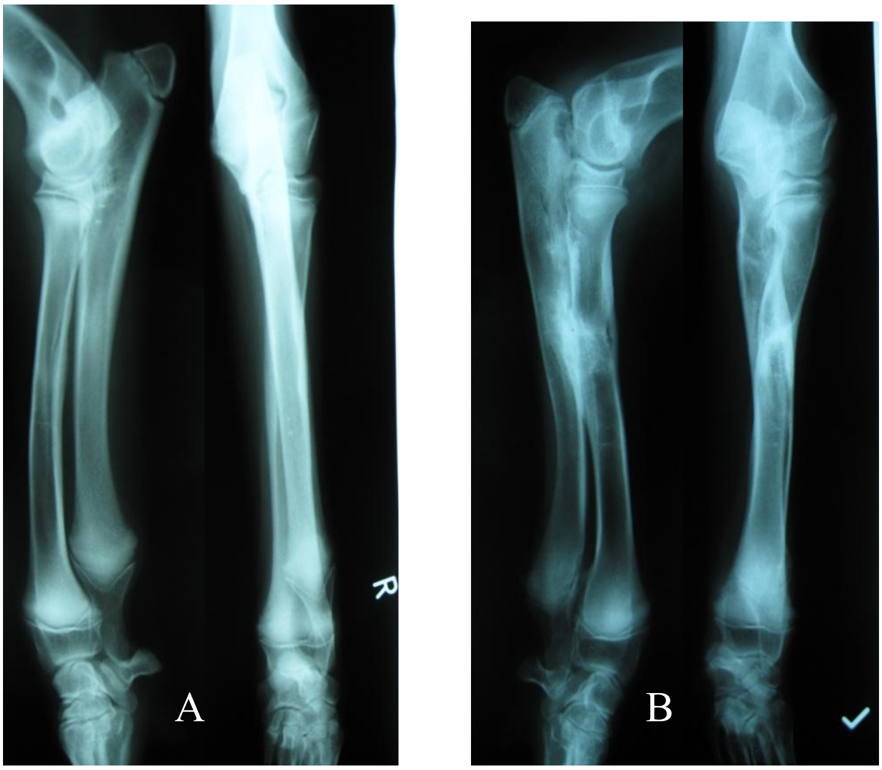


Figure IV-11 Radiographs of the right (A) and left (B) forelimbs of dog described in case 3 before surgery. The length of the right forelimb is in physiologic, while the left forelimb was diagnosed with canine radius ulna synostosis formation at the proximal to middle part. The elbow joint of the left forelimb was malformated. The epiphyseal plates of both forelimbs were not completely closed.

Figure IV-12 Post-operative radiograph after ostectomy at the proximal part of the ulna in the dog that described in case 3. In order to stabilize the ulna after ostectomy, two pins were placed into the intramedullar cavity of the ulna.

Figure IV-13 Post-operative radiograph after correct osteotomy of the radius and ulna in the dog that described in case 3. The malangulation of the left forelimb was corrected and fixed with external skeleton fixators.

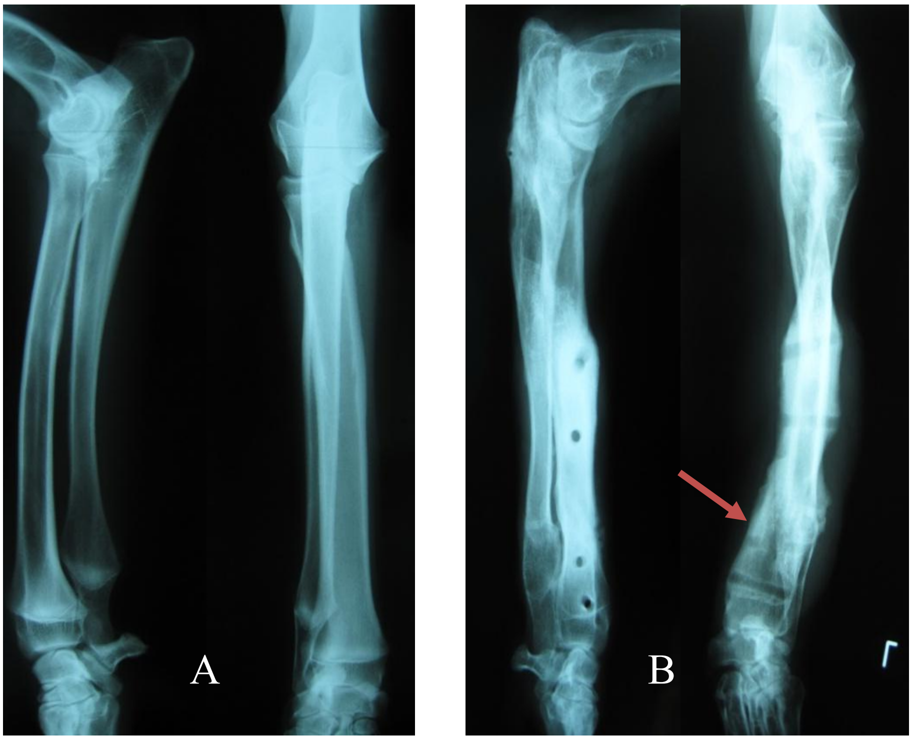


Figure IV -14 Radiographs of right (A) and left (B) forelimbs from the dog described in case 3. At the time these radiographs were taken, the dog was nine month of age. Figure A display the right forelimb is of physiologic length. Figure B display the left forelimb was affected by growth deformity, 5 month corrected osteotomy, carpal valgus and radius curvus were slightly present (red arrow).

**Case 4**

Due to lameness, a 6 year- and 2 month- old, female Giant Schnauzer dog was presented on July 2008 to the Small Animal Clinic, Freie Berlin Universität. The dog was reluctant to move in the morning, rejected to jump into the car, and rejected to walk up and down stairs. This dog was adopted from the animal shelter and no information of a possible previous trauma was available for owner. Physical examination, laboratory analysis, and radiographic examination were performed. On the radiographic examination, the dog was diagnosed with synostosis formation between radius and ulna on the left forelimb (Figure IV-15). Conservative treatment with analgesia was performed.

On February 2011, around 3 years later, the dog was presented again at the Small Animal Clinic. The dog suffered from lameness after running in the meadow. Rupture of the cranial cruciate ligament in combination with a defect of the median meniscus was diagnosed. The dog was treated by surgery at the left knee.

On February 2012, the dog was referred to the Small Animal Clinic again due to lameness of the left forelimb. The lameness was present since four months. Conservative treatment with analgesic and nutritional joint support was performed but not effective. Physical examination revealed mild swelling of the soft tissue on the antebrachial region. The left carpus was painful during motion. The maximum supination degree was 90° and the maximum pronation degree was 30°. Radiographic examination and computed tomography from both forelimbs were performed (Figure IV-16 and 17). The dog had no clinical sign at shoulder, elbow and carpal joints. The radiographs showed synostosis formation at the distal third of radius and ulna and the proliferative periosteal reaction at the metaphyseal region. The surgical treatment included ulna ostectomy and resection of synostosis. At the time of surgery, the dog was 9 years and 11 month old. 2.5 cm of ulna bone was excised, no biomaterial was use to replace the remaining space. A cast bandage was placed on the surgical limb and remained for two weeks in order to support the weight burden on the leg. A follow-up examination was performed two months later, no signs of lameness re-occurred.

Figure IV-15 Synostosis formation between radius and ulna on the left forelimb (red arrow) in the dog described in case 4. This radiograph was made on July 2008. The dog was 6 years- and 2 month old.

Figure IV- 16 Radiograph of the left forelimb on February 2012 of the dog described in case 4. Synostosis formation between radius and ulna and the swelling of soft tissue were seen. The periosteal reaction of both radius and ulna metaphyseal was interpreted as proliferation (red arrow).

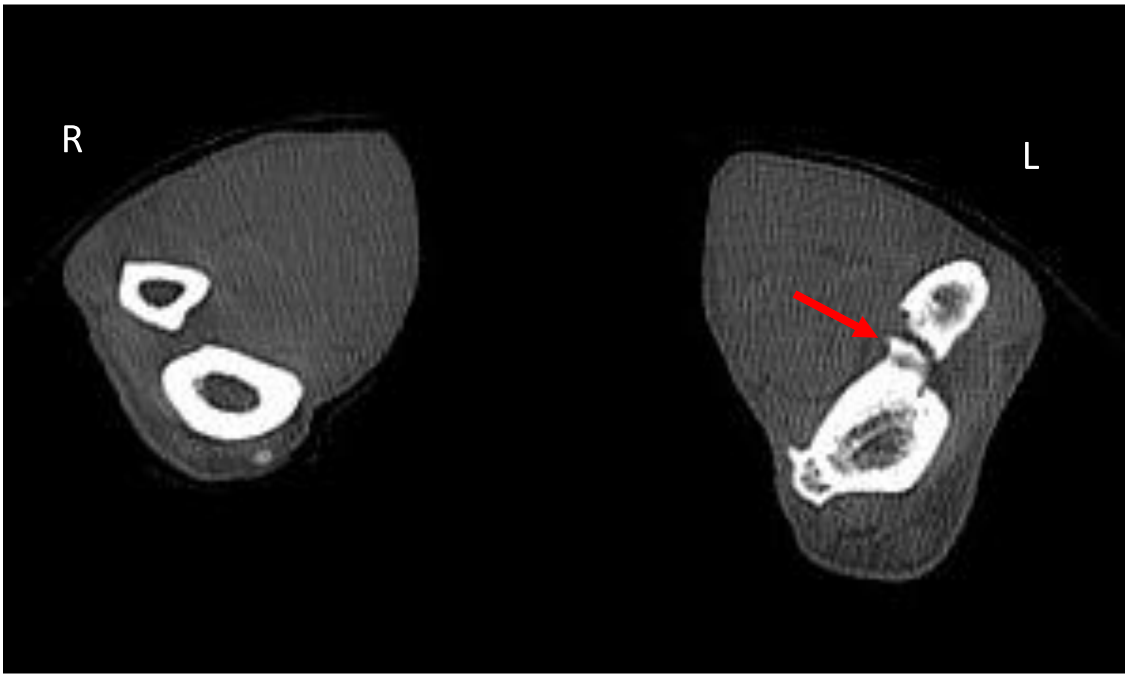


Figure IV-17 Computer tomography scan of the dog described in case 4. Both forelimbs were scan and compared. Synostosis between radius and ulna (red arrow) was presented at the left forelimb.

# Chapter V Discussion

## Study I: Retrospective study

## Characteristics, complications, and outcome of canine radius-ulna fractures in 188 cases (1999 to 2009)

In this study, one hundred and eighty-eight cases of canine radius and ulna fractures could be identified within 10 years, on average 18.8 cases per years. Radius and ulna fractures were found in all breeds and at all ages. The majority cause of fractures in this region was trauma from road traffic accidents. This cause can be avoided and prevented by using a leash and obtaining traffic regulations when the owner takes his dog for a walk. Because radius and ulna are pair bones, the management of radius and ulna fractures is defined as difficult and accompanied with complications[12, 34, 35]. In order to stabilize fractured pair bones, exact and firm fixation of both radius and ulna are of highest priority. Therefore, in this study, surgical treatment was the method most often applied to the patient. Bone plates and screws were the implant applied most likely to the radius and ulna. External skeleton fixation reduces the risk of complications was applied in contaminated bone fractures or non reducible comminuted fractures patients. Several patients in this study received more than one fixation method in order to provide rigid stability. Conservative treatment including cast bandage and resting of the patient was performed in three dogs diagnosed with green stick fracture. This type of fracture was considered to be relatively stable. Because of limited muscle and tissue covering of the radius and ulna, most of the patients had both of the radius and ulna fractured. The location of the fracture lines were usually at the same level of both bones. The predominant fracture location was the distal third of the radius and ulna. These finding are in agreement with several reports by other investigators[29, 37, 45, 51, 53,57].

In this study, the duration of bone healing was defined to start on the day of the first surgery until the day of removal of the bone implant. This duration was delayed when revision surgeries were required. After the performance of the surgery, many patients performed their follow-up at private clinics or hospitals, 38.30% of the dog patients in this study did not return for the scheduled implant removal. However, 19.44 % from those 38.30 % were show the radiographic bone union at the last day of follow up on our clinic. All of absence of post operative follow-up information dogs had received bone plates and screws as osteosynthesis. The duration of bone healing and union of the radius and ulna fracture of the patients included in this study was in agreement with other reports [44, 51, 57]. In this study, green stick fractures treated with cast bandages were identified to have the shortest healing period. Reasons for these finding may include stability of the green stick fracture. Additionally, in this group of patients, no trauma of the soft tissue caused from surgery occurred which may also lead to faster bone healing. The use of ESF compared to the use of bone plates and screws in this study was noted for a prolonged time to union. This finding may be due to the fact that ESF was applied most likely in patients with high risk of complication such as open fractures or comminuted fractures. Unfortunately, the time of fracture onset until bone union could not be determined in every case because of lost of follow-up (38.3%).

In this study, 10.64 % of the patients suffered from a revision surgery of the radius and ulna fracture. This incidence is lower than the incidence rate which reported in studies of Wallace *et.al.* (2009)[78] in cats (23.1%), and Larsen *et. al.* (1999)[45] in dogs (18 %). In the study of Larsen *et. al.* (1999)[45] was pointed only in the small and miniature dogs which had the relatively high incidence of revisions when compared with this study. It can be explained by the high risk of complications of the small and miniature dog. Bone healing in those breed is poor due to the marginal surrounding of soft tissue and a relatively poor blood supply at the antebrachial region. In the study of Wallace *et.al.* (2009)[78], the revision surgery rate was higher than this study which may explain by the different specie of the studied patients (cats VS dogs). However, the revision rate of animal patients included in this study was higher compared to the animals in the study of Haas *et.al*. (2003)[29]. Haas *et. al.* reported a revision rate of 0 % in dogs and cats treated with tubular external fixation. One cat in Haas's study developed malalignment but the owner rejected to do further surgery and two dog were applied external splint instead of re-surgery. In this study, revision surgery was higher than Haas's study which may be concerned to the highly occurrence of open fractures (15.42% in this study VS 9.09% in

Haas study). Open fracture and Bite injuries are the important factors which cause the bacterial infections (10.6% in this study) in the fractured bone and the failure of osteosythesis. Revision surgery needed to perform in those groups of patients. Increasing number of revision operations were also accompanied with an increased problem of malalignment, radial torsion, and carpal valgus and could be identified by several techniques such as the gonimeter measurement, the CORA system, the computer tomography scan. The presence of carpal valgus after surgical treatment of the radius and ulna fractures was also seen in one dog in the study of Haas *et.al.* (2003)[29].

The overall complications rate (the presence signs of bacterial infection, the implant failure, the post-traumatic synostosis, the shortening of forelimbs, the re-fracture of the bone after implant removal, the bone lysis after 5 times revision surgery suspected of bone tumors lead to forelimb amputation, the non-healing/ non-union, the antebrachiocarpal joint instability) in this study was 31.38 %. Compared to the report of Haas *et. al.* (2003)[29], and Larsen *et.al.* (1999) [45], the complication rate in this study is lower (40% and 54%, respectively) which may be explain from the bigger size of the study patients, the variety of dog breeds, and the variety of treatment methods in this study.

The predominant complication in this study was the presence of signs of bacterial infection (10.6%). Despite the short median duration from the onset of fracture to the day of surgery (mean value was one day), the presence of bacterial infections leading to revision ($R = 0.411$, $p < 0.01$) was still present. All patients included in this study received intravenous pre-operative broad spectrum antibiotic by using Amoxicillin-Clavulanate at least 30 minutes before surgery. Despite using prophylactic antibiotic, post-operative bacterial infections occurred in 10.6% of all patients treated, 4.2 % were open fractured patients and 6.4 % were close fractured patients. These results are an indicator, that the evidence of post operative bacterial infection cannot be eradicated by the one-term using of pre-operative antibiotic. The use of intravenous injection of Amoxicillin-Clavulanate for prophylactic treatment of surgical patients was a standard treatment in the Small Animal Clinic, Free University Berlin for more than 10 years. Wayne *et.al.* (2011)[79] reported Amoxicillin-Clavulanate to be the antibiotic most frequently used in dogs. Based on these facts, we might speculate that the sensibility of bacteria to this antibiotic may be decreased. Resistance to this type of antibiotics may also occur due to the presence of resistant bacteria in the Small Animal Clinic. In case of a high infection risk for the patients (e.g. open wound fractures, bite wound fractures), an aggressive prevention of infection, the treatment of contaminated bacterial lesion, and antibiotic therapy should be performed based on a standard protocol. Sterile techniques, gentle tissue handling, tissue debridement, drainage of the contaminated wound, the use of systemic antimicrobial agents, rigid stabilization of the fracture limb, the performance of a direct bone culture, and the use of delayed wound closure should be considered.

In this study, the second highest cause of complication was post traumatic synostosis (18/188 cases, 9.6%) which was diagnosed only in the radiographs. Some of those patients might not show clinical sign of lameness caused by synostosis at those days. However, it should be mentioned synostosis as one of the common complication in canine patients presented with radius-ulna fractures. Until to date, canine synostosis formation was not well documented in veterinary medicine. Only a few studies of synostosis in dogs and cats are available and most of them are case reports of one to two patients providing only limited information. Haas *et. al.* (2003)[29]and Wallace *et. al.* (2009)[78] ranked synostosis formation to be a minor complication which does not required surgery. In their studies they reported the incidence of synostosis in 2/22 (9.09%) dogs and 2/26 (7.69%) cats respectively. Post-traumatic synostosis is well documented in human medicine. The most common cause is known to be a forearm fracture treated by surgery. Human patients with a high level of energy and activity, human patients suffering from comminuted fractures, open wound fractures, high soft tissue trauma, hematoma formation between radius and ulna, using of bone graft application, or head trauma appear to have an increased risk of synostosis. Synostosis between radius and ulna impairs the movement of the affected forearm [1,6, 85]. In veterinary medicine, radius and ulna synostosis may cause further problems such as humero-ulnar subluxation, shortening of the forelimb, angular deformity and antebrachio-carpal joint alterations (carpal valgus or varus)[21, 43, 83]. Thus radius and ulna synostosis should not be underestimated and further studies in cats and dogs with this symptom are required.

Technical failures which include a failure of implants and a failure of techniques to stabilize of the fracture were identified as the third highest complication in this study (4.8%). Understanding the biomechanics of the orthopedic implants as well as the experience of the surgeons are important to achieve a successful result of operation. However, in this study was not show the significantly different between the level of experience between surgeons (professor, board certified surgeon, resident, clinician, doctoral student). It may be cause of the well organization system of the clinic. Most of the orthopedic surgeries were done under guiding by professor. The post-operative radiographs needed to be proof and discussed by professor and clinical team. When the technical failure or failure of the osteosynthesis was found, the re-vision surgeries were performed by the team. Then no difference showed in the statistical evaluation between the levels of surgeons experience in this study. The technical failure of bone plate and screw fixations was higher than the technical failure of external skeleton fixations (ESF) in the present study which may due to practical and non-complicated of ESF system and the skill of surgeons on using ESF system. The most common technical failure of bone plate and screw fixations included undersized implant selection which leaded to plate breakage, the use of an improper number of orthopedic screws and incorrect length of the bone plate, as well as incorrect attachment of the bone plate and screws on the fractured bone. Placing orthopedic fixations in both of radius and ulna may be required for providing a stronger stabilization in some of the large dog in this study.

Most patients with external skeleton fixation returned to the Small Animal Clinic in order to remove the fixation frame. Many patients with internal fixation plate did not return to reassessment and removal of the implants (38.30%). Due to this low returning rate to remove the implants in our clinic (61.70%, 116 of 188 cases), we may assume the rest patients (38.30%) pursued post-operative follow-up by private clinics or hospitals. In three cases (1.6%), the affected limbs of these patients were re-fractured after removal of the bone plate. This incidence rate is comparable to those reported in the human literature (3.63 %)[42]. All of those three cases were received revision surgeries in our clinic and the new bone internal fixations were persistently applied to those animals. The localization of the re-fractured site was seen close to the old fracture line or next to the screw hold and occurred within a month of plate removal. The factors that may have promoted the re-fracture might be an early removal of implants, the type of fracture (complicated fracture or displacement fracture), and the lack of protection of the healed bone following implant removal. The removal of fixation is recommended due to many reasons e.g. classifying the implant as foreign body that might cause irritable reactions of the body. Additionally, the implant might cause lameness especially in cold environment. Some literatures in human medicine report the temporary benefit of plates and screws [42]. However, as soon as the fracture is healed, the benefits are replaced by the danger of demineralization of the bone and persisting screw holes[42]. Therefore, it is frequently stated to remove bone plates and screws as soon as the union of the bone is assured. However, in veterinary medicine, the removal of the implant in small animals is still debates such as internal fixations induce osteoporosis, the short lifespan of small animals when compare with human, the risk of anesthesia and also the cost of surgery to remove the implants. In the present study, the removal of implants was used as the key of the successful of the therapy because in those patients, the complete steps of the orthopedic surgery and treatment by our clinic were identified. All re-fracture after the removal of bone implants patients were received new implants which were not included in the group of successful treatment.

In four patients included in this study, the outcome of the surgery was not as expected. In one case, limb amputation was performed after five times revision surgeries and the bone lysis which suspected of the sign of bone tumor was found at the last surgery. In three cases, on the last day before lost of follow-up, they still had non-healing fractures. In this study, the carpal arthrodesis was performed in two patients in order to improve the persisting lameness caused by instability of antebrachiocarpal joint from the very distal end of radius and ulna fracture. The malalignment of the radius and ulna fractures could clearly be identified by using the technique of CORA system. Measurements of these system were based on two plane radiographs (anteroposterier and lateral views) after the fracture was healed and the bone implants removed. The center of rotation of angulation varies in each dog and is breed specific, thus comparing those values between the individual dogs remained challenging. The limb that was not affected was utilized for determining the physiologic joint angulation in the individual patient. In this study, comparison of the center of rotation of angulation was performed within the canine radial axes in healthy dogs reported in the study of Fox *et.al.* (2006)[24]. Therefore the results of malalignment of canine radius and ulna after the fracture healed may be not accurate. However, it seems that an increased number of revision surgeries are highly correlated with an increased lateral distal radial angle (LDRA) and the clinical signs of carpal valgus.

## Study II: Retrospective study

## Incidence and correlation factors of post-traumatic radius and ulna synostosis in dogs: 24 cases (1999-2009)

In this study, the radiographic finding of the post-traumatic synostosis between the canine radius and ulna was one of common complications (10.86 %) after the trauma of antebrachium region. Hence, the occurrence of this complication had a relatively high impact on the functional outcome of the surgery performed on the affected forelimb. Most of the previous studies in veterinary medicine focus on the animal activity after surgery. However, long term of post traumatic synostosis which causes chronic lameness of the effected forelimb in those patients is not well documented. Synostosis is the concealing factor to cause malformation of the limb, humero-ulna joint subluxation, and impaired movement of the antebrachial limb after bone healing. In order to minimize the incidence, prevention and treatment of this complication, understanding of the nature of synostosis is required. Many factors are considered to be related to post-traumatic synostosis after the occurrence of a radius and ulna fracture. This study identified statistically significant factors accompanied with post traumatic canine radius and ulna synostosis: complication due to bacterial infection, high body weight, lateral distal radial angle (LDRA) and frontal plane alignment (FPA).

This present study identified synostosis as one of the common complication of fracture radius and ulna in dogs. Based on these findings, surgeons should consider this complication when treating radius ulna fractures, especially in dogs with high body weight. Previous publications about the interosseous blood supply of the canine radius reported an increased density of the metaphyseal blood supply in the large-breed dogs compared to small-breed dogs[79,81]. When large-breed dogs suffer from trauma and concurrent fracture of the radius and ulna, they will be subject to abundantly bleeding at the metaphyseal and interosseous membrane. The severity of hematoma at the interosseous membrane increases due to high blood supply may assume to cause synostosis formation in large-breed dogs.

Another major factor correlated to synostosis formation is complication due to bacterial infection. Despite the well known risk for complications of fracture healing in animals with bacterial infections, this cause is still present in many study populations[12, 33, 34, 35]. In this study, wound and bone healing complications due to bacterial infection was significantly related to the presence of bite injuries and also the presence of open wound fractures. Fractures affected by bacterial infection may be able to carry the weight burden of the animal, but synostosis formation after bone healing can be the consequent problem. The use of broad spectrum antibiotics and shortening of the duration between the onsets of fracture until the day of surgery are known to decrease the incidence of infection but these factors were not significantly correlated in this study. Additionally, the duration of the operation is also related to the number and severity of complications. Unfortunately, limited data in our database did not allow for investigation of the duration time of the operation in our study. However, the findings in this study suggest that aseptic surgery in combination with gentle tissue and bone manipulation should be of highest priority to the surgeon.

The management of fractures located at the radius and ulna usually involves two bones and therefore has been classified as “difficult”[29, 44, 45, 49, 51, 53, 57, 69]. The trauma of the metaphyseal plate of radius or ulna may also result in a complication which known as antebrachial growth deformity [2, 18, 35, 62, 74, 80]. Synostosis between radius and ulna has been documented to restrict the synchronous growth of the radius and ulna and leads to deformities of the limb[1,45]. One of the previous studies was performed in the experimental design by placing cross-pins between the radius and ulna which resulted subsequently in subluxation of humero-ulna joint[46]. In two other studies were cases reports of malformation of the forelimb was described[2,43]. However, all those studies did not include the resulting change of angulation at the elbow and carpal joints. In this study, the center of rotation of angulation technique (CORA) was performed to identify the deformity of the antebrachial limb. After removing the implant devices, two plain radiographs of the antebrachial limb (lateral view and antero-posterier view) were performed. Synostosis formation between the radius and ulna was significantly involved in an increased lateral distal radial angle and a decreased frontal plane alignment. The angle of the lateral side of the carpal joint was increased after the fracture healing which, clinical visible in carpal varus. Carpal varus causes an unphysiologic rotation motion of the carpal joint and hinders physiologic weight bearing of the affected limb. The malalignment of the forelimb causes an increase angle of supination of the paw, resulting in clinical lameness. Osteoarthritis is the long term outcome. The short and the long term effects of synostosis were shown in dogs of this study. The clinical signs of synostosis patients that received the consultation and/or treatment in our clinic were progressive lameness at forelimb, reluctant to jump up and down from car, reluctant to use the stairs, intermittent lameness at forelimb, growth disturbance in combination with an elbow joint incongruence and subsequently shortening forelimb. Two dogs were operated to correct synostosis within seven months and three dogs were operated after two years of synostosis detection. Because the most common position of post-traumatic radius ulna synostosis is the distal third followed by the midshaft and the less common is proximal third of radius and ulna, the luxation of humeroulnar joint was not diagnosed in this study. Outcome of the limb function after the bone healing requires further investigation e.g. by using dynamic gait analysis. In human medicine, it has a study showed the high correlation between static radiographs and the dynamic gait analysis to determine the alignment of the leg[33]. However that kind of studies has not been performed in synostosis dogs per date.

All synostosis formation detected in this study occurred close to the previous fracture site and was not depending on the types of fixation implants used. Synostosis even occurred when using only a monocortical screw. There were two dogs presenting synostosis formation in the area of penetration of the bone screw though the ulna. Therefore avoiding trauma of the interosseous membrane by using drills and appropriate length of the screws are recommended. The properly reduction of the radius and ulna fragment in dogs with high bodyweight is required to decrease the incidence of synostosis at the fracture site. Approaching ulna and fixation by using intramedullary pins requires caution of the surgeon as protrusion of the pin from the ulna cortex may cause trauma of the interosseous membrane which may subsequently lead to synostosis formation.

## Study III: Experimental study

## Measurement of pronation and supination in cadaveric dogs with surgical intervention to simulation of radius and ulna synostosis

This study confirms that synostosis formation between radius and ulna interferes with the function of supination and pronation in the canine forelimb. The supination and pronation of the canine forelimb may be less likely to be influenced than in the feline forelimb. In cats, these functions are very important to climb trees or to capture the pray. Dogs do not depend on those actions. However the passive supination and pronation of the canine forelimb is used in conjunction with directional changes involved in racing and hunting dogs[66]. Supination and pronation also plays a role in many daily life activities e.g. walking up and down the stairs, jumping in and out the car, and removing foreign bodies from the paw. In active dogs, synostosis will cause severe and progressive lameness.

In order to perform pronation and supination, the functions of the proximal and distal radio-ulnar joints need to be combined[40]. The action of pronation and supination requires the gliding movement of the radius head on the ulna head, the relative physiologic length of both radius and ulna, and the interosseous membrane. Synostosis formation between radius and ulna can alter the function of forelimb rotation due to the formation of callus. Synostosis destroys the interosseous membrane and decreases the flexibility of the ligamentous complex. The callus bridge also limits the gliding movement of the radius. In immature patients, the callus bridge between radius and ulna can lead to limb deformities and shortening of the limb.

Mean of supination angles before surgery obtained from 14 fresh cadaver forelimbs was 71 ± 9.60°. This means values are higher compared to the result of a study performed by Roos *et.al.* (1992)[66] (varied from 46° to 50° in three cadaveric dogs) but lower than results obtained in the study of Millis *et.al.* (2004)[50] (varied from 80° to 90° in 10 mixed breed dogs). Mean pronation angels before surgery of cadaveric dogs in this study was 43.86 ± 12.88° which is similar to the report of Millis *et.al.* (2004)[50] (40° to

50°), but higher compared to the study of Roos *et.al.* (1992)[66] (18° to 32°). The measured range of supination and pronation may depend on many factors e.g. the investigator, the breed of the dogs, the method of measurement, and the preservation of the flexibility of muscle and ligament in the cadaver investigated. This present study used fresh cadaver specimen because its tissue and ligament was still unpreserved and therefore was considered to simulate the living patient most appropriate. The use of the whole cadaver body was performed in order to influence the shoulder joint and some muscles related e.g. bicep brachii, brachioradialis m., supinator m. on the function of pronation and supination of the canine forelimb[58]. All measurements were performed by one investigator and the degree of supination and pronation was double checked by using direct goniometer measurement as well as using measurement based on photographs in the computer[15, 16, 20]. A cortical screw was used as artificial bony bridge occurring in synostosis formation. However, the power of this cortical screw might have been stronger than the power of a natural callus.

The increasing range of supination angle and decreasing range of pronation in animals with synostosis was clearly shown in measurements performed after simulation surgery. This result supports the findings of case IV in study IV(90 °supination and 30° pronation). Malfunctioned movement of affected forelimb consequently proves synostosis to cause the radial malrotation, malalignment and torsion of forelimb which identified by the changed degree of LDRA and FPA in the study II. The decreasing movement range of pronation was indicated functional compensation for the increasing range of supination.

## Study IV: Case report

## Outcome of treatments of post traumatic canine radius and ulna synostosis in four dogs including 2- year follow-up

Synostosis formation between radius and ulna in the dog is one of the common complication of radius and ulna fractured patients. Synostosis can be classified into the congenital form and the post-traumatic form[43, 67, 83]. Various factors are considered crucial in the formation of a bony bridge such as severe trauma of soft tissue and hematoma formation at the interosseous membrane. The age of the dog at time of diagnosis and operation were varies, but synostosis was most commonly seen in young dogs (4 to 15 month of age). In this study, only one dog was diagnosed synostosis in mature age. Because this dog was adopted from the animal shelter, the exact age remains unknown. Synostosis can be present in all areas between radius and ulna. The method of treatment was not related to the formation of synostosis. Many therapies for treating synostosis are described e.g. restriction the activity, use non-steroidal anti-inflammation, physiotherapy, and surgical operation. The selection of treatment depends on the individual case. In some animals, conservative treatment may be successful and was based on a combination of resting, analgesia and physiotherapy. Especially toy or small breed dogs, conservative treatment was preferred. In this study, dogs that underwent surgery to correct the synostosis formation were predominantly large breed dogs, dogs with high body weight and/or dogs with a high activity level and dogs with spontaneously healing of radius and ulna bone without the surgical intervention. The Age of presenting clinical sign of synostosis on our clinic varied in a wide range (4 month-old to 9 year- and 11 month-old). The decision to perform surgery in affected patients depend on the agreement between the surgeon and the owner, the age of the patient at the time of diagnosis, the prognosis of the treatment and the severity of the clinical signs. In immature dogs, operation is usually performed immediately after the diagnosis in order to prevent the growth deformities, elbow joint incongruence, shortening leg and humero-ulnar subluxation of the affected limb after synostosis formation. In many mature dogs, treatment is started with conservative actions and only if clinical signs do not improve, surgical procedure is required. The clinical signs of synostosis can deteriorate from several factors such as high activity level, cold weather, walking stairs, concurrent musculoskeletal disease in the other limb e.g. cranial cruciate ligament rupture which leads to surgical treatment.

There are many report of synostosis correction in human medicine [4, 6, 7, 30, 52, 65, 72, 73, 83, 84]. Synostosis typically recurs despite surgical excision of the bony bridge. The unpredictable results after operative excision alone have lead to recommendation to perform interposition with a variety of materials, including muscle, silicone rubber sheets, or vascularized fat graft[83]. Using low-dose radiation therapy within the first five days after surgery may also prevent the re-ossification[83]. Some authors report the used of the tendon transfer to improve supination[30, 72]. Overall, results of surgical treatment are fair, with high failure and recurrence of synostosis[6]. Operative treatment of synostosis formation between radius and ulna in veterinary medicine is based on very little published information. Durmus *et.al.* (2008)[21] reported successful results after resection synostosis by placing autogeneous fat tissue in the empty space. After four month follow-up in this dog, no signs of bony bridge recurrence could be detected. Alexander *et.al.* (1978)[2] also reported the malformation of forelimbs due to synostosis in two dogs. However, this report aimed to describe the correction of the deformity of forelimb by ulna osteotomy and reduction the elbow luxation with bone plate and screws, without the use of interpositional material. The recurrence of synostosis was not mentioned.

In this present study, the long term follow up over a minimum of 2 years was recorded in 4 cases. The operation to correct synostosis was performed by resection the bony bridge with ulna ostectomy, no interpositional material was filled in the empty space between radius and ulna. This operation is easy to perform and the decision not to use interpositional material decreases the time of anesthesia and expenses. The dogs in this study had no sign of lameness after surgery. However recurrence of synostosis was proven and re-operation was performed in one case at two years later. This time span is similar compared to the maintaining period in human medicine using vascularized fat graft for interposition material[84]. The restriction activity of the dog is considered to influence the outcome of the surgical treatment.

# Chapter VI Summary

**Objectives:** The aim of this study was the determination of complications of post-traumatic radius-ulna synostosis associated with antebrachium fractures in dogs. The characteristics, common complications, and the outcome of canine radius and ulna fractures were described in order to indicate the influence of synostosis in the canine patient population. Incidence, location, risk factors, the center of rotation of angulation (CORA), and outcome of treatment of post-traumatic radius-ulna synostosis in dogs were determined. To demonstrate the function of affected canine forelimbs (pronation and supination) due to synostosis, an experimental study in cadaveric dogs was included.

**Study designs:** Four separate studies are subject of this dissertation:

Study I: Retrospective study: characteristics, complications, and outcome of canine radius-ulna fractures in 188 cases (1999 to 2009)

Study II: Retrospective study: incidence and correlation factors of post-traumatic radius and ulna synostosis in dogs: 24 cases (1999-2009)

Study III: Experimental study: synostosis between radius and ulna and the function of pronation and supination in cadaveric dogs

Study IV: Case report: outcome of radius ulna synostosis treatment in four dogs including a two year follow- up period

**Data and Patients:** The medical records of 221 cases in 213 dogs with received operations at radius ulna region submitted during 1999 to 2009 at the Small Animal Clinic, Freie Universität Berlin, Berlin, Germany were reviewed. Furthermore, follow-up during 2009 to 2012 was performed in four synostosis patients. Seven cadaveric dogs were used in the experimental study.

**Methods:** Medical data and radiographs of canine radius and ulna fractures which were caused by traumatic fractures and as well as operative fractures (osteotomy) to correct

antebrachial growth deformities were analysed. Post-traumatic synostosis was identified from the radiographs. Over a two years period, follow-up in four synostosis patients was performed. Comparison of pronation and supination of forelimbs before and after surgery to simulate radius and ulna synostosis in cadaveric dogs was investigated. Descriptive statistics, t-test and Pearson's correlation coefficiency were applied in this dissertation.

**Results:** 188 cases of traumatic radius ulna fractures in 179 dogs were identified. 53 breeds were presented; the most common breed was large mixed breed (13.83%). The age of the affected dog at the time of treatment varied from 1 to 173 months. The median age was 21 months (1.75 years). The causes of traumatic fracture were road traffic accident (34.57%), falling or jumping from high places (12.76%), biting injuries (6.91%), trauma due to other causes (17.55%), and no information (26.59%). Mean duration of bone healing was 108.11 ± 77.91 days. Revision surgeries were performed in 20 cases (10.64%) which were statistically significant correlated with the presence of an open fracture ($R=0.176$, $p<0.05$), the biting injuries ($R=0.232$, $p<0.01$), the street accidents ($R=0.154$, $p<0.05$), and the bacterial infection ($R=0.41$, $p<0.01$). The increasing time of revision surgery had an effect to the alignment of the radius and ulna bone after the bone healing ($p< 0.05$). An increased lateral distal radial angle (LDRA), is significantly correlated to the presence of radial curvus and carpal valgus, which was shown in the dogs that obtained the revision surgery.

In the study II, 24 cases (10.86%) with radius and ulna synostosis were presented. All synostosis formations occurred at the fractured site and the most common location was distal third of radius and ulna (n=13 cases; 50%). Dogs with high body weights and dogs with the presenting sign of infection had high risk of synostosis ($R= 0.17$ and $R=0.167$; respectively, $p< 0.05$). The degree of the lateral distal radial angle (LDRA) and the frontal plane alignment (FPA), which obtained from radiographs, were also significantly correlated with synostosis ($R= 0.216$ and $R= -0.216$; respectively). These parameters indicated the malalignment of the limb (carpal varus) after the bone healing which were caused by the formation of synostosis between radius and ulna. An extended degree of supination ($p<0.01$), and a reduced degree of pronation ($p<0.05$) of forelimbs were presented on cadaveric dogs in the experimental study in order to simulate synostosis.

Over a two years period, follow-up was performed in four patients. The age of the animal at the time of surgery to correct synostosis varied in a wide range (4 months to 119 months). Recurrence of synostosis after surgical treatment was observed and one case was required a second operation in two years after a first operation.

**Conclusions and clinical relevance:** Dogs with high bodyweight and/or dogs with signs of bacterial infection (e.g. bite wound fractures or open fractures) have high risk of post-traumatic synostosis formation after healing of the radius-ulna fracture. To decrease the incidence of synostosis, it is very important to perform careful tissue handling. In order to obtain an accurate bone alignment, trauma of the interosseous membrane shall be prevented and an efficient reduction of both of radius and ulna fragments is required. Synostosis alters the angle of supination and pronation on the affected forelimb, which may lead to short and long term problems. Recurrence of synostosis after resection of bony bridge and ulna ostectomy can be seen.

**Keywords:**

radius, ulna, fracture, dogs, movement disorders, growth disorders, deformities

synostosis (MeSH)

bone malalignments (MeSH)

# Chapter VII Zusammenfassung

## Radius-Ulna Frakturen und post-traumatischen Radius-Ulna Synostosen bei Hunden

**Ziel der Studie:** Das Ziel dieser Studie war die Ermittlung von Komplikationen der post-traumatischen Radius/Ulna-Synostose, sowie den vergesellschafteten Antebrachium-Frakturen bei Hunden. Die Charakterisierung von Radius/Ulna-Frakturen, sowie häufige Komplikationen und die Folgen dieser Frakturen werden beschrieben um die Bedeutung der Synostose in der kaninen Patientenpopulation zu erfassen. Die Inzidenz, Lokalisation, Risikofaktoren, das Rotationszentrum des Winkels (CORA) sowie die Auswirkungen der Therapie von post-traumatischen Radius/Ulna-Synostosen des Hundes wurde ermittelt. Um die funktion der von Synostose betroffenen Vordergliedmaße zu demonstrieren, wurde eine experimentelle Studie an Kadaverhunden durchgeführt.

**Studienaufbau:** Vier eigenständige Studien sind Gegenstand dieser Dissertation
Studie I: Retrospektive Studie: Charakterisierung, Komplikationen und Folgen von kaninen Radius-Ulna-Frakturen in 188 Fällen (1999 bis 2009)

Studie II: Retrospektive Studie: Inzidenz und Zusammenhänge von Einflussfaktoren auf post-traumatische Radius und Ulna Synostose bei 24 Hunden (1999 bis 2009)

Studie III: Experimentelle Studie: Synostose zwischen Radius und Ulna und die Funktion von Pronation und Supination bei Kadaverhunden

Studie IV: Fallbericht: Die Langzeitfolgen der Behandlung der Radius/Ulna-Synostose bei vier Hunden während der Dauer von zwei Jahren

**Daten- und Patientengut:** 221 Hunden mit nachweislicher Radius/Ulna-Fraktur, die während der Jahre 2009-2012 in der Klinik und Poliklinik für kleine Haustiere and der Freien Universität Berlin behandelt wurden, waren Gegenstand dieser Studie. Weiterhin wurde bei vier Patienten mit einer Synostose der Krankheitsverlauf während der Jahre 2009 bis 2012 verfolgt. Sieben Hundekadaver wurden für die experimentelle Studie verwendet.

**Methoden:** Medizinische Daten und radiologische Aufnahmen von Hunden mit traumatischen Radius/Ulna-Frakturen, also auch medizinische Daten sowie Röntgenaufnahmen von Hunden mit korrektur antebrachialen Osteotomie wurden analysiert. Post-traumatische Synostosen wurde anhand der radiologischen Aufnahmen identifiziert. Bei vier Hunden mit Synostose wurde weitere zwei Jahre der medizinische Verlauf ausgewertet. Im Experimentellen Versuch wurde bei Kadaverhunden eine Radius/Ulna-Synostose simuliert. Die vergleichende Supination und Pronation der Vordergliedmaßen vor und nach Operation wurde durchgeführt. In dieser Dissertation wurde deskriptive Statistik, der T-test sowie Pearson's Korrelation-Koeffizient angewandt.

**Ergebnisse:** An 179 Hunden konnten 188 Radius/Ulna-Frakturen identifiziert werden. Dreiundfünfzig Hunderassen waren betroffen, große Mischlingshunde waren am häufigsten (13.83%) vertreten. Das Alter der Hunde zum Zeitpunkt der Behandlung variierte zwischen einem und 173 Monaten, das durchschnittliche Alter betrug 21 Monate (1.75 Jahre). Als Frakturursachen wurden Verkehrsunfälle (34.57%), Sprung oder Sturz aus großer Höhe (12.76%), Bißverletzungen (6.91%), oder Trauma unbekannter Genese (17.55%), bzw. keine Informationen (26.59%) angegeben. Die Frakturheilung dauerte durchschnittlich 108.11 ± 77.91 Tage. Revisionsoperationen wurden in 20 Fällen (10.64%) durchgeführt. Die Notwendigkeit einer Revisionsoperation korrelierte statistisch signifikant mit dem gleichzeitigen Auftreten einer offenen Fraktur ($R=0.176$, $p<0.05$), Bissverletzungen ($R=0.232$, $p<0.01$), Verkehrsunfällen ($R=0.154$, $p<0.05$) und bakteriellen Infektionen ($R=0.41$, $p<0.01$). Die durchführung einer Revisionschirurgie beeinflusste den Frakturschluss von Radius und Ulna sowie die Gesamtdauer der Frakturheilung ($p< 0.05$) negativ. Ein vergrößerter lateraler-distaler Radiuswinkel (LDRA) korreliert statistisch signifikant mit dem Vorkommen eines Radius Curvus und Carpus Valgus.

In Studie II wurden 24 Hunde (10.86%) mit einer Radius/Ulna Synostose identifiziert. Die Synostosen befanden sich ausschließlich in der frakturierten Region, die häufigste Lokalisation war das distale Drittel von Radius und Ulna (n=13 ; 50%). Hunde mit einem schweren Körpergewicht, sowie Hunde mit klinischen Hinweisen auf eine bakterielle Wundinfektion hatten ein erhöhtes Risiko für Synostose ($R= 0.17$, bzw. $R=0.167$; $p< 0.05$). Die auf Röntgenbildern erfasste Ausprägung des lateraldistalen Radiuswinkels (LDRA) sowie des frontalen plane alignment (FPA), korrelierte statistisch signiifikant mit dem Auftreten einer Synostose (R=0.216 bzw. R=-0.216). Diese Parameter weisen auf das Vorkommen eines inkorrekten Frakturschlusses hin (Carpus Varus). Im Rahmen der experimentellen Studie wurde an Hundekadavern mit simulierter Synostose eine Hyperextension der Supination ($p<0.01$), sowie eine reduzierte Pronation ($p<0.05$) der Vordergliedmaßen festgestellt. An vier Patienten wurde für die Dauer von zwei Jahren die weitere medizinische Behandlung evaluiert. Das Alter der Tiere zum Zeitpunkt der Synostososresektion variierte zwischen vier und 119 Monaten. Das erneute Auftreten der Synostose und eine nachfolgende erneute Operation wurde bei einem dieser Hunde dokumentiert.

**Zusammenfassung und klinische Relevanz:** Hunde mit schwerem Körpergewicht und/oder Hunde mit Hinweisen auf eine bakterielle Infektion (z.B. Bisswunden, offenen Frakturen) haben ein erhöhtes Risiko für die Bildung von posttraumatischen Synostosen nach Heilung der Radius/Ulna-Fraktur. Um die Inzidenz von Synostosen zu reduzieren, ist eine vorsichtige Behandlung des Wundgewebes wichtig. Um eine korrekten Frakturschluss zu gewährleisen, sollte ein Trauma der Zwischenknochenmembran vermieden werden und eine effiziente Reduktion des Radius und Ulna-Fragments ist wichtig. Synostosen verursachen eine Malfunktion der Supination und Pronation der Vordergliedmaße, was sowohl zu Kurz-, als auch zu Langzeitproblemen führen kann. Das erneute Auftreten einer Synostose nach vorheriger Resektion der knöchernden Brücke und Radius/Ulna-Ostektomie wird beobachtet.

**Schlüsselwörter:**
Radius, Ulna, Fraktur, Hund, Bewegungsstörungen, Wachstumsstörungen, Deformitäten
Synostose (MeSH)
Knochen Fehlstellungen (MeSH)

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## Selbständigkeitserklärung

Hiermit bestätige ich, dass ich die vorliegende Arbeit selbstständig angefertigt habe. Ich versichere, dass ich ausschließlich die angegebenen Quellen und Hilfen in Anspruch genommen habe.

Berlin, den 27. März 2013 Areerath Akatvipat