LOCKING PLATE SYSTEM FOR THE MANAGEMENT OF UNSTABLE DIAPHYSEAL, METAPHYSEAL FRACTURES OF FEMUR, HUMERUS AND RADIUS IN DOGS

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CERTIFICATE

This is to certify that the thesis entitled **“LOCKING PLATE SYSTEM FOR THE MANAGEMENT OF UNSTABLE DIAPHYSEAL, METAPHYSEAL FRACTURES OF FEMUR, HUMERUS AND RADIUS IN DOGS”** submitted in part fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY OF VETERINARY SCIENCE in VETERINARY SURGERY AND RADIOLOGY** to the Tamilnadu Veterinary and Animal Sciences University , Chennai is a record of bonafide research work carried out by **R.RAMESH** under my supervision and guidance and that no part of this thesis had been submitted for the award of any other degree, fellowship or similar titles.

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DEDICATED TO
MY FAMILY…

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Dr.R.Ramesh

ABSTRACT

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Title	: LOCKING PLATE SYSTEM FOR THE MANAGEMENT OF UNSTABLE DIAPHYSEAL,METAPHYSEAL FRACTURES OF FEMUR, HUMERUS AND RADIUS IN DOGS.
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The study was carried out in 22 dogs of different breeds, sex and body weight ranging from 10 to 30 kgs presented to the Small Animal Orthopaedic Unit of the Madras Veterinary College Teaching Hospital with history of lameness and clinical symptoms suggestive of unstable diaphyseal or metaphyseal fractures involving the humerus, radius and femur. Thirteen cases of unstable diaphyseal long bone fractures and nine cases of unstable metaphyseal long bone fractures were treated with locking plate system under C-arm guidance. In the present study, Road Traffic Accident (40.8%) was the primary cause for the fracture in dogs followed by fall from height (18.3%), unknown cause (18.3%), slipped on the floor (13.5%), falling down when playing (9.1%).

A cranio-lateral approach to the fracture of humerus and femur and medial and dorsal approach to the diaphysis and metaphysis of radius were surgical approaches undertaken in this study. Diaphyseal fractures were stabilized by open reduction and internal fixation using linear 2.7mm and 3.5mm locking compression plates, distal radial fractures were stabilized by open reduction and internal fixation using 3.5mm locking ‘T’ plates and one case of condylar fracture was stabilized by open reduction and internal fixation using 3.5mm locking condylar plate. Plates were applied as a

buttress in comminuted fractures and as a compression in transverse fractures. Locking ‘T’ plates and locking condylar plates were developed for the study.

The functional outcome was graded excellent, good, fair and poor based on post operative assessment. One case was lost at follow up. Radiographic evaluation of clinical cases indicated either primary healing with no callus formation in cases subjected to compression plating or secondary healing in cases subjected to buttress plating and was related to stability at the fracture site. Dependent oedema, seroma formation, self mutilated wound, stress protection and exposure of plate was the postoperative complications encountered during the study.

The fluorimetric reading of peak absorbance of pre and 45th post operative day serum showed increased intensity of BSAP at 45th post operative day as compared to values of pre operative samples indicating osteogenic activity and progressive fracture healing.

Biomechanical studies were carried out on screw pullout strength, bending strength of on bone, bone plate, bone plate construct and gap model. The mean screw pull out strength on humeral diaphysis showed an yield load of 749.33±5.7019 N and ultimate load of 813.83 ± 1.7401N whereas humeral metaphysis showed an yield load of 501.50 ± 7.6365 N and an ultimate load of 540.67 ± 2.8245 N. Hence comparatively, it is inferred that the screw pull out strength on diaphysis was stronger when compared with metaphysis.

In the present study, it was observed that the mean bending load for mechanical failure of femur, 3.5mm linear locking compression plate, linear locking compression bone plate construct and linear locking compression plate construct with gap model was 1520.33±5.34N, 1670.16±8.89N, 215.33±3.71N and 319.66±5.26N respectively. In the present study, the yield load of linear locking compression plate construct was 1670.16N (167 kgs) which was almost eight times greater than the average body weight of a dog. Similarly, the bending strength of the linear locking compression plate construct was significantly lower than the individual strength of either bone or the linear locking compression plate.

In the present study, the locking compression plating technique provided adequate apposition, stable fixation and promoted early weight bearing of traumatized limb. The locking plate system had a unique combi hole design in a single implant and enabled to select the function best suited for the fracture configuration to achieve the most stable fixation. The locking plate system acted as a single beam construct which increased the stiffness of the implant and was effective in management of unstable diaphyseal and metaphyseal simple and comminuted fractures of humerus, radius and femur.

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1. INTRODUCTION

Fracture of long bones is the most common orthopaedic condition observed in dogs. Femur is the most frequently fractured long bone in dogs comprising almost half of all long bone fractures (Piermattei and Flo, 1997). Radius and ulna fractures constituted about 17 to 18 percent of all fractures in dogs (Egger *et al.* 1993). Humerus is the third most commonly fractured long bone (Marcellin-little, 1998). Oblique fractures were most commonly recorded in different long bones. Comminuted fractures were often encountered, especially in femur and tibia (Harasen, 2003). Fractures occurred secondary to high impact injuries from vehicles, falls (high-rise syndrome) or gunshot wounds (Whitehair and Vasseur, 1992).

The goal of any fracture treatment is to restore the anatomical shape of the bone and provide stability to the fractured bone with suitable implants and return to early function of the affected limb (Johnson and Hulse, 2002). The results of external coaptation of unstable diaphyseal fractures of long bones are less than desirable in most cases and results in fracture disease. Common sequelae of fracture disease include joint stiffness, muscle atrophy, osteopenia, limb shortening, malunion and muscle contracture. Unstable comminuted diaphyseal and metaphyseal fractures are technically demanding to treat and involve the application of internal fixation or external fixation techniques. These techniques require extensive reconstruction and fixation using appropriate implants. Remarkable improvements in fracture management techniques during the last decade have dramatically lessened the mortality and morbidity associated with these fractures. These improvements have accelerated in the last few years producing a versatile system of instrumentation and implants for the treatment of fractures. Advances in the understanding of bone biology and fracture complications have led to modification in the approach to internal fixation using plating techniques.

Open reduction and internal fixation with suitable implants is the procedure of choice for management of closed unstable fractures of long bones.

The common goal of any fracture fixation device is to achieve bony union. Conventional methods allow direct healing across the fracture and generally work well for simple fractures; however, these methods are less advantageous in comminuted, metaphyseal, and/or osteoporotic fractures. Conventional plating using AO/ASIF guidelines involves the use of anatomical reduction and rigid fixation with interfragmentary compression. Locking compression plating system is a recent concept of fracture reduction for the management of unstable diaphyseal and metaphyseal fractures. Locking internal fixators allow for callus formation through increased flexibility in stabilization (Egol *et al*, 2004). The Locking Compression Plate (LCP) offers the possibility of inserting conventional and locking head screws into specially designed combination holes. This new plate hole design permitted the use of both of standard screws and locking head screws (LHS) resulting in fixed-angle stability. Early data on the biomechanical and clinical performance of these implants are encouraging. Current indications for locked plating include periarticular fractures and typically those with metaphyseal comminution. Biomechanical studies have suggested that locked-plate constructs are stiff and suppress interfragmentary motion to a level that may be insufficient to reliably promote secondary fracture-healing. Condylar locking compression plates and locking compression 'T' plates are being used in human fracture treatment. However, there is paucity of literature on the application of these plating systems in small animal practice. Hence, these plating systems were adopted for management of distal condylar fractures of the femur and distal radial fractures in small animals. Bone specific serum alkaline phosphatase estimation provides an index of the rate of bone formation and has been widely used to evaluate fracture healing (Farley *et al.*1992).

Two hundred and seventy three Small Animal Orthopaedic surgeries were performed at the Small Animal Orthopaedic Unit, Veterinary Teaching Hospital, Madras Veterinary College, during the period March 2009 to March 2011. Twenty two cases of unstable diaphyseal and metaphyseal fractures of long bones fractures constituting 7.7 percent of cases operated were considered for the study.

Hence, the present study was undertaken with the following objectives.

1. To study the occurrence of unstable diaphyseal and metaphyseal fractures of humerus, radius and femur in dogs and classify the fractures based on Montavon system.
2. To evaluate the biomechanical strength of locking plate system
3. To evaluate the functional outcome of open reduction and internal fixation using locking plate system based on clinical, radiological and biochemical evaluation.
4. To study the intra operative and post operative complications if any.

2. REVIEW OF LITERATURE

2.1 ANATOMY OF HUMERUS

2.1.1 Gross and Functional Anatomy

The humerus is enlarged proximally and forms a smooth articular surface that articulates with the scapular glenoid. Immediately adjacent laterally and anteriorly is the largest protuberance, the greater tubercle. Medially a much smaller lesser tubercle exists. The proximal humerus tapers through the metaphysis and forms the diaphysis. The humeral diaphysis tapers to an isthmus. The distal humerus enlarges through the metaphysis and forms the medial and lateral humeral condyles. The medial condyle is larger than the lateral condyle and occupies a position more in axial alignment with the diaphysis than the lateral condyle. The articulating surfaces of the humeral condyles are called the trochlea, which apposes the ulna, and the capitulum, which apposes the radial head. The humeral shaft is straight when viewed cranially; however, when viewed laterally it is S-shaped. Beginning proximally the diaphysis curves first caudally to midshaft then curves cranially as the diaphysis approaches the distal condyles (Braden, 1975).

2.1.2 Neurovascular Anatomy

The diaphysis of the humerus receives anterior circumflex artery which is the branch of brachial artery. The biceps brachii and corachobrachialis muscles are being supplied by the anterior circumflex artery at diaphyseal region of the humerus. Deep brachial artery arising from the posterior part of the brachial artery supplies long and medial head of triceps and tensor faciae antibrachi. Axillary nerves runs downward and accompany with posterior circumflex artery at back of the shoulder joint and reaches the deep face of the deltoideus at proximal humerus region. It is divided into dorsal branch which ends in the terminal part of the brachiocephalicus and ventral branch which passes over the lateral head of triceps and continues as the dorsal or anterior cutaneous nerve of forearm (Dyce *et al.*1996).

2.2 ANATOMY OF RADIUS

2.2.1 Gross and Functional Anatomy

The radius is formed proximally by the oval and concave radial head, which articulates with the humeral capitulum. The metaphyseal area tapers slightly to become the flattened radial diaphysis. The diaphysis is of uniform shape, flattened cranial-caudally, and curves slightly as it moves from a lateral position at the elbow to a medial position at the carpus. Distally the metaphysis enlarges and enters the epiphysis. The distal epiphysis has a concave articular surface that sits upon the radial carpal bone. A medial pointed prominence, the styloid process serves as proximal attachment of the medial collateral ligament. The craniomedial surface of the radius and the caudal lateral surface of the ulna are not covered by muscle and can be easily palpated to serve as landmarks for location of the incision. Extensor muscles are located cranial to and flexor muscles caudal to the radius and can be retracted to expose the bone. The cephalic vein crosses the medial portions to the distal radius. The lateral radial head is palpable beneath the extensor muscles of the forearm (Slatter, 1993a).

2.2.2 Neurovascular Anatomy

Median artery supplies the muscles of the fore-arm region. It gives common intraosseous artery at proximal forearm region which continued as dorsal intraosseous in the radio ulnar groove. The median artery terminates in to radial and ulnar arteries which supplies distal part of the forearm. All the extensors muscles of the forearm are supplied by collateral radial artery and flexors are supplied by collateral ulnar artery. Median and ulnar nerve supplies the flexor muscles of forearm. Radial nerve supplies extensor muscles of the forearm (Dyce *et al*. 1996).

2.3 ANATOMY OF FEMUR

2.3.1Gross and Functional Anatomy

Slatter (1993b) reported that the tubular diaphysis was composed almost entirely of cortical bone with trabecular support. In dogs, the diaphysis has a slight cranial bow. The central two third is fairly uniform in diameter, with its narrowest point located proximally. The shaft is free of muscle attachments except along the caudal border, where the adductor muscle attaches. Proximally and distally, the shaft flares to form the metaphysis; cortical bone thins, and trabecular bone progressively increase in density. Weight bearing forces transmitted between medially positioned condyles create compression forces caudomedially and tension forces craniolaterally. Immediate under the skin, fascia lata followed by biceps femoris and the vastus lateralis muscles are located. At distal part of femur origin of the vastus lateralis is located.

2.3.2 Neurovascular anatomy

Slatter (1993c) reported that the femoral diaphysis does not have muscle insertion on its cranial, medial and lateral surface but does have a loose association with the overlying muscles of the quadriceps group. The location of the sciatic nerve is caudal to the femoral diaphysis and deep to the biceps femoris muscles and is considered during retraction and fracture reduction to avoid iatrogenic injury. The principle nutrient artery is a branch of the medial circumflex femoral artery that passes to the femoral diaphysis.

2.4 FRACTURES OF HUMERUS

2.4.1 Incidence

Patil *et al.* (1991) reported 58.6 per cent fractures in dogs of different breeds. Out of 471 clinical cases during the period of 1978 to 1988. The highest incidence was recorded in femur (35 %), followed by tibia (23%) humerus (13.3 %) and radius-ulna (11.4%) respectively.

Raghunath *et al.* (2007) reported highest incidence of fractures in femur (78.0%) followed by humerus (12%) and tibia (10%) respectively out of 103 long bone fractures in a retrospective study of 100 dogs.

2.4.2 Etiology

Marcellin-Little *et al.* (1994) evaluated 157 dogs with humeral fractures. They concluded that Cocker spaniels were more likely to have humeral condylar fractures (HCFs) than other breeds. Male Cocker spaniels were at increased risk and cocker spaniels had more bilateral HCFs than other breeds of dogs. Eighteen dogs with HCFs of unknown cause or occurring with normal activity were further studied and suggested an association between incomplete ossification of the humeral condyle in Cocker spaniels and Brittany spaniels and a high prevalence of HCFs. Eight affected Cocker spaniels with available pedigree information were found to be genetically related, suggesting that incomplete ossification of the humeral condyle may be a genetic disease with a recessive mode of inheritance.

Vannini *et al.* (1988) evaluated repair of 135 distal humeral condylar fractures in dogs and cats and reported that most distal humeral fractures in dogs and cats involved the humeral condyle.

2.4.3 Fracture type and Location

Ness (2009) treated 13 Y-T humeral fractures, known as distal humeral dicondylar fractures, according to a surgical protocol which involved combined medial and lateral surgical approaches.

2.5 FRACTURES OF RADIUS

2.5.1 Incidence

Philips (1979) reported that about 17.5-18.0 percent of fractures in dogs were of radius and ulna.

Dvořák *et al.* (2000) reported that radial fractures were most commonly seen and accounted for 28.66 percent of the documented long bone fractures.

Boudrieau (2003) reported that approximately 18 percent of the fractures that occur in dogs and cats involved the radius and ulna.

Milovancev and Ralphs (2004) reported that fractures of the radius and ulna were commonly encountered in the small animal population. Fracture of radius and ulna in young animal might be managed with external coaptation. Extremely proximal and distal fractures required special consideration, especially if articular involvement were presented.

2.5.2 Etiology

McCartney *et al.* (2010) reported that fracture of the distal radius and ulna in dogs weighing less than 3 kg was relatively common. The injury frequently occurred following jumping down from a height and had a high chance of causing non-union fracture, probably due to a relatively low intraosseous blood supply.

2.5.3 Fracture type and location

Milovancev and Ralphs (2004) reported that diaphyseal fractures were the most common location and were often repaired with the use of external fixators or a bone plate.

2.6 FRACTURES OF FEMUR

2.6.1 Incidence

Kolata *et al.* (1974) reported that higher incidence of femur fracture occurred in males (67.1 per cent) than female dogs (32.9 per cent).

Wong (1984) observed that more than 80 per cent of the fractures occurred in animals that were less than two years old. Male animals were more frequently involved. In the dog, the femur, tibia, pelvis, radius and ulna were most often affected based on a survey of 61 canine fractures diagnosed between January 1980 and June 1983 at a Veterinary Teaching Hospital in Malaysia.

Unger *et al.* (1990) reported that diaphyseal fractures were more common in tibia and fibula (72.0%) as compared with femur (50.0%) and humerus (47.0%). Diaphyseal fractures were either simple or incomplete in 45.0 per cent, wedged in 40.0 per cent and complex in 15.0 per cent of the cases.

Aithal *et al*. (1999) reported that the pattern of bone fractures secondary to nutritional bone disease in 38 dogs fractures were either caused by a fall (28.95%)

or showed no history of direct trauma (31.58%). Mongrels were more commonly affected by pathological fractures, followed by Dobermann pinscher and German Shepherds. Significantly more ($P < 0.05$) fractures were found in dogs aged less than 6 months (64.71%). The incidence of such fractures was significantly higher in males than in females. Fractures were found significantly more frequently ($P < 0.01$) in the femur (81.58%) than in any other bone.

2.6.2 Etiology

Kolata *et al.* (1974) stated that approximately 75 per cent of the cases fell into 3 categories namely motor vehicle accidents, animal interaction and unknown cause based on a study conducted at the Trauma and Emergency Service (TES) of the Small Animal Hospital, School of Veterinary Medicine, University of Pennsylvania, USA.

Thilagar and Balasubramanian (1988) concluded that fractures in male dogs were seen significantly as a result of animal interaction and in female dogs as a result of fall from heights and crushing injuries in their studies on 204 cases of fractures admitted to the Small Animal Clinic of Madras Veterinary College.

Kumar *et al.* (2007) undertook retrospective study on occurrence and pattern of long bone fractures. The authors concluded that out of 310 cases of fractures recorded, the bones were osteopenic in 91 cases (29%). Minor trauma was the principal cause of fracture in dogs with osteopenia (25%), and indigenous breeds were most commonly affected (38%). Fractures in dogs with osteopenic bones were most commonly recorded in the age group of 2-4 months (53%), whereas fractures in normal dogs were almost equally distributed between 2 and 8 months of age. Male dogs were affected significantly more often in both groups.

2.6.3 Fracture type and location

Kumar *et al.* (2007) reported that in osteopenic bones, most fractures were recorded in the femur (56%), and they were distributed equally along the length of the bone, whereas in normal bones, fractures were almost equally distributed in radius/ulna, femur and tibia, and were more often recorded at the middle and distal third of long bones. Oblique fractures were most common in both groups; however, comminuted fractures were more frequent in normal bones, whereas incomplete fractures were more common in osteopenic bones.

2.7 CLASSIFICATION

Unger *et al*. (1990) developed a computer filing system for classification of fractured long bones that included definition of terms and a method of classification based on fracture criteria seen on radiographs. With this classification system, the fractures were ranked in increasing severity and complexity for various anatomical locations and provided prognostic and therapeutic information. The first symbol of the alpha-numeric code represented the fractured bone: 1 humerus, 2 radius/ulna, 3 femur and 4 tibia/fibula. The second symbol represented the segment of the long bone in which the fracture was centered: 1 proximal, 2 diaphyseal and 3 distal. Diaphyseal fractures were divided into 3 types: simple (A), wedge (B) and complex fractures (C)

2.8 BONE HEALING

2.8.1 Biology of bone healing

Schenk (1986) reported that when fracture occurred, a series of events was initiated, which culminated in the remarkable ability of bone to regenerate and return to its original tissue structure.

The reduced vascularity corresponded to the region associated with a poor prognosis for fracture healing in small-breed dogs. This regional association suggested that a decreased vascular supply in the distal radius may contribute to a higher frequency of delayed union and non union in smaller dogs (Welch *et al*, 1997).

Butterworth and Denny (1999) stated that the time taken for a fracture to heal was dependent on a number of factors including – type of bone involved (epiphyseal, metaphyseal or diaphyseal) type of fracture, age of patient, method of treatment, other specific diseases (Cushing’s disease, chronic renal failure, dietary inadequacies such as nutritional secondary hyperparathyroidism), vascular supply and infection (e.g. open fracture).

2.8.2 Indirect bone healing

Piermattei and Flo (1997) stated that callus formation was subdivided on the basis of location as medullary bridging callus, periosteal bridging callus or intercortical bridging callus. In general, stabilization of fractures by external splintage, external fixator, buttress (bridging) plates and intramedullary pins were characterized by the formation of callus in all three areas.

Stiffler and Kevin (2004) reported that indirect bone healing occurred when the fracture was reduced, but the repair was not rigidly stabilized. Interfragmentary micro motion caused high level of strain on the fractured ends leading to bone resorption, followed by callus formation and transformation of fibrocartilage to bone. This was common when wires and pins were the only fixation devices utilized.

Epari *et al.* (2005) stated that healing occurred in slightly flexible fixation by a process known as secondary healing, which involved bone formation by both intramembranous and endochondral ossification. The mechanical environment provided by the fixation stability was thought to influence the proliferation and differentiation of the various cell types and hence the morphological appearance of the callus.

Ziran *et al. (*2007) observed developing callus during weight bearing due to load-sharing during early phase of fracture healing in dogs.

2.8.3 Direct bone healing

Yamada (1970) reported a minimal amount of strain is a precondition for mechanical induction of callus. Compression applied to the fracture produces preloaded continuous contact and thus minimizes interfragmentary strain. This enabled the osteones to cross the fracture at compressed surfaces.

Rahn *et al.* (1971) stated that direct bone healing occurred under conditions of stable injuries or rigid internal fixation, fracture compression and where there was complete apposition of fracture fragments with little or no bridging / external callus formation, because of no mechanical instability.

Perren (1991) reported that the disadvantages of using broad limited contact dynamic compression plate being due to the greater bone contact surface area which influenced the periosteal blood supply and healing ability of the fracture bone.

Hulse and Hyman (2003) reported that primary osteonal reconstruction occurred with anatomical alignment of the fracture ends and absolute stability. Primary osteonal reconstruction was further subdivided into contact healing and gap healing. Contact healing occurred in the zones of cortical bone contact and was characterized by osteonal remodelling across the fracture plane. During osteonal remodelling, cutting cones were formed at the ends of the osteons nearest the fracture. Osteoblasts lined the rear of the cutting cones in preparation for bone formation. Bone resorption and bone formation occurred simultaneously as the cutting cones advanced and crossed the fracture plane from one fragment to other at a rate of 50 – 80 µm/day. Gap healing occurred in the small fragment gaps between contact zones. Interfragmentary deformation had to be less than 2 per cent, and the gap width might not exceed approximately 1 mm for gap healing to occur. Osteonal remodelling occurred with callus and was called secondary osteonal reconstruction.

Bottlang *et al.* (2010) opined that locked bridge plating relied on secondary bone healing which required interfragmentary motion for callus formation. The authors evaluated the healing of fractures stabilized with a locked plating construct and a far cortical locking construct, which was a modified locked plating approach. This system promoted interfragmentary motion in a ovine tibial osteotomy model with a 3-mm gap size at fracture site. The authors concluded that inconsistent and asymmetric callus formation with locked plating constructs was likely due to their high stiffness and asymmetric gap closure. Far cortical locking constructs form more callus by providing flexible fixation and nearly parallel interfragmentary motion. The callus on weekly radiographs was greater in the far cortical locking constructs than in the locked plating constructs.

2.9 DIAGNOSIS

2.9.1 Clinical Signs

Fossum (2007) reported that affected animals were usually non-weight bearing on the affected limb and had palpable swelling, crepitation and pain at the fracture site. The fracture might be open with or without soft tissue loss and animals having abnormal proprioceptive responses because they were reluctant to move with affected limb.

2.9.2 Physical examination

Roush and McLaughlin (1999) stressed that a complete orthopaedic examination should be performed to identify musculo-skeletal abnormalities. Patients were to be observed for weight bearing stance, muscle mass and symmetry. Palpation of the affected limb with associated joints had to be carried out.

2.9.3 Lameness Grading

Braden and Brinker (1973) developed a grading scale based on visual examination of the animal. The grading system was as follows.

Grade 1 - Normal weight bearing on all limbs at rest and when Walking.

Grade 2 - Normal weight bearing at rest, favors affected limb while walking.

Grade 3 - Partial weight bearing at rest and while walking.

Grade 4 - Partial weight bearing at rest and does not bear weight on affected limb when walking.

Grade 5 - Does not bear weight on limb at rest or when walking.

Zimmermann *et al.* (2010) reported a femoral fracture repair using a 16 hole 4.5mm locking distal plate in an adult captive polar bear. They observed that at 11.5 weeks, the lameness grade was 2/5 and at about 11 months, lameness was no longer evident.

2.9.4 Fracture patient assessment score (FPAS)

Fracture Patient Assessment Score (FPAS) was followed for preoperative decision making. The assessment was carried with simple 1-10 scoring system as described by Palmer (2000). Fracture Patient Assessment Score was considered the mechanical, biological and clinical factors which influenced fracture healing.

2.9.5 Use of Fluoroscopy

Johnson *et al.* (1998) reported that intra operative fluoroscopy could aid the surgery in achieving anatomical closed reduction of certain fractures. The imaging allowed visualization results of traction and counter traction of fragments and guidance for implants placement. He explained that intra operative fluoroscopy was essential to determine the screw placements in interlocking nailing external fixator pin placement during closed reduction and to assess limb alignment and position of the plate and alignment of fragments post operatively.

Haaland *et al.* (2009) reported that a portable C-arm image intensifier was used for serial intra operative imaging and immediate post operative evaluation of plate fixation to determine correct axial and rotational alignment.

2.9.6 Radiography

Braden and Brinker (1976) reported the radiographic evaluation of dogs in femur fractures stabilized by tension bone plates. The first radiographs were taken during surgery and then immediately after surgery to record the status of reduction, alignment and fixation and after that 4th and 10th postoperative weeks to monitor healing and success rate was recorded 91.0 percent.

Newton and Nunamaker (1985) stated that atleast two radiographic views including the joints above and below the fracture were needed for fracture diagnosis and also the opposite limb should be radiographed for comparison. The specific radiographic sign were break in the continuity of bone, a line of radiolucency when the fragments were distracted and a line for radio-opacity when the fragments were compressed or superimposed.

Langley-Hobbs (2003) reported that the intervals at which follow-up radiographs were taken vary depending on the age of the patient, the severity of the fracture, the confidence of the clinician in the repair and the progress of the patient. Generally, radiograph would be taken every two to three weeks for immature animal and every four to six weeks for mature cases. Follow-up radiographs would be evaluated both in isolation and in comparison with the previous radiograph. Immediate post operative radiographic assessment was the four 'A's like apposition, alignment, angulation and apparatus and follow-up post operative radiographic assessment was the "six A "s like apposition, alignment, angulation, apparatus, activity and architecture.

Dernanz *et al.* (2007) suggested that the fracture was considered healed when a visible callus bridging at least one cortex or by disappearance of the fracture line was present on both the lateral and cranio caudal radiographic views.

Schmokel *et al.* (2007) reported that well positioned, orthogonal radiographic views of both the fractured and the contralateral intact limb segments were required to develop a preoperative plan of the procedure

2.10 ANAESTHETIC PROTOCOL

2.10.1 Premedication

Raghavan *et al.* (1979) studied the influence of xylazine as a preanaesthetic drug in dogs in different dosage levels. At 1mg/kg b.wt intramuscularly, it produced a considerable increase in anaesthetic period.

Kolata and Rawlings (1982) administered premedication with atropine at the rate of 0.04 mg/kg b.wt intramuscular and induced anaesthesia in dogs by administering a combination of xylazine and ketamine at the dose rate of 1.10 mg and 11.00 mg /kg b.wt respectively intramuscularly. This procedure was suitable for short duration surgeries.

Deneuche *et al*. (2004) reported that the preoperative administration of meloxicam was a safe and effective method of controlling postoperative pain for upto 24 hours in dogs undergoing orthopaedic surgery.

2.10.2 Induction

Hilbery (1992) stated that ketamine could be given intravenously at a dose rate of 5mg/kg body weight following the administration of diazepam (0.20 mg/kg b.wt). This combination provided quiet, smooth and slow induction of anaesthesia.

2.10.3 Maintenance

Bednarski (1996) stated that the inhalation agents Isoflurane, Halothane and Methoxyfluarane were used for maintenance in dogs at the rate of 1.5 to 3.0 percent, 1.0 to 2.0 per cent and 0.5 to 1.5 per cent respectively. The initial and subsequent anesthetic vaporizer settings vary with the condition of the patient, the type of vaporizer used, the type of breathing circuit used and the fresh gas flow rate. The relatively high fresh gas flow rate and vaporizer setting that were initially used after induction and later were decreased to maintenance settings when the palpebral reflex disappeared and the heart rate began to decrease.

2.11 SURGICAL PROCEDURE

2.11.1 Surgical approach to humerus

Fossum *et al*. (1994) reported that for approaching the humerus diaphysis, the skin incision was made from cranial border of the tubercle of the humerus to the lateral epicondyle distally. The incision formed the shape of normal curvature of the humerus. The incision was made on the subcutaneous fat and brachial fascia along the same line of skin incision. Care was taken not to injure the cephalic vein and should be ligated. Incision was continued on the brachial fascia along the border of the brachiocephalicus muscle and lateral head of triceps. The incision was continued until the radial nerve was identified. The brachiocephalicus and superficial pectoral muscles were retracted cranially and brachialis muscle caudally to expose the proximal and central humeral shaft.

2.11.2 Surgical approach to radius

Piermattei and Greeley (1979) described an approach to distal radius and antebrachio carpal joint by placing a medial skin incision on the mid dorsal surface of the joint extending middle of the metacarpus. The deep fascia and joint capsule was incised mid way between the tendon of extensor carpi radialis and tendon of common digital extensor.

Piermattei and Greeley (1993a) reported that for approaching the medial shaft of the radius, the skin incision was made over the medial aspect of the bone. The subcutaneous fascia was incised in the same line as the skin incision. Care was taken to protect the cephalic vessels and radial nerve crossing the field at midshaft, while approaching the shaft of the radius.

Sardinas and Montavon (1997) reported that medial plating of the radius was chosen against dorsal plating in his study because of the superior bending properties, a lack of interference with the dorsally located extensor tendons, easier intra-operative reduction and better bone exposure for the screws in a medio-lateral direction.

2.11.3 Surgical approach to femur

Piermattei and Greeley (1993b) suggested that the craniolateral approach of the femur provided adequate exposure with minimal soft tissue and vascular trauma to the femoral diaphysis.

2.12 LOCKING COMPRESSION PLATE TECHNIQUE

2.12.1 Principles

The basic principles of an internal fixation procedure using a conventional plate and screw system (compression method) were direct, anatomical reduction and stable internal fixation of the fracture. The screws were tightened to fix the plate onto the bone, which then compressed the plate onto the bone. The actual stability resulted from the friction between the plate and the bone. A technique for bridging plate osteosynthesis has been developed for multifragmentary shaft fractures that permitted healing with callus formation, as seen after locked nailing. Since the damage to the soft tissues and the blood supply was less extensive, more rapid fracture healing was achieved. The newly developed, so-called locked internal fixators (e.g. PC-Fix and Less Invasive Stabilization System (LISS)), consisted of plate and screw systems where the screws were locked in the plate. This locking minimized the compressive forces exerted by the plate on the bone. This method of screw-plate fixation meant that the plate did not need to touch the bone at all, which was of particular advantage in so-called Minimal Invasive Percutaneous Osteosynthesis (MIPO). Precise anatomical contouring of a plate was no longer necessary because the plate did not need to be pressed on to the bone to achieve stability. This prevented primary dislocation of the fracture caused by inexact contouring of a plate (Wagner, *et al.* 2004).

2.12.2 History

Modern bone plating started in the 1950's when a group of fifteen surgeons lead by Maurice Muller formed AO/ASIF (Arbeitgemeinshaft fur osteosynthesfragen/ Association for the study of internal fixation) to improve the principles of bone plating. AO/ASIF remained a medical organization to advance the study of fracture treatment while Synthes was the commercial arm of the AO. The Dynamic Compression Plate (DCP) was introduced in 1969 and was the standard AO plate until a few years ago. The holes were shaped like an inclined and transverse cylinder. The screw head can slide down the incline when tightened in a vertical direction. The horizontal force of the screw head as it impacts the side of the angled hole results in movement of the bone fragment.

In an effort to balance rigid fixation and preservation of blood supply to the bone, the Limited Contact Dynamic Compression Plate (LC-DCP) was developed for use in 1990. The plate had many design features that improved the biomechanics and use of the plate such as, thinner design while maintaining equal stiffness at the screw holes and between them, better hole design and minimal contact to the periosteum in between the holes. Subsequently, systems such as the Less Invasive Stabilization System (LISS), Point Contact Fixator (PC-Fix) and Schuhlis systems used principles of external fixation, internal fixation and locking technology theory. The Locking Compression Plate (LCP) with a combi hole was developed in 2000 so that the techniques of conventional and locked screw technology could be used in one plate.

2.12.3 Locking compression plate in small animals

Plate osteosynthesis using the locking compression plate system offered the possibility of inserting conventional and locking head screws into specially designed combination holes. This system combined the facilities of conventional plate osteosynthesis with those of the internal fixator systems (Sommer *et al.* 2003).

Frigg (2003) reported the development of the locking compression plate system for the fracture fixation to overcome the lacunae observed in application of the conventional plating system.

Schwandt and Montavon (2005) reported a repair of concomitant fractures of radius-ulna and tibia-fibula in a six-month-old, male Bernese Mountain dog which were treated each with a 3.5 mm Locking Compression Plate. Following the surgery, radiographs of both operated legs were taken and revealed adequate fracture alignment of the fracture in both limbs. The follow-up radiographs taken at days 14 and 53 revealed uneventful healing of both fractures.

Anglen *et al.* (2009) reported that locking of the screws to plate made the fixation construct more resistant to failure from sequential screw loosening and pullout. In addition the fixed angle nature of the plate and screw fixation resisted cantilever bending stresses and reduced the risk of angular deformity in metaphyseal fractures that were comminuted and were unable to share the load.

Tan and Balogh (2009) suggested that relative stability plating with angular stable fixation using locking compression plates was recommended for complex diaphyseal/metaphyseal fractures with extensive comminution in long bones.

Haaland *et al.* (2009) carried out a retrospective study on appendicular fracture repair in dogs using the locking compression plate system in 47 cases. The authors radiographically assessed immediate post operative day and subsequent post operative radiograph for fracture alignment, apposition and healing on every three weeks from the time of surgery and suggested that locking compression plate system was a favourable method for fracture management in dogs.

2.12.4 Locking compression plate in large animals

Schmid *et al.* (2011) reported that range of movement of the tail was improved and there was no narrowing of the pelvic canal in open reduction and internal fixation of sacral fractures in cattle and that locking compression plate - osteosynthesis of the spinous processes provided sufficient stability for internal fixation of sacral fractures.

2.12.5 Criteria for implant selection

Brinker (1984a) stated that the important factors to be considered in choosing the size of implant were size of bone, weight of the animal, type and location of the fracture, activity and condition of soft tissue. Among these, the most consistent factor in choosing the size of the implant was the animal weight. The author also advocated guidelines for selecting bone plate and screws based on the type of bone involved and weight of the animal. Recommendation for the time of plate removal based on the age of the dog was suggested.

Piermattei and Flo (1997) reported that the implant selection was based on animal body weight according to different long bones. In humerus, radius and femur, 2.00 mm dynamic compression plate for 1 kg to 13 kgs, 2.7 mm dynamic compression plate for 8 kgs to 23 kgs, 3.5 mm narrow dynamic compression plate for 14 kgs to 34 kgs and 4.5 mm narrow dynamic compression plate for 25 kgs to 54 kgs were used.

Conzemius and Swainson (1999) stated that prior to applying a bone plate, the surgeon should decide as to how the plate has to function. Plates could be applied to bone to function in a dynamic compression, neutralization or buttress mode. Dynamic compression plating provided compression of the fracture ends which resulted in increased strength of the repair. This was accomplished by taking advantage of the gliding holes.

Fossum (2007) reported that cortical bone screws and ASIF bone plate were made of 316L stainless steel or titanium and might be or might not be self-tapping. A non-self – tapping screw required that threads be cut into bone with a tap. Most commonly used ASIF screws were non-self tapping. Cortical screws were available in a variety of sizes ranging from 1.5 mm to 6.5 mm. Bone screws were used either to anchor bone plate to bone or to hold bone fragments in place. For each different size, screws had a drill bit corresponding to the inner core diameter of the screw and a tap corresponding to the threads of the screws.

2.12.6 Operative time in plating

Dudley *et al*. (1997) reported that the surgical time for plating was 157 minutes (ranged 90 to 285 minutes)

Johnson (2003) reported the application of 3.5 mm and 4.5. mm dynamic compression plate in highly comminuted femoral fractures in 35 dogs and observed that bridging plate was quicker to perform (mean surgery time 116.5 minutes and ranged 50 to 190 minutes) and resulted in faster healing than the fragment reconstruction and bone plate fixation (mean surgery time 191.8 minutes and ranged 125 to 255 minutes).

2.12.7 Implant used

2.12.7.1 Linear locking compression plating system

Ellis *et al*. (2001) reported that the placement of the screws should be placed as close to the fracture site as possible in order to reduce the amount of strain to promote stable fixation and fracture healing.

Wilson (2002) reported that the locking compression plate was not compressed to the bone on account of its design and did not compromise the periosteal circulation and hence the cortical necrosis by compression was prevented during the fracture fixation.

Gautier and Sommer (2003) reported that the placement of the locking head screws in the locking hole of the plate influence the stability of the fixation. In order to engage the screw threads in the corresponding threads in the plate, the threaded drill guides should be inserted perpendicularly to the plate and altering the angle of the screws might alter the stability of the fixation and was not recommended. The locking compression plate was reported to be equally stable with mono-cortical or bi-cortical screws due to the angular stability of the screws. They also recommended minimum of two screws per segment with at least three cortices for simple fracture and at least four cortices for comminuted fractures in good quality bone.

Perren (2003) reported that minimizing the plate footprint on the bone was of advantage in accelerating bone healing and increasing local resistance to infection in management of fractures with locking compression plating system.

Several factors have been shown to influence the stability of a locking compression plate construct, such as working length (i.e. the length of plate between the two screws closest to the fracture), number and placement of screws, distance between plate and bone, and size of the implant (Stoffel *et al.* 2003).

Aguila *et al.* (2005) reported that the disadvantages of linear locking compression plate when compared to traditional methods included inferior torsional stiffness and difficulty with soft tissue closure due to the implant profile.

Kubiak *et al.* (2006) reported that the linear locking compression has obvious advantages of protecting the viability of bone by maintaining micro vascular circulation within the cortex and its surrounding tissues.

Wagner and Frigg (2006) reported design and development of the locking compression plate and its use in clinical cases. The direction of the combi hole deviated towards the centre of the plate. The combination of hole in the locking compression plate allowed internal fixation to be achieved by the insertion of either conventional screws or locking head screws with angular stability. The compression could be achieved by using conventions screws on non locking plate holes and locking could be achieved by using locking screws on locking side of the plate hole. AO/ASIF recommendations were followed for the design and diameters of the locking and non locking side of the combihole.

Miller and Goswami (2007) reviewed the locking compression plate biomechanics and their advantages as internal fixators in fracture healing. The authors reported that conventional methods allowed direct healing across the fracture and worked well for simple fractures; however, these methods were less advantageous in comminuted, metaphyseal, and/or osteoporotic fractures. Locking internal fixators allowed for callus formation through increased flexibility in stabilization and did not depend on the screw purchase in bone which was advantageous in comminuted and osteoporotic fractures. The bone–plate interface created a ‘‘single beam’’ construct in that there was no movement between individual parts resulting in an increased resistance to pullout. The strength of locking compression plate construct had four times more strength than the conventional plating and unlike the conventional plate which converted an axial load to a shear stress; locking constructs convert an axial load to a compressive force. The stability of the conventional plate was dependent on the friction at the bone–plate interface which was equivalent to the sum of the torques on each screw; on the other hand, the strength of the locking plate was equivalent to the sum of all bone–screw interfaces.

Roberts *et al.* (2007) reported that combining the locking compression plate with intramedullary pins allowed for monocortical screw placement without loss of holding power as compared to bicortically placed bicortical screws.

Haaland *et al.* (2009) stated that there were no accepted guidelines for proper application of locking compression plate device as an internal fixator in small animal practice in small dogs and experience from human osteosynthesis was therefore extrapolated to veterinary cases. In the present study, AO/ASIF guidelines were adapted for application of locking compression plate application. They also reported that the maintenance of the holding power of the monocortical locking head screw was beneficial when other implants prevented the use of bicortical screws in locking compression plating systems. The authors also reported that linear locking compression plate system in combination with a less invasive surgical approach was found advantageous in comminuted fractures where the linear locking compression plate was used as a bridging plate, in situations when exact plate contouring was difficult, and when other implants prevented the use of bi-cortical screws. A too long middle segment may cause a reduction of implant stiffness and result in plate bending. The authors also reported reduced surgical time with internal fixator, lesser manipulation of fracture fragments and reduced need for plate contouring in his study on appendicular fracture repair in dogs using the locking compression plate system: 47 cases.

Anglen *et al*. (2009) reported that the fixed angle nature of plate and plate fixation resist cantilever bending stresses and reduced the risk of angular deformity in metaphyseal fracture that are comminuted, missing bone or otherwise mechanically unable to share the load.

Tan and Balogh (2009) reported that the goal of fracture fixation was to achieve bone healing and restore the function of the injured limb in the shortest possible time without compromising safety. Newer technologies such as the locking compression plate (LCP) and its derivatives were valuable additions to the orthopaedic traumatologist’s armamentarium. It was vital that surgeons involved in fracture care were aware of when locked plating was superior to other methods and also when they should use another treatment modality. The authors reviewed the use of locked plating as a fixation method and described the perspective on locked plating, general indications, specific modes and techniques, patterns of failure, and an anatomical overview of current indications for locked plating.

Ness (2009) reported that friction between plate and bone was essential for stability with dynamic compression plating, but was not required with locking plates. This was due to the fact that when locking compression plates were contoured, the integrity of the plate thread was disturbed with consequent loss of the locking facility.

Filipowicz *et al*. (2009) reported that locking compression plate permitted more biological surgical approach, unhampered periosteal blood supply to the fracture site and potentially increased stability by engaging fewer cortices in each fragments may make the locking compression plate suited for stabilization of the metaphyseal and comminuted fractures.

Walia *et al*. (2009) conducted a study to evaluate the results of Locking Compression Plate in 50 cases of long bone fractures in humans by clinical and radiological evaluation and concluded that 72 % of cases were achieved excellent to good results.

Anglen *et al*. (2009) reported that locking compression plates promoted rigid stability by providing axial and rotational alignment and acted as a single beam construct stabilizing the fracture.

Bottlang *et al.* (2010) opined that locked bridge plating relied on secondary bone healing, which required interfragmentary motion for callus formation and evaluated the healing of fractures stabilized with a locked plating construct and a far cortical locking construct, which is a modified locked plating approach that promoted interfragmentary motion in a ovine tibial osteotomy model with a 3-mm gap size at fracture site. The authors concluded that inconsistent and asymmetric callus formation with locked plating constructs was likely due to their high stiffness and asymmetric gap closure. Far cortical locking constructs form more callus by providing flexible fixation and nearly parallel interfragmentary motion, and the callus on weekly radiographs was greater in the far cortical locking constructs than in the locked plating constructs.

Ochman *et al.* (2010) compared locking and non-locking plates for fixation of metacarpal fractures in an animal model. The authors concluded that the new generation of locking plates could be used to achieve a higher stability for fixation of metacarpal fractures. Monocortical, stable fixation was able to minimize flexor tendon interference and probably reduced bone and soft tissue trauma.

Woon *et al.* (2010) reported that during locking compression plate application, both plate and bone fragments can move independently, making accurate screw placement difficult as small shifts at the plate translate to great deviations at the level of bone. With a single screw in place, plate movement was confined to rotation in one plane and once two or more screws are placed alterations in plate position was no longer possible. Unlike the more forgiving traditional fixator, the mono axial nature of the locking head screw trajectory reduces the ability to compensate for imperfect placement, making it mandatory that anatomical reduction be achieved prior to placement of first screw.

2.12.7.2 Locking compression 'T' plate

Hamilton and Langley Hobbs (2005) reported use of the AO (Arbeitsgemeinschaft für Osteosynthesefragen) veterinary mini 'T'-plate for stabilization of distal radius and ulna fractures in toy breed dogs . The AO mini 'T'-plate was used as the final means of fixation in 14 dogs which weighed 3.5 kg or less. It was used as the primary form of stabilization in ten dogs, and in four dogs it was used at revision surgery. The authors concluded that the AO veterinary mini 'T'-plate was a suitable choice of implant for stabilization of distal radius and ulna fractures in toy breed dogs.

Dhanalakshmi *et al.* (2007) described the management of a distal metaphyseal radial fracture in a spitz dog using a mini T-plate (316-L stainless steel) with seven round holes which was developed at small animal orthopaedic unit of Madras Veterinary College Hospital for the successful treatment of unstable distal metaphyseal fracture of the right radius and ulna.

2.12.7.3 Condylar locking plate

Locking plates were ideal for distal femoral fractures with or without articular involvement. Malalignment of the articular surface was not uncommon, especially in inexperienced hands using the minimally invasive technique (Tan and Balogh, 2009).

2.12.8 Locking compression plate and MIPO

Wagner (2003) described the basic principles of locked internal fixators and some clinical results with the LISS and LCP systems to illustrate the potential of these new systems. The authors reported that the locked internal fixator technique was an approach to optimize internal fixation in spite of the complication of additional trauma and disturbance of the bone blood supply during internal fixation. Locked internal fixator technique aimed at flexible elastic fixation to imitate spontaneous healing, including induction of callus formation. The technology supported what was currently called "minimally invasive plate osteosynthesis" (MIPO), which provided priority to biology over mechanics. An implant system called "Locking Compression Plate (LCP)" was developed, based on many years of experience with compression plating and good clinical results obtained with internal fixators, such as the Less Invasive Stabilization Systems (LISS). It provided two treatment methods (ie, the compression plating and locked internal fixation methods) into one system.

2.12.9 Locking compression plate and Plate rod construct

Hulse *et al.* (1997) reported that addition of an intramedullary pin to a linear locking compression plate decreased strain on the plate to two fold and addition of an intramedullary pin also increased the bending strength and fatigue life of the plate twice.

Reems *et al. (*2003) reported that biological osteosynthesis did not rely on anatomic reconstruction and the large fracture gaps that remained, reduced the interfragmentary strain. In biological osteosynthesis, bone healing was a result of formation of fibrous connective tissue followed by cartilaginous callus between fractured fragments. The authors reported that plate rod was capable of supporting the fragment adequately until callus formation. When a plate was only used, a defect in the cortex opposite the plate could result in large bending movement in the plate predisposing to mechanical failure. Addition of an intramedullary pin reduced the strain on a plate by about half, which increased the predicted failure life of the plate by a feature of 10 or more. Use of plate rod constructs for fixation of highly comminuted fracture that could not be anatomically reconstructed reduced the risk of catastrophic plate failure during the early post operative period as well as the potential risk of fatigue failure during fracture healing.

Vannini (2004) reported the advantages of the plate rod system as a buttressing device for indirect fracture reduction techniques as follows 1. The intramedullary pin assisted the surgeon in re-establishing spatial alignment of the limb. 2. The intramedullary pin maintained reduction of the main bone fragments as the plate was placed on the bone, and 3. The intramedullary pin reduced plate strain thereby increasing fatigue life of the construct. If the intramedullary pin occupied 35-40% of the diameter of the narrow cavity, it still allowed micro strain of the fracture plane which was important for callus formation.

Dirsko *et al*. (2005) stated that surgical repair of comminuted long bone diaphyseal fractures in dogs routinely involved the use of bone plates. When cortical reconstruction was not performed, a bone plate may be subjected to excessive cyclic bending. Consequently bone plates may fail during conditions of continuous cyclic bending, particularly in animals with delayed bone healing. To reduce plate strains and the risk of catastrophic plate failures, a combination of a bone plate with an intra medullary pin (IMP) were used. The authors reported that the use of plate rod combination had been associated with a high (98%) success rate.

2.12.10 Locking compression plate and fracture healing

Dudley *et al.* (1997) stated that the healing times for external skeletal fixators and orthopaedic plates were similar. Healing time of 10 weeks in young animals and 19 weeks in older animals were typical in most cases and healing was assessed with radiographs at approximately four weeks postoperatively. The mean time of earliest radiographic evidence of a healed fracture was 87.4 days (ranged 41 to 185 days).

Schwandt and Montavon (2005) reported a repair of concomitant fractures radius-ulna and tibia-fibula in a six-month-old, male Bernese mountain dogs in which were treated with 3.5 mm locking compression plate. Fracture healing in the case reported was considered to be relatively short based on the findings of follow-up radiographs. Fracture healing was enhanced by callus formation, a typical component of indirect bone healing, which stabilizes the fracture ends by reducing the moment of inertia. The authors reported that in the present case, the callus were well developed in both fractures as seen on the follow-up radiographs

Haaland *et al.* (2009) studied healing patterns from the medical records and radiographs of 47 dogs treated with linear locking compression plate retrospectively. The fractures were treated using the linear locking compression plate as an internal fixator; in some cases as a plate and rod construct. Forty-six of 47 fractures reached radiographic union. Mean healing time of the fractures was seven weeks (95% confidence interval from 5.8 to 8.3 weeks). The statistical analysis showed that significant differences in healing time between juvenile (age less than one year) and adults.

2.12.11 Intra operative Complications of locking compression plate

Wagner (2003) reported that the space between plate and bone improved periosteal blood flow, resulting in reduced bone necrosis under the plate and also decreases the infection rate.

Ehlinger *et al.* (2009) reported that the most challenging problem encountered specific to locking screw system was jamming of screw in the plate which was secondary to poor drilling orientation and poor positioning of targeting device or drill sleeve or not using a targeting device. The quality of the screw placement depended on how accurately the targeting device was placed. The most common cause of screw jamming was screwing the screw in too forcefully without using torque controlling screw driver. Excessive force while inserting the screw leads to threading lesion on the screw head and plate hole.

Tan and Balogh (2009) reported that linear locking compression plate used as internal fixators offset from the periosteal surface can cause tendon and soft tissue irritation if the plate was too prominent.

Hayes *et al.* (2010) studied difficulties of removing temporary fracture fixation devices due to excessive bony on-growth and reported extended surgical time which led to excessive blood loss, debris contamination and potentially refracture. The authors assessed screw removal torque, percentage of bone contact and tissue-material response in a bilateral sheep tibia non fracture model on commercially available locking plates and screws that were manufactured for clinical use and reported that a micro-rough surface contributed to the excessive bony on-growth. The authors suggested that polishing of locked plate/screw systems improved ease of removal and reduced implant related removal complications encountered due to excessive strong bony on-growth while maintaining biocompatibility and implant stability.

2.12.12 Post operative care

Bojrab (1990) stated that gentle flexion and extension of hip and stifle joints for 3 to 5 minutes for a minimum of three times daily should be instituted within 2 to 3 days of surgery. This would be helpful in early return of limb function.

Jones (1994) suggested to restrict the activity of the operated animal for minimum 3 weeks and to perform physical therapy like straight leg raising exercise to ensure the normal joint function.

Dueland *et al.* (1999) advocated antibiotic prophylaxis for a minimum ninety six hours for those dogs which had open reduction and internal fixation.

Roush and McLaughlin (1999) reported that after surgery, the incision must remain clean and dry. The authors encouraged limited exercise to promote muscle tone and joint mobility. Controlled walking on a leash was usually permitted, though the amount of activity allowed depend on the nature of the fracture and the stability of the repair. The fracture site should be monitored radiographically to assess healing and check for any complications.

Denny and Butterworth (2000) suggested that in most cases it was preferable to apply a Robert Jones Bandage for 30 days. Exercise restriction would be implemented until radiographic healing of the fracture was apparent, usually 4-8 weeks depending on the nature of the fracture and age of the patient.

2.12.13 Outcome of plating

Braden and Brinker (1973) reported the post operative functional limb usage for plating in femur fracture of Beagles. Dogs with bone plates regained normal, full function of the injured limb in about 3.5 weeks.

Larsen *et al.* (1999) reported that 16 cases (89.0%) had successful return to function in 22 radius and ulnar fractures treated with linear locking compression plates.

Ganesh *et al.* (2004) reported that the postoperative fracture healing and analysis of gait were good to excellent in long bone fractures that were treated with plate osteosynthesis in five dogs.

Mukherjee *et al*. (2009) reported that average time for full functional limb usage was 49 days in six femur diaphyseal transverse fractures in dogs treated by bone plating. The fracture gap was completely obliterated and remodeled imparting uniformity in radiographic features at 9th postoperative week at the proximal and distal bone fragments. The thickness of cortex at the site of union was similar to that of normal bone.

2.12.14 Plate removal

O’ Sullivan *et al*. (1989) suggested the removal of plate at an early phase of healing, in order to avoid the long –term effects of stress protection.

Wilson (1991) suggested that plate removal was advised after bone union. Implants were not removed before the architecture of the bone had become radiographically normal. The prestress of the implant slowly dissipated as bone healing and remodelling occurred. Complete remodelling generally took between 12 – 18 months.

Emmerson and Muir (1999) reported that bone plate failure was in less than 15% of cases due to implant instability in their study on plate removal in dogs and cats.

Hudson *et al.* (2009) reported that patient intolerance of the implant was one reason for implant removal.

2.12.15 Postoperative complications of plating

Woo (1976) observed that osteoporosis due to rigid plate fixation occurred by thinning of cortex rather than the reduction of mechanical property of the osseous tissue. Osteopenia under the plates was a well accepted occurrence that causes weakening of bone. Porosis under plate with internal fracture fixation of fractures may occur in response to either altered cortical perfusion or stress shielding.

Wilson (1991) suggested that corrosion of the plate and bone under a plate never became physiologically or biomechanically normal. Cortical osteopenia occurred in the bone directly underneath the plate. Osteopenia appeared related to interference with periosteal blood flow under the plate. Rigid plate prevented the bone from responding to normal physiological stimuli because of elasticity between the bone and the implant. Rigid plate led to thinning of the underlying cortices. This response was called stress protection.

Morgan and Leighton (1995) opined that the fatigue fracture of the plate was one of the most serious complications, resulting from excessive motion at the fracture site with repetitive stress to the plate and occurred in unstable implants subjected to prolonged cyclic loading. The authors also reported synostosis between radius and ulna fracture.

Eugester *et al*. (2004) observed that reduced operating time decreases the risk of infection in their study.

Piermattei and Flo (1997) reported that young animals have more bony turnover as compared to older animals. Malunion was probably related to improper apposition and alignment during fracture repair.

Perren (2002) observed that reduction and alignment of fracture fragments depended on the extent of muscle relaxation, the presence or absence of soft tissue adhesions, type of fracture and time since its occurrence.

Schwandt and Montavon (2005) observed slight valgus following radial fracture repair in their study on locking compression plate fixation of radial and tibial fractures in a six-month-old, male Bernese mountain dog. The authors also observed sudden valgus deformation of the tibia following a short leash walk two days post surgery. The authors reported that this was due to collapse of the fracture and plate bending to an angle of 25° to the lateral side.

Roush and McLaughlin (1999) reported that complications of plate and screw fixation included implant failure, nonunion, malunion, stress protection, lameness in cold weather, infection, implant associated sarcoma and allergic reactions to metals. In most cases, complications resulted from improper implant selection or application, severe disruption of the soft tissue and blood supply to the bone during surgery. Intraoperative break in sterile technique or failure to prevent excessive activity after surgery.

Weese (2008) reported that surgical site infections were an inherent risk in orthopedic surgery. The development and implementation of an infection controlled program, including surgical site infection surveillance could be an important tool for patient management.

Captug *et al.* (2009) reported the complications of long bone fractures management by open reduction with bone plate and screws in 32 cases of dogs and found screw loosening and fixation failure in 9 cases and broken bone plate in 7 cases.

Haaland *et al.* (2009) reported that prophylactic antibiotic medications were not routinely administered to the animals in their study which led to post-operative infection in one case. The site of the infection was not related to the linear locking compression plate and concluded that less invasive surgical approach was found to reduce the infection rate substantially compared to open reduction and rigid fixation techniques in human patients. They also reported a total number of six complications. These consisted of one case of osteomyelitis around an ulnar IM pin and five implant failures. Of the implant failures, four were due to plate fatigue, and one was due to plastic deformation

Filipowicz *et al.* (2009) reported implant failure and was attributed to cyclic deformations which lead to screw loosening and could be dramatic with locking compression plate whose combi-holes are not fully circumferential.

2.13 ESTIMATION OF BONE SPECIFIC ALKALINE PHOSPHATASE

Moss (1987) studied changes in serum alkaline phosphatase that were of main diagnostic importance resulting from increased entry of enzyme into the circulation. The results showed that there was increased osteoblastic activity in bone disease and increased synthesis of alkaline phosphatase by hepatocytes in hepatobiliary disease. The liver and bone forms of alkaline phosphatase were differently-glycosylated forms of a single gene product. Abnormal expression of genetically-distinct alkaline phosphatase isoenzymes was valuable in monitoring cancers, particularly germ-cell tumors in human. These isoenzymes include Regan and Nagao isoenzymes, which corresponded respectively to normal placental and placental-like alkaline phosphatases, and the Kasahara isoenzyme which appeared to result from re-expression of a fetal intestinal alkaline phosphatase gene.

Sanecki *et al.* (1993) developed an assay for the quantification of canine serum alkaline phosphatase of bone origin (BAP). The authors used wheat germ lectin (WGL) to selectively precipitate BAP in serum which was preincubated for 1 hour at 37°C before conducting the assay. Use of these two assay techniques in combination allowed the quantification of LAP, BAP, and CAP activity in canine serum and the sera from adult dogs of various ages, BAP activity represented a mean of 21.27 ± 11.4 U/L, with a small statistical decrease in BAP activity with age.

Jackson *et al*. (1996) reported that bone healing was a local process that had an effect on systemic mineral homeostasis. Total alkaline phosphatase (AP) activity in serum was used to monitor bone metabolism in different species. However, total alkaline phosphatase lacked bone specificity because the total activity in serum was made up of several isoenzymes, of which the liver and bone isoforms predominate.

Allen *et al.* (2000) measured serum levels of BALP in 35 dogs of different ages using two assay techniques , one based on wheatgerm lectin precipitation followed by a simple enzymatic reaction, (the second on a specific enzyme-linked immunoassay). The authors concluded that BALP concentrations decreased with age. The authors reported that there was excellent correlation between the results from the two assay techniques. The correlation between BALP and total ALP activities was poor and indicated that total ALP should be considered unreliable as an indicator of BALP activity in canine serum. The immunoassay demonstrated acceptable (13 per cent) cross-reactivity with the liver isoform of ALP. The authors concluded that though the wheatgerm lectin/enzymatic technique was preferred in situations where the activities of all three isoforms of ALP were required, the immunoassay should be considered whenever the activity of BALP was the focus of interest.

Serial determination of serum ALP activity during fracture healing could be an additional tool in predicting fractures at risk of developing a nonunion, helping the clinician to choose the appropriate intervention (Komenov *et al*. 2005).

Mohamadnia *et al.* (2007) reported that bone ALP activities were significantly increased after surgery (during bone formation) in an experimental radial ostectomy study in sheep dogs. The bridging callus was completed in the fourth week of the experiment, and the gap was fully filled with new bone. However, increased levels of total ALP and bone-specific ALP activity were maintained throughout the study and did not reduce at 4 weeks. The increased intensity was probably associated with increased rate of bone resorption compared to bone formation in the fracture healing period

Paskalev *et al.* (2005) studied the changes in serum concentrations of some bone markers in experimentally-induced normal healing femoral fracture in dogs. The serum samples collected on pre and post operative procedure were subjected for analysis of serum concentrations of total and ionized calcium, inorganic phosphate, total and bone alkaline phosphatase, osteocalcin and carboxy-terrninal telopeptide of collagen type I (ICTP). The authors observed significant alterations in the levels of bone markers and concluded that within a period of one month, the markers of bone resorption were altered whereas the markers of bone formation showed only a tendency towards decrease.

2.14 BIOMECHANICS

2.14.1 FRACTURE BIOLOGY AND BIOMECHANICS

Perren and Rahn (1980) reported that internal fixation of fractures altered the physical environment of living bone. The authors studied the reaction of living bone to the force and motion. Cortical bone did not undergo pressure necrosis when compression was applied in internal fixation which increased the stability of the reduction and led to uneventful healing without resorption whereas inter fragmentary motion produced callus and resorption of the contact surfaces. The static compression applied to cortical bone did not induce a change in the rate of internal remodelling and that the static forces should exceed the dynamic load to maintain close coaptation at the contact surface.

Hulse and Hyman (2003) observed that bones got fractured when extrinsic or intrinsic forces were applied and both elastic (reversible) and plastic (irreversible) deformation occurred before breakage. In an oblique fracture, shear and compression forces predominate and in transverse fracture, rotational or torsion forces predominate.

Fossum (2007) reported that fractures resulted from forces applied to the bone. Bending caused a transverse fracture on the tension side and slight oblique fracture on the compression side of the bone. Axial compression caused an oblique fracture. Combination of axial compression and bending caused oblique comminuted fracture and torsion caused a spiral fracture, whereas high velocity forces caused a comminuted, non-reducible fracture.

2.14.2 SCREW PULLOUT

Radiological measurement 24 weeks after osteotomy of femur in 36 beagle dogs showed cortical thickness reduced by 6% under titanium alloy and 19 % under stainless steel, while histological measurement showed total loss of 3.7% under titanium and 11% under stainless steel. Moreover, unicortical configurations have 50% less rigidity than bicortical purchase (Aro and Chao, 1993).

Lawson and Brems (2001) studied the effect of insertion torque on the holding strength of 4.5-mm ASIF/AO cortical bone screws *in vitro* and determined the screw holding strength using an Instron materials testing machine on lamb femora and human tibiocortical bone sections. The authors tested different insertion torques such as low, intermediate, high, and thread-damaging insertion torque. The authors concluded that screws inserted with thread-damaging torque and single cortex engaging screws inserted to high torque tightening moments showed diminished holding strength and the loss of strength amounted to 40%-50% less than screws inserted with less torque.

Murphy e*t al.* (2001) reported that technique for self tapping screw insertion which emphasized addition of 2 mm to the measured depth of the drilled hole to ensure that the cutting flutes completely exit the trans cortex in bicortical insertion of the screws in both diaphysis and metaphysis of the bone model.

Gautier and Sommer (2003) reported that bicortical screws offer a higher resistance to torque because of their increased working length in their biomechanical study canine cadaveric bone model.

Gordon *et al.* (2010) stated that screws placed in a medio-lateral plane were significantly stronger than screws applied in a cranio-caudal plane and he also reported that the recommended torque for locking screws was 1.5Nm in his biomechanical study on screw pull out.

Demko *et al.* (2008) performed an *in vitro* experimental cadaveric mechanical testing on bone collected from mature dogs weighing between 18–33 kg and compared the axial pull-out strength of 3.5 mm cortical and 4.0 mm cancellous bone screws inserted in the canine proximal tibia using manual and power tapping techniques. 3.5 cortical and 4.0 cancellous bone screws were inserted in canine cadaver proximal tibiae using a manual or power tapping technique. Axial pull-out strength was recorded relative to the total bone width and total cortical width of each tibia. The mean axial pull-out strength for all constructs was 717.8±56.5 N without any statistically significant difference among groups. The axial pull-out strength in proportion to cortical and total bone width was not significantly different among groups and axial pull-out strengths of 3.5 mm cortical and 4.0 mm cancellous bone screws inserted in the proximal tibial metaphysis were not significantly different. The authors concluded that axial pull-out strength was not affected by the use of power tapping in either screw type.

DeTora and Kraus (2008) demonstrated that there were differences in the bending strength between the LCP (Limited Contact Plate), LC-DCP, 3.5 mm Broad LC-DCP (Limited Contact Dynamic Compression Plate), and SOP (String of Pearls) orthopaedic bone plates performing single cycle four point bending test on each orthopaedic implant following the ASTM standard test method to evaluate bending, the most common loading encountered *in vivo*. The area moment of inertia, bending stiffness, bending strength, and bending structural stiffness were calculated for each implant. Significant differences ($p<0.001$) in bending strength and stiffness between the four orthopaedic implants (3.5 Broad LC-DCP>SOP>LCP=LC-DCP) were reported. The 3.5 mm linear locking compression provided *in vivo* strength and stiffness similar to LC-DCP. The SOP provided strength and stiffness that was greater than a comparable LC-DCP but less than a 3.5 mm Broad LC-DCP.

2.14.3 BENDING STRENGTH

Saha *et al.* (1977) studied the mechanical properties of canine long bones and reported that the mean and standard deviation of the maximum load supported by six fresh canine femurs in 3-point bending was 1366±253 N. All the bones sustained a considerable amount of plastic deformation before failure. The mechanical property such as the modulus of elasticity (GN/m2), ultimate tensile stress (MN/m2) and yield stress (MN/m2) were 13.86, 108.3 and 88.3 for humeral specimens and 13.88, 142.1 and 104.0 for tibial specimens, respectively.

Brooks *et al.* (1970) reported that screw hole could significantly weaken bone and would influence the behavior of the fracture.

Wolcott and Himel, (1997) reported that stainless steel did not have any significant difference between maximum torque and torque at failure, whereas titanium showed a significant differential between maximum torque and torque at failure in their study.

Gautier and Sommer (2003) who reported that longer the plates provided more stability because of less pull out force acting on the screw.

Stoffel *et al*. (2003) stated that omitting one hole one each side of the fracture improved flexibility by 60% in compression and 30% in torsion. The authors also suggested that long plates should be used to optimize axial stability and that the plastic deformation of the plate was significantly reduced when the screws closest to the fracture site are removed. This results because the working length of the plate was increased and more flexibility was tolerated. The screw placement, number of screws used and plate length influenced the construct stiffness and amount of motion at the fracture.

Gardner *et al*. (2005) reported that hybrid constructs were mechanically similar to locked constructs, and both are significantly more stable than unlocked constructs under torsional cyclic loading.

Gardner *et al*. (2005) reported that the bending strength of bone might be influenced by the composite and isotropic nature of material, ductility, resistant to fatigue failure and increased stiffness of the implant compared to the orthopaedic implants.

Fulkerson *et al,* 2006 compared locking plates to conventional compression plate fixation for diaphyseal fractures based on cyclic loading and three point bending tests. The authors reported that significantly less displacement occurred after axial loading with bicortical locked screws than with bicortical nonlocked screws. Increased distance of the plate from the bone surface, and use of unicortical locked screws led to early failure with cyclic loading for constructs with locked screws. It was inferred from the study that plating with bicortical locked screws can be used as an alternative to conventional plating for comminuted diaphyseal fractures in osteoporotic bone.

Roberts *et al*, (2007) conducted trials on biomechanical evaluation of locking plate radial shaft fixation comparing unicortical locking fixation and mixed bicortical and unicortical fixation in a saw bone model. The authors concluded that replacing a single set of unicortical locked screws with locked or unlocked bicortical screws distant from the fracture site improved torsional stability of the construct by more than 50%, providing stability equal to standard unlocked plating. The hybrid fixation, with locked bicortical end screws has the best stability in anterio-posterior bending. The authors also stated that constructs compose entirely of locking unicortical screws was significantly weaker in torsion than locking bicortical screws.

Maxwell *et al.* (2009) reported that reasonable estimate of physiological load would be 60% of the dog's total body weight, or less than 150 Newton for dogs weighing 25 kg or less in normal weight bearing dogs.

Filipowicz *et al.* (2009) compared 3.5 locking compression plate (LCP) fixation with 3.5 limited contact dynamic compression plate (LC-DCP) fixation in a canine cadaveric distal humeral metaphyseal gap model. The authors concluded that humeral constructs stabilized with linear locking compression plates were significantly stiffer than those plated with LCDCP when loaded in static axial compression and the linear locking compression plate constructs were significantly less stiff than the LC-DCP constructs when they were subjected to load in axial compression. Constructs plated with linear locking compression plates were significantly less resistant to torsion over 500 cycles than those plated with LC-DCP. The increased stiffness of linear locking compression plate constructs in monotonic loading compared to constructs stabilized with non-locking plates may be attributed to the stability afforded by the plate-screw interface of locking plates. The authors also reported that screws were no longer allowed to toggle when the locking compression plate construct was subjected to an axial load, bone at the screw bone interfaces was subjected to a compressive force. The linear locking compression bone plate construct maintained its rigidity until yield load was reached. This yield load was thirteen and half times greater than the average body weight of the dog.

3. MATERIALS AND METHODS

The study was carried out in 22 dogs of different breeds of either sex and body weight ranging from 10 to 30 kgs presented to the Small Animal Orthopedic Unit of the Madras Veterinary College Teaching Hospital, over a period of two years. Clinical cases presented with the history of lameness and clinical symptoms suggestive of unstable diaphyseal or metaphyseal fractures involving the humerus, radius and femur were considered for the study.

3.1 INCIDENCE

Data regarding the incidence of diaphyseal or metaphyseal fractures involving the humerus, radius and femur presented to the Small Animal Orthopedic Unit of the Madras Veterinary College Teaching Hospital between January 2009 and December 2010 were collected and the breed, sex, age and location of fractures involving the humerus, radius and femur were recorded and analyzed.

3.2 ETIOLOGY

A detailed history of the etiology of fractures in the 22 cases studied were elicited.

3.3 DESIGN OF STUDY

Dogs presented with the history and clinical signs suggestive of femur, humerus and radius fractures were subjected to detailed physical, orthopaedic and radiographic examination to confirm the diagnosis. Of the animals screened, 22 animals with unstable diaphyseal or metaphyseal fractures of femur, humerus and radius fractures, free of other concurrent neurological, metabolic or infectious diseases were considered for the study. The cases were subjected to detailed orthopaedic examination to determine a tentative diagnosis.

TYPES OF FRACTURE	**NO. OF CLINICAL CASES**	**CASE DISTRIBUTION**	
Unstable diaphyseal long bone fractures (Humerus, Radius and Femur)	13	Humerus	n = 3
		Radius	n = 4
		Femur	n = 6
Unstable metaphyseal long bone fractures (Humerus, Radius and Femur)	9	Humerus	n = 3
		Radius	n = 3
		Femur	n = 3
TOTAL	**22**		

3.4 FRACTURE PATIENT ASSESSMENT SCORE (FPAS)

Fracture Patient Assessment Score (FPAS) was followed for preoperative decision making. The assessment was carried out using a 1 – 10 scoring system as described by Palmer (2000). Fracture patient assessment score considered the mechanical, biological and clinical factors involved in fracture management.

3.5 PRE OPERATIVE RADIOGRAPHIC EVALUATION

The fractured limb was subjected to lateral and craniocaudal views to evaluate diaphyseal fractures of humerus, radius and femur, lateral and craniocaudal views to evaluate metaphyseal fractures of humerus and radius and lateral and craniocaudal views to evaluate metaphyseal fractures of femur.

3.6 FRACTURE CLASSIFICATION

3.6.1 Fracture of Humerus

The diaphyseal fractures of humerus were classified as 12-A (diaphyseal, simple or incomplete), 12B (diaphyseal, wedge) and 12C (diaphyseal, complex).

12A, 12B and 12C were further subclassified as incomplete (A1), oblique (A2) and transverse (A3); one reducible wedge (B1), several reducible wedges (B2), non-reducible wedges (B3) for diaphyseal fractures and reducible wedges (C1), segmental (C2), and non-reducible wedges (C3) for metaphyseal fractures respectively.

3.6.2 Fracture of Radius

The diaphyseal fractures of radius were subclassified as 22-A (diaphyseal, radial incomplete simple), 22-B (diaphyseal, radial wedge) and 22-C (diaphyseal, radial complex). 22-A, 22-B and 22-C were further classified as incomplete or of one bone only (A1), simple, distal zone (A2) and simple, proximal zone (A3); with simple ulnar fracture (B1), distal zone, multifragmentary ulnar (B2), proximal zone, multifragmentary ulnar (B3) and with ulnar simple or wedge fracture (C1), segmental radial, complex ulnar (C2), and complex ulnar (C3) respectively.

3.6.3 Fracture of Femur

The diaphyseal fractures of femur were classified as 32-A (diaphyseal, simple or incomplete), 32-B (diaphyseal, wedge) and 32-C (diaphyseal, complex). 32-A, 32-B and 32-C were further classified as incomplete (A1), oblique (A2) and transverse (A3); one reducible wedge (B1), several reducible wedges (B2), non - reducible wedge (B3) for diaphyseal fractures and reducible wedges (C1), segmental (C2), and non- reducible wedges (C3) for metaphyseal fractures respectively.

3.7 PRE OPERATIVE PLAN

A pre operative plan was prepared using a small animal preoperative planning guide developed by the AO/ASIF (Small animal group) using plain radiographs. Preoperative lateral radiograph of the contralateral limb was used to determine the diameter and length of the plates and the craniocaudal view was used to determine the diameter and length of the screws (Plate 1). The proximal fracture fragments were first traced on the transparent tracer paper (Plate 2) and distal fracture fragments were traced subsequently (Plate 3). A vertical line was drawn on separate tracer sheet and the fracture was reduced by laying each of the fragments tracing over the straight line tracing and a final composite drawing was made on the sheet. The template of appropriate implants was added to the composite drawing to get the final fracture reduction and based on the final drawing, the implants were selected (Plate 4).The size of the plate and the number of screw holes in the plate were selected based on the weight of the animal and length of the bone (Brinker, 1984).

3.8 INCIDENCE OF FRACTURES:

Incidence of fractures, etiology and limb involved are represented in Table 1, 2 and 3.

3.9 INSTRUMENTATION AND IMPLANTS

Table 1. Fracture of Humerus – Case study

CASE No.	BREED	AGE	SEX	BWT (Kg)	CAUSE	FRACTURE TYPE AND LIMB
1	German Shepherd	9 Months	Male	25	Road traffic Accident	Unstable oblique diaphysis - Rt. humerus
2.	Mongrel	3 Years	Male	15	Fell down from height	Unstable oblique diaphysis - Lt. humerus
3	Doberman	3 Years	Male	30	Unknown	Unstable oblique diaphysis – Rt. humerus
4	Mongrel	2 Years	Male	15	Road Traffic Accident	Unstable transverse metaphysis - Rt. humerus

5	Rajapalayam	8 Months	Male	15	Road Traffic Accident	Unstable transverse metaphysis - Rt. Humerus
6.	Doberman	5 Months	Male	15	Fell down from height	Unstable transverse metaphysis -Lt. humerus

Table 2. Fracture of Radius - Case study

CASE No.	BREED	AGE	SEX	BWT (Kg)	CAUSE	FRACTURE TYPE AND LIMB
7.	Doberman pinscher	4 Months	Female	15	Fell down from a height	Unstable transverse metaphysis - Rt.Radius ulna
8.	Mongrel	2 Years	Female	18	Road Traffic Accident	Unstable transverse diaphysis - Rt. Radius ulna
9.	Rajapalayam	8 Months	Female	15	Unknown	Old fracture, Malunion diaphysis - Rt. Radius ulna
10.	Sptiz	3Years	Male	10	Fell down from a height	Unstable transverse diaphysis - Rt. Radius ulna
11.	Mongrel	3 Years	Male	15	Road traffic Accident	Unstable transverse metaphysis - Rt. Radius ulna
12.	German shepherd	6 Months	Female	12	Slipped on the floor	Unstable transverse metaphysis - Lt. Radius ulna
13.	Golden Retriever	3Years	Male	30	Fell down when Playing	Unstable transverse diaphysis -Rt. Radius ulna

Table 3. Fracture of Femur - Case study

CASENo.	BREED	AGE	SEX	BWT (Kg)	CAUSE	FRACTURE TYPE AND LIMB
14.	Doberman	8 Male	Female	20	Fell down when Playing	Unstable transverse diaphysis - Lt.Femur
15.	Doberman	3 Years	Female	18	Road Traffic Accident	Unstable short oblique metaphysis- Rt.Femur
16.	Mongrel	8 Male	Female	15	Road Traffic Accident	Unstable transverse diaphysis - Lt.Femur
17.	Dalmatian	3 Years	Female	25	Slipped on the floor	Unstable multiple supra condylar - Lt.Femur
18.	German shepherd	1 Years	Male	28	Road Traffic Accident	Unstable transverse diaphysis - Lt.Femur
19.	Golden Retriever	10 Male	Male	17	Slipped on the floor	Unstable transverse diaphysis - Rt. Femur
20.	Doberman	1 Years	Male	18	Road Traffic Accident	Unstable long oblique diaphysis - Lt.Femur
21.	Mongrel	1 Years	Male	17	Unknown	Unstable transverse diaphysis – Rt. Femur
22	Mongrel	1 Years	Male	15	Unknown	Unstable short oblique metaphysis – Rt. Femur

3.9.1 INSTRUMENTATION

A standard orthopedic set (Plate 5), a general surgical instrumentation set and an AO/ASIF plate instrumentation set (Plate 6) were used in the study**.**

3.9.2 IMPLANTS

3.9.2.1 Locking Condylar Plates

In the present study, Locking condylar plates were manufactured with surgical grade 316L stainless steel metal alloy. The 3.5 mm locking condylar plates were 55mm long, 15mm wide and 3.5m thick and had longitudinal flat ventral surface (Plate 7). A 3.5 mm locking condylar plate with nine threaded plate holes, 6 on the vertical proximal portion of the plate in a combi hole pattern and 3 on horizontal distal portion of the plate with round hole pattern were used in the study. Self tapping locking screws with 3.5mm cortical diameter (Plate 8) to fit into the threaded condylar plate holes were used. Lateral condylar locking plates were selected based on the size of the distal condyle and body weight of the dog.

3.9.2.2 Locking ‘T’ plates

In the present study, Locking ‘T’ plates were manufactured with surgical grade 316L stainless steel metal alloy. The 2.7mm locking ‘T’ plates were 60mm long, 15mm wide and 2.7mm thick and had longitudinal flat ventral surface (Plate 9). 2.7 mm locking head screw for 2.7 mm locking ‘T’ plates were developed for the study. Locking ‘T’ plates were selected according to the size of the radius and body weight of the dog.

3.9.2.3 Linear Locking Compression Plates

Linear locking compression plates manufactured from 316L stainless steel metal alloy were used in this study. The 4.5 mm thickness, 3.5 mm thickness and 2.7 mm thickness plates were developed. Plate selection was based on the body weight of the dog, configuration of fracture and size of the bone involved. The 4.5mm linear locking compression plates had 12 combi holes and were 20mm width and 140mm in length (Plate 10). The 10 hole and 12 hole 3.5 mm linear locking compression plates and 8 hole and 10 hole 2.7mm locking plates were used in the study. The 3.5mm plate had 15 mm width and 140 mm in length for 10 hole plate and 15mm width and 160 mm length for 12 hole plate (Plate 11). The 2.7mm plate had a 15 mm width and 120 mm length for 8 hole plate and 15mm width and 140 mm length for 10 hole plate (Plate 12). All plates had a ventral flat surface and were scalloped. The diameters of the locking and non locking side of the combi hole were manufactured based on standard AO/ASIF recommendation (Wagner and Frigg, 2006).

3.10 SURGICAL TECHNIQUES

3.10.1 Patient preparation

In all the dogs, feed was withheld for 12 hours before surgery and water was provided until four hours prior to surgery.

3.10.2 Preparation of surgical site

The affected limb was prepared by clipping the surgical site from greater tubercle of the humerus proximally to distal epicondyle of both lateral and medial side of the limb for humerus (Plate 13), from elbow joint to carpal joint on both medial and lateral side of the limb for radius (Plate 14) and from greater trochanter to distal condyles of both medial and lateral side of the limb for femur (Plate 15). The surgical site was initially scrubbed with povidone iodine scrub (7.5% w/v) followed by a sterile scrub with 70% alcohol.

3.10.3 Premedication and Anaesthesia

The dogs were premedicated using atropine sulphate[1] at the dose rate of 0.04 mg/kg b.wt intramuscularly followed by xylazine hydrochloride[2] at a dose rate of 1 mg/kg b.wt intramuscularly. General anesthesia was induced using ketamine hydrochloride[3] at a dose rate of 5 mg/kg body weight intravenously and diazepam[4] at a dose rate of 0.2 mg/kg b.wt intravenously. Anaesthesia was maintained with administration of required concentration (2%-3%) of Isoflurane[5] using a Boyle's anesthetic machine. Cefotaxime[6] and Meloxicam[7] were administered intravenously at a dose rate of 20 mg/kg b.wt and 0.2 mg/kg b.wt intravenously respectively intraoperatively 30 minutes prior to induction.

3.10.4 Positioning of the Animal

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[1] Atropine sulphate	Mount Mettur Pharmaceuticals Ltd, Tamil Nadu
[2] Xylaxine hydrochloride	Indian Immunological Ltd, AndhraPradesh.
[3] Ketamine hydrochloride	Mount Mettur Pharmaceuticals Ltd, Tamil Nadu.
[4] Diazepam	Biochhem Pharmaceuticals Ltd, Mumbai.
[5] Forane	Abbott Laboratories Ltd, Queen borough, Kent, Meft,5EL, England
[6] Cefotaxime (Zovitax)	Parenteral Drug Ltd, Himachal Pradesh.
[7] Meloxicam (Melonex)	Sarabhai Zydus Pharmaceuticals Ltd, Ahmedabad.

In cases involving open reduction and internal fixation of diaphyseal fractures of humerus (Plates 16) and diaphyseal and supracondylar fractures of femur (Plates 17), the animal was placed in lateral recumbency with the affected limb placed uppermost on the operating table. In cases involving open reduction and internal fixation of distal fractures of radius, the animal was placed in dorsal recumbency with the affected limb placed in extension (Plate 18). In cases involving open reduction and internal fixation of diaphysis of the radius, the animal was placed in lateral recumbency with the affected limb placed on the operating table with the medial aspect of the limb facing the surgeon (Plate 19). The distal portion of the limb was covered with a sterile wrap using elastocrepe and the surgical site was draped as per standard protocol.

3.11 SURGICAL APPROACHES

3.11.1 SURGICAL APPROACH TO THE HUMERUS

3.11.1.1 Surgical approach to the diaphysis of the humerus

The fracture site was exposed by a craniolateral approach to the shaft of the humerus. A longitudinal skin incision was made along a line extending from the greater tubercle of the humerus proximally to the lateral epicondyle distally following the craniolateral border of the humerus (Plate 20). Subcutaneous fat and brachial fascia was incised along the lateral border of the brachiocephalicus muscle and distally over the cephalic vein (Plate 21). The radial nerve at the lower third of the humerus was located between the lateral head of the triceps and brachialis muscles and was isolated and protected. The brachiocephalicus muscle was reflected cranially and the brachialis muscle was reflected caudally to expose the shaft of the humerus (Fossum *et al.* 1994).

3.11.2 SURGICAL APPROACH TO THE RADIUS

3.11.2.1 Surgical approach to the diaphysis of radius

A linear skin incision was made on the medial aspect of the radius at the level of the fracture (Plate 22). The subcutaneous tissues and common digital extensor and extensor carpi radialis muscles (Plates 23) were separated by blunt dissection to expose the fracture fragments (Piermattei and Greeley, 1993a).

3.11.2.2 Surgical approach to the metaphysis of radius

The craniomedial surface of the distal radius was palpated to serve as landmark for location of the incision. The skin and subcutaneous tissue were incised dorsally from distal radial diaphysis to the proximal metacarpus. The cephalic vein was identified and protected. The common and lateral digital extensor muscles and tendons were retracted. The extensor tendons was laterally elevated and retracted as required for the fracture visualization (Plate 24).

3.11.3 SURGICAL APPROACH TO THE FEMUR

3.11.3.1 Surgical approach to the diaphysis of the femur

The fracture site was approached by making a cranio-lateral incision. A linear skin incision was made along a line extending from the trochanter major to the lateral surface of the patella (Plate 25). The subcutaneous tissues were divided bluntly and tensor fascia lata was exposed. The attachments of the cranial border of the biceps femoris muscle with tensor fascia lata was severed to expose the vastus lateralis muscle cranially and biceps femoris muscle caudally (Plate 26). The belly of the biceps femoris muscle was reflected caudally and vastus lateralis and fascia lata were reflected cranially. The intermuscular septum between the two muscles was divided to expose the fractured fragments (Piermattei and Greely, 1993b).

3.11.3.2 Surgical approach to the distal femur

Metaphyseal femur fractures were approached through a standard lateral approach to the femoral shaft combined with a lateral approach to the stifle (Plate 27). An incision was made through the fascia lata followed by retraction of biceps femoris caudally and vastus lateralis and fascia lata cranially. The fascia lata incision was continued distally over the lateral side of the stifle and arthrotomy was performed to visualize the distal femur.

3.11.4 FRACTURE REDUCTION

The fracture fragments were exposed using Hohmann retractors (Plate 28) with minimal separation of attached soft tissues. The ends of the fragments were debrided using a Liston bone cutter (Plate 29). Periosteal elevator was used to remove redundant soft tissue

(Plate 30). Fracture reduction was carried out using serrated reduction forceps and held in apposition in femur (Plate 31) and in distal radius (Plate 32).

3.11.5 PLATE AND SCREW FIXATION

AO/ASIF principles were followed for plate fixation (Brinker, 1984). The 2.7mm linear locking compression plate was used in dogs weighing between 10 and 15 kgs and 3.5 mm linear locking compression plate was used in dogs weighing between 15 and 30 kgs. Unstable distal metaphyseal fractures of radius were stabilized with 2.7mm locking compression 'T' plate. Unstable distal metaphyseal fractures of femur were stabilized with 3.5mm locking condylar plate. A neutral thread hole was drilled on the proximal and distal bone fragments (Plate 33) through both the cortices to correspond to the first and last screw hole in the plate. A 2.0 mm drill bit for 2.7 linear locking compression plate, and a 2.7mm drill bit for 3.5mm linear locking compression plate was placed through the locking drill sleeve and drilled using a electrical bone drill for linear locking compression plate (Plate 34) and locking 'T' plate (Plate 35) respectively. During drilling, sterile normal saline was used to irrigate the site to cool the drill bit and to flush the debris and to prevent thermal necrosis. The length of the hole was measured with a depth gauge (Plate 36). The linear locking compression plate was fixed to the bone at the proximal and distal screw hole with 3.5 mm locking screws for 3.5mm linear locking compression plate or 2.7mm locking screws for 2.7mm linear locking compression plate, 1 to 2 mm longer than the measured length in such a way that the screw positioned the plate close to the bone and was locked at locking hole of the linear locking compression plates using appropriate hexagonal screw driver (Plate 37a). A similar technique was adopted for fixing the locking 'T' plate in distal radial fractures (Plate 37b) and condylar locking plate in supracondylar fractures.

The screws were not fully tightened. Using corresponding eccentric drill guide, the gliding hole close to the fracture was drilled through both the cortices of the fragments (Plate 38a). A similar technique was followed for locking 'T' plate fixation (Plate 38b) and condylar locking plate fixation. 3.5 mm locking screws for 3.5 mm plate or 2.7mm locking screws for 2.7mm plates were inserted and tightened using a hexagonal screw driver of size 3.5mm and 2.7mm respectively compressing the fracture.

The remaining locking screw holes in the plate were drilled, the depth measured and 3.5 mm or 2.7mm locking screws were inserted based on the size of the plate. In some cases, unicortical screws were applied at locking screw holes in the proximal or distal cortex. Finally, all the screws were tightened on the proximal and distal fragments alternately using corresponding 3.5 mm or 2.7 mm hexagonal screw driver. A minimum of two screws in the proximal and three screws in the distal fragment were inserted for linear locking compression plate (Plate 39). This procedure was performed for all cases of unstable diaphyseal fractures of humerus, radius and femur. Unstable distal radial fractures were stabilized with 2.7mm locking ‘T’ plate in dogs weighing between 10 and 15kgs (Plate 40) and unstable metaphyseal fractures of femur was stabilized with 3.5mm locking plates in a dog weighing 20kgs (Plate 41). Comminuted fractures were buttressed without interfragmentary compression. Ancillary fixation with cerclage wiring (Plate 42) or intramedullary pins were used depending on the fracture configuration.

In cases subjected to open reduction and internal fixation with locking ‘T’ plate, the horizontal part of the plate was placed first on the distal fragment, and central locking hole was filled with appropriate sized locking head screw. The upper vertical portion of the implants was placed over the proximal fracture fragment and the locking screws were placed and screws tightened alternatively to stabilize the fracture fragments.

In cases subjected to open reduction and internal fixation with locking condylar plate, the horizontal part of the plate was placed first on the distal fragment. The upper vertical portion of the plate was placed over the proximal fracture fragment. The locking screws were placed first on the distal fragment and then on the proximal fragment. The locking screws were tightened alternatively to stabilize the fracture fragments in position.

3.12 C-ARM IMAGE INTENSIFIER

The C-arm image intensifier is a ‘C’ shaped mobile X-ray television system (Multimobil 5C: Siemens Ltd, Medical Solutions Division, and Goa, India). It is a high frequency imaging system with 230mm diameter image intensifier and voltage between 40-110 kV at variable tube currents between 0.5 to 5 Amps (Plate 43).

The main control unit with mobile trolley contains an operating console, lifting column, trigram and holder for C-arm image intensifier tube with CCD (charge coupled device) camera and H.F (high frequency) single tank with iris collimator. The X-ray tube has a stationary anode with a nominal kV of 110kV. There are two monitors, one each for live/ last image hold (LIH) and stored memory display with a temporary storage capacity of up to four images. The unit is connected to a desktop computer in which the images are stored using iMagic software, and it can be exported and further processed. The C- arm table can be tilted up or down, left or right when connected to electrical power supply.

3.13 CLOSURE OF THE SURGICAL WOUND

3.13 .1 Humerus

The triceps and brachialis muscles were isolated and sutured with No. 1 PGA. The brachiocephalicus muscle and brachialis muscle were sutured using No.1 PGA in a continuous suture pattern. Subcutaneous facia was sutured with No1 PGA in a continuous suture pattern. The skin was sutured with No1 black braided silk in a cruciate pattern (Plate 44).

3.13.2 Radius

The extensor carpi radialis and common digital extensor muscles were apposed using No. 1 PGA in a continuous suture pattern. Subcutaneous fascia was closed using No.1 PGA in a continuous suture pattern. Skin was sutured with No. 1 black braided silk in a cruciate suture pattern (Plate 45).

3.13.3 Femur

The vastus lateralis and biceps femoris muscle were opposed using No 1 PGA in a continuous suture pattern. The tensor fascia lata was opposed with No 1 PGA in a simple continuous pattern. Subcuticular sutures were applied in continuous pattern using No 1 PGA. Skin was opposed with No 1 black braided silk in a cruciate pattern (Plate 46).

3.14 POST OPERATIVE CARE AND MANAGEMENT

The animals were kept under observation on the floor in a well ventilated room with its neck in extended position until complete recovery from anesthesia. The animal’s movements were restricted until complete recovery. A modified Robert Jones bandage (Plate 47) was applied from the digits up to proximal joint of fractured bone (Elbow/stifle) and changed periodically every week for six weeks. An Elizabethan collar was applied to prevent disturbance of the bandage and protect the surgical site. Ice packs were applied over the surgical site for 10 minutes four times daily immediately after surgery for the first 24 hours followed by warm packs for the next 24 hours.

Post operatively, a combination of Ceftriaxone and tazo bactam and Meloxicam were administered at a dose rate of 20mg/kg and 0.1mg/kg body weight intravenously for five days. Animals were allowed limited exercise with short duration leash walk for 4-6 weeks. Sutures were removed on the 10th post operative day. Passive exercises of the affected limb was performed twice daily during the convalescent period from second week post surgery.

3.15 IMPLANT REMOVAL

Implants were removed under general anesthesia in cases which had good functional outcome with evidence of bony union under plain radiographs. Implants were also removed in failed fixations. Skin incision was made over the palpable plate and the implant was removed using the appropriate hexagonal screw driver. (Plate 48) The incision was closed with No.1 black braided silk in a cruciate pattern. Modified Robert Jones bandage was applied for two weeks following implant removal.

3.16 PARAMETERS EVALUATED

3.16.1 CLINICAL EVALUATION

3.16.1.1 Evaluation of body condition, range of motion, limb girth and limb length

The evaluation was based on subjective assessment. Body condition, range of motion, limb girth and limb length were recorded in all the cases. Body condition was evaluated using the Hills pet nutrition body scoring system and classified as thin, fair good or obese. The range of motion was evaluated by hyperflexion and hyperextension of the affected limb and graded as normal, increased or decreased. The limb girth was graded as mild increase, if circumference of fractured limb was greater than 1cm as compared to normal contralateral limb, graded as moderate increase, if circumference of fractured limb was greater than 2cm as compared to normal contralateral limb, graded as severe increase, if circumference of fractured limb was greater than 3cm as compared to normal contralateral limb. The limb length was graded normal if the fractured limb had the same length as the normal contralateral limb, was graded as decreased if the fractured limb was shorter than the normal contralateral limb.

3.16.1.2 Lameness grade (Braden and Brinker, 1973)

A lameness grade was assigned on the basis of severity of clinical signs on day 0, 15th day, 30th day, 45th day and 60th day in all animals to assess the response to treatment. Weight bearing was graded as follows:

Grade 1	-	Normal weight bearing on all limbs at rest and when walking
Grade 2	-	Normal weight bearing at rest, favored affected limb while walking.
Grade 3	-	Partial weight bearing at rest and while walking.
Grade 4	-	Partial weight bearing at rest and does not bear weight on affected limb when walking.
Grade 5	-	Does not bear weight on limb at rest or when walking.

3.16.1.3 Functional outcome (Roush and McLaughlin, 1999)

Based on periodical clinical examinations at 15th , 30th , 45th and 60th post operative day, the functional outcome was assessed for the animals as excellent, good, fair and poor.

3.16.1.4 Radiographic evaluation

The affected limb was radiographed in lateral and cranio-caudal views to evaluate diaphyseal and metaphyseal fractures of humeral, diaphyseal fractures of radial and diaphyseal and metaphyseal femoral fractures. Craniocaudal views were taken to evaluate distal radial fractures preoperatively, immediate post-operative day, and 15th 30th, 45th and 60th post operative days. Periodical radiographic evaluation for alignment, implant stability and biological activity were evaluated to assess the progress of fracture healing. The radiographs were taken using a Siemens 500 mA 3 phase 6 pulse x ray generator at focal film distance of 100 cm using 50-60 kVp, 70-80mA and 8 to 16 mAs.

Radiographic evaluation was carried out based on four ‘A’s (Apposition, Alignment, Angulation and Apparatus) on immediate post operative day and follow up radiographs on 15th post operative day, 30th post operative day, 45th post operative day and 60th post operative day based on six ‘A’ s(Apposition, Alignment, Angulation, Apparatus, Activity and Architecture)(Langely-Hobbs,2003).

The score for Apposition and Alignment (0-3) was recorded (Cooks *et al*, 1999).

0-Anatomical reduction

1-Minimal (< 1mm) malreduction

2-Moderate (< 1-3mm) malreduction

3- Severe (> 3mm) malreduction

3.17 BIOCHEMICAL EVALUATION

Bone specific serum alkaline phosphatase (BALP) was estimated using SenoLyte FDP Alkaline Phosphatase Assay Kit by fluorimetric method (Plate 49).

3.17.1 Collection and testing of serum samples

Cephalic venous blood samples were collected into sterile tubes and allowed to clot. All samples were collected in the morning to minimize the possibility of diurnal variation in BALP activity and specimens were processed within 30 minutes of collection. The tubes were centrifuged at 2000 rpm for 10 minutes and the serum decanted into two 2 ml polypropylene cryovials. Serum samples were frozen and stored at –20°C until assayed. All the serum samples were assayed in one batch. Bone specific serum alkaline phosphatase was estimated on preoperative and 45th post operative day. The signal of fluorescence was read by a Ultra Violet Visible Near Infrared[1] (UV-VIS-NIR) spectrophotometer and Photo luminescence reader[2] at 405 nm.

3.17.2 Procedure for Estimation of Bone Specific Alkaline Phosphatase

All the kit components were warmed to room temperature before starting the estimation.

FDP stock solution was prepared by adding 250 µL of DMSO (component F-500 µL) into the FDP vial (component A- 1 vial) and the reagents were mixed well. This stock solution was stored at -20°C in a dark room.

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1. Cary 5E UV-VIS- NIR Spectrophotometer
2. Florolog Photo Luminescence Reader

FDP reaction mixture was prepared by diluting FDP stock solution (component A) 1:100 with 2X assay buffer (component B – 30 ml) and this mixture was kept away from light. Fresh reaction mixture was prepared for each estimation.

3.17.3 Detection of alkaline phosphatase activity:

50 µL of each pre operative serum sample to be estimated was added to the sterile test tube and labelled appropriately. The 45th post operative day serum sample to be estimated was also prepared in the same way and labelled appropriately. 50 µL of FDP reaction mixture was added to all the serum samples after thawing to room temperature. Reagents were mixed thoroughly by gently shaking the test tubes for 30 seconds and incubated for 15 minutes at room temperature in a dark room and subjected for measurement for fluorescence signal. 10 µL of each sample from incubated test tubes were transferred to absorbance cuvette (Plate 50) and three fourth of the volume of the cuvette was filled with normal saline solution. The samples were subjected for absorbance reading. Fluorescence intensity (optical density values) was measured at 405nm using UV-VIS-NIR Spectrophometer[1] (Plate 51). Emission / excitation was performed in the Photo Luminescence Reader[2] (Plate 52). The fluorescence reading from the pre operative samples were compared with post operative samples to provide a qualitative assessment of fracture healing.

3 .18 BIOMECHANICAL EVALUATION

Various biomechanical testing procedures were done to determine the different properties of bone, bone plate and bone plate construct. A tabletop Instron Universal Testing Machine was used to perform these tests (Plate 53). Custom made fixtures were used to hold the bones for the respective tests in the testing machine. A pilot study was carried out initially using syn bones to standardize the testing procedures (Plate 54).

3.18.1 COLLECTION, PREPARATION AND PRESERVATION OF CADAVER BONE

Three pairs of canine humerus, radius and femur bones were collected from adult medium to large breed mongrel dogs of either sex and body weight (Range from 13- 19.5 kg) of unknown age immediately from animals euthanized for reasons not related to this study . The cadavers were donated by the humane society. The cadaver limbs were harvested with soft tissue attached. The major external musculature was removed to the level of both extremities and was stripped of soft tissue. Orthogonal radiographs were taken of the bone to ensure skeletal maturity and to rule out bone deformities or any pre-existing pathology. The bones were double bagged and fresh frozen at –20^0 C. Each bone was sequentially thawed for 12 hours in water at room temperature, plated and subjected to mechanical testing.

3.18.2 DESCRIPTION OF UNIVERSAL TESTING MACHINE

Name of the machine : Instron

Software : Bluehill

Model : K-3367

Temperature Range : -70 ° C to 250 ° C

Maximum Load : 30kN

3.18.3 AXIAL PULL-OUT STRENGTH

3.18.3.1 Fixture/Device for screw pullout strength

A custom made fixture to hold the bone during screw pull out test was designed and manufactured using 316L stainless steel alloy (Plate 55). The bones were clamped between two adjustable ‘V’ block plates (Plate 56).

3.18.3.2 Bracing of locking screw

3.5 mm locking screws were selected for the test. Bracing of locking screw was performed at 450^{0}C. A hexagonal Allen key made of iron was used to brace with the head of the locking screw (Plate 57). The length of the projected Allen key from the locking screw was 20 mm and was fixed to the dorsal plate of the universal testing machine for the testing procedure (Plate 58).

3.18.3.3 Selection of bone, bone plates and screws

Screws were inserted into metaphyseal and diaphyseal region of cadaveric canine femur at the rate of 3 r/min to a depth of 20 mm for the purpose of evaluating screw pullout strength (POS). A standard AO/ASIF technique was used for plate and screw fixation. Pilot holes were drilled in the bone using 2.7 mm drill bit to match the screw minor diameter followed by hand insertion of screws using torque screw driver (TSD - 15) with a torque ranging from 0.1 – 1.5 Newton Meter (Plate 59). To be consistent with the standard clinical technique for insertion of screws into the bone, the holes were not tapped.

3.18.3.4 Screw pull out test on bone plate construct

The test was performed on six canine humerii. A 9 hole 2.7mm linear locking compression plate was applied to the cranio lateral surface of canine cadaveric humeri. Pilot holes were drilled using a 2.5mm drill bit. 2.7mm locking screws with braced Allen key was inserted using a torque screw driver bicortically in to the bone to a depth of 20mm set to a maximum torque of 1.5Nm. A single screw was inserted into each bone, one at metaphyseal and one at diaphyseal region. All the screws were individually subjected to axial screw pull out strength using an Instron Universal Testing machine at speed rate of 1mm per minute (Plate 60). The load and displacement data were recorded and plotted on a graph. All testing parameters were according to the Standard Specification and Test Methods for Metallic Medical Bone Screws ASTM F 543-07 (ASTM Designation: F 1691-96, 1996).

3.18.4 BENDING STRENGTH:

3.18.4.1 Three-point bending test

Axial compression tests were performed on a servo hydraulic testing machine in displacement control (static testing) or load control (dynamic testing). Six canine cadaveric femurs were tested in axial compression until failure which was defined as the first point of major discontinuity in the load versus displacement curve. After an initial preload of 1.5N was applied, compression was applied at 5mm/min with data capture set at 10Hz. Load versus deformation curves were generated and recorded and strength at failure was evaluated.

3.18.4.2 Mechanical testing to evaluate bending strength of the bone

The test was performed on six canine femorii. Canine cadaveric femurs were tested in three-point bending method using Instron universal testing machine. A custom made fixture for three point bending test was designed and manufactured with two loading points, 50 mm apart from each other (Plate 61). The femurs were positioned horizontally with the anterior surface upwards and centered on supports on the stage of the testing machine. The bones were compressed at the femoral mid shaft using a constant compression speed of 1 mm/min (Plate 62). The pressing force was directed vertically to the airshaft of the bone and compressed until failure. The bending breaking force was defined as the maximal bending load at failure. The load vs deformation curve was recorded and the load at failure upon bending was determined. The strength of the femoral shaft was determined as the maximal load at failure.

3.18.4.3 Mechanical testing to evaluate bending strength of the plate

The test was performed on six plates. 3.5mm 9 hole linear locking compression plates were fixed to the custom made fixture and subjected to three-point bending test using Instron universal testing machine. The plates were positioned horizontally with the anterior surface upwards and centered on supports on the stage of the testing machine. The plates were compressed at its centre by a constant compression speed of 1 mm/min (Plate 63). The compression force was directed vertically to the airshaft of the plate. The plates were compressed until failure (Plate 64). The bending breaking force was defined as the maximal bending load at failure. The load curve was recorded and the load at failure upon bending was determined. The strength of the bone plate was determined as the maximal load at failure.

3.18.4.4 Mechanical testing to evaluate bending strength of the bone plate construct

The test was performed on six canine humerii. Canine cadaveric humeri were plated craniolaterally with 8 hole 3.5mm linear locking compression plate based on AO/ASIF technique. Self- tapping, 3.5mm locking screws were placed bicortically in all the screw holes and were tightened to 1.5Nm with a torque screw driver. The compression force was directed vertically to the shaft of the construct (Plate 65). The bone plate construct was compressed until failure. The bending breaking force was defined as the maximal bending load at failure. The load curve was recorded and load at failure upon bending was determined. The strength of the bone plate construct was determined as the maximal load at failure.

3.18.4.5 Mechanical testing for evaluating bending strength of the bone plate construct in osteotomy gap model

The test was performed on six canine femorii. Canine cadaveric femurs were plated craniolaterally with 9 hole 3.5mm locking compression plate based on AO/ASIF technique. Self- tapping, 3.5mm locking screws, three screws at the proximal fragment and three screws at the distal fragments were placed through both cortices and tightened to 1.5Nm with a torque screw driver. A 10 mm osteotomy gap was created at the mid shaft of femur. The bending strength of the construct was evaluated (Plate 66). The static axial bending load was directed vertically on the mid shaft of plate at the osteotomy gap of the construct. The bone plate construct was compressed until failure (Plate 67).

4. RESULTS

4.1 INCIDENCE

One thousand and eight cases of fractures involving various long bones were recorded in dogs between September 2009 and March 2011 at the Small Animal Orthopaedic Outpatient Unit of Madras Veterinary College Teaching Hospital, Chennai. Among the total of 1008 cases of long bone fracture reported, humerus, radius and femur fracture accounted for a total of 231, 381 and 396 cases respectively. Among the humerus fracture cases, humerus diaphyseal fractures accounted for 157 cases (67.9 %) whereas metaphyseal, physeal and epiphyseal fractures constituted a total of 74 cases (32.1 %). Among the radius fracture cases, radius diaphyseal fracture accounted for 242 cases (63.5 %) whereas metaphyseal, physeal and epiphyseal fractures constituted a total of 139 cases (36.5 %). Among the femur fracture cases, femur diaphyseal fracture accounted for 258 cases (65.1%) where as metaphyseal, condylar and supracondylar fractures accounted a total of 138 cases (34.9 %). In radius diaphyseal fracture 8 cases were bilateral. Among the total humerus, radius and femur fractures; eight, forty two and sixty seven cases involved multiple bone fragments. Out of 157 cases of humerus diaphyseal fracture, right humerus diaphyseal fracture constituted 97(61.7 %), whereas left humerus diaphyseal fracture constituted 60 (38.3 %). Out of 242 cases of radius diaphyseal fracture, right radius diaphyseal fracture constituted 153(63.2 %), whereas left radius diaphyseal fracture constituted 89 (36.8 %). Out of 258 cases of femur diaphyseal fracture, right femur diaphyseal fracture constituted 132(51.1 %), whereas left femur diaphyseal fracture constituted 126 (48.9 %).

The incidence of humerus, radius and femur fractures according to location is represented in Table.1, Table 2 and Table 3.

Table.1 Incidence of humerus fractures according to location

Location	Number	%
Diaphyseal fractures	157	67.9
Metaphyseal, physeal and epiphyseal fractures	74	32.1
Total	**231**	**100%**

Table.2 Incidence of radius fractures according to location

Location	Number	%
Diaphyseal fractures	242	63.5
Metaphyseal, physeal and epiphyseal fractures	139	36.5
Total	**381**	**100%**

Table.3 Incidence of femur fractures according to location

Location	Number	%
Diaphyseal fractures	258	65.1
Proximal and distal metaphyseal and condylar fracture	138	34.9
Total	**396**	**100%**

4.1.1 Breed, Sex and Age wise incidence of unstable diaphyseal fracture of humerus

In the present study, the highest incidence was recorded in Non-descriptive breed about 117 cases (50.6 %), followed by Spitz 34 cases (14.7%), Labrador 18 cases (7.7%) German Shepherd 22 cases (9.5%), Doberman Pinscher 11 cases (4.7 %), Cross breed 12 cases (5.1%) and others (Dalmatian, Pug, Dachshund, Great Dane, Lhasapso, Cocker Spaniel, Rajapalayam, Boxer, Beagle and Siberian husky) 18 cases (7.7%).

Regarding sex, 90 cases (57.3%) of unstable diaphyseal humerus fracture were recorded in male dogs and 67 cases (30.4%) were recorded in bitches. The highest incidence of 102 cases (44.1%) was recorded in the dogs aged between one and three years.

4.1.2 Breed, Sex and Age wise incidence of unstable metaphyseal fracture of humerus

In the present study, the highest incidence was recorded in Non-descriptive breed 15 cases (20.3%), followed by Spitz 12 cases (16.2%), Labrador 10 cases (13.5%) German Shepherd 12 cases (16.2%), Doberman Pinscher 8 cases (10.9%), Cross breed 11 cases (14.8%) and others (Dalmatian, Pug, Dachshund, Great Dane, Lhasapso, Cocker Spaniel, Rajapalayam, Boxer, , Beagle and Siberian husky) 6 cases (8.1%).

Regarding sex, 54 cases (72.9%) of unstable metaphyseal humerus fractures were recorded in male dogs and 20 cases (27.1%) were recorded in bitches. The highest incidence of 43 cases (58.1%) was recorded in dogs aged between one and three years.

4.1.3 Breed, Sex and Age wise incidence of unstable diaphyseal fracture of radius

In the present study, the highest incidence was recorded in Spitz breed about 98 cases (40.5%), followed by Non-descriptive breed 43(17.7%), Labrador 23 cases (9.5%) German Shepherd 19 cases(7.8%), Doberman Pinscher 16 cases (6.7%), Cross breed 17 cases (7.0%) and others (Dalmatian, Pug, Dachshund, Great Dane, Lhasapso, Cocker Spaniel, Rajapalayam, Boxer, Beagle and Siberian husky) 26 cases (10.8%).

Regarding sex, 154 cases (63.6%) of unstable diaphyseal radius fracture were recorded in male dogs and 88 cases (36.4%) were recorded in bitches. The highest incidence of 143 cases (59.2%) was recorded in dogs aged between 6 months and 1 year.

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4.1.4 Breed, Sex and Age wise incidence of unstable metaphyseal fracture of radius

In the present study, the highest incidence was recorded in Spitz breed 53 cases (38.1%), followed by Non-descriptive breed 23(16.5%), Labrador 16 cases (11.5%) German

Shepherd 11 cases (7.9%), Doberman Pinscher 9 cases (6.5%), Cross breed 13 cases (9.4%) and others (Dalmatian, Pug, Dachshund, Great Dane, Lhasapso, Cocker Spaniel, Rajapalayam, Boxer, Beagle and Siberian husky) 14 cases (10.1%).

Regarding sex, 98 cases (70.5%) of unstable diaphyseal radius fracture were recorded in male dogs and 41 cases (29.5%) were recorded in bitches. The highest incidence of 82cases (58.9%) was recorded in dogs aged between 6 months and 1 year.

4.1.5 Breed, Sex and Age wise incidence of unstable diaphyseal fracture of femur

In the present study, the highest incidence was recorded in Non-descriptive breed 102 cases (39.5%), followed by Spitz 27 cases (10.5%), Labrador 35 cases (13.5%) German Shepherd 24 cases (9.3%), Doberman Pinscher 29 cases (11.4%), Cross breed 19 cases (7.3%) and others (Dalmatian, Pug, Dachshund, Great Dane, Lhasapso, Cocker Spaniel, Rajapalayam, Boxer, Beagle and Siberian husky) 22 cases (8.5%).

Regarding sex, 145 cases (56.3%) of unstable diaphyseal radius fracture were recorded in male dogs and 113 cases (43.7%) were recorded in bitches. The highest incidence of 192cases (74.4%) was recorded in dogs aged between one and three years.

4.1.6 Breed, Sex and Age wise incidence of unstable metaphyseal fracture of femur

In the present study out of 138 cases studied, the highest incidence was recorded in Non-descriptive breed about 37 cases (48.4%), followed by Indian Spitz 29 cases (16.2%), Labrador 23 cases (7.1%) German Shepherd 19 cases (7.6%), Doberman Pinscher 14cases (4.8%), Cross breed 9 cases (7.6%) and others (Dalmatian, Pug, Dachshund, Great Dane, Lhasapso, Cocker Spaniel, Rajapalayam, Boxer, Beagle and Siberian husky)7 cases (8.3%).

Regarding sex, 74 cases (53.6%) of unstable diaphyseal radius fracture were recorded in male dogs and 64 cases (46.4%) were recorded in bitches. The highest incidence of 85 cases (61.6%) was recorded in dogs aged between one and 3 years.

The breed, sex and age wise distribution of unstable diaphyseal and unstable metaphyseal fractures of humerus, radius and femur are represented in Fig.1-18.

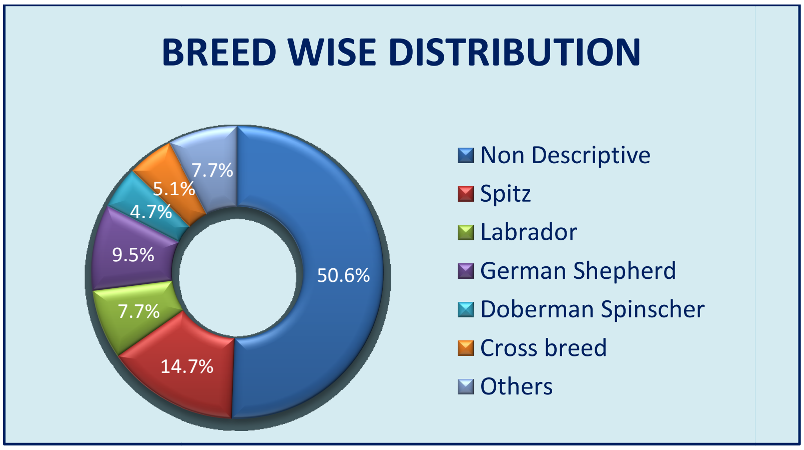

Fig.1 Breed wise distribution of unstable diaphyseal fracture of humerus

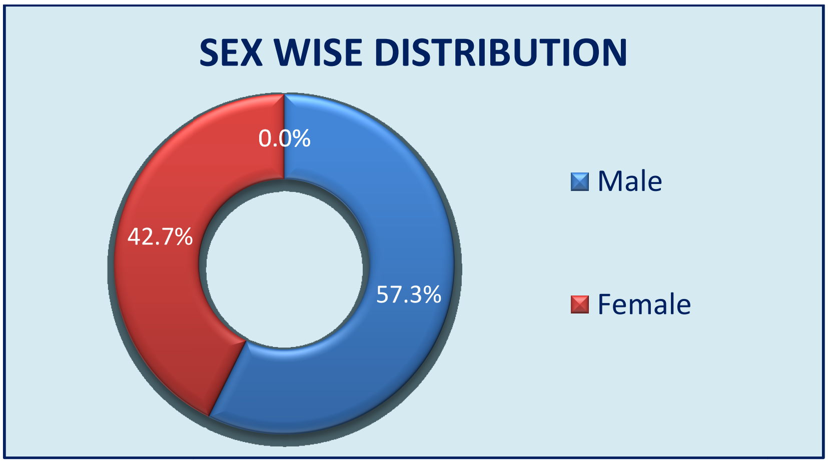

Fig.2 Sex wise distribution of unstable diaphyseal fracture of humerus

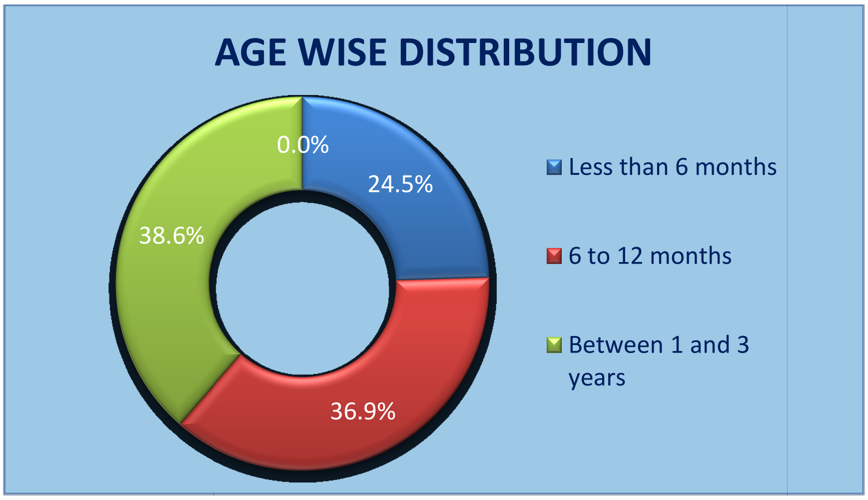

Fig.3 Age wise distribution of unstable diaphyseal fracture of humerus

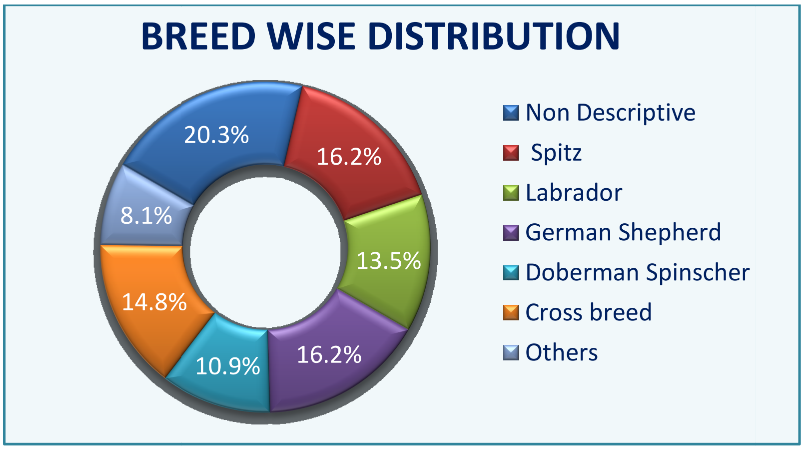

Fig.4 Breed wise distribution of unstable metaphyseal fracture of humerus

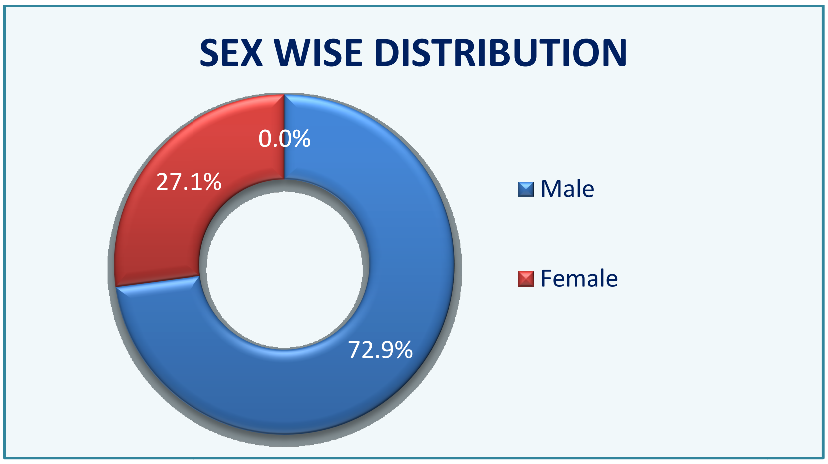

Fig.5 Sex wise distribution of unstable metaphyseal fracture of humerus

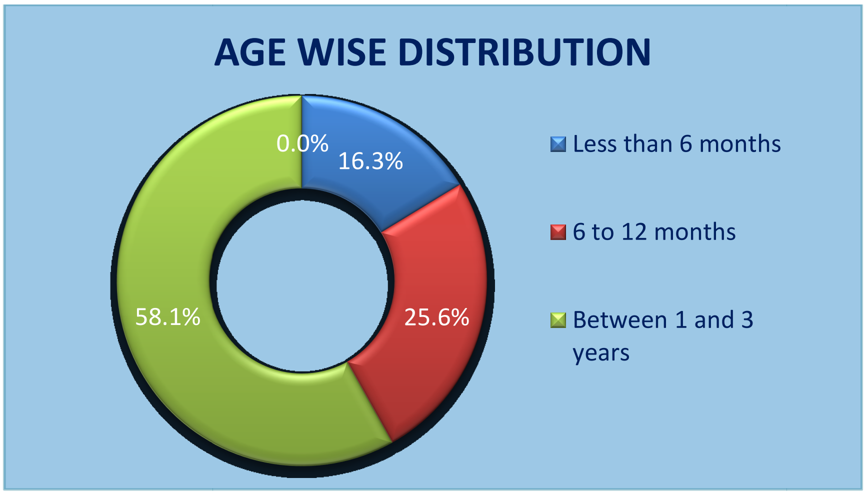

Fig.6 Age wise distribution of unstable metaphyseal fracture of humerus

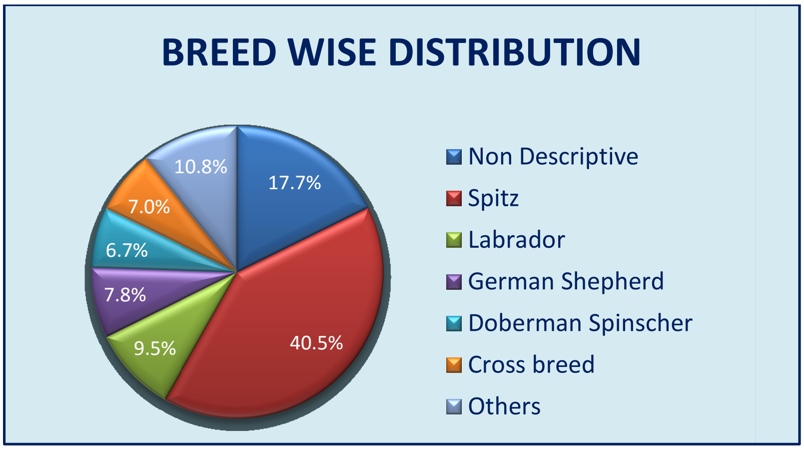

Fig.7 Breed wise distribution of unstable diaphyseal fracture of Radius

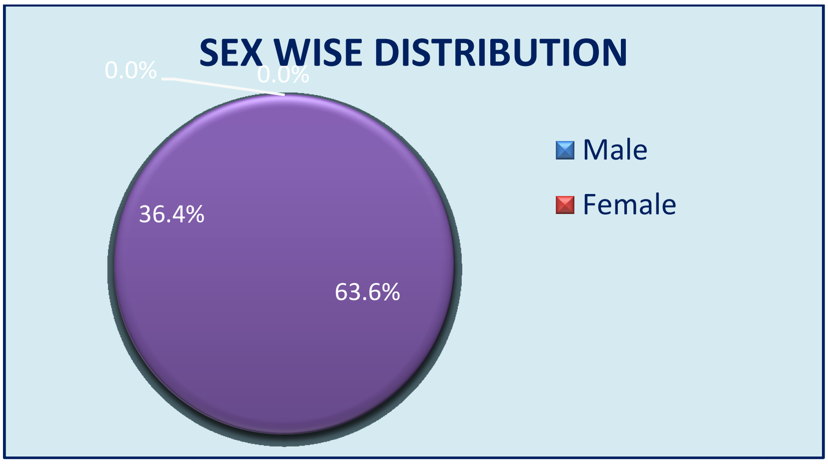

Fig.8 Sex wise distribution of unstable diaphyseal fracture of Radius

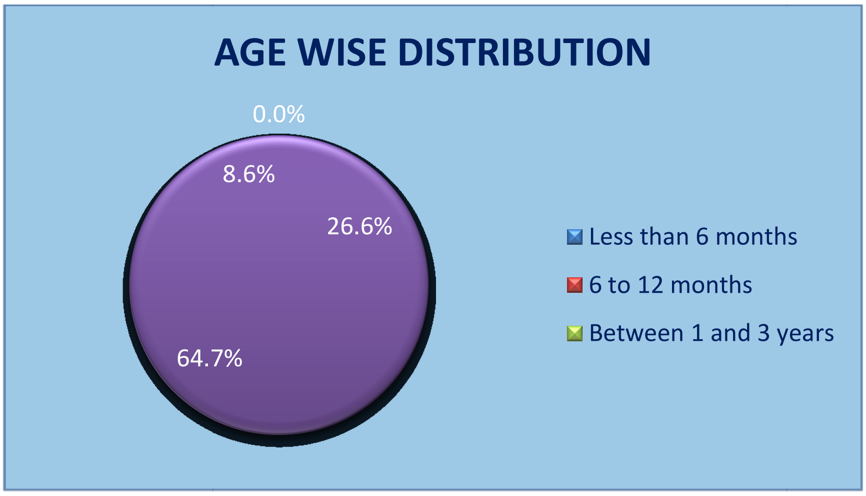

Fig.9 Age wise distribution of unstable diaphyseal fracture of Radius

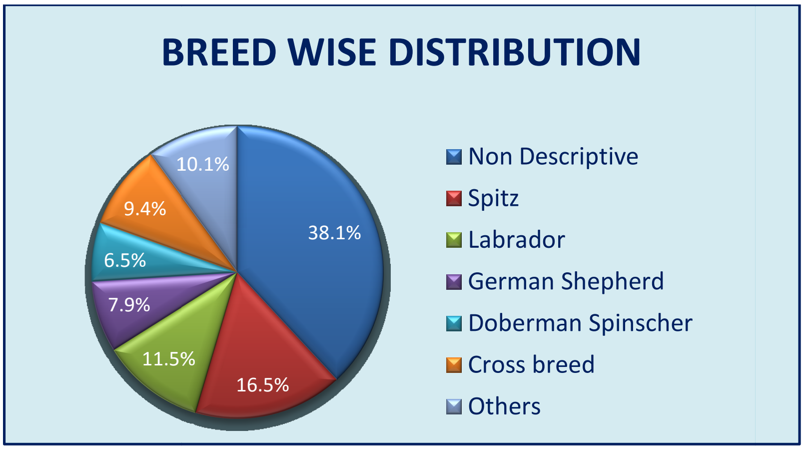

Fig.10 Breed wise distribution of unstable metaphyseal fracture of Radius

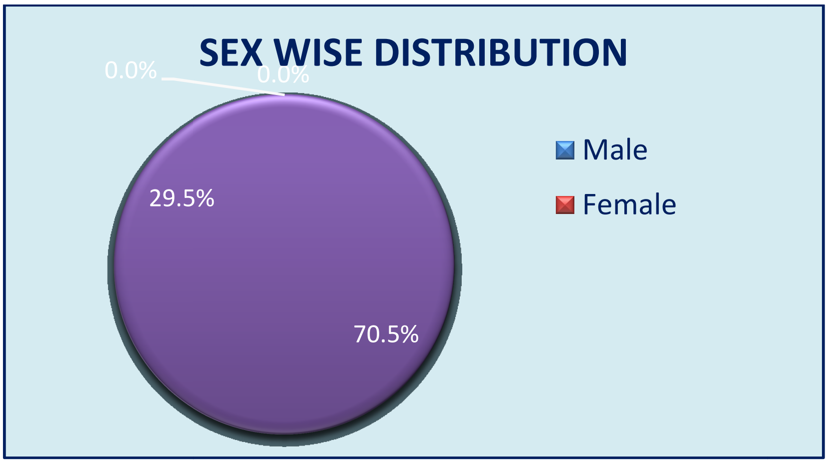

Fig.11 Sex wise distribution of unstable metaphyseal fracture of Radius

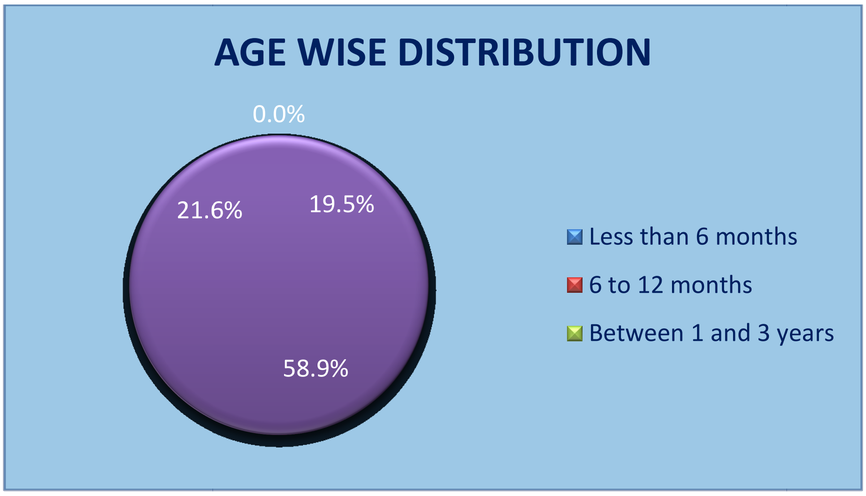

Fig.12 Age wise distribution of unstable metaphyseal fracture of Radius

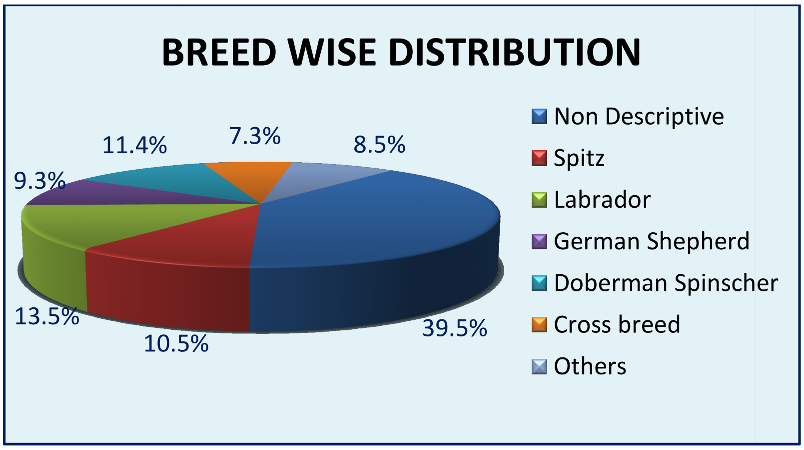

Fig.13 Breed wise distribution of unstable diaphyseal fracture of femur

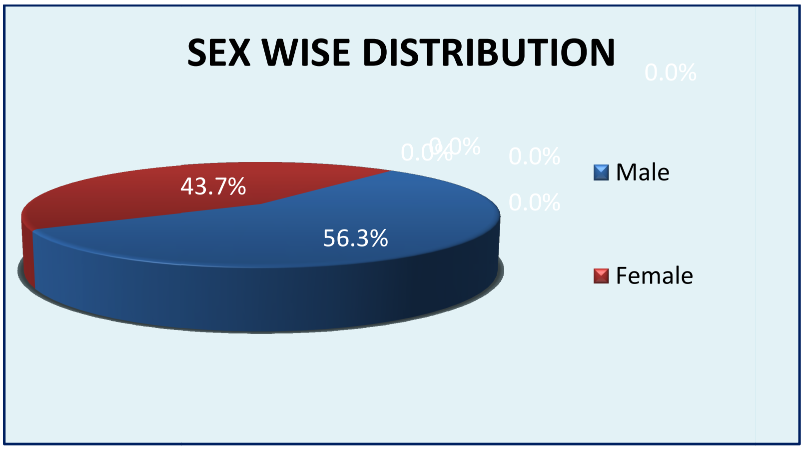

Fig.14 Sex wise distribution of unstable diaphyseal fracture of femur

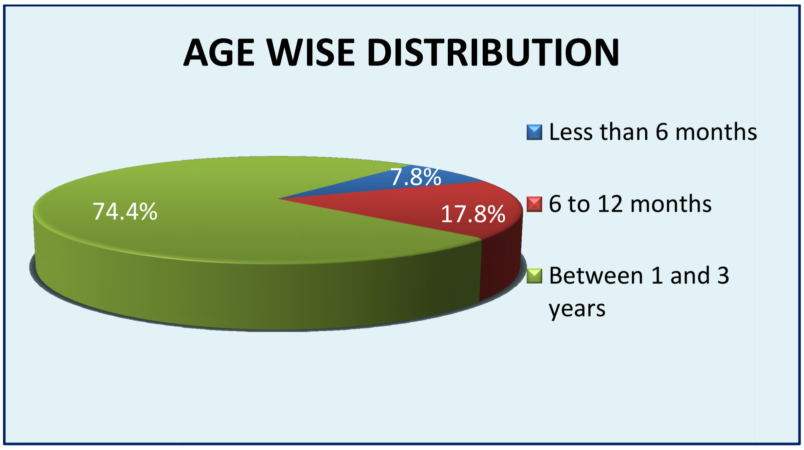

Fig.15 Age wise distribution of unstable diaphyseal fracture of femur

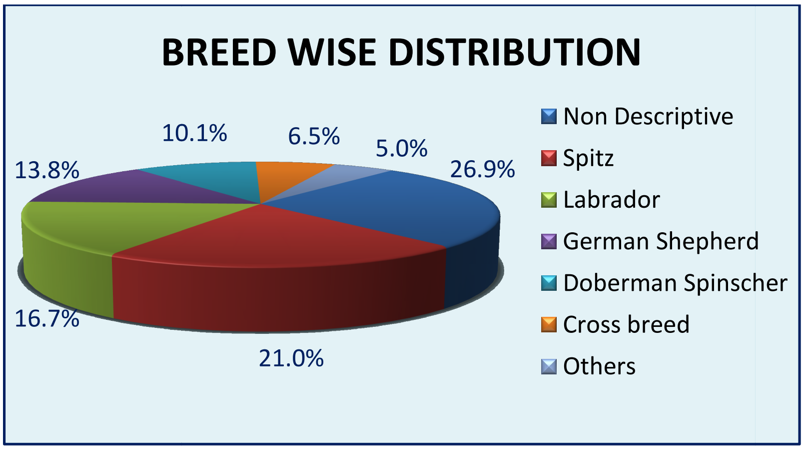

Fig.16 Breed wise distribution of unstable metaphyseal fracture of femur

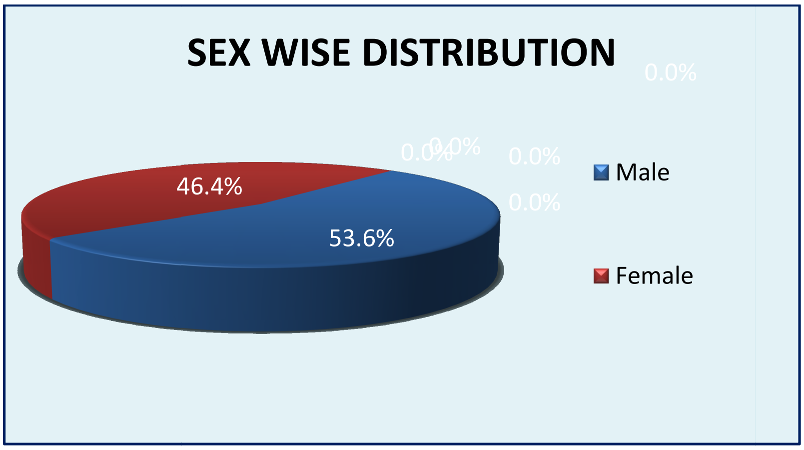

Fig.17 Sex wise distribution of unstable metaphyseal fracture of femur

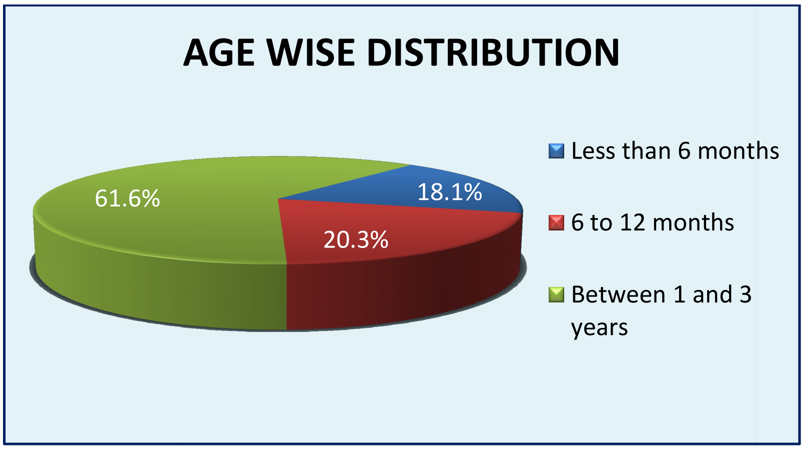

Fig.18 Age wise distribution of unstable metaphyseal fracture of femur

4.2 ETIOLOGY OF FRACTURES

Etiology of unstable diaphyseal and metaphyseal fractures of humerus, radius and femur are represented in Table 4. In the present study, the highest incidence (42.8%) was recorded due to road traffic accident (RTA).

Table 4.Showing etiology of fractures

Sl. No.	Causes of fractures	Number	(%)
1	RTA	9	40.8
2	Fell down from height	4	18.3
3	Unknown	4	18.3
4	Playing	2	9.1
5	Slipped on the floor	3	13.5
	Total	**22**	**100**

4.3 CLASSIFICATION OF FRACTURES (MONTAVON SYSTEM, 1990).

Classification of unstable diaphyseal and metaphyseal fractures of humerus, radius and femur considered for the study are represented in Table 5.

4.3.1 Fracture of Humerus

In the present study, three cases of long oblique diaphyseal fracture 12 – A2 (Plate 70), and three cases of transverse distal metaphyseal 13 – A1 (Plate 71) fractures were recorded.

4.3.2 Fracture of Radius

One case of simple transverse diaphyseal fracture 22 – A2(Plate 72), two cases of short transverse metaphyseal fractures 22 – A1(Plate 73), one case of malunion at mid diaphyseal region and three cases of transverse metaphyseal fractures of radius with simple ulna fracture 22- B1(Plate 74) were recorded.

4.3.3 Fracture of Femur

Out of nine of femur fractures, one case of multiple supracondylar fracture 33 – A3 (Plate 75), five cases of transverse wedge diaphyseal fracture 32 – A3 (Plate 76), and three cases of oblique proximal metaphyseal fracture 33 – A2 (Plate 77), were recorded.

The percentage of various fractures is represented in Fig.19a, 19b and 19c.

Table 5. Fracture classification based on Montavon system

Case No.	BREED	AGE	SEX	BWT (Kg)	ETIOLOGY	FRACTURE TYPE AND LIMB
1	German Shepherd	9 M	M	25	Road Traffic Accident	Unstable long oblique diaphysis - Rt. Humerus 12-A2
2.	Mongrel	3 Y	M	15	Fell down from height	Unstable long oblique diaphysis - Lt. Humerus 12-A2
3	Doberman Pinscher	3 Y	M	30	Unknown	Unstable overriding diaphyseal - Lt humerus 12 – B3
4	Rajapalayam	8 M	M	15	Road Traffic Accident	Unstable long oblique metaphysis - Rt. Humerus 12- A2
5	Doberman Pinscher	5 M	M	15	Fell down from height	Unstable oblique metaphysis -Lt. Humerus 13 – A2
6.	Mongrel	2.5 Y	M	15	Road Traffic Accident	Unstable transverse metaphysis - Rt. Humerus 13 - A1
7.	Doberman Pinscher	3Y	M	30	Playing	Unstable short oblique diaphyseal -Lt. Radius ulna 22 – B1
8.	Mongrel	3 Y	M	17	Road traffic Accident	Unstable transverse diaphysis - Rt. Radius ulna 22 - C1
9.	Rajapalayam	8 M	M	15	Unknown	Old fracture, Malunion diaphysis - Rt. Radius ulna 22 – A2
10.	Sptiz	3 Y	M	8	Fell down from a height	Unstable transverse diaphysis - Rt. Radius ulna 22 – B2
11.	Mongrel	2.5 Y	F	18	Road Traffic Accident	Unstable transverse metaphysis – Rt Radius ulna 23 - C1

12.	German shepherd	6 M	F	12	Slipped on the floor	Unstable transverse metaphysis - Lt. Radius ulna 23 – C1
13.	Doberman Pinscher	4 M	F	15	Fell down from a height	Unstable transverse metaphysis - Rt. Radius ulna 23 – C1
14.	Doberman Pinscher	8 M	F	20	Playing	Unstable multiple diaphysis - Lt.femur 32 – C3
15.	Doberman Pinscher	3 Y	F	18	Road Traffic Accident	Unstable transverse diaphysis - Rt.femur 32 – A3
16.	Mongrel	8 M	F	15	Road Traffic Accident	Unstable transverse diaphysis - Lt.femur 32 – A3
17.	Dalmatian	3 Y	F	25	Slipped on the floor	Unstable multiple supra condylar - Lt.femur 33 – C3
18.	German shepherd		M	28	Road Traffic Accident	Unstable transverse diaphysis - Lt.femur 32 – A3
19.	Golden Retriever	10 M	M	17	Slipped on the floor	Unstable transverse diaphysis - Rt. Femur 32 – A3
20	Doberman Pinscher	1 Y	M	18	Road Traffic Accident	Unstable short oblique diaphyseal fracture - Lt.femur 32 – A2
21.	Mongrel	1 .5 Y	M	17	Unknown	Unstable transverse metaphysis – Rt. Femur 33 – A2
22	Mongrel	1 Y	M	15	Unknown	Unstable transverse metaphysis – Rt. Femur 33 – A2

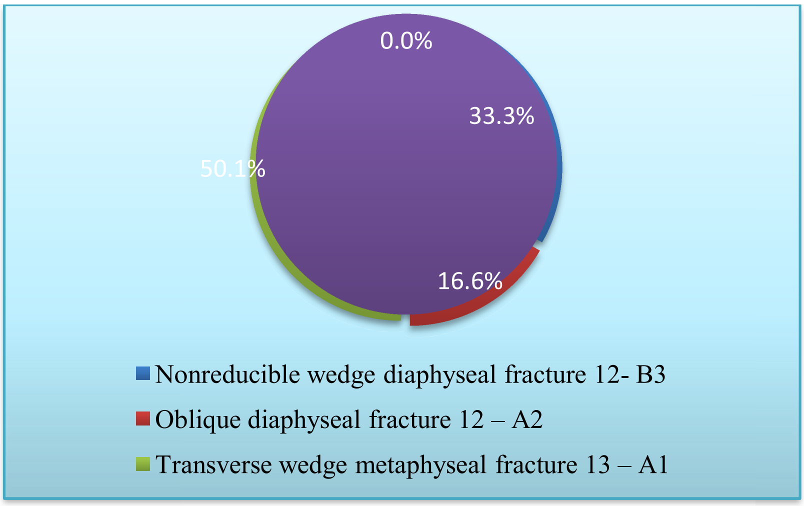

Fig.19a. Showing percentage of humerus fractures

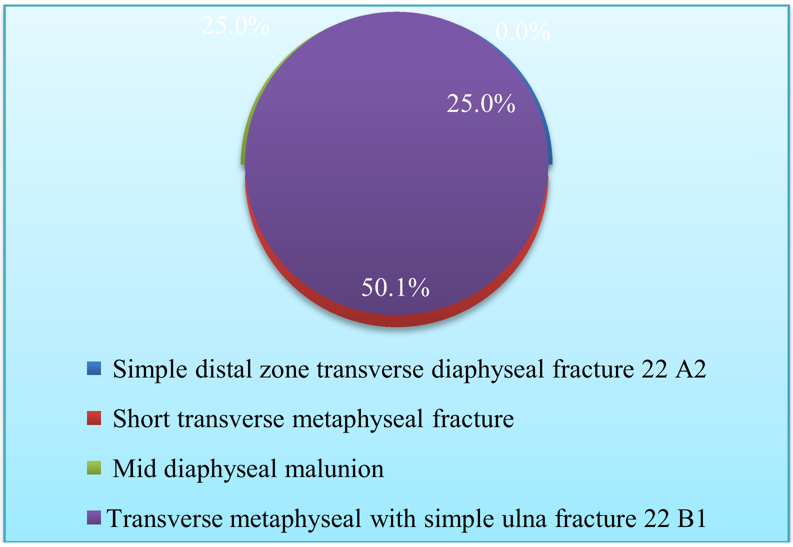

Fig.19b. Showing percentage of radius fractures

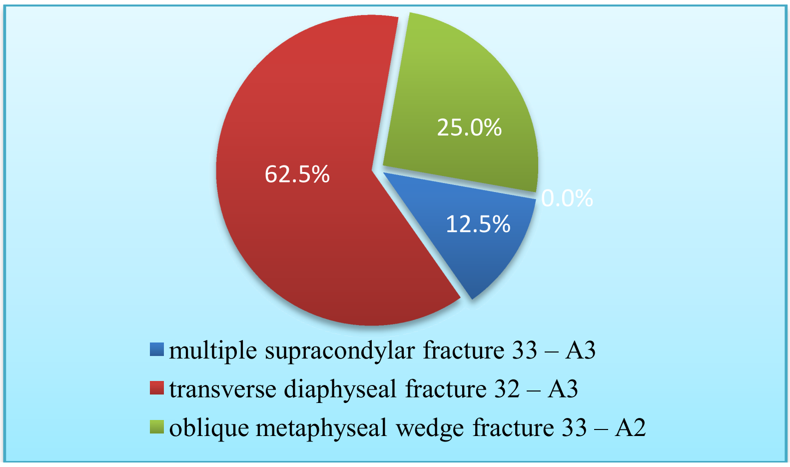

Fig.19c. Showing percentage of femur fractures

4. 4 FRACTURE PATIENT ASSESSMENT SCORE (FPAS)

Fracture patient assessment score (FPAS) in animals with unstable diaphyseal and metaphyseal fractures of humerus, radius and femur is represented in Table 6.

In the present study, lower scale (< 4) indicates an unfavourable prognosis, a middle range (5-6) indicates a guarded prognosis and a higher scale (>7) indicates a favourable prognosis.

4.5 DIAGNOSIS

Clinical evaluation provided a tentative diagnosis of fracture and its location. Lateral and craniocaudal views provided information the stability (stable / unstable) of fracture, nature of the fracture (complete/ incomplete) and soft tissue involvement. Lateral and craniocaudal radiographic views were essential to classify the fractures, formulate fracture fixation plans and to determine the size and length of the plate and screws.

4.6 PRE OPERATIVE PLAN

Preoperative plan using the lateral and craniocaudal radiograph of the contralateral limb was essential to determine the size and length of the plate and screws. In the present study, this preoperative plan was found appropriate.

Table 6. Fracture Patient Assessment Score (FPAS)

Unstable diaphyseal and metaphyseal fracture of humerus							
Case No.	**BREED**	**AGE**	**SEX**	**BWT (Kg)**	**Fracture Patient Assessment Score (FPAS)**		
					Mechanical	**Biological**	**Clinical**
1	German Shepherd	9 M	M	25	6	6	7
2.	Mongrel	3Y	M	15	7	7	4
3	Mongrel	2.5 Y	M	15	7	7	6
4	Rajapalayam	8 M	M	15	6	6	4
5	Doberman Pinscher	5 M	M	15	4	7	6
6.	Doberman Pinscher	3 Y	M	30	6	7	6
Unstable diaphyseal and metaphyseal fracture of radius							
7.	Doberman Pinscher	4 M	F	15	6	6	7
8.	Mongrel	2.5 Y	F	18	6	7	6
9.	Rajapalayam	8 M	M	15	7	7	7
10.	Sptiz	3 Y	M	8	6	7	5
11.	Mongrel	3 Y	M	17	6	6	6
	German shepherd	6 M	F	12	7	6	7

12.							
13.	Golden Retriever	3 Y	M	40	5	7	6
Unstable diaphyseal and metaphyseal fracture of femur							
14.	Doberman Pinscher	8 M	F	20	7	6	4
15.	Doberman Pinscher	3 Y	F	18	7	7	6
16.	Mongrel	8 M	F	15	6	7	7
17.	Dalmatian	3 Y	F	25	5	6	8
18.	Germanshepherd	1 Y	M	28	6	7	4
19.	Golden Retriever	10 M	M	17	8	8	8
20	Doberman Pinscher	1 Y	M	18	6	5	7
21.	Mongrel	1 .5 Y	M	17	7	6	5
22	Mongrel	1 Y	M	15	7	6	6

4.7 SURGICAL TECHNIQUE

4.7.1 Surgical Approach to the Humerus

Three cases of unstable diaphyseal and three cases of unstable metaphyseal fractures were approached through a cranio lateral incision. This approach provided adequate exposure of the bone with minimal soft tissue disruption and also facilitated open reduction and internal fixation of the fractured fragments using linear locking compression plating technique.

4.7.2 Surgical Approach to the Radius

The animals with unstable diaphyseal were approached through a craniomedial incision on the fractured fragment. This approach provided adequate exposure of the bone with minimal soft tissue disruption and also facilitated open reduction and internal fixation of the fractured fragments using lineal locking compression plating technique.

Craniodorsal incision for open reduction and internal fixation of distal metaphyseal fractures using T plates was found appropriate in the study.

4.7.3 Surgical Approach to the Femur

A craniolateral incision provided adequate exposure of the bone with minimal soft tissue disruption and also facilitated open reduction and internal fixation of the fractured diaphyseal fragments using linear locking compression plating technique. A distal craniolateral incision was adequate for condylar fracture fixation using condylar plates. Arthrotomy of the stifle joint was performed in one cases of supracondylar fracture.

4.7.4 Locking Compression Plating Technique

4.7.4.1 Linear locking compression plating technique

2.7mm linear locking compression plate was used in six cases and 3.5mm linear locking compression plate were used in eleven cases. The plate and screws were selected based on the pre operative plan of plate fixation and were found to be suitable for the procedure. Fixing the plate to the bone by applying the most proximal and most distal screws initially and later filling all the remaining screws holes was found to be technically suited for the plate fixation. Comminuted fractures with non reducible wedges were buttressed by application of screws in the locking holes of the plate. A minimum of three screws in the proximal and distal fracture fragments provided adequate stability. Compressing unstable transverse and oblique fractures using the gliding hole of the plate ensured rigid stability of the fracture fragments.

4.7.4.2 Locking compression “T” plating technique

Locking compression T plates were used in three cases for internal fixation of unstable metaphyseal fractures of the distal radius. The horizontal part of the plate was manipulated to fit on the distal radius and the vertical part of the combi hole plate was used stabilise the shaft of the radius. Locking T plate technique used in this study was found to be an appropriate method of fixation for management of distal radial fractures especially in dogs weighing less than 10kg. This technique found to be suitable for management of distal radial fracture in small breeds..

4.7.4.3 Condylar locking compression plating technique

One case of distal condylar fracture of the femur was stabilized with 3.5mm locking condylar plating technique. The horizontal part of the plate was manipulated to fit on the lateral condyle and the vertical part of the combi hole plate was used to stabilise the shaft of the femur. Comminuted fractures with non reducible wedges of the supracondylar region were buttressed by application of screws in the locking holes of the plate Condylar plating technique combined with cross pins was found to be appropriate and an alternate method of fixation for management of supracondylar fractures of the femur

4.7.4.4 Locking compression plating technique and C-arm guidance

The post operative C-arm study facilitated evaluation of fracture reduction, alignment and implant position.. C-arm guidance provided serial real time visual images during the manipulation procedure and enabled the operator to provide precise information to surgeon on the alignment and apposition of the fracture fragments. This information enabled immediate decision making for further manipulation to promote stability at fracture site The up/down, angulation, horizontal, swivel and the orbital movement of the c- arm facilitated accurate imaging of the bones. Intra-operative evaluation of reduction and alignment of fracture fragments and proper positioning of plate to the bone provided precise under C-arm guidance. The time taken for the fracture fixation with C – arm guidance was longer than the fracture reduction without C-arm guidance. The average surgical time was 1.37hrs (1.45 to 2.50hrs) for fixation of unstable diaphyseal fractures of humerus, 1.15hrs(1.20 to 2.30hrs) for the fixation of unstable diaphyseal and metaphyseal fracture of radius and 1.55 hrs(2.0 to 3.10hrs) for the fixation of unstable diaphyseal and metaphyseal fractures of femur.

4.7.5 Implants

4.7.5.1 Unstable diaphyseal and metaphyseal fractures of humerus

A 10 hole 3.5mm linear locking compression plate was used in one dog (case No. 1) and 8 hole 3.5 linear locking compression plate was used in two dog (case No. 2 and 3). In case No. 1 the plate was stabilised with six 3.5mm locking head screws in proximal fragment and two 3.5 locking head screws in distal fragment. In case No. 2 and 3, five 3.5 mm locking head screws placed on the proximal fragment and two 3.5mm locking head screws on the distal fragment. The locking hole at the fracture line was kept open. In all the cases, fully threaded locking head screws were used. The size of the screws ranged from 14mm to 24mm for dogs with body weight ranging from 10 – 15 kgs and 16mm to 30mm for dogs with body weight ranging from 15-30 kgs. This procedure was found appropriate. In all the cases, screws were applied bicortically.

An 8 hole 3.5mm linear locking compression plate was used in two dogs (case No.4, 6) and 9 hole 3.5 linear locking compression plate was used in one dog (case No.5). In case No. 4 and 6, the plate was stabilised with five 3.5mm locking head screws in proximal fragment and two. 3.5 locking head screws in distal fragment. In case No. 5, six 3.5 mm locking head screws were placed on the proximal fragment and two 3.5mm locking head screws were placed on the distal fragment. The locking hole at the fracture line was kept open. In all the cases, fully threaded locking head screws were used. In all the cases, screws were applied bicortically. The size of the screws ranged from 14mm to 24mm for dogs with body weight ranging from 10 – 15 kgs and 16mm to 30mm for dogs with body weight ranging from 15-30 kgs.

4.7.5.2 Unstable diaphyseal and metaphyseal fractures of radius

An 8 hole 2.7mm linear locking compression plate was used in four dogs. In case No. 8, 9 and 13, the plate was stabilised with four 2.7mm locking head screws in proximal fragment and with three 2.7mm locking head screws in distal fragment. In case No. 10, five 2.7mm locking head screws were placed on the proximal fragment and two 2.7mm locking head screws were placed on the distal fragment (Plate 78). The locking hole on the fracture line was kept open in all the 4 cases. In all the cases, fully threaded locking head screws were used. In all the cases screws were applied bicortically. The size of the screws ranged from 14mm to 24mm for dogs with body weight ranging from 10 – 15 kgs and 16mm to 30mm for dogs with body weight ranging from 15-30 kgs. This procedure was found appropriate.

Out of three dogs with unstable metaphyseal radius fracture (case No.7, 11, and 12), 8 hole 2.7mm locking T plate was used in one dog (case no 7). In two dogs (case No. 11 and 12), a 9 hole T plate was used (Plate 79). . The T plate with 8 hole was stabilised with two 2.7mm locking head screws in proximal fragment and with five 2.7mm locking head screws in distal fragment. In case No. 11 and 12, 9 hole 2.7mm locking T plate were used. Four 2.7mm locking head screws were placed on the proximal fragment and four 2.7mm locking head screws were placed on the distal fragment (Plate n) in both the cases. The locking hole on the fracture line was kept open in all the 7 cases. In all the cases, fully threaded locking head screws were used. In all the cases screws were applied bicortically. The size of the screws ranged from 14mm to 24mm for dogs with body weight ranging from 10 – 15 kgs and

16mm to 30mm for dogs with body weight ranging from 15-30 kgs. This procedure was found appropriate.

4.7.5.3 Unstable diaphyseal and metaphyseal fractures of femur

A 9 hole 3.5mm linear locking compression plate was used in three dogs (case No.14, 15 and 18) and 8 hole 3.5 linear locking compression plate (Plate 80) was used in one dog (case No.16). In case No. 14 and 15 and 18, the plate was stabilised with three 3.5mm locking head screws in proximal fragment and five 3.5 locking head screws in distal fragment. In case No. 14, an 8 hole locking compression plate was stabilised with three 3.5mm locking head screws in the proximal fragment and with five 3.5 locking head screws in the distal fragment. The fracture further stabilized with 3mm intramedullary Steinmann pin In case No. 17, 9 hole condylar locking compression plate was used. The condylar plate was stabilised with five 3.5 mm locking head screws placed on the proximal fragment and three 3.5mm locking head screws on the distal fragment along with 2mm cross pin (Plate 81).

A 10 hole 3.5mm linear locking compression plate was used in three dogs. The plate was stabilised with three 3.5mm locking head screws in the proximal fragment and six 3.5 locking head screws in distal fragment. In three cases, 10 hole 3.5mm linear locking compression plate was used. The plate was stabilised with four 3.5mm locking head screws in proximal fragment and four 3.5 locking head screws in distal fragment. In all the cases screws were applied bicortically except in one case where the distal screw was applied unicortically. The fracture was further stabilized with 3mm intramedullary steinmann pin and 20G cerclage wires. The size of the screws ranged from 14mm to 24mm for dogs with body weight ranging from 10 – 15 kgs and 16mm to 30mm for dogs with body weight ranging from 15-30 kgs. This procedure was found appropriate.

The specification of the implants used and the type of fixation in humerus, radius and femur fractures is represented in Table No. 7, 8 and 9.

Table No. 7 Showing the specification of the implants used and the type of fixation –

Humerus.

Unstable diaphyseal and metaphyseal fracture of humerus								
CaseNo.	**Breed**	**Age**	**Bwt (Kg)**	**Type of fracture**	**Implants**			**Type of fixation**
					LCP	**Screws no.(Size)**		
						Proximal	**Distal**	
1	German Shepherd	9 M	25	Unstable long oblique diaphysis - Rt. Humerus 12-A2	3.5mm 10 hole	6	2	Compression LCP Ancillary fixation with 3mm IMP
2.	Mongrel	3 Y	15	Unstable long oblique diaphysis - Lt. Humerus 12-A2	3.5mm 8 hole	5	2	Buttress LCP
3	Mongrel	2.5 Y	15	Unstable overriding diaphyseal - Lt humerus 12 – B3	3.5mm 8 hole	5	2	Buttress LCP
4	Rajapalayam	8 M	15	Unstable long oblique metaphysis - Rt. Humerus 12- A2	3.5mm 8 hole	5	2	Compression LCP
5	Doberman Pinscher	5 M	15	Unstable oblique metaphysis -Lt. Humerus 13 – A2	3.5mm 9 hole	6	2	Compression LCP
6.	Doberman Pinscher	3 Y	30	Unstable transverse metaphysis - Rt. Humerus 13 - A1	3.5mm 8 hole	5	2	Compression LCP

Table No. 8 The specification of the implants used and the type of fixation in radius bone fractures.

Unstable diaphyseal and metaphyseal fracture of radius								
Case No.	**Breed**	**Age**	**B.wt (Kg)**	**Type of fracture**	**Implants**			**Type of fixation**
					LCP	**Screws no.(Size)**		
						Proximal	**Distal**	
7.	Doberman Pinscher	3 Y	30	Unstable short oblique mid diaphyseal -Lt. Radius ulna 22 – B1	2.7mm 8 hole	2	4	Compression T plate
8.	Mongrel	3 Y	17	Unstable transverse distal diaphysis - Rt. Radius ulna 22 - C1	2.7mm 8 hole	4	3	Compression LCP
9.	Rajapalayam	8 M	15	Old fracture, Malunion distal diaphysis - Rt. Radius ulna 22 – A2	2.7mm 8 hole	4	3	Compression LCP Ancillary fixation with 3mm IMP
10.	Sptiz	3 Y	8	Unstable transverse distal diaphysis - Rt. Radius ulna 22 – B2	2.7mm 8 hole	5	2	Compression LCP
11.	Mongrel	2.5 Y	18	Unstable transverse distal metaphysis - Rt.Radius ulna 23 - C1	2.7mm 9 holes	4	4	Compression T plate
12.	German shepherd	6 M	15	Unstable transverse distal metaphysis - Lt. Radius ulna 23 – C1	2.7mm 9 holes	4	4	Compression T plate
13.	Doberman Pinscher	4 M	15	Unstable transverse distal metaphysis – Rt.Radius ulna 23 – C1	2.7mm 9 holes	4	3	Compression LCP

Table No. 9 The specification of the implants used and the type of fixation in femur bone fractures.

Unstable diaphyseal and metaphyseal fracture of femur								
CaseNo.	**Breed**	**Age**	**Bwt (Kg)**	**Type of fracture**	**Implants**			**Type of fixation**
					LCP	**Screws no.(Size)**		
						Proximal	**Distal**	
14.	Doberman Pinscher	8 M	20	Unstable comminuted diaphysis - Lt.femur 32 – C3	3.5mm 9 hole	3	5	Compression LCP Ancillary fixation with 3mm IMP
15.	Doberman Pinscher	4 Y	18	Unstable transverse mid diaphysis - Rt.femur 32 – A3	3.5mm 9 hole	3	5	Compression LCP
16.	Mongrel	8 M	15	Unstable transverse distal diaphysis - Lt.femur 32 – A3	3.5mm 8 hole	4	5	Buttress LCP Ancillary fixation with 3mm IMP
17.	Dalmatian	3 Y	25	Unstable comminuted supra condylar - Lt.femur 33 – C3	3.5mm 9 hole	5	3	Buttress Ancillary fixation with 2mm cross pins
18.	Germanshepherd	1 Y	28	Unstable transverse diaphysis - Lt.femur 32 A 3	3.5mm 9hole	3	5	Compression LCP
19.	Golden Retriever	10 M	17	Unstable transverse diaphysis - Rt. Femur 32 – A3		3	4	Compression LCP
20	Doberman Pinscher	1 Y	18	Unstable short oblique metaphysis - Lt.femur 32 – A2	3.5mm 10 holes	5	4	Compression Ancillary fixation with 3mm IMP and cerclage wiriing
21	Mongrel	1 .5 Y	17	Unstable transverse metaphysis – Rt. Femur 33 – A2	3.5mm 10 holes	5	4	Compression LCP
22	Mongrel	1 Y	15	Unstable transverse metaphysis – Rt. Femur 33 – A2	3.5mm 10 holes	5	4	Compression LCP

4.8 PARAMETERS STUDIED

4.8.1 Clinical Evaluation

4.8.1.1 Evaluation of body condition, range of motion, limb girth and limb length

Animals with unstable diaphyseal and metaphyseal fractures of humerus were clinically evaluated for body condition. The body condition of case no.1, 3 and 4 was good, case no. 2 and 5 were fair and case no.6 was mild obese. The range of motion was decreased in all cases except case No. 4 which normal. Limb girth was mildly increased in case No. 3, moderately increased in case No. 1,2,4 and severely increased in case No. 5 and 6. Limb length was decreased in case No. 2,3,4,6 and was normal in case No. 1 and 5.

Animals with unstable diaphyseal and metaphyseal fractures of radius were clinically evaluated for the body condition. The body condition of case no.7, 9, 12 and 13 was good, case no. 8 and 10 were fair and case no.13 was mild obese. The range of motion was increased in all cases except case No. 12 which was normal. Limb girth was mildly increased in case No.8 and 12, moderately increased in case No. 7,9,11 and severely increased in case No. 10 and 13. Limb length was decreased in case No. 8, 9, 12 and 13 and was normal in case No. 7, 10 and 11.

Animals with unstable diaphyseal and metaphyseal fractures of femur were clinically evaluated for the body condition. The body condition of case no.14, 15, 17, 18 ,19,21 and 22 were good, case no. 16 and 20 were fair and case no.18 was mild obese. The range of motion was increased in all cases except case No. 21 which was normal. Limb girth was mildly increased in case No.14,16, 20 and 22, moderately increased in case No. 15, 17,19 and severely increased in case No. 18 and 21. Limb length was decreased in case No. 16, 18, 20, 21 and 22 and was normal in case No. 14, 15, and 17 and 19.

Clinical evaluation of range of motion, limb girth and limb length are represented in table No. 10.

TableNo.10 Showing clinical evaluation of animals.

Bone fractures		Case No.	Body Weight (Kgs)	Range of Motion	Limb Girth			Limb Length	
					Mild Increase	Moderate Increase	Severe Increase	Normal	Decreased
Humerus	Diaphysis	1	25	D	-	++	-	N	-
		2	15	D	-	++	-	-	D
		3	30	D	+	-	-	-	D
	Metaphysis	4	15	N	-	++		-	D
		5	15	D	-	-	+++	N	-
		6	15	D	-	-	+++	-	D
Radius	Diaphysis	7	15	D	-	++	-	N	-
		8	18	D	+	-	-	-	D
		9	15	D	-	++	-		D
		10	8	D	-	-	+++	N	-
	Metaphysis	11	17	D	-	++	-	N	-
		12	12	N	+	-	-	-	D
		13	30	D	-	-	+++	-	D
Femur	Diaphysis	14	20	D	+		-	N	-
		15	18	D	-	++	-	N	-
		16	15	D	+	-	-	-	D
	Supra Condylar	17	25	D	-	++	-	N	-
	Diaphysis	18	28	D	-	-	+++	-	D
		19	17	D	-	+	-	N	-
		20	18	D	+	-	-	-	D
	Metaphysis	21	17	N	-	-	+++	-	D
		22	14	N	+	-	-	-	D

Note: D-Decreased, N-Normal

4.8.1.2 Lameness grade

In all the cases, the lameness grade was 5 on preoperative day (Plate 82) except in case No. 15 which had a lameness grade was 4.

In animals with unstable diaphyseal and metaphyseal fracture of humerus, the lameness grade improved in all cases on immediate post operative day to grade 4. Normal weight bearing on all the limbs at rest and walking was noticed in case No.4 (Plate 83) on 15th post operative day, case No.1 2, and 3 on 30th post operative day and in case No.5 and 6 on 45th post operative day.

The lameness grade improved in all cases with diaphyseal and metaphyseal radius fracture on immediate post operative day to grade 4. Normal weight bearing on all the limbs at rest and walking was noticed in case No7 (Plate 84), and 10 in 15th post operative day, in case No. 8 9, and 11 on 30th post operative day, in case No.12 and 13.

In animals with unstable diaphyseal and metaphyseal fracture of femur, the lameness grade improved in all cases on immediate post operative day to grade 4. Case No 15, 20 ,21 and 22 which was graded as 4 improved to grade 3 on immediate post operative day. Normal weight bearing on all the limbs at rest and walking was noticed in case No.14 and case No.19 (Plate 85) in 30th post operative day, in case No.16 and 18 on 60th post operative day. Case No. 17 was lost at follow up.

The lameness grading of the fractures involving Humerus, Radius and Femur are represented in Table No.11

Table No.11 Showing lameness grading.

Bone fracture		Case No.	Lameness Grade					
			Pre operative	Post operative				
				Day 1	Day 15	Day 30	Day 45	Day 60
Humerus	Diaphysis	1	5	4	3	2	1	1
		2	5	4	3	2	2	1
		3	5	4	3	2	1	1
	Metaphysis	4	5	4	3	2	1	1
		5	5	4	3	2	1	1
		6	5	4	2	1	2	2
Radius	Diaphysis	7	5	4	3	1	2	1
		8	5	4	2	1	1	1
		9	5	4	2	1	1	1
		10	5	4	2	1	1	1
	Metaphysis	11	5	3	2	1	1	1
		12	5	4	3	2	2	1
		13	5	4	2	1	1	1
Femur	Diaphysis	14	5	4	2	1	1	1
		15	4	3	3	2	1	1
		16	5	4	2	2	1	1
	Supra Condylar	17	5	4	Lost at follow up			
	Diaphysis	18	5	4	3	2	1	1
		19	5	4	2	1	1	1
	Metaphysis	20	5	4	2	1	1	1
		21	5	4	2	1	1	1
		22	5	3	2	1	1	1

4.8.1.3 Functional out come

At 60th post operative day, all the cases under this study were examined for functional limb outcome and categorized as excellent, good, fair and poor. The functional outcome in was graded excellent in 4 cases(Plate 86, Plate 87 and Plate 88) (66.8%) and good in 1 case (16.6%) and fair in 1 (16.6%) case out of 6 cases of fractures of the humerus considered in the study. The functional outcome in was graded excellent in 4 cases (57.1%) and good in 2 case (28.6%) and fair in 1 case (14.3%) out of 7 cases of fractures of radius considered in the study . The functional outcome in was graded excellent in 5 cases (62.5%) and good in 2 case (25%) and fair in 2(12.5%) case out of 9 cases of fractures of the femur considered in the study. Functional

4.8.2 Radiographic Evaluation

Periodical radiographic evaluation using lateral and craniocaudal views preoperatively and post operatively for diaphyseal and metaphyseal fractures of humerus, radius and femur were assessed.

4.8.2.1 Humerus

The studies were carried out preoperatively (Plate 89) immediate post – operative day (Plate 90), 15th post – operative day (Plate 91), 30th post – operative day (Plate 92), 45th post – operative (Plate 93) and 60th post – operative day (Plate 94).

4.8.2.2 Radius

4.8.2.2.1 Linear Locking compression plate fixation

The studies were carried out preoperatively (Plate 95) immediate post – operative day (Plate 96), 15th post – operative day (Plate 97), 30th post – operative day (Plate 98), 45th post – operative (Plate 99) and 60th post – operative day (Plate 100).

4.8.2.2.2 T-Plate fixation

The studies were carried out preoperatively (Plate 101) immediate post – operative day (Plate 102), 15th post – operative day (Plate 103), 30th post –

operative day (Plate 104), 45th post – operative (Plate 105) and 60th post – operative day (Plate 106).

4.8.2.3 Femur

4.8.2.3.1 Linear Locking compression plate fixation

The studies were carried out preoperatively (Plate 107) immediate post – operative day (Plate 108), 15th post – operative day (Plate 109), 30th post – operative day (Plate 110) 45th post – operative (Plate 111) and 60th post – operative day (Plate 112).

4.8.2.3.2 Condylar plate fixation

The studies were carried out preoperatively (Plate 113) and immediate post – operative day (Plate 114). The case was lost at follow-up and was unable to carryout radiological study.

4.8.2.4 Immediate postoperative radiographic evaluation

4.8.2.4.1 Apposition, Alignment, Angulation and Apparatus

Immediate post operative radiographic assessment score for apposition and alignment and status of angulation and apparatus in animals with diaphyseal and metaphyseal fractures of humerus, radius and femur are represented in Table 12, 13 and 14.

In dogs with unstable diaphyseal and metaphyseal fractures of humerus, the post operative apposition and alignment of the fractured fragments with adequate cortical contact between fractured fragments were present in all the cases. The fracture alignment and apposition score for all the cases was 0 at immediate post operative day except case 1 which was scored as 1. The angulation of the bone was normal in all the cases. The plate length, size and position were appropriate in all the cases. Screw length, size, position and placement was appropriate in all the cases except in case no.5 where the proximal cortical screws were longer and penetrated through the transcortex

In dogs with unstable diaphyseal and metaphyseal fractures of radius, the apposition and alignment of the fractured fragments with adequate cortical contact between fractured fragments were present in all the cases. The fracture alignment and apposition score for all the cases was 0 at immediate post operative day except case 7 which was scored as 1. The angulation of the bone was normal in all the cases. The plate length, size and position were appropriate in all the cases. Screw length, size, position and placement was appropriate in all the cases except in case no.11 where the proximal cortical screws were longer and penetrated through the transcortex.

In dogs with unstable diaphyseal and metaphyseal fractures of femur, the apposition and alignment of the fractured fragments with adequate cortical contact between fractured fragments were present in all the cases except in case no. 15. The fracture alignment and apposition score for all the cases were 0 at immediate post operative day except case no 15 where the alignment of transcortex was slightly deviated and was scored as 1. The angulation of the bone was normal in all the cases. The plate length, size and position was appropriate in all the cases. Screw length, size, position and placement was appropriate in all the cases except in case no. 18 where the first, second and third proximal cortical screws were longer and penetrated through the transcortex.

The immediate post operative radiographic assessment score for apposition and alignment and status for angulation and apparatus are shown in Table 12, 13 and 14 respectively.

Apposition and alignment score (Langley-Hobbs, 2003)

Score	Apposition and Alignment	
0	Anatomical reduction	
1	Minimal	(< 1mm) malreduction
2	Moderate	(< 1-3mm) malreduction
3	Severe	(> 3mm) malreduction

Table. 12 Showing immediate post operative radiographic assessment score for apposition and alignment and status for angulation and apparatus.

Case No.	Animals with diaphyseal and metaphyseal Humerus fracture			
	Apposition and Alignment	Angulation	Apparatus (Length , Position, Size)	
			Plate (LCP)	Screw
1	1	A	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
2	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
3	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
4	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
5	0	N	L – Approp P – Approp S – Approp	L – Long P – Approp S – Approp
6	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp

Note: L- Length, P- Position, S- Size, N- Normal, Approp – Appropriate,

Table. 13 Showing immediate post operative radiographic assessment score for apposition and alignment and status for angulation and apparatus.

Case No.	Animals with diaphyseal and metaphyseal Radius fracture			
	Apposition and Alignment	Angulation	Apparatus (Length , Position, Size)	
			Plate (LCP)	Screw
7	1	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
8	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
9	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
10	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
11	0	N	L – Approp P – Approp S – Approp	L –Longer P – Approp S – Approp
12	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
13	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp

Note: L- Length, P- Position, S- Size, N- Normal, Approp – Appropriate,

Table. 14 Showing immediate post operative radiographic assessment score for apposition and alignment and status for angulation and apparatus.

Case No.	Animals with diaphyseal and metaphyseal Femur fracture			
	Apposition and Alignment	Angulation	Apparatus (Length , Position, Size)	
			Plate (LCP)	Screw
13	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
14	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
15	1	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
16	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
17	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
18	0	N	L – Approp P – Approp S – Approp	L –Long P – Approp S – Approp
19	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
20	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
21	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp
22	0	N	L – Approp P – Approp S – Approp	L – Approp P – Approp S – Approp

Note: L- Length, P- Position, S- Size, N- Normal, Approp – Appropriate

4.8.2.5 Follow-up postoperative radiographic evaluation

4.8.2.5.1 Radiographic evaluation of Apposition and Alignment, Angulation and Apparatus

In dogs with unstable diaphyseal and metaphyseal fractures of humerus, apposition and alignment of the fractured fragments with adequate cortical contact between fractured fragments were maintained at 15th post operative day in all the cases except in case no. 1 which showed malreduction and was graded as 2. Apposition and alignment in case no. 3 was scored as 1 during the 15th post operative day. Mild valgus was noticed in case no. 1 (Plate 115) and case no 3 at 45th and 60th post operative day respectively. Plate was in position in all the cases. A part of the plate was exposed through the surgical incision in case no.1 at 30th post operative day. Locking head screws were appropriate and in position in all the cases. No case showed any evidence of screw loosening throughout the post operative period.

In dogs with unstable diaphyseal and metaphyseal fractures of radius, apposition and alignment with adequate cortical contact between fractured fragments were maintained at 15th post operative day in all the cases except case no.13 which showed mild malreduction. Mild valgus was noticed in case no. 9 and 11 at 30th and 60th post operative day respectively (Plate 6). A part of the plate was exposed through the surgical incision in case no.11 at 30th post operative day. Locking head screws were appropriate and in position in all the cases. No case showed any evidence of screw loosening throughout the post operative period.

In dogs with unstable diaphyseal and metaphyseal fractures of femur, apposition and alignment with adequate cortical contact between fractured fragments were maintained at 15th post operative day in all the cases except case no.15 which showed mild malreduction. In case no.18, the fractured fragments were stabilized with plate rod technique. The intra medullary pin was removed on 30th post operative day. Locking head screws were appropriate and in position in all the cases. No case showed any evidence of screw loosening throughout the post operative period. Case no. 17 was lost at follow up.

Follow-up postoperative radiographic assessment for apposition and alignment and status of angulation and apparatus in animals with diaphyseal and metaphyseal fractures of humerus, radius and femur are represented in Table 15, 16 and 17.

4.8.2.5.2 Radiographic evaluation of activity

The follow-up radiograph evaluation of activity in animals with unstable diaphyseal and metaphyseal fractures of humerus, radius and femur is represented in Table no. 20.

In dogs with unstable diaphyseal and metaphyseal fractures of humerus, evidence of primary bone healing was noticed in all cases at 30th post operative day except in case No. 1 and 3 which showed evidence of secondary bone healing. Clinical union in primary healing was evidenced by absence or minimal external callus of callus, closure of fracture gap and disappearance of the fracture line. Clinical union in secondary healing was evidenced by closure of fracture gap and presence of periosteal callus.

In dogs with unstable diaphyseal and metaphyseal fractures of radius, evidence of primary bone healing (Plate 116) was noticed at 30th post operative day in all cases except in case No. 13 which showed evidence of secondary bone healing.

In dogs with unstable diaphyseal and metaphyseal fractures of femur, evidence of primary bone healing was noticed at 30th post operative day in all cases except case no 19 (Plate 117) which showed evidence of secondary bone healing. Case no.17 was lost at follow up.

4.8.2.5.3 Radiographic evaluation of architecture (Soft tissue)

The follow-up radiograph evaluation of architecture (Soft tissue) in animals with unstable diaphyseal and metaphyseal fractures of humerus, radius and femur is represented in Table no. 21.

In the present study, soft tissue swelling at fracture site was noticed in case No. 5 and 6 with humerus fracture at 15th post operative day. The soft tissue swelling persisted in case no 5 at 30th post operative day.

Soft tissue swelling at fracture site was noticed in case No. 10 and 13 with radius fracture at 15th post operative day.

Soft tissue swelling at fracture site was noticed in case No. 18 and in case no.20 (Plate 118) with femur fracture at 15th post operative day.

4.8.2.5.4 Radiographic evaluation of architecture (Bone)

The follow-up radiograph evaluation of architecture (Bone) in animals with unstable diaphyseal and metaphyseal fractures of humerus, radius and femur is represented in Table no. 22.

In the present study, radiographic evaluation indicated there was no alteration of bone density except in case No.7 with metaphyseal radial fracture which showed evidence of increased bone density at 30th post operative day

Evidence of stress protection was noticed in case no. 7 with metaphyseal radial fracture at 30th post operative day (Plate 119)

Evidence of periosteal reaction was noticed in case No.16 with diaphyseal femur fracture at 15th post operative day (Plate 120).

Table. 15 Showing Follow-up radiographic assessments for Apposition and Alignment.

Case No.	Animals with diaphyseal and metaphyseal fracture-Humerus				Case No	Animals with diaphyseal and metaphyseal fracture-Radius				Case No	Animals with diaphyseal and metaphyseal fracture- Femur			
	D15	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**
1	2	2	2	2	**7**	0	0	0	0	**14**	0	0	0	1
2	0	0	0	0	**8**	0	0	0	0	**15**	1	1	1	1
3	0	1	1	1	**9**	0	0	0	0	**16**	0	0	0	0
4	0	0	0	0	**10**	0	0	0	0	**17**	Lost at follow up			
5	0	0	0	0	**11**	0	0	0	0	**18**	0	0	0	0
6	0	0	0	0	**12**	0	0	0	0	**19**	0	0	0	0
					13	1	1	1	1	**20**	0	0	0	0
										21	0	0	0	0
										22	0	0	0	0

D – Day.

Table. 16 Showing Follow-up radiographic assessments for Angulation

Case No.	Animals with diaphyseal and metaphyseal Humerus fracture				Case No	Animals with diaphyseal and metaphyseal Radius fracture				Case No	Animals with diaphyseal and metaphyseal Femur fracture			
	D15	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**
1	N	N	MV	MV	**7**	N	N	N	N	**14**	N	N	N	N
2	N	N	N	N	**8**	N	N	N	N	**15**	N	N	MV	N
3	N	N	MV	MV	**9**	N	N	MV	MV	**16**	N	N	N	N
4	N	N	N	N	**10**	N	N	N	N	**17**	Lost at follow up			
5	N	N	N	N	**11**	N	N	MV	MV	**18**	N	N	N	N
6	N	N	N	N	**12**	N	N	N	N	**19**	N	N	N	N
					13	N	N	N	N	**20**	N	N	N	N
										21	N	N	N	N
										22	N	N	N	N

D – Day, N – Normal, MV – Mild Valgus

Table. 17 Showing Follow-up radiographic assessments for Apparatus (LCP).

Case No.	Animals with diaphyseal and metaphyseal Humerus fracture				Case No	Animals with diaphyseal and metaphyseal Radius fracture				Case No	Animals with diaphyseal and metaphyseal Femur fracture			
	D15	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**
1	IP	EXP	IP	IP	**7**	IP	IP	IP	IP	**14**	IP	IP	IP	IP
2	IP	IP	IP	IP	**8**	IP	IP	IP	IP	**15**	IP	IP	IP	IP
3	IP	IP	IP	IP	**9**	IP	IP	IP	IP	**16**	IP	IP	IP	IP
4	IP	IP	IP	IP	**10**	IP	IP	IP	IP	**17**	Lost at follow up			
5	IP	IP	IP	IP	**11**	IP	EXP	IP	IP	**18**	IP	IP	IP	IP
6	IP	IP	IP	IP	**12**	IP	IP	IP	IP	**19**	IP	IP	IP	IP
					13	IP	IP	IP	IP	**20**	IP	IP	IP	IP
										21	IP	IP	IP	IP
										22	IP	IP	IP	IP

IP – In Position, EXP – Exposed through skin, D- Day.

Table. 18 Showing Follow-up radiographic evaluations of apparatus (Screw).

Case No.	Animals with diaphyseal and metaphyseal Humerus fracture				Case No	Animals with diaphyseal and metaphyseal Radius fracture				Case No	Animals with diaphyseal and metaphyseal Femur fracture			
	D15	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**
1	IP	EXP	IP	IP	**7**	IP	IP	IP	IP	**14**	IP	IP	IP	IP
2	IP	IP	IP	IP	**8**	IP	IP	IP	IP	**15**	IP	IP	IP	IP
3	IP	IP	IP	IP	**9**	IP	IP	IP	IP	**16**	IP	IP	IP	IP
4	IP	IP	IP	IP	**10**	IP	IP	IP	IP	**17**	Lost at follow up			
5	IP	IP	IP	IP	**11**	IP	EXP	IP	IP	**18**	IP	IP	IP	IP
6	IP	IP	IP	IP	**12**	IP	IP	IP	IP	**19**	IP	IP	IP	IP
					13	IP	IP	IP	IP	**20**	IP	IP	IP	IP
										21	IP	IP	IP	IP
										22	IP	IP	IP	IP

IP – In Position, D- Day. EXP – Exposed through skin,

Table. 19 Showing follow-up radiographic evaluations of Activity.

Case No.	**Animals with diaphyseal and metaphyseal - Humerus fracture**				**Case No**	**Animals with diaphyseal and metaphyseal -Radius fracture**				**Case No**	**Animals with diaphyseal and metaphyseal - Femur fracture**			
	D15	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**		**D15**	**D30**	**D45**	**D60**
1	NEBH	NEBH	PH	PH	**7**	NEBH	NEBH	SH	CU	**14**	NEBH	PH	PH	PH
2	NEBH	NEBH	PH	PH	**8**	NEBH	NEBH	SH	SH	**15**	NEBH	PH	PH	PH
3	NEBH	SH	SH	SH	**9**	NEBH	NEBH	CU	CU	**16**	NEBH	SH	CU	CU
4	NEBH	PH	PH	PH	**10**	NEBH	CU	PH	PH	**17**	Lost at follow up			
5	NEBH	NEBH	PH	PH	**11**	NEBH	NEBH	SH	SH	**18**	NEBH	PH	PH	PH
6	NEBH	SH	SH	SH	**12**	NEBH	SH	PH	PH	**19**	NEBH	PH	PH	PH
					13	NEBH	NEBH	SH	SH	**20**	NEBH	SH	SHP	SHP
										21	NEBH	PH	PH	PH
										22	NEBH	SH	SH	SH

NEBH	- No evidence of bone healing
PH	- Primary Healing
CU	- Clinical Union
SH	-Secondary Healing

Table.20 Showing Follow-up radiographic evaluations of Architecture (soft tissue).

Case No.	Animals with diaphyseal and metaphyseal Humerus fracture				Case No	Animals with diaphyseal and metaphyseal Radius fracture				Case No	Animals with diaphyseal and metaphyseal Femur fracture			
	D15	D30	D45	D60		D15	D30	D45	D60		D15	D30	D45	D60
1	N	N	N	N	7	N	N	N	N	14	N	N	N	N
2	N	N	N	N	8	N	N	N	N	15	N	N	N	N
3	STS	N	N	N	9	STS	N	N	N	16	N	N	N	N
4	N	N	N	N	10	N	N	N	N	17	Lost at follow up			
5	N	STS	N	N	11	N	N	N	N	18	N	N	N	N
6	N	N	N	N	12	N	STS	N	N	19	N	N	N	N
					13	N	N	N	N	20	STS	N	N	N
										21	N	N	N	N
										22	N	N	N	N

STS – Soft Tissue Swelling, N – Normal

Table.21 Showing Follow-up radiographic evaluations of Architecture (Bone).

Case No.	Animals with diaphyseal and metaphyseal Humerus fracture				Case No	Animals with diaphyseal and metaphyseal Radius fracture				Case No	Animals with diaphyseal and metaphyseal Femur fracture			
	D15	D30	D45	D60		D15	D30	D45	D60		D15	D30	D45	D60
1	N	N	N	N	7	N	N	N	N	14	N	N	N	N
2	N	N	N	N	8	N	synostosis	N	N	15	N	N	N	N
3	N	N	N	N	9	N	N	N	N	16	Periosteal reaction	N	N	N
4	N	N	N	N	10	N	N	N	N	17	Lost at follow up			
5	N	N	N	N	11	N	N	N	N	18	N	N	N	N
6	N	N	N	N	12	N	N	N	N	19	N	synostosis	N	N
					13	N	N	N	N	20	N	N	N	N
										21	N	N	N	N
											N	N	N	N

N-Normal

4.8.3 Complications

4.8.3.1 Intra operative complication

Malreduction occurred in one case (case No.1) of unstable metaphyseal fracture of humerus. Iatrogenic fracture of the ulna occurred in one case (case no 9) of distal radial fracture during the surgical procedure and the fragment was removed leaving a cortical defect (Plate 121). However this did not affect the outcome of the study.

Fractures which underwent surgical intervention less than 48 hours of fracture occurrence could be reduced and aligned comparatively more easier than fractures that underwent surgical intervention after 72 hours of incidence.

Segmental separation and longitudinal fissure occurred in one case no.21 during the surgical procedure.

4.8.3.2 Post operative complications

Dependent oedema of the fractured limb was observed in case No.5 at 30th post operative day. Seroma formation was observed in case No. 12 at first post operative day. Self mutilated wound and exposure of plate was noticed in case no 1 at 30th post operative day in dog with diaphyseal humerus fracture and self mutilated wound and exposure of T plate was observed in case no.11 at 30th post operative day with distal radial fracture (Plate 122). Complete healing of wound was observed at 60th post operative day.

4.8.3.3 Implant removal

The plate was removed in case no. 3 and 5 on 80th post operative day in dogs with humerus fractures. The T plate was removed in case No. 7 and 11on 95th post operative day (Plate 123) as the functional out was good in dogs with radius fractures. The case no. 17 which was stabilized with condylar plate lost at follow up. The plate was removed in case no. 16, 18 and 21 on 110th of post operative day as the functional outcome was good and radiological evidence of healing of fracture.

5.9. BIOCHEMICAL EVALUATION

5.9.1 Bone specific serum alkaline phosphatase – Fluorimetric reading

The fluorimetric reading of peak absorbance of pre and 45th post operative day serum samples in case no. 3, 11, 19 and 20 were observed and tabulated in Table 25.

Table.22 showing fluorimetric reading of pre and 45th post operative readings.

S.No.	Sample Code	Wave Length (Nm)	Intensity (cps)
1.	Pre op 1	512.99	312240
2.	Pre op 2	450.44	356300
3.	Pre op 3	450.91	146140
4.	Pre op 4	471.92	222100
5.	Post op 1	513.46	306760
6.	Post op 2	512.99	406020
7.	Post op 3	513.46	349300
8.	Post op 4	472.00	305790

Nm: Nanometre, cps: counts per seconds

The observations of fluorimetric reading on pre operative samples were lower than the 45th post operative day.

5.10. BIOMECHANICAL EVLUATION

From the biomechanical tests, load versus displacement graph were recorded and analyzed and tabulated.

5.10.1 SCREW PULLOUT TEST

In the present study, it was observed that the screw pull out strength on humeral diaphysis showed an yield load of 750N and ultimate load of 813N whereas a Humeral metaphysis showed an yield load of 500N and ultimate load of 540N. Hence comparatively, it is inferred that the screw pull out strength on humeral diaphysis was stronger when compared with humeral metaphysis. Screw pull out strength on femoral diaphysis showed a yield load of 994N and an ultimate load of 1460N whereas s femoral metaphysis showed a yield load of 780N and an ultimate load of 830N. Hence comparatively, it is inferred that the screw pull out strength on femoral diaphysis was stronger when compared with femoral metaphysis.

The results of the study are represented in Table 22.

Figure 20 - 23 represents the graphic representation of load – deformation curve for Screw Pullout Test on diaphysis and metaphysis of humerus and femur.

Table.23 Showing Screw Pullout strength of diaphysis and metaphysis of humerus and femur.

Sl.No	Type of Test	Condition of Setup	Yield Load (N)	Ultimate Load (N)
	Screw Pull Out Test	Diaphasis Humerus	750	813
		Metaphasis Humerus	500	540
		Diaphasis Femur	994	1460
		Metaphasis Femur	780	830

N - Newtons

Statistical analysis (Student t - test) revealed significant difference (p<0.01) in screw pull out in diaphysis and metaphysis of humerus and femur.

VARIABLES	**Diaphysis**			**Metaphysis**			**t - Test**	**P - Value**	**Result**
	N1	**MEAN(X)**	**±SE (X)**	**N2**	**MEAN(Y)**	**±SE(Y)**			
Humerus-Yield load	6	749.33	5.7019	6	501.50	7.6365	26.00	0.0000	**
Femur – Yield load	6	993.50	3.2838	6	779.17	2.5744	51.37	0.0000	**
Humerus-Ultimate load	6	813.83	1.7401	6	540.67	2.8245	82.34	0.0000	**
Femur-Ultimate load	6	1459.33	4.6164	6	830.67	3.3830	109.84	0.0000	**

Note: ** - highly significant (p<0.01)

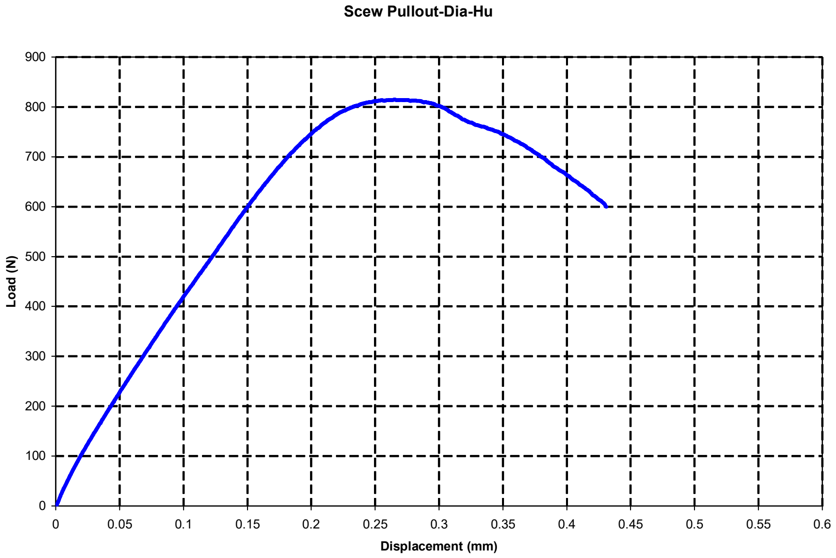

Figure 20. Showing graphical presentation of load – deformation curve for diaphysis of humerus.

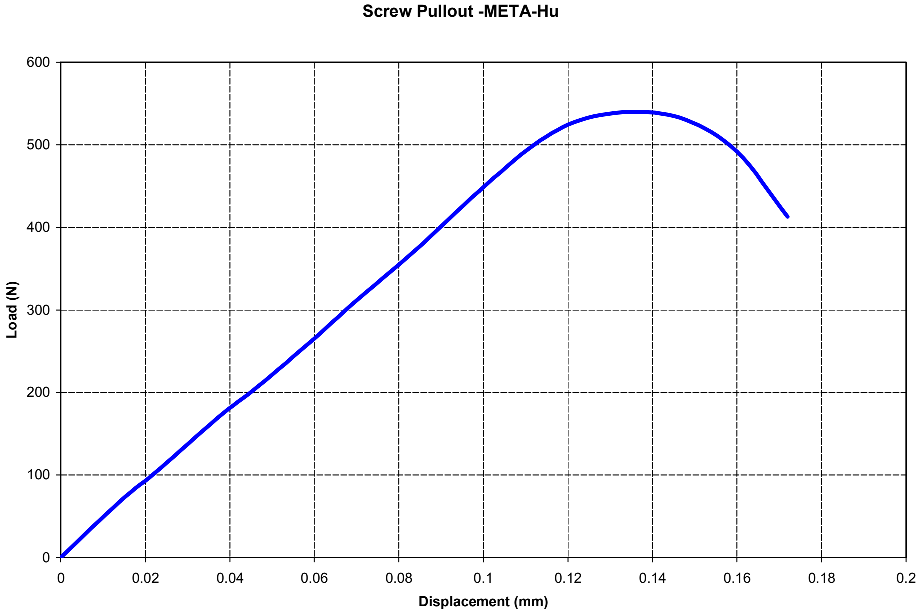

Figure 21. Showing graphical presentation of load – deformation curve for metaphysis of humerus.

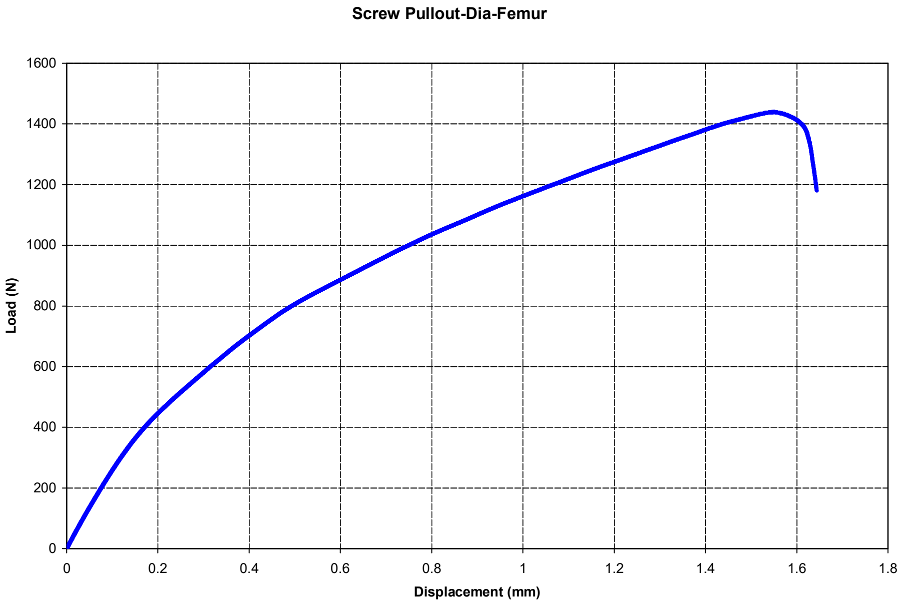

Figure22. Showing graphical presentation of load – deformation curve for diaphysis of femur.

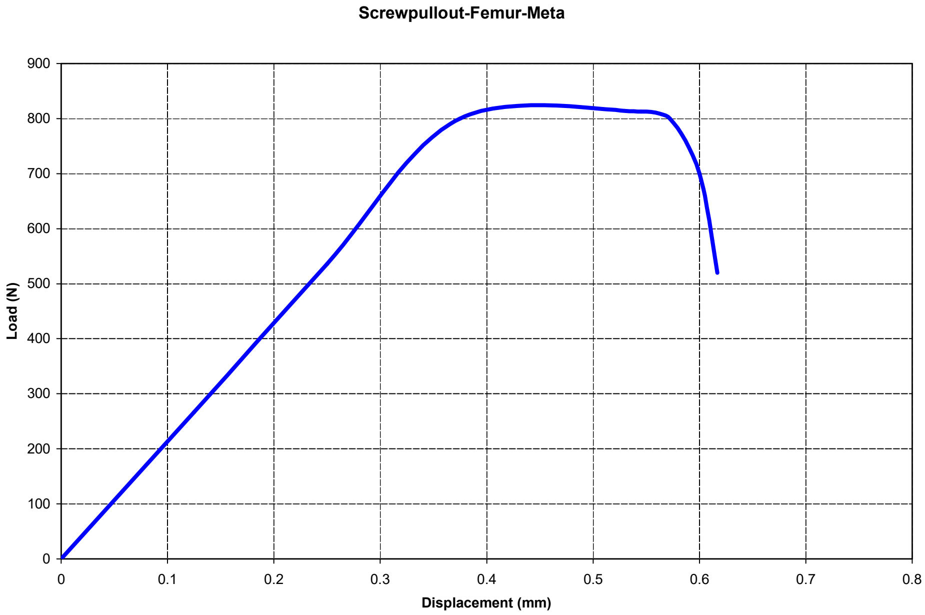

Figure 23. Showing graphical presentation of load – deformation curve for metaphysis of femur.

5.10.2 THREE POINT BENDING TEST

The maximum bending load for deformation of femur, plate, bone plate construct and bone plate construct (Gap model) was observed as 1520N, 1620N, 215N and 320N respectively. It was observed that bending strength of the bone plate construct and gap model was much lower than individual strength of either bone or the bone plate. The results of the study are represented in Table.23. It was observed that bending strength of the bone plate construct and gap model was much lower than individual strength of either bone or the bone plate. The results of the study are represented in Table.23. Figure 24 - 27 represents the graphic representation of load - deformation curve for bone, plate, bone plate construct and bone plate construct gap model.

Table.24 Showing three point bending test results of bone, plate, bone plate construct and bone plate construct gap model.

Sl.No	Condition of Setup	Maximum bending load for Deformation (N)
1	Femur Bone	1520
2	Bone Plate (3.5mm LCP)	942
3	Femur Bone + LCP Construct	215
4	Femur Bone + LCP Construct (Gap Model)	320

N - Newton

Table.24 Showing three point bending test results of bone, plate, bone plate construct and bone plate construct gap model.

Sl.No	**Condition of Setup**	**Maximum bending load for Deformation (N)**
1	Humerus Bone	1630
2	Bone Plate(3.5mm LCP)	1671
3	Humerus Bone + LCP Construct	315
4	Humerus Bone + LCP Construct (Gap Model)	418

N - Newton

Axial compression tests were performed on a servo hydraulic testing machine in displacement control (static testing) or load control (dynamic testing). Three humerii were tested in an axial compression until failure (Plate 124) (failure was defined as the first point of major discontinuity in the load versus displacement curve). A point of discontinuity (failure) was noted in the load versus deformation curves where an acute drop in the force during the elastic regions of the curve was followed by a small amount of deformation.

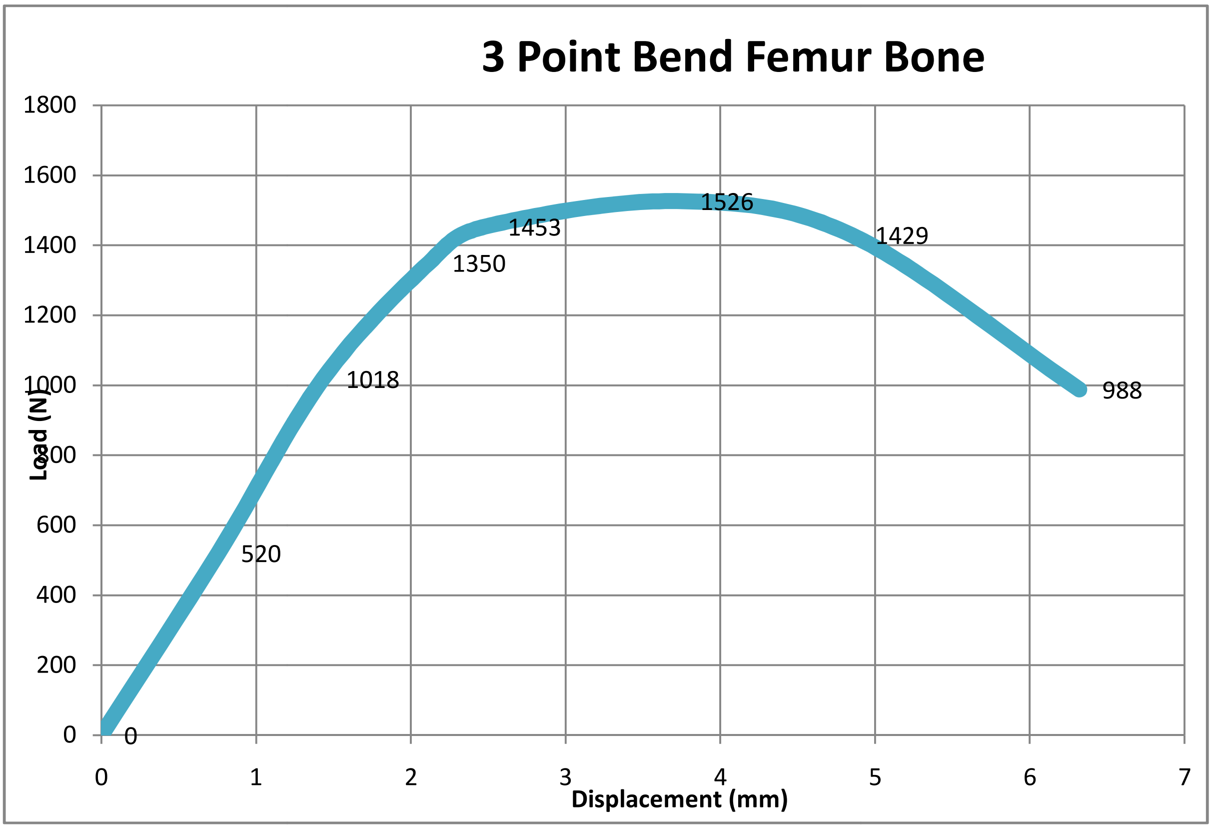

Figure 24. Showing graphical presentation of load - deformation curve for femur.

After an initial preload of 1.5N was applied, compression was applied at 5mm/min with data capture set at 10Hz. Load versus deformation curve were generated and recorded. Stiffness, defined as load per displacement in the elastic region of the curves, and strength at failure were evaluated.

Axial compression tests were performed on a servo hydraulic testing machine in displacement control (static testing) or load control (dynamic testing). Three 2.7mm linear locking compression plates were tested in an axial compression until failure (Plate 125) (failure was defined as the first point of major discontinuity in the load versus displacement curve). A failure (point of discontinuity) was noted in the load versus deformation curves where an acute drop in the force during the elastic regions of the curve was followed by a small amount of deformation.

After an initial preload of 1.5N was applied, compression was applied at 5mm/min with data capture set at 10Hz. Load versus deformation curve were generated and recorded.

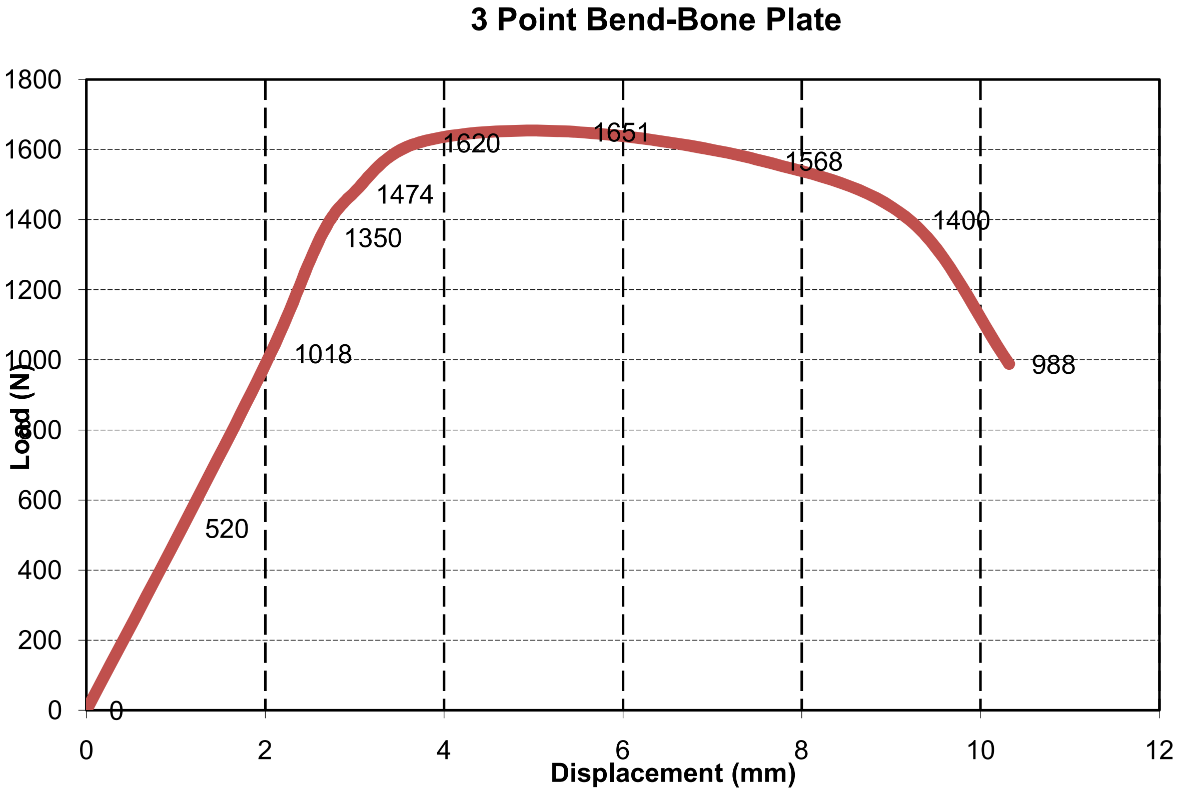

Figure 25. Showing graphical presentation of load - deformation curve for LCP plates.

Axial compression tests were performed on a servo hydraulic testing machine in displacement control (static testing) or load control (dynamic testing). The bone plate construct (femur and locking compression plate) were tested in an axial compression until failure (Plate 126) (failure was defined as the first point of major discontinuity in the load versus displacement curve). A failure (point of discontinuity) was noted in the load versus deformation curves where an acute drop in the force during the elastic regions of the curve was followed by a small amount of deformation.

After an initial preload of 1.5N was applied, compression was applied at 5mm/min with data capture set at 10Hz. Load versus deformation curve were generated and recorded.

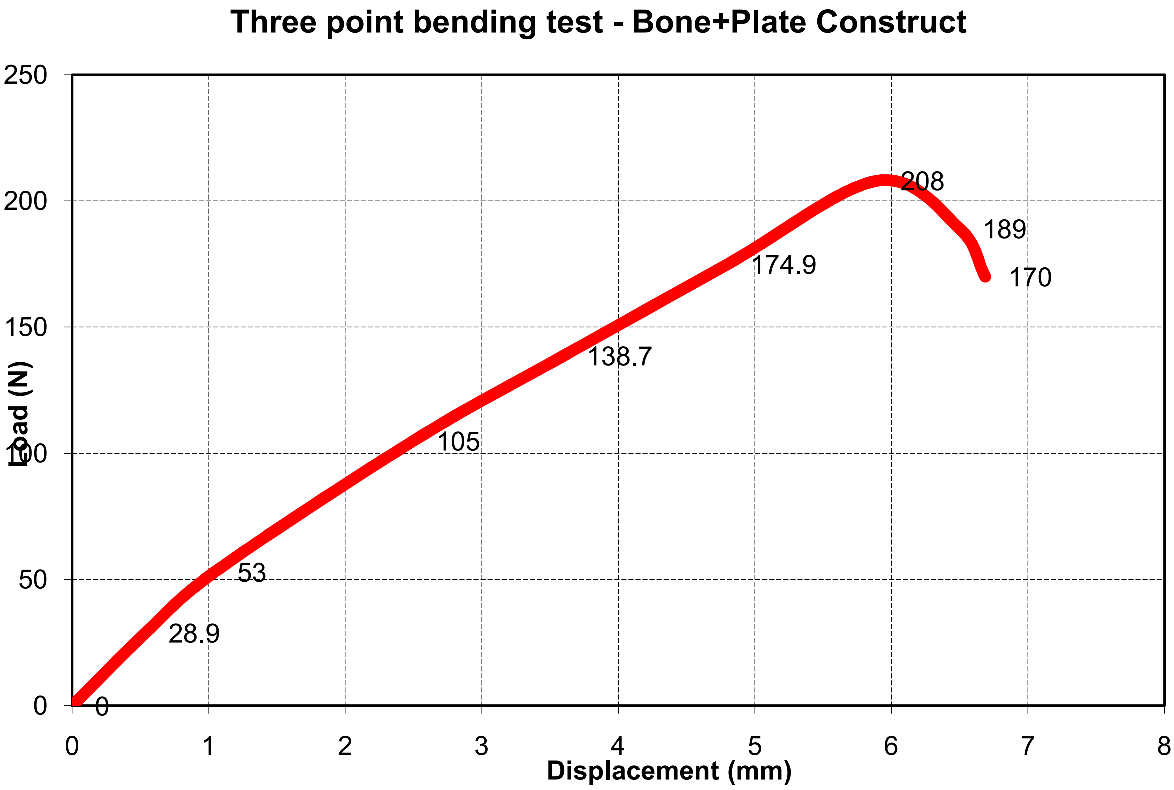

Figure 26. Showing graphical presentation of load - deformation curve for bone - plateconstruct.

4.10.2.4 Mechanical testing for bending strength of the bone plate constructs (Gap model.)

Axial compression tests were performed on a servo hydraulic testing machine in displacement control (static testing) or load control (dynamic testing). The bone plate construct with 10mm osteotomy gap at mid diaphysis of bone (femur and locking compression plate) were tested in an axial compression until failure (Plate 127) (failure was defined as the first point of major discontinuity in the load versus displacement curve). A failure (point of discontinuity) was noted in the load versus deformation curves where an acute drop in the force during the elastic regions of the curve was followed by a small amount of deformation.

After an initial preload of 1.5N was applied, compression was applied at 5mm/min with data capture set at 10Hz. Load versus deformation curve were generated and recorded.

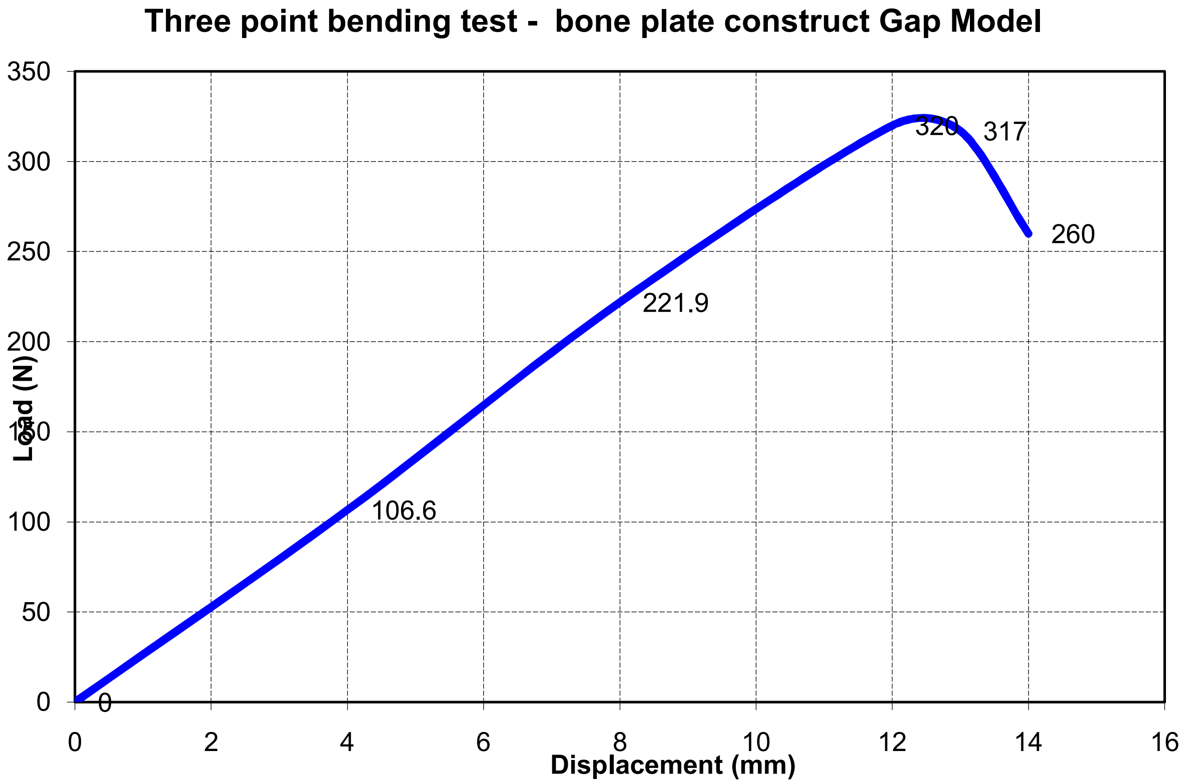

Figure 27. Showing graphical presentation of load - deformation curve for bone – plate construct gap model.

5. DISCUSSION

5.1 INCIDENCE

Among the long bone fractures recorded between January 2009 to December 2010, humerus accounted for a total of 231 cases (22.9%) out of 1008 cases reported. The humerus fracture cases constituted the third highest incidence of all long bone fracture. This finding concurred with the observation of Marcellin-Little (1998) who reported humeral fractures represented 34% of the forelimb fractures and was the third highest incidence recorded. Incidence of humerus fracture was the least among the long bone fractures evaluated in the study probably because of its anatomical position and extensive muscle coverage.

Among the long bone fractures recorded between January 2009 to December 2010, radius accounted for 381 cases (37.7%) out of 1008 cases reported. The radius fracture cases constituted the second highest incidence of all long bone fractures. This finding differed from the report of Dvořák *et al.* (2000) who reported that radius is the most commonly fractured long bone.

Among the long bone fractures recorded between January 2009 to December 2010, femur accounted for a total of 396 cases (39.3%) out of 1008 cases reported. The femur fractures constituted the highest incidence of all long bone fractures evaluated in the study. This finding concurred with the report of Kolata *et al.* (1974) and Raghunath *et al* (2007) who reported highest incidence of femur fracture. This observation differed from the report of Unger *et al.* (1990) who stated that diaphyseal fractures were more common in tibia and fibula (72.0%) as compared with femur (50.0%) and humerus (47.0). Incidence of femur fracture was the highest among the long bone fractures probably because it was most vulnerable to physical trauma on account of its position.

In the present study, road traffic accidents as a cause of fracture accounted for 40.8 per cent, followed by falling down from a height (18.3%) and unknown cause (18.3%). Kolata *et al.* (1974) reported that 75 per cent of the cases fell into 3 categories viz. motor vehicle accidents, animal interaction and unknown cause.

This result differed from the observations of Thilagar and Balasubramanian (1988) who stated that animal interaction is the primary cause of fracture particularly in male dogs followed by fall from height and crushing injury.

In the present study, among the humerus fracture, 157 cases (67.9%) were diaphyseal fractures and 74 cases (32.1%) were metaphyseal, physeal and epiphyseal fractures. In the present study, among the radius fracture, 242 cases (63.5%) were diaphyseal fractures and 139 cases (36.5%) were metaphyseal, physeal and epiphyseal fractures. In the present study, among the femur fracture, 258 cases (65.1%) were diaphyseal fractures and 138 cases (34.9%) were proximal and distal metaphyseal and condylar fractures. These results differed with observation of Kumar *et al.* (2007) who reported that the fractures were distributed equally along the length of the bone.

5.1.1 Breed, Sex and Age wise incidence of unstable diaphyseal and fracture of humerus

In the present study, the highest incidence was recorded in Mongrels constituting 117 cases (50.6 %), followed by Spitz 34 cases (14.7%), Labrador 18 cases (7.7%) German Shepherd 22 cases (9.5%), Doberman Pinscher 11 cases (4.7 %), Cross breeds 12 cases (5.1%) and others 18 cases (7.7%). Mongrels had the highest incidence probably due to the fact that they formed a major proportion of the dog population in the city of Chennai and reported most frequently to the Small Animal Orthopaedic Outpatient Unit, Madras Veterinary Teaching Hospital, Chennai, India.

In the present study, the highest incidence of humerus fractures was recorded in 144 male dogs (62.3%) where as in female dogs it was 87 (37.6%). This finding concurred with the observation of Thilagar and Balasubramanian (1988) who reported that male dogs were more frequently involved. This was probably attributed to higher male dog population being kept as pet than the female dogs and to the straying behavior of male dogs. This may be influenced by socio economic factors which does not encourage female dogs as pets due to a high rate of fecundity.

5.1.2 Breed, Sex and Age wise incidence of unstable metaphyseal and fracture of humerus

In the present study, the highest incidence was recorded in Mongrels 15 cases (20.3%), followed by Spitz 12 cases (16.2%), Labrador 10 cases (13.5%) German Shepherd 12 cases (16.2%), Doberman Pinscher 8 cases (10.9%), Cross breed 11 cases (14.8%) and others 6 cases (8.1%). Regarding sex, 54 cases (72.9%) of unstable metaphyseal humerus fractures were recorded in male dogs and 20 cases (27.1%) were recorded in bitches. The highest incidence of 43 cases (58.1%) was recorded in dogs aged between one and three years. Humerus fractures accounted for 22.3% of fractures evaluated in the study. Raghunath *et al.* (2007) reported only 12 per cent of humerus fractures in a retrospective study of 100 dogs with long bone fractures.

5.1.3 Breed, Sex and Age wise incidence of unstable diaphyseal fracture of radius

In the present study, the highest incidence was recorded in Spitz breed constituting a total of 98 cases (40.5%), followed by Mongrels 43 (17.7%), Labrador 23 cases (9.5%) German Shepherd 19 cases (7.8%), Doberman Pinscher 16 cases (6.7%), Cross breed 17 cases (7.0%) and others 26 cases (10.8%). These results are differed from Boudrieau (2003) who reported 18 per cent incidence of radius and ulna fractures in dogs. Regarding sex, 154 cases (63.6%) of unstable diaphyseal radius fracture were recorded in male dogs and 88 cases (36.4%) were recorded in bitches. The highest incidence of 143 cases (59.2%) was recorded in dogs aged between 6 months and 1 year. Milovancev and Ralphs (2004) reported that unstable diaphyseal radial fractures were the most common fractures encountered in the small animal population. Incidence of radial fracture was second highest in this study and differed from the findings of Milovancev and Ralphs (2004).

5.1.4 Breed, Sex and Age wise incidence of unstable metaphyseal fracture of radius

In the present study, the highest incidence was recorded in Spitz breed constituting a total of 53 cases (38.1%), followed by Mongrels 23(16.5%), Labrador 16 cases (11.5%) German Shepherd 11 cases (7.9%), Doberman Pinscher 9 cases (6.5%), Cross breed 13 cases (9.4%) and 14 cases (10.1%). Regarding sex, 98 cases (70.5%) of unstable diaphyseal radius fracture were recorded in male dogs and 41 cases (29.5%) were recorded in bitches. The highest incidence of 82 cases (58.9%) was recorded in dogs aged between 6 months and 1 year. These results are differed from the report of McCartney *et al.* (2010) who reported that the fractures of distal radius and ulna in dogs weighing less than 3 kg were relatively common. In the present study, the average weight of the dogs recorded was 14 kgs. The less muscular coverage of the distal part of the limb and subsequently less soft tissue protection predisposed toy and small breed dogs to injuries to the distal part of the radius and ulna

5.1.5 Breed, Sex and Age wise incidence of unstable diaphyseal fracture of femur

In the present study, the highest incidence was recorded in Mongrels constituting a total of 102 cases (39.5%), followed by Spitz 27 cases (10.5%), Labrador 35 cases (13.5%) German Shepherd 24 cases (9.3%), Doberman Pinscher 29 cases (11.4%), Cross breed 19 cases (7.3%) and others 22 cases (8.5%). Regarding sex, 145 cases (56.3%) of unstable diaphyseal radius fracture were recorded in male dogs and 113 cases (43.7%) were recorded in bitches. These results concurred with report of Kolata *et al.* (1974) who reported higher incidence of femur fracture as compared to female dogs. The highest incidence of 192 cases (74.4%) was recorded in dogs aged between one and three years. These findings are concurred with findings of Wong *et al.* (1984) who observed that 80 per cent of the femur fractures occurred in animals that are less than 2 years old.

5.1.6 Breed, Sex and Age wise incidence of unstable metaphyseal fracture of femur

In the present study out of 138 cases studied, the highest incidence was recorded in Mongrels constituting a total of 37 cases (48.4%), followed by Spitz 29 cases (16.2%), Labrador 23 cases (7.1%) German Shepherd 19 cases (7.6%), Doberman Pinscher 14 cases (4.8%), Cross breed 9 cases (7.6%) and others 7 cases (8.3%). Regarding sex, 74 cases (53.6%) of unstable diaphyseal radius fracture were recorded in male dogs and 64 cases (46.4%) were recorded in bitches. The highest incidence of 85 cases (61.6%) was recorded in dogs aged between one and 3 years. These results were similar to the observations of Wong *et al.* (1984) who observed that 80 per cent of the femur fractures occurred in animals that are less than 2 years old.

5.2 ETIOLOGY OF FRACTURES

Among the 22 cases subjected to the surgical procedure, the highest incidence was recorded due to road traffic accident (RTA) in 9 cases (42.8%) followed by fall from height, four cases (18.3%), unknown causes, four cases (18.3%), slipped on the floor causes, three cases (13.5%) and fell down when playing, two cases (9.1%). These observations were in agreement with the report of Kolata *et al.* (1974), and McCartney *et al.* (2010) who reported that majority of fractures were caused by road traffic accidents. This is probably attributed to owner negligence and frequent straying behavior of dogs.

5.3 CLASSIFICATION OF FRACTURES

In the present study, 13.0% of unstable oblique diaphyseal fractures (12 - A2) and 13.0% unstable transverse metaphyseal fractures (13 – A1) of humerus were recorded. Similarly, simple transverse diaphyseal fracture 22 - A2, transverse metaphyseal fractures 22 – A1, malunion at diaphyseal region (22 - A1) and transverse diaphyseal fractures of radius with simple ulna fracture 22- B1 were 4.6.0%, 13.6.0%, 4.6% and 9.0% respectively. Multiple supracondylar fracture 33 – C3, multiple diaphyseal fracture 33 – A3, transverse wedge diaphyseal fracture 32 – A3, short oblique metaphyseal fracture 32 – A2 and long oblique metaphyseal fracture 33 – A2 were 4.6%, 4.6%, 13.6%, 9.0% and 9.0% respectively in femur fracture. This classification was found appropriate for the study and indicated that unstable diaphyseal fractures of humerus, radius and femur were more common than the unstable metaphyseal fracture of humerus, radius and femur. These finding concurred with the report of Raghunath *et al.* (2007) who recorded simple diaphyseal fractures (42A) constituting 60% of the total cases, followed by wedge (42B) constituting 20% of the total cases and two complex fracture (42C) constituting 20% of the total cases. Classification of fractures preoperatively provided information to the surgeon with regard to nature and location of fractures and degree of comminution. Preoperative classification enabled preoperative planning and aided in decision making during surgery.

5.4 FRACTURE PATIENT ASSESSMENT SCORE (FPAS)

The fracture patient assessment score considered mechanical, biological and clinical factors to obtain a final subjective score. The mechanical factors were patient weight and load sharing between implant and bone, the biological factors were soft tissue injury, age and health of the patient and clinical factor was owner compliance. In this study, the fracture patient assessment score correlated positively with the clinical situation. The fracture patient assessment score helped to tentatively predict clinical outcome in this study. The scoring was accordance with the system developed by Palmer (2000).

5.5 PRE OPERATIVE PLAN

Preoperative plan using the lateral, craniocaudal or craniocaudal radiographs of the contralateral limb was essential to determine the size and length of the plate and screw. Pre contouring of plate as used in conventional plate system was not done because of the single beam construct of locking plate system. The size of the plate and screws were selected based on the preoperative composite drawing of proximal and distal fracture fragments superimposed on normal contra lateral limb radiographs of the animal to obtain a final template.

In the present study, the preoperative plan using composite drawing facilitated selection of appropriate implants. Factors such as body weight of the animal, fracture configuration and location of the fracture also influenced implant selection. Schmokel *et al.* (2007) reported that well positioned, orthogonal radiographic views of both the fractured and the contralateral intact limb segments were required to develop a preoperative plan of the procedure. Brinker (1984) stated that the important factors to be considered in choosing the size of implant were size of bone, weight of the animal, type and location of the fracture, activity and condition of soft tissue. Among this, the most consistent factor in choosing the size of the implant was the weight of the patient.

5.6 SURGICAL TECHNIQUE

5.6.1 Surgical approach to the diaphysis and metaphysis of the humerus

Craniolateral approach to diaphysis of humerus provided adequate exposure with minimal soft tissue and vascular trauma to the fracture site. This approach also facilitated open reduction and internal fixation of fracture fragments. This procedure concurred with the procedure of Fossum, (2007).

5.6.2 Surgical approach to the shaft of the radius

The craniomedial approach to the diaphysis of radius provided adequate exposure with minimal soft tissue and vascular trauma to the fracture site. This approach also facilitated open reduction and internal fixation of fracture fragments. This procedure concurred with the procedure of Piermattei and Greely (1993a).

Dorsal approach to the metaphysis of radius provided adequate exposure with minimal soft tissue and vascular trauma to the fracture site. This approach also facilitated open reduction and internal fixation of fracture fragments. This procedure study concurred with the procedure of Piermattei and Greely (1979).

5.6.3 Surgical approach to the shaft of the femur

The craniolateral approach to the diaphysis of femur provided adequate exposure with minimal soft tissue and vascular trauma to the fracture site. This approach also facilitated open reduction and internal fixation of fractured fragments. This procedure concurred with the procedure of Piermattei and Greely (1993b).

A standard lateral approach to the femoral shaft combined with a lateral approach to the stifle provided adequate exposure with minimal soft tissue and vascular trauma to the metaphyseal region. This approach also facilitated open reduction and internal fixation of fractured fragments. The distal femur can also be approached through a medial incision and through a combined medial and lateral incision (Piermattei and Greely, 1993b).

5.7 LOCKING COMPRESSION PLATING TECHNIQUE

Relative stability plating with angular stable fixation using locking compression plates is recommended for complex diaphyseal/metaphyseal fractures with extensive comminution (Tan and Balogh*,* 2009). In the present study, 2.7mm and 3.5 mm linear locking plate system, 2.7mm locking ‘T’ plate system and 3.5 mm condylar locking plate system were developed in the study using 316L stainless steel alloy. The developments of the plates were based on the designs originally proposed by Frigg, (2003). Plate osteosynthesis using the locking compression plate system offered the possibility of inserting conventional and locking head screws into specially designed combination holes. This system combined the facilities of conventional plate osteosynthesis with those of the internal fixator systems (Sommer *et al*. 2003). Locking of the screws to the plate at a fixed angle obviates the need for the linear locking compression plate to be compressed to the bone, as with dynamic compression plating, minimizes the need to disrupt the surrounding periosteum and soft tissue, and prevents primary dislocation of the fracture caused by inexact contouring of the plate. Locking of the screws to plate makes the fixation construct more resistant to failure from sequential screw loosening and pullout. In addition the fixed angle nature of the plate and screw fixation resists cantilever bending stresses and reduces the risk of angular deformity in metaphyseal fractures that are comminuted and are unable to share the load (Anglen *et al*, 2009). In the present study, the locking compression plate was used as a buttress in comminuted fractures to provide a rigid linear locking compression plate construct and create a firm interface. The locking compression plate was also used as a conventional compression plate for open reduction and internal fixation of transverse fractures. Locking screws were used in place of cortical screws throughout the study. Comminuted fractures with non reducible wedges were buttressed by application of screws in the locking holes of the plate. Compressing unstable transverse and oblique fractures using the gliding hole of the plate ensured rigid stability of the fracture fragments. There are however no accepted guidelines for proper application of locking compression plates as an internal fixator in dogs and techniques used in human beings were adapted for use in small animal practice. In the present study, AO/ASIF principles applicable for conventional plating such as using a plate to span the entire length of the bone, appropriate size of the plate based on the body weight of the dog and number and placement of screws were factors that influenced the stability of the plate. A specially devised locking drill guide ensured that the drill hole was made in the correct direction perpendicular to the plate during fracture fixation in all clinical cases in this study. In order to engage the corresponding threads in the plate, the threaded drill guides should be inserted perpendicularly to the plate and altering the angle of the screws is not recommended. A minimum of two screws per segment with at least three cortices for simple fracture and at least four cortices for comminuted fractures in good quality bone should be used. (Gautier and Sommer, 2003). This technique was adopted in the present study.

During plate application, both plate and bone fragments can move independently, making accurate screw placement difficult as small shifts at the plate translate to great deviations at the level of bone. With a single screw in place, plate movement is confined to rotation in one plane and once two or more screws are placed such that alterations in plate position are no longer possible. Unlike the more forgiving traditional fixator, the mono axial nature of the locking head screw trajectory reduces the ability to compensate for imperfect placement, making it mandatory that anatomical reduction be achieved prior to placement of first screw (Woon *et al.* 2010). In the present study, proper placement of screws were ensured using a threaded drill guide which was fit precisely in to the threaded screw hole of the plate before drilling. Further, the plate was firmly secured by using a pair of serrated reduction forceps to prevent any change in orientation during plate fixation.

The plate was not contoured to the shape of the bone as is the procedure followed with conventional plating. With dynamic compression plating, friction between plate and bone is essential for stability but is not required with locking plates. This is due to the fact that when locking compression plates are contoured, the integrity of the plate thread is disturbed with consequent loss of the locking facility. This was in accordance with the technique of Ness, (2009). In this study, biological osteosynthesis was promoted by retaining all the fragments having soft tissue attachment and soft callus. This was in agreement with the report of Reems *et al.* (2003).

5.7.1 Linear locking compression plating technique

The linear locking compression plates used in this study were applied either in buttress or in compression mode. To facilitate compression, the locking screws when inserted through the eccentrically placed hole close to the fracture, the bone and the plate move longitudinal to one another, the plate came under tension, the bone came under compression and the fracture gap was narrowed. In buttress plating, the plate was applied on the bone and held in position by placing locking screws through locking holes. To avoid stress risers, all the holes in the plate were filled up except the hole in the plate corresponding to the fracture line or to the wedge fragments. Stoffel *et al.* (2003) stated that omitting one hole one each side of the fracture improved flexibility by 60% in compression and 30% in torsion. They also observed that insertion of more than three screws in each main fragment did not increase axial stiffness and using more than four screws in each main fragment did not increase torsional rigidity. The locking compression plate is reported to be equally stable with mono-cortical or bi-cortical screws due to the angular stability of the screws (Gautier and Sommer, 2003). In the present study, two or more screws were used in the proximal and distal fracture fragments in all the cases. In the present study, bicortical screws were used to provide rigid stability. This was due to the fact that the screws used in the study were made of 316L stainless steel as an alternative to titanium screws. Stainless steel has a lesser modulus of elasticity and is more prone to corrosion and implant loosening as compared to titanium. Stainless steel also does not have any significant difference between maximum torque and torque at failure, whereas titanium showed a significant differential between maximum torque and torque at failure (Wolcott and Himmel, 1997). Radiological measurement 24 weeks after osteotomy of femur in 36 beagle dogs showed cortical thickness reduced by 6% under titanium alloy and 19 % under stainless steel, while histological measurement showed total loss of 3.7% under titanium and 11% under stainless steel. Moreover, unicortical configurations have 50% less rigidity than bicortical purchase (Aro and Chao, 1993). When linear locking compression plate was applied on the tension side of the bone, the plate screw interface acted as a locking system and functioned as a single beam construct which provided adequate fracture stability. The procedure of compression and buttress plating was in agreement with the procedure of Brinker (1984). The implant is not compressed to the bone on account of its design and herby does not compromise the periosteal circulation (Wilson, 2002). Minimizing the plate footprint is of advantage in accelerating bone healing and increasing local resistance to infection (Perren, 2003). In the present study minimal periosteal contact was maintained between plate and bone.

Out of 22 clinical cases, rigid fixation using the linear locking compression plate was performed using 2.7mm linear locking compression plate in four cases, 3.5mm linear locking compression plate in fourteen cases. Fixing the plate to the bone by applying the most proximal and most distal locking screws initially and later filling all the remaining screws holes was found to be technically suited for the plate fixation.

Linear locking compression plates were applied to the medial aspect of the radius in unstable diaphyseal fracture. In the study, screws were applied in a medio-lateral plane. Gordon *et al.* (2010) stated that screws placed in a medio-lateral plane were significantly stronger than screws applied in a cranio-caudal plane. Medial plating of the radius was chosen as opposed to dorsal plating because of the superior bending properties, a lack of interference with the dorsally located extensor tendons, easier intra-operative reduction and better bone purchase for the screws in a medio-lateral direction (Sardinas and Montavon, 1997). Early weight bearing was observed in nine cases. This is probably attributed to load – sharing between bone and implant during weight bearing which stimulated a developing callus until the bony union. This is in agreement with the findings of Ziran *et al.* (2007) who observed developing callus during weight bearing due to load-sharing.

In the present study, plate rod technique was followed in four cases using 3mm intra medullary steinmann pin as ancillary fixation. In one case, the fixation was further stabilized using cerclage wire. Addition of an intramedullary pin to a linear locking compression plate has been shown by Hulse *et al.* (1997) to decrease strain on the plate two fold. Addition of an intramedullary pin also increased bending strength twice and fatigue life of the plate hundred fold. The intramedullary pin mechanically replaced the defect in the diaphysis and helped in establishing the spatial alignment of the limb. This was in agreement with Vannini (2004). The intramedullary pin also helped to counter bending forces. This was in accordance with the observation of Denny (2000). Application of cerclage wire was in concurrence with the principles propounded by the AO/ASIF group that suggested cerclage can be applied when the length of the fracture exceeded more than two times the diameter of the bone.

Combining the Locking compression plate with intramedullary pins allows for monocortical screw placement without loss of holding power as compared to bi cortically placed screws (Roberts *et al.* 2007). The maintenance of the holding power of the monocortical locking head screw was also beneficial when other implants prevented the use of bicortical screws. (Haaland *et al.* 2009). However, in the present study, bicortical screws could be placed without infringing on the intramedullary pin. The intramedullary pins selected for the study occupied 40 percent diameter of the medullary cavity and was placed by a normograde technique. Stoffel *et al.* (2003) suggested that long plates should be used to optimize axial stability and that the plastic deformation of the plate is significantly reduced when the screws closest to the fracture site are removed. In the present study, linear locking compression plate spanning the entire length of the bone was used. This was in accordance with Gautier and Sommer (2003) who reported that longer plates provided more stability because of less pull out force acting on the screw.

5.7.2 Locking compression 'T' plating technique

The 2.7 mm locking 'T' plate used in this study was developed for stabilization of unstable metaphyseal fracture of radius in animals weighing between 10 and 15 kgs. This was in accordance with the concepts of decision making in plate fixation developed by Brinker (1984). Craniocaudal placement of the horizontal portion of 'T' plate on distal fragment in metaphyseal radial fracture provided significant stability to the fixation. No incidence of ulnar resorption or decreased carpal flexion were observed in the present study. Distal radial fractures in small breed dogs are difficult to treat due to poor vascularity. In small-breed dogs, there was decreased vascular density at the distal diaphyseal-metaphyseal junction compared with large-breed dogs. The reduced vascularity corresponded to the region associated with a poor prognosis for fracture healing in small-breed dogs. This regional association suggests that a decreased vascular supply in the distal radius may contribute to a higher frequency of delayed union and non union in smaller dogs (Welch *et al.* 1997). The mini T-plate was a suitable choice of implant for stabilizing unstable distal radial fractures in toy breed dogs, as the distal fragment is very small (Hamilton and Langley-Hobbs, 2005). In the present study, 2.7mm locking 'T' plate was developed for the study. Locking 'T' plate was applied in compression based on AO/ASIF techniques. Presently there is no literature available on the application of 2.7mm locking 'T' plate for unstable distal metaphyseal radial fracture in dogs. The locking 'T' plate developed for this study was found to be a suitable implant for providing stable fixation of unstable distal metaphyseal radial fracture dogs. The utility of the locking 'T' plate for the management of unstable metaphyseal radial fractures in dogs have to be studied in detail.

5.7.3 Condylar locking plating technique

3.5 mm human locking condylar plate was used for this study. One case of comminuted fracture with non reducible wedges of the supracondylar region was buttressed with a left lateral locking condylar plate. Locking plates are ideal for distal femoral fractures with or without articular involvement. Malalignment of the articular surface is not uncommon, especially in inexperienced hands using the minimally invasive technique (Tan and Balogh, 2009). In the present study, an ancillary fixation with cross pins was carried out to promote additional stability at the fracture site. Human locking condylar plates are specifically made according to the limb involved. Since, limited information is available on the use of condylar locking plate in veterinary practice further extensive study is needed to evaluate this technique for the management of supracondylar fractures of femur.

5.7.4 Implant development

In the present study, 8, 9 and 10 hole 3.5mm linear locking compression plates were used in dogs weighing between 15-30kgs. 8 and 9 hole 2.7mm locking T locking plates were used in dogs weighing between of 12-15 kgs. 9 hole human 3.5mm locking condylar plate was used in one dog with a body weight of 25 kgs. Locking compression plates manufactured from 316L stainless steel metal alloy were used in this study. The direction of the combi hole deviated towards the centre of the plate. The diameters of the locking and non locking side of the combihole were manufactured based on standard AO/ASIF recommendation (Wagner and Frigg, 2006). Self tapping locking screws with a thread diameter of 2.7mm, core diameter of 1.9mm and pitch of 1.0mm, hexagonal socket of 2.5mm and head diameter of 5.0mm for 2.7mm locking plates and thread diameter of 3.5mm, core diameter of 2.4mm and pitch of 1.25mm, hexagonal socket of 2.5mm and head diameter of 6.0mm, for 3.5mm plates manufactured as per AO/ASIF specifications were used in the study.

5.7.5 C-arm evaluation and Operative time

A portable C arm image intensifier was used for serial intra operative imaging and immediate post operative evaluation of plate fixation. Successful application of the implant and correct axial and rotational alignment were confirmed by post operative fluoroscopy (Haaland *et al,* 2009). The C-arm study provided a clear visual image for interpretation and decision making in plate fixation.

In the present study, the average surgical time taken for the fracture fixation with C – arm guidance was 1.37hrs (1.45 to 2.50hrs) for fixation of unstable diaphyseal fractures of humerus, 1.15hrs (1.20 to 2.30hrs) for the fixation of unstable diaphyseal and metaphyseal fracture of radius and 1.55 hrs (2.0 to 3.10hrs) for the fixation of unstable diaphyseal and metaphyseal fractures of femur. The duration of surgery for conventional plating technique was 191.8 minutes with a mean total operating time of 125 to 255 minutes (Johnson *et al.* 1998). Dudley *et al.* (1997) reported a surgical time on plating as 157 minutes. Haaland *et al.* (2009) reported reduced surgical time with internal fixator and attributed it to lesser manipulation of fracture fragments and reduced need for plate contouring. In the present study, the duration for plating was similar to conventional plating probably due to the fact more number of proximal and distal screws were applied and the procedure was hence prolonged.

5.8 PARAMETERS STUDIED

5.8.1 Clinical Evaluation

5.8.1.1 Evaluation of body condition, range of motion, limb girth and limb length

In the present study, in 18 cases (81.82%), the range of motion was decreased, whereas in 4 cases (18.18%), the range of motion was normal. The limb girth was mildly increased in 7 cases (31.82%), moderately increased in 9 cases (40.91%) and severely in 6 cases (27.27%). The increased limb girth was probably related to the extent of soft tissue damage and size of haematoma. The limb length was normal in 9 cases (40.91%) and decreased in 13 cases (59.09%).

The limb length was decreased in fractures with unstable overriding transverse and oblique fractures. In the present study, nutritional status of all the cases indicated normal growth and development of bone.

5.8.1.2 Lameness grade

The lameness grade was 5 on pre operative day in all cases except in case no 15 which had lameness grade 4. Post operatively lameness grade showed gradual improvement to normal weight bearing over the period of study in all the cases. The lameness grade was carried out in accordance with the protocol developed by Braden and Brinker (1973). Normal weight bearing on all limbs at rest and when walking which was graded as 1 and this was attributed to adequate fracture reduction, load sharing between implant and bone and minimal disruption of the soft tissue. In the present study, the lameness grading score was in accordance with the fundamental principles of AO/ASIF which aims to promote pain free mobility through stable internal fixation and preservation of vascularity with minimal soft tissue trauma. Zimmermann *et al.* (2010) reported a femoral fracture repair using a 16 hole 4.5mm locking distal plate in an adult captive polar bear. They observed that at 11.5 weeks, the lameness grade was 2/5 and at about 11 months, lameness was no longer evident.

5.8.1.3 Functional out come

In the present study, all the dogs were evaluated for functional out come at 60th post operative day and categorized as excellent good, fair and poor based on the classification suggested by (Roush and McLaughlin, 1999).

The functional outcome was graded excellent in 4 cases (66.8%), good in one case (16.6%) and poor in one (16.6%) case out of 6 cases of fractures of the humerus considered in the study. The functional outcome was graded excellent in 4 cases (57.1%), good in 2 cases (28.6%) and fair in one case (14.3%) out of 7 cases of fractures of radius considered in the study. The functional outcome was graded excellent in 4 cases (66.8%), good in 2 cases (25%) and fair in 2 cases (12.5%) out of 9 cases of fractures of the femur considered in the study. One case was lost at follow up. Larsen *et al.* (1999) reported that 16 cases (89.0%) have successful return to function in 22 radius and ulnar fractures treated with linear locking compression plates. Braden and Brinker (1973) reported return to normal, full function of the injured limb in about 3.5 weeks by conventional bone plating. Locking compression plate permitted more biological surgical approach, unhampered periosteal blood supply to the fracture site and potentially increased stability by engaging fewer cortices in each fragments may make the locking compression plate suited for stabilization of the metaphyseal and comminuted fractures (Filipowicz *et al.* 2009). The fixed angle nature of plate and plate fixation resist cantilever bending stresses and reduces the risk of angular deformity in metaphyseal fracture that are comminuted, missing bone or otherwise mechanically unable to share the load (Anglen *et al.* 2009). In the present study, the functional outcome influenced directly by the stability of the fixation.

5.8.2 Radiographic Evaluation

In the present study, radiographic study was evaluated with periodically mediolateral and craniocaudal views for humerus and femur bone and craniocaudal views for distal radial fracture. The studies were carried out pre operatively, immediate post operative day, 15th post operative day, 30th post operative day, 45th post operative day and 60th post operative day to assess the apposition and alignment, angulation, apparatus (linear locking compression plate and screws), activity and architecture (soft tissue and bone). This evaluation was in accordance with Haaland *et al.* (2009) who reported that radiographic assessment at immediate post operative day and subsequent post operative radiographic evaluation on every three weeks in a retrospective study on appendicular fracture repair in dogs using the locking compression plate system in 47 cases. The fracture was considered healed when a visible callus bridging at least one cortex or by disappearance of the fracture line was present on both the lateral and cranio caudal radiographic views, as suggested by Dernanz *et al.* (2007).

5.8.2.1 Apposition and alignment

In the present study, apposition and alignment of fractured fragments with adequate cortical contact between fractured fragments were present in all cases at immediate post operative day and score for all cases were 0. Cook *et al.* (1999) developed a fracture reduction and apposition scoring system based on radiological evaluation following open reduction and internal fixation of fractures. This system was used in the present study. Quality of the fracture reduction was assessed by alignment of the fragments and shift on the craniocaudal and lateral projection. Anatomical reduction was necessary for successful fracture management. This finding concurred with observation of Haaland *et al.* (2009) who stated that correct axial and rotational alignment of the fracture fragments following application of linear locking compression plates were confirmed by immediate post operative radiographs. Braden and Brinker (1976) suggested that first radiographs should be taken during surgery and immediately after surgery to record the status of reduction, alignment and fixation and at subsequent post operative days to monitor healing. This was carried out in the present study. Schwandt and Montavon (2005) reported a repair of concomitant fractures radius-ulna and tibia-fibula in a six-month-old, male Bernese Mountain dog in which was treated each with 3.5 mm Locking compression plates to stabilize both the fragments. They reported that following surgery, radiographs of both operated legs were taken which revealed adequate fracture alignment of the fracture in both limbs.

Apposition and alignment of fractured fragments with adequate cortical contact between fractured fragments were present in case no. 2, 4, 5 and 6 in humerus fractures fixation; 7, 8, 9, 10 and 12 in radius fracture fixation and 14, 16, 18, 19, 20, 21 and 22 in femur fracture fixation up to 60th post operative day. Locking compression plates promote rigid stability by providing axial and rotational alignment and act as a single beam construct stabilizing the fracture. This was in accordance with the findings of Anglen *et al.* (2009). Malreduction was observed in all the cases except case no. 1, 3, 13 and 15 Case no. 17 was lost at follow up on 15th post operative day. Malreduction is attributed to technical error during the attempted reduction and may probably be due to muscle contracture, insufficient release of adhesions, attached soft tissues and callus at the fracture site.

5.8.2.2 Angulation

In the present study, angulation was graded as normal or mild valgus. Mild valgus was observed in case no.1. These finding were in accordance with Schwandt and Montavon (2005) who observed slight valgus following radial fracture repair in their study on locking compression plate fixation of radial and tibial fractures in a six-month-old, male Bernese mountain dog. They also observed sudden valgus deformation of the tibia following a short leash walk two days post surgery. They reported that this was due to collapse of the fracture and plate bending to an angle of 25° to the lateral side.

5.8.2.3 Apparatus

The plate length, size and position were appropriate in all the cases at immediate post operative day. Proximal segment screws were little longer than the distal segmental screws in case no. 5. The screws on proximal and distal fragments close to the fracture line were little longer than the remaining screws in case no. 4. Screw size was appropriate in all cases. Follow up post operative radiographic evaluation indicated that the plate was in position in all the cases until 60th post operative day except case no. 1 where plate and screw loosened on 30th post operative day. Follow-up post operative radiographic evaluation indicated that the plate was in position in all the cases and no plate bending was observed in this study. These finding indicated that in the present study, all cases maintained rigid internal fixation. Placement of the screws in the present study concurred with observation of Ellis *et al.* (2001) who concluded that the screws should be placed as close to the fracture site as possible in order to reduce the amount of strain to promote stable fixation and fracture healing.

Several factors have been shown to influence the stability of a locking compression plate construct, such as working length (i.e. the length of plate between the two screws closest to the fracture), number and placement of screws, distance between plate and bone, and size of the implant (Stoffel *et al.* 2003). Haaland *et al*. (2009) stated that there are no accepted guidelines for proper application of locking compression plate device as an internal fixator in small animal practice in small dogs and experience from human osteosynthesis is therefore extrapolated to veterinary cases. In the present study, AO/ASIF guidelines were adapted for application of locking compression plate application.

5.8.2.4 Radiographic evaluation of activity

Fracture healing depends upon a variety of factors including the age and breed of the animal, the type of fracture, the degree of disruption of blood supply to the bone and the nutritional condition of the animal. Evidence of primary healing was observed in case no. 4, 14, 15, 18 and 21 on 30th post operative day and in case no.5, 11 and 12 on 45th post operative day. Primary healing was evidenced by absence of external callus formation. In primary healing, initial resorption at fracture ends increased the fracture gap, reduced inter fragmentary strain and promoted osteogenesis. The observation on primary healing in this study was in accordance with Rahn *et al.* (1971) who stated that direct bone healing occurred under conditions of stable injuries or rigid internal fixation, fracture compression, complete apposition of fracture fragments and there was little or no bridging / external callus formation because of no mechanical instability.

In the present study, primary healing occurred in fracture cases subjected to compression which resulted in a reduced fracture gap and interfragmentary compression. A minimal amount of strain seems to be a precondition of mechanical induction of callus. Compression applied to the fracture produces preloaded continuous contact and thus minimizes interfragmentary strain. This enables the osteones to cross the fracture at compressed surfaces (Yamada, 1970).

Evidence of bony union was observed in case no.7 at 60th day and case no. 9 and 10 on 45th post operative day. Bony union indicated progressive fracture healing. Case no.1 had malunion with evidence of bony activity on 30th post operative day. This bony activity observed in the study was in accordance with Piermattei and Flo (1997) who reported that young animals have more bony turnover as compared to older animals. Malunion was probably related to improper apposition and alignment during fracture repair.

Evidence of secondary healing was observed in case no. 1, 3, 6, 13, 16, 19, 20 and 22 on 30th post operative day and case no.2, 7 and 8 on 45th post operative day. Secondary healing was observed in the present study. Secondary healing was characterized by development of a bridging periosteal and endosteal callus. Epari *et al.* (2005) stated that healing occurred in slightly flexible fixation by a process known as secondary healing, which involved bone formation by both intramembranous and endochondral ossification. The mechanical environment provided by the fixation stability is thought to influence the proliferation and differentiation of the various cell types and hence the morphological appearance of the callus. In the present study, the flexible fixation stability probably provided by locking compression plate technique applied as a buttress resulted in secondary healing. This finding concurred with observations of Epari *et al.* (2005).

It is hypothesized that longer healing times in single fractures can occur as compared to comminuted fractures. Lesser healing time in comminuted fracture may probably be due to number of bony fragments with soft tissue attachments which contribute to osteogenic activity. Single fractures undergo bony resorption at the fracture ends to reduce interfragmentary strain before new bone is laid down. This may probably account for longer healing times. However, this was not statically confirmed in the present study. Reems *et al.* (2003) reported that there was negative linear association between fracture length and healing times when plotting the two variables against each other. Positive association between number of fragments and healing has been reported by Haaland *et al.* (2009).

In the present study, cortical bone loss and osteopenia was observed in case no. 7 which concurred with Woo (1976) who observed that osteoporosis due to rigid plate fixation occurred by thinning of cortex rather than the reduction of mechanical property of the osseous tissue. Osteopenia under the plates was a well accepted occurrence that causes weakening of bone. Porosis under plate with internal fracture fixation of fractures may occur in response to either altered cortical perfusion or stress shielding (Wilson, 1991). In the present study, osteopenia in case no. 7 may have occurred due to rigid internal fixation with excessive load sharing by the implant**.**

5.8.2.5 Radiographic evaluation of architecture (Soft tissue and bone)

In the present study, evidence of soft tissue swelling was observed in case no. 5 and 6 on 15th post operative day, case no.10 and 13 on 15th post operative day and case no.19 on 60th post operative day. Soft tissue swelling might be due to skin and soft tissue irritation over the plate and screws or it may be associated with seroma formation due to increased dead space at fracture site. Post operative evaluation indicated that there was synostosis in case no. 8 on 30th post operative day. Morgan and Leighton (1995) reported synostosis between radius and ulna fracture. However, the functional ability of the limb was unaffected.

5.8.3 Intra operative Complications

Open reduction and internal fixation was technically demanding and occasionally unsuccessful. Handling the protective tissue and drill sleeves required practice of the technique. Hand tightening the screw head with a hexagonal screw driver caused damage to the head recess in some screws and had to be replaced. Proximal and distal fracture fragment malalignment was observed in one case (case no. 1) and is attributed to technical error. Iatrogenic fracture of ulna occurred in case no. 9 during the drilling process. This iatrogenic fracture occurred inadvertently. However, this did not affect the functional outcome of the study probably because the ulna was a nonweight bearing bone in medium sized dogs. Compartment syndrome with extensive soft tissue swelling and haematoma was observed in one case indicating extensive extravasation of blood between muscle planes due to trauma. The surgical planes of incision and muscle separation were technically demanding in this case. One reducible wedge stabilized with a cerclage wire fissured during drilling and was removed. Segmental separation and longitudinal fissure occurred in case no.21 during the surgical procedure. High speed electrical drilling probably may have propagated a microcrack and led to segmental separation and longitudinal fissure in this case. Reduction and alignment of fracture fragments depended on the extent of muscle relaxation, the presence or absence of soft tissue adhesions, type of fracture and time since its occurrence. This finding was in accordance with finding of Perren (2002).

5.8.4 Post operative Complications

In the present study, dependent oedema of the fractured limb was observed in case no.5 at 30th post operative day. Seroma formation was observed in case no. 12 at first post operative day. Post operative seroma might probably be due to dead space at fracture site and implant irritation at surgical site. Self mutilated wound and exposure of plate was observed in case no 1 and 11 at 30th post operative day. Self mutilated wound and exposure of plate observed in might be probably due to tension at the surgical incision site and insufficient exposure of surgical site during plate fixation. The disadvantages of linear locking compression plate when compared to traditional methods included inferior torsional stiffness and difficulty with soft tissue closure due to the implant profile (Aguila *et al* 2005). Nerve or soft tissue irritation or damage can also occur if care is not taken with surgical approaches and implant placement. Linear locking compression plate used as internal fixators offset from the periosteal surface can cause tendon and soft tissue irritation if the plate is too prominent (Tan, 2009). In case no. 1, plate protrusion at the distal humerus was observed on 30th post operative day. Implant failure attributed to inadequate screw fixation, bone thermal necrosis and resorption and poor owner compliance. It was inferred from the owners that the animal had a fall during the post operative period. Repeated and uncontrolled cyclic loading was considered to be functionally relevant in its contribution to implant failure and disruption of osteosynthesis (Aguila *et al.* 2005).

Weese (2008) reported that surgical site infections were an inherent risk in orthopaedic surgery. Reduced operating time decreases the risk of infection

(Eugester *et al*. 2004). In the present study, only two cases of (9.09%) out of 22 cases showed evidence of osteomyelitis. This may probably due to inadequate pre and post operative antibiotic coverage breakin sterility during surgical procedure, invasive procedure and reduced immunity of the cases. Immediate decision on fracture fixation after trauma and the type of fractures also influenced the rate of surgical infection. In the present study, only closed fractures were evaluated. Haaland *et al* (2009) reported a total number of six complications. These consisted of one case of osteomyelitis around an ulnar IM pin and five implant failures. Of the implant failures, four were due to plate fatigue, and one was due to plastic deformation. Implant failure is attributed to cyclic deformations which lead to screw loosening and could be dramatic with locking compression plate whose combi-holes are not fully circumferential (Filipowicz *et al.* 2009).

5.8.5 Implant Removal

Plate removal was carried out based on satisfactory functional outcome and radiological confirmation of bony union. This was in accordance with the time for removal of plates suggested by Brinker (1984). Bone plate removal had been reported in less than 15% of cases due to implant instability (Emmerson and Muir, 1999). In the present study, linear locking compression plate was removed in case no.1 on 70th post operative day due to implant failure.

Morgan and Leighton (1995) stated that plate removal would be considered if stress protection was suspected and if there was mechanical irritation of overlying tendon or ligaments. In the present study, the implant was removed in one case due to osteopenia and evidence of stress protection. Hudson *et al.* (2009) reported that patient intolerance of the implant was one reason for implant removal.

Newton and Nunamaker *et al.* (1985) reported that the routine removal of plates and screws led to refracture rate in approximately 4.0 per cent of cases. Plate removal seemed to cause a decrease in bone strength following removal of the implants after a period of four to six weeks. In the present study no refracture was observed during the study period.

5.9 BIOCHEMICAL EVALUATION

5.9.1 Bone specific serum alkaline phosphatase – Fluorimetric reading

Bone healing is a local process that has an effect on systemic mineral homeostasis. For many years total alkaline phosphatase (AP) activity in serum has been used to monitor bone metabolism in different species. However, total alkaline phosphatase lacked bone specificity because the total activity in serum is made up of several isoenzymes, of which the liver and bone isoforms predominate (Jackson *et al.* 1996). Bone ALP is a glycoprotein localised in the plasma membrane of osteoblasts. Bone ALP comprises approximately 50% of total circulating ALP in normal subjects. Bone-specific alkaline phosphatase (BALP) shows potential as a marker of bone formation in the dog. Recent studies have indicated that serum BALP may provide a useful, non-invasive indicator of skeletal health in dogs, and as a diagnostic and prognostic marker in the management of dogs with musculoskeletal or metabolic disorders (Allen *et al*, 2000). Serial determination of serum ALP activity during fracture healing could be an additional tool in predicting fractures at risk of developing a nonunion, helping the clinician to choose the appropriate intervention (Komenov *et al*, 2005)

In the present study, bone specific alkaline phosphatase activity was evaluated pre surgically and at 45th post operative day following implant fixation in case no. 3, 5, 11, 13, 19 and 20. The osteogenic activity at fracture site was evaluated qualitatively by measuring the fluorescence intensity of the of the serum samples subjected to fluorimetric method. It was observed that fluorimetric reading on the 45th post operative day of serum samples showed significant difference in the values as compared to pre operative samples. In the present study, increased intensity of BSAP was evident at 45th day and corroborated with the findings of Mohamadnia *et al.* (2007) reported that bone ALP activities were significantly increased ($P > 0.05$) after surgery in an experimental radial ostectomy study in sheep dogs. The bridging callus was completed in the fourth week of the experiment, and the gap was fully filled with new bone. However, increased levels of total ALP and bone-specific ALP activity were maintained throughout the study and did not reduce at 4 weeks. The increased intensity is probably associated with increased rate of bone resorption compared to bone formation in the fracture healing period. It was observed in the present study that difference in intensity between pre and postoperative evaluation indicated a significant spurt in BSAP activity at 45th post operative day. This may probably be due to higher osteogenic activity associated with a predominantly cancellous bone turnover at the fracture site and better vascularisation at fracture site. In the present study, BSAP evaluation helped to assess progress of fracture healing and hence predict healing outcome.

5.10 BIOMECHANICAL EVALUATION

Various biomechanical testing procedures were performed in *vitro* to determine the different properties of bone, linear locking compression plate and linear locking compression plate construct. Cadaveric bones stripped off all surroundings soft tissue were subjected to biomechanical evaluation. However, this does not mimic a clinical situation where in the fracture stability is promoted by surrounding soft tissue. Hence, static testing was performed by applying single load to failure.

5.10.1 SCREW PULLOUT STRENGTH

The measurement of axial pull-out strength is traditionally used to evaluate and compare the holding power of screws inserted in to bone (Demko *et al.* 2008).

Locking screws were tightened to recommended torque of 1.5 Newton meter using torque screw driver (TSD - 15) with a torque ranging from 0.1 – 1.5 Newton Meter. Using this device for insertion of locking screws found appropriate in the study and concurred with recommendation of Gordon *et al*. (2010) who stated that locking plates failed at when excess torque was applied to the plate.

In the present study, it was observed that the mean screw pull out strength on humeral diaphysis showed an yield load of 749.33±5.7019 N and an ultimate load of 813.83 ± 1.7401N whereas humeral metaphysis showed an yield load of 501.50 ± 7.6365 N and an ultimate load of 540.67 ± 2.8245 N. Hence, it is inferred that the screw pull out strength on humeral diaphysis was stronger when compared with humeral metaphysis. Screw pull out strength on femoral diaphysis showed a yield load of 993.50±3.2838 N and an ultimate load of 1459.33±4.6164 N whereas femoral metaphysis showed a yield load of 779.17± 2.5744 N and an ultimate load of 830.67± 3.3830 N. Hence, it is inferred that the screw pull out strength on femoral diaphysis was stronger when compared with femoral metaphysis.

In the present study, screw pull out strength at diaphysis of femur was 1.3 times greater than the screw pull out strength at diaphysis of humerus on yield load. Similarly, screw pull out strength at diaphysis of femur was 1.7 times greater than the screw pull out strength at diaphysis of humerus on ultimate load. The relative differences in cortical thickness between humerus and femur probably may have influenced screw pull out strength.

In the present study, screw pull out strength at metaphysis of femur was 1.56 times greater than the screw pull out strength at metaphysis of humerus on yield load. Similarly, screw pull out strength at metaphysis of femur was 1.53 times greater than the screw pull out strength at metaphysis of humerus on ultimate load. The statistical analysis of the study indicated that there was a highly significant difference in screw pull out in diaphysis compared to metaphysis. Bicortical insertion of the screws in both diaphysis and metaphysis of the bone model followed in this study inferred with the recommendation of AO/ASIF technique for self tapping screw insertion which emphasizes addition of 2 mm to the measured depth of the drilled hole to ensure that the cutting flutes completely exit the trans cortex (Murphy e*t al.* 2001). This study suggests that AO/ASIF principles can be applied to obtain optimal results in locking plate system. Construct composed of locking bicortical screws are significantly stronger in torsion when compared to unicortical screws. This is attributed to working length of the screw and amount of bone purchase. Thus, clinically it is recommended that bicortical screw should be used wherever possible. Bicortical screws offer a higher resistance to torque because of their increased working length, (Gautier and Sommer, 2003).

5.10.2 THREE POINT BENDING TEST

Comminuted mid-diaphyseal fractures are frequently encountered in small animal practice and are commonly managed by open reduction and internal fixation using a dynamic compression plate or a locking compression plate placed in buttress fashion. When such plates are used they must withstand all of the forces applied to the fracture, including axial compression, axial tension, compression, and bending. Approximately 85% of all stress acting on long bones is the bending force. Biomechanical studies were hence, conducted to determine bending strength.

Fatigue and impact loads are the most common reasons for bone fractures. Axial compression tests were performed on a servo hydraulic material testing machine in displacement control (static testing). Each six cadaveric femur, 3.5mm linear locking compression plates, linear locking compression plate constructs and linear locking compression plate constructs gap models were tested in axial compression until failure.

In the present study, it was observed that the mean bending load for mechanical failure of femurii, 3.5mm linear locking compression plates, linear locking compression bone plate constructs and linear locking compression plate constructs with gap models were 1520.33±5.34N, 1670.16±8.89N, 215.33±3.71N and 319.66±5.26N respectively. The finding of the present study concurred with Saha *et al*. (1977) who stated that the mean and standard deviation of the maximum load supported by six fresh canine femurs in a 3-point bending was 1366±253 Newton.

It is inferred from the present study that the bending strength on 3.5mm linear locking compression plates were 1.09 times stronger when compared with femurs and the bending strength of linear locking compression plate constructs was 1.48 times stronger when compared with linear locking compression plate construct gap models.

According to the load versus displacement curve recorded in three point bending test, it was observed that bending strength of the 3.5 mm linear locking compression plate was much greater than the bending strength of the bone. This may be attributed to the composite and isotropic nature of material, ductility, resistant to fatigue failure and increased stiffness of the implant compared to the bone (Gardner *et al*. 2005). DeTora and Kraus (2008) observed that 3.5mm broad limited contact dynamic compression plate was significantly stiffer and stronger when subjected to four point bending test than the locking compression plate and was advantageous in large breed dogs only. However, disadvantages exists with use of broad limited contact dynamic compression plate being due to the greater bone contact surface area which influences the periosteal blood supply and healing ability of the fracture bone (Perren *et al.* 1991). In comparison, the linear locking compression has obvious advantages of protecting the viability of bone by maintaining micro vascular circulation within the cortex and its surrounding tissues (Kubiak *et al,* 2006). The space between plate and bone improve periosteal blood flow, resulting in reduced bone necrosis under the plate and also decreases the infection rate (Wagner, 2003).

Results of static axial compression test supported the hypothesis that linear locking compression plate provided greater stiffness than similar non locking plates. Comminuted metaphyseal fractures stabilized with locking compression plate had greater stiffness when subjected to an axial and torsional load. The increased stiffness can be attributed to the interface between the screw head and the plate that fixes the angle between these two components. As these screws are no longer allowed to toggle when the construct was subjected to an axial load, bone at the screw bone interfaces is subjected to a compressive force. The linear locking compression bone plate construct maintained its rigidity until yield load was reached. This yield load was thirteen and half times greater than the average body weight of the dog (Filipowicz *et al,* 2009). In the present study, the yield load of linear locking compression plate construct from the three point bending test was 1670.16N (176 kgs) which was eight times greater than the average body weight of the dog.

Similarly, the bending strength of the linear locking compression plate construct was significantly lower than the individual strength of either bone or the linear locking compression plate. The lower strength of the linear locking compression plate construct was probably due to drilling of bone for screw fixation prior to testing, which resulted in bone loss and hence reduced the total strength of the bone. The finding agreed with the observation of Brooks *et al.*(1970). The screw placement, number of screws used and plate length influences the construct stiffness and amount of motion at the fracture (Stoffel *et al.* 2003). In the present study, the plate was used to span the entire length of the bone and bicortical locking screws were used to fill all the holes in the plates other than that close to the fracture. This procedure ensured stable fixation.

A reasonable estimate of physiological load would be 60% of the dog's total body weight, or less than 150 Newton for dogs weighing 25 kg or less in normal weight bearing dogs. (Maxwell *et al.* 2009). In the present study, the average body weight of the dogs was 20 kgs (Range10 – 30 kgs), 60% of the average total body weight of the dog was 12 kgs which was equivalent to 120 Newton. The maximum bending load at failure in 3.5mm linear locking compression bone plate construct with gap model was 319.66 Newton. It was observed that the maximum bending load at failure of the bone plate construct was beyond the limit of reasonable physiological load .The load at failure in 3.5mm linear locking compression plate with gap model was 2.66 times greater than the average physiological load of normal bone. Hence, it is inferred that a linear locking compression plate provided both axial stiffness and torsional rigidity. Load sharing by the implant was higher compared to load sharing by the bone in fracture fixation with locking compression system .

6. SUMMARY

The study was carried out in 22 dogs of different breeds, sex and body weight ranging from 10 to 30 kgs presented to the Small Animal Orthopedic Unit of the Madras Veterinary College Teaching Hospital, over a period of two years. Clinical cases presented with history and clinical signs suggestive of unstable diaphyseal or metaphyseal fractures involving the humerus, radius and femur were considered for the study.

Twenty two cases with unstable diaphyseal or metaphyseal fractures of femur, humerus and radius fractures, free of other concurrent neurological, metabolic or infectious diseases were considered for the study. The fractured limb was subjected to lateral and craniocaudal views to evaluate diaphyseal fractures of humerus, radius and femur, lateral and craniocaudal views to evaluate metaphyseal fractures of radius and lateral and craniocaudal views to evaluate metaphyseal fractures of femur. These radiographic techniques were found appropriate to evaluate the fractures.. A pre operative plan was prepared using a small animal preoperative planning guide developed by the AO/ASIF (Small animal group) using plain radiographs. A tentative plan assisted in deciding on the size of the plate and screws and the length of the plate. In the present study, 3.5 mm locking condylar plates, 2.7mm locking 'T' plates and 4.5mm, 3.5mm and 2.7mm linear locking compression plates were developed. Plate selection was based on the body weight of the dog, configuration of fracture and size of the bone involved.

A cranio-lateral approach to the fracture of humerus and femur and medial and dorsal approach to the diaphysis and metaphysis of radius were surgical approaches undertaken in this study. These approaches were found appropriate and provided sufficient exposure of the fracture fragments for implant fixation following reduction.

Diaphyseal fractures were stabilized by open reduction and internal fixation using linear locking compression plates, distal radial fractures were stabilized by open reduction and internal fixation using locking 'T' plates and one case of condylar fracture was stabilized by open reduction and internal fixation using locking condylar plate. Plates were applied as a buttress in comminuted fractures and as a compression in transverse fractures. Intra operative assessment of fracture reduction was performed using C-arm image intensifier. This enabled the surgeon in intraoperative decision making.

A lameness grade was assigned on the basis of severity of clinical signs on day 0, 15th day, 30th day, 45th day and 60th day in all animals to assess the response to treatment.

In animals with unstable diaphyseal and metaphyseal fracture of humerus, the lameness grade improved in all cases on immediate post operative day to grade 4. Normal weight bearing on all the limbs at rest and walking was noticed in case no.4 at 15th post operative day, case no.1 2, and 3 at 30th post operative day and in case no.5 and 6 at 45th post operative day. However, case no.1 had developed post operative complication and was graded as 3 at 60th post operative day.

The lameness grade improved in all cases with diaphyseal and metaphyseal radius fracture on immediate post operative day to grade 4. Normal weight bearing on all the limbs at rest and walking was noticed in case no.7 and 10 at 15th post operative day, in case no. 8 9, and 11 at 30th post operative day and in case no.12 and 13 at 45th post operative day. In animals with unstable diaphyseal and metaphyseal fracture of femur, the lameness grade improved in all cases on immediate post operative day to grade 4. Case No 15, 20, 21 and 22 which was graded as 4 improved to grade 3 on immediate post operative day. Normal weight bearing on all the limbs at rest and walking was noticed in case no.14 and case no.19 at 30th post operative day and in case no.16 and 18 at 60th post operative day. Case no. 17 was lost at follow up.

The functional outcome was graded excellent in four cases (66.8%), good in one case (16.6%) and poor in one case (16.6%) out of six cases of fractures of the humerus evaluated in the study. The functional outcome was graded excellent in four cases (57.1%), good in two case (28.6%) and fair in one case (14.3%) out of seven cases of fractures of radius considered in the study. The functional outcome was graded excellent in four cases (66.8%), good in two cases (25%) and fair in two cases (12.5%) out of nine cases of fractures of the femur considered in the study. One case was lost at follow up.

Radiographic evaluation was carried out based on four 'A's (Apposition, Alignment, Angulation and Apparatus) on immediate post operative day and follow up radiographs on 15th post operative day, 30th post operative day, 45th post operative day and 60th day based on six 'A' s(Apposition, Alignment, Angulation, Apparatus, Activity and Architecture). The score for Apposition and Alignment (0-3) was recorded.

Apposition and alignment of fractured fragments with adequate cortical contact between fractured fragments were present in case no. 2, 4, 5 and 6 in humerus fractures fixation; 7, 8, 9, 10 and 12 in radius fracture fixation and 14, 16, 18, 19, 20, 21 and 22 in femur fracture fixation up to 60th post operative day. In dogs with unstable diaphyseal and metaphyseal fractures of humerus, apposition and alignment of the fractured fragments with adequate cortical contact between fractured fragments were maintained at 15th post operative day in all the cases except in case no. 1 which showed malreduction and was graded as 2. Mild valgus was noticed in case no. 1 and case no 3 at 45th and 60th post operative day respectively. Evidence of primary healing was observed in case no. 4, 14, 15, 18 and 21 on 30th post operative day and in case no.5, 11 and 12 on 45th post operative day. Primary healing was evidenced by absence of external callus formation. Evidence of bony union was observed in case no.7 at 60th day and case no. 9 and 10 on 45th post operative day. Bony union indicated progressive fracture healing. Case no.1 had malunion with evidence of bony activity on 30th post operative day. Evidence of secondary healing was observed in case no. 1, 3, 6, 13, 16, 19, 20 and 22 on 30th post operative day and case no.2, 7 and 8 on 45th post operative day. Secondary healing was characterized by formation of periosteal bridging callus. Secondary healing was observed in the present study. In the present study, primary bone healing was observed in fractures stabilized in compression and secondary healing was observed in fracture stabilized with buttress fashion.

Self mutilated wound and exposure of plate was observed in case no 1 and 11 at 30th post operative day. Self mutilated wound and exposure of plate might be probably due to tension at the surgical incision site and insufficient exposure of surgical site during plate fixation. In case no. 1, plate protrusion at the distal humerus was observed on 30th post operative day. Implant failure was attributed to inadequate screw fixation, bone thermal necrosis and resorption and poor owner compliance. Stress protection was observed in one case of distal radial fracture and was attributed to excessive load sharing by the implant.

Bone specific serum alkaline phosphatase was estimated using SenoLyte FDP Alkaline Phosphatase Assay Kit by fluorimetric method. In the present study, the fluorimetric reading of peak absorbance of pre and 45th post operative day serum samples in case no. 3, 5, 11, 13, 19 and 20 were observed. It was observed that fluorimetric reading on the 45th post operative day showed increased intensity as compared to pre operative values indicating osteogenic activity and progressive fracture healing.

Biomechanical studies were carried out on screw pullout strength, bending strength of on bone, bone plate, bone plate construct and gap model. A tabletop Instron Universal Testing Machine was used to perform these tests. Custom made fixtures were used to hold the bones for the respective tests in the testing machine.

In the present study, it was observed that the mean screw pull out strength on humeral diaphysis showed an yield load of 749.33±5.7019 N and an ultimate load of 813.83 ± 1.7401N whereas humeral metaphysis showed an yield load of 501.50 ± 7.6365 N and an ultimate load of 540.67 ± 2.8245 N. Hence comparatively, it is inferred that the screw pull out strength on humeral diaphysis was stronger when compared with humeral metaphysis. Screw pull out strength on femoral diaphysis showed a yield load of 993.50±3.2838 N and an ultimate load of 1459.33±4.6164 N whereas femoral metaphysis showed an yield load of 779.17± 2.5744 N and an ultimate load of 830.67± 3.3830 N. Hence comparatively, it is inferred that the screw pull out strength on femoral diaphysis was stronger when compared with femoral metaphysis.

In the present study, it was observed that the mean bending load for mechanical failure of femur, 3.5mm linear locking compression plate, linear locking compression bone plate construct and linear locking compression plate construct with gap model was 1520.33±5.34N, 1670.16±8.89N, 215.33±3.71N and 319.66±5.26N respectively. The linear locking compression bone plate construct maintained its rigidity until yield load was reached. In the present study, the yield load of linear locking compression plate construct from the three point bending test was 1670.16N (176 kgs) which was eight times greater than the average body weight of the dog. Similarly, the bending strength of the linear locking compression plate construct was significantly lower than the individual strength of either bone or the linear locking compression plate. The maximum bending load at failure in 3.5mm linear locking compression bone plate construct with gap model was 319.66 Newton. It was observed that the maximum bending load at failure was beyond the limit of reasonable physiological load. The load at failure in a 3.5mm linear locking compression plate with gap model was 2.66 times greater than the average physiological load needed for the fixation failure.

In conclusion, the locking compression plating technique provided stable fracture stabilization for unstable diaphyseal and metaphyseal fractures. This plating system has a combi hole for the use of locking and nonlocking screws and can be used both as a compression plate or a buttress plate to achieve a stable fixation. Locked plates created a single beam construct by controlling the axial orientation of the screw to the plate and provided angular stability, did not interfere with the vascularity to the injured bone, promoted bone healing with decreased risk of infection, prevented bone resorption and non union. The surgical procedure was less complicated as it did not involve the contouring of the plate and probable reduction in surgical time is possible with this procedure. The LCP system, can be successfully used for treating comminuted diaphyseal and metaphyseal fractures of long-bone as it provides a definitive clinical and mechanical advantage in terms of functionality and can be used either as a buttress or compression plating system in small animal practice.

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