USE OF STRING OF PEARLS LOCKING PLATE SYSTEM FOR

STABILIZATION OF FEMORAL FRACTURES IN CANINES

By

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No part of the thesis has been submitted by the student for any other degree or diploma. The published part has been fully acknowledged. All the assistance and help received during the course of investigation have been duly acknowledged by the author of the thesis.

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DECLARATION

I, **GURRALA VENKATA ASHOK KUMAR REDDY** (ID No. RVM/2016-04), hereby declare that the thesis entitled **"USE OF STRING OF PEARLS LOCKING PLATE SYSTEM FOR STABILIZATION OF FEMORAL FRACTURES IN CANINES"** submitted to P. V. Narsimha Rao Telangana Veterinary University for the degree of MASTER OF VETERINARY SCIENCE in VETERINARY SURGERY AND RADIOLOGY, is a result of original research work done by me. I also declare that the thesis or any part thereof has not been published earlier in any manner.

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ABSTRACT

The present clinical study was conducted on seven dogs presented with femoral fractures to Department of Surgery and Radiology at College of Veterinary Science Rajendranagar, Hyderabad. The age of the seven dogs ranged from 4 - 48 months. Out of these seven dogs, four were male and three were female. Among the seven dogs, five dogs belonged to non-descript breed, one dog belonged to spitz breed and one dog belonged to German shepherd breed. The body weight of the dogs ranged from 4.5 to 27.2 kg.

The seven cases of femoral fractures were diagnosed by clinical signs, orthopaedic examination and survey radiography. The symptoms observed in the dogs presented for treatment were pain on manipulation, abnormal angulation, and lameness immediately after traumatic injury, swelling, non-weight bearing, dangling of the limb and crepitation at the fracture site. Pre-operative radiographic examination in two orthogonal views, i.e., anteroposterior and mediolateral radiographs revealed proximal

diaphyseal fracture in two dogs, mid diaphyseal fractures in two dogs and distal diaphyseal fractures in three dogs. Pre-operative radiographs also showed the type of femoral fractures as transverse fracture of femur in four dogs, short oblique fracture in two dogs and comminuted diaphyseal fracture in one dog. All the seven dogs had closed fractures.

These fractures stabilized with 2.7 mm and 3.5 mm String of Pearls Locking Plates (SOP) resulted in good fracture fixation and immobilization. The length of the plates to be used was determined by the length of the bone as measured from the radiographs. The lengths of screws were determined by measuring the transcortical diameter of the bone at different regions from the anteroposterior radiographs obtained pre-operatively. Craniolateral approach used provided good exposure of the fracture site and enabled good fracture fixation.

Post-operative radiographic evaluation confirmed proper placement of the plates and screws, apposition and alignment of the fracture fragments in all the seven dogs. Immobilization was considered satisfactory in all the cases. The plate length, size and position were appropriate in all cases. Screw length, size and position were considered appropriate in all cases. Follow-up radiographs taken on 7^{th}, 15^{th}, 30^{th} and 45^{th} post-operative days revealed secondary bone healing with periosteal callus formation. Good implant stability throughout the treatment period without any complications could be achieved in five dogs. In two dogs, plate breakage was observed at the fracture site by 30^{th} post-operative day. However, intermittent weight bearing was noticed by 45^{th} post-operative day in both the dogs.

All the dogs which were diagnosed for femoral fractures showed grade V lameness before surgical treatment. Post-operatively, five dogs progressed to grade I lameness and two dogs progressed to grade II lameness by the end of 45^{th} post-operative day.

Haematological evaluation revealed that the progressive increase of haemoglobin level, packed cell volume and total erythrocyte count on post-operative days indicated erythropoiesis. The total leukocyte count was significantly decreased on post-operative days indicated leucocytopenia which is suggestive of gradual decrease in inflammatory reaction. The differential leucocyte count like neutrophil was significantly decreased on post-operative days indicated neutropenia. Contrary to this, the lymphocyte count was statistically increased on 15th and 45th post-operative days indicated gradual decrease of inflammatory reaction.

Serum biochemical evaluation revealed that the serum alkaline phosphatase and serum calcium values significantly increased from day 0 to 15th day and thereafter reached to normal values by 45th postoperative day. The increased serum alkaline phosphatase levels during the first two weeks indicated increased chondroblastic proliferation to cause bone formation during fracture repair. The serum phosphorous values showed no significant variation and the values were within the normal range.

Based on present study, it was concluded that String of Pearls Locking plates (SOP) was successful in the treatment of femoral fractures and offered good recompense and remarkable improvement in limb function in five out of seven dogs. The application of SOP plates was found to be effective with features like being light in weight, versatile owing to its ability to contouring to any shape of bone, high bending strength and maintaining limited contact with bone. The implant used in this technique is economical, making it amenable to use in veterinary practice. In the opinion of the author, SOP locking plate has potential for application in other long and flat bones.

LIST OF ABBREVIATIONS

%	-	Percentage
Fig.	-	Figure
kg	-	Kilogram (s)
IV	-	Intravenous
mg	-	Milligram
mm	-	Millimeter
g	-	Gram (s)
dL	-	Decilitre
µl	-	Microlitre
<	-	Less than
±	-	Plus or Minus
U/L	-	Units/Litre
No.	-	Number
ANOVA	-	Analysis of Variance
SOP	-	String of Pearls Locking Plate
LCP	-	Locking Compression Plate
DCP	-	Dynamic Compression Plate
LC-DCP	-	Limited Contact Dynamic Compression Plate

CHAPTER I

INTRODUCTION

Fracture of long bones is the most common musculoskeletal condition reported in small animal practice especially in dogs. Among the long bone fractures, femur has the highest incidence 37% followed by radius-ulna (28.7%), tibia-fibula (20.4%) and humerus (7.9%) (Kallianpur *et al.* 2018). Femoral fractures are often related to trauma due to severe impact from automobile accidents and jump from a height. Most femur fractures are closed fractures because of the heavy overlying muscle, unless caused a penetrating injury such as a gunshot wound (Beale, 2004).

The main goal in fracture treatment is preservation of intramedullary and periosteal vascularization, anatomical reduction, interfragmentory compression of bone fragments and early return to normal locomotory function (Newton, 1985). Many implant systems like intramedullary pins, bone plate and screws, external skeletal fixation, lag screws and interlocking nails are suitable for femoral fracture repair (Johnson *et al.* 1998).

Due to disadvantages of intramedullary pins which includes poor resistance to axial and rotational loads and that of external skeletal fixation technique which includes premature pin loosening, pin tract infections and pin breakage, plate osteosynthesis remains the treatment choice for femoral fractures in dogs (Fossum, 2013). Bone plates when applied properly effectively resist the axial loading, bending and torsional forces acting on the fractured bones. Bone plates like Dynamic Compression Plate (DCP), Limited Contact Dynamic Compression Plate (LC-DCP) and Locking Compression Plate (LCP) are routinely used in small animal practice for long bone fracture repair.

New plate designs like Unilock plate, Advanced Locking Plate System (ALPS), Fixin systems and String of Pearls Locking plates (SOP) have been introduced into small animal practice with several advantages over the other bone plates.

Among the currently developed locking bone plates, the SOP plate is a novel orthopaedic plate system designed for Veterinary and Human orthopaedic use. As with all locking plate systems, the SOP can be thought of mechanically as an internal-external fixator. The SOP locking plate consists of a series of cylindrical sections (internodes) and spherical components (pearls). The cylindrical component, or internode, has an area moment of inertia greater than the corresponding DCP's. The SOP differs from other locking plate systems; that the SOP can be contoured in six degrees of freedom; medial to lateral bending, cranial to caudal bending and torsion using specially designed bending irons without compromising the locking function (Kraus and Ness, 2014). Properly performed, contouring results in bending or torsion at the internode, preserving the locking function of pearl. The use of inserts (SOP bending tees) placed into the pearls protects the pearl absolutely and preserves locking function completely during contouring.

Mechanical testing using ASTM (American Society for Testing and Materials) standards has demonstrated that the 3.5 mm SOP is approximately 50% stiffer, and has a bending strength (load at which the plate bends) of 16-30% greater than 3.5 mm LCP, DCP, or LC-DCP (DeTora and Kraus, 2008 and Kraus and Ness, 2014). Mechanical testing has demonstrated that, a SOP bent through 40 degrees remain almost (96%) as stiff as an untouched 3.5 mm DCP. Similarly, a SOP twisted through 20 degrees remains significantly stiffer than the new and untouched 3.5 mm DCP (Kraus and Ness, 2014).

The primary utility of the SOP plate is for communited fractures of femur, humerus, tibia and radius-ulna. Although the SOP can be used in conventional 'open approach' fracture surgery, it is especially valuable with so called biologic fixation methods and minimally invasive techniques. Generally communited diaphyseal femoral fractures are best repaired using the SOP in combination with an under sized intramedullary pin, also known as rod and beam fixation. A second SOP can be applied on the contralateral or orthogonal side of bone, or two SOP's can be nested side by side (Kraus and Ness, 2014).

Search of the published literature revealed that there are only a few published studies on the clinical use of String of Pearls Locking plate system (SOP) for stabilization of femoral fractures in dogs.

Hence, the present study was contemplated in seven dogs with femoral fractures with the following objectives:

1. To diagnose and treat the cases of femoral fractures in dogs by using String of Pearls Locking plates.
2. To evaluate the fracture healing clinically and radiographically.
3. To study the efficacy of String of Pearls Locking plates used for fixation of femoral fractures in dogs.

CHAPTER II

REVIEW OF LITERATURE

2.1 ANATOMY OF FEMUR

The femur (osfemoris), the skeleton of the thigh, is the strongest of the long bones. The body is regularly cylindrical, except near extremities, where it is wider and compressed craniocaudally. The proximal end curves medially so that the proximal articular surface, the head is offset to the long axis of the shaft. The articular surface is interrupted by a non-articular area (fovea) to which the intra capsular ligament attaches. The fovea is round and central in the dog. The femoral diaphysis does not have muscle insertions on its cranial, medial and lateral surfaces but does have a loose association with the overlying muscles of the quadriceps group. The location of the sciatic nerve caudal to the femoral diaphysis and deep to the biceps femoris muscle should be considered during retractions and fracture reduction to avoid iatrogenic injury. The principle nutrient artery is a branch of the medial circumflex femoral artery that passes into the femoral diaphysis through the nutrient foramen on the proximal third of the diaphysis.

The distal extremity articulates with the tibia and patella. The articulation with the tibia is accomplished by two condyles directed caudo distally and separated by a deep inter condylar fossa. The abaxial surfaces of the condyles are roughened and give attachment to the collateral ligaments of the stifle (Dyce *et al*. 1996).

2.2 INCIDENCE OF FEMORAL FRACTURES

High incidence of mid or distal shaft femoral fractures were reported in young male non-descript dogs when compared to other long bones fractures (Maala and Celo 1975; Phillips 1979 and Singh *et al*. 1983).

Alcantara and Stead (1975), Phillips (1979), Singh *et al*. (1983), Thilagar and Balasubramanian (1988) also reported that femoral fractures were most commonly encountered in the mid-diaphyseal region.

Unger *et al*. (1990) studied 1038 long bone fractures in dogs and cats. Among these, 45% of fractures represented femoral fractures, a rate more than double than that of other long bone fractures.

Johnson *et al*. (1994) reported high incidence of canine appendicular musculo-skeletal disorders and opined that the femur was the most commonly fractured bone in young male dogs.

Balagopalan *et al*. (1995) reported high incidence of femoral fractures in Alsatians (27.9%) and also opined that males were more prone for femoral fractures than females.

Aithal *et al*. (1999) conducted a study on 402 clinical cases of fractures in dogs and stated that of all bones, the highest number of fractures were seen in femur (38.56%) followed by tibia-fibula (17.16%), radius-ulna (16.92%) and humerus (7.71%). Their survey revealed highest incidence of fractures among non-descript dogs and higher incidence of fracture in the age group of 1 to 3 years (35.52%) followed by dogs in the age group of 6 to 12 months. A higher incidence of fracture in male dogs was also reported.

Gahlod *et al*. (2004) made a retrospective study on 109 cases of canine fractures and reported that majority of fractures were seen in young dogs of 0 to 6 months of age (44.95%). Small breeds of dogs such as Pomeranian, Lhasa apso and Cocker Spaniel had a higher incidence of fractures (58.71%) than the large breeds (41.28%). Males were more commonly affected than females. Automobile accidents and jumps from heights were prime causes of fractures in dogs. Among the long bones, the incidence of fractures were highest in femur (45.87%), followed by radius-ulna (18.34%) and tibia-fibula (12.44%).

Simon *et al*. (2010) conducted a survey on the incidence of pelvic limb fractures in dogs. They reported highest incidence in young animals (46.02 %) less than six months of age. Majority of the fractures were recorded in non-descript dogs (47.48 %). Male dogs were affected more (61.5 %) than female dogs of all the age groups. Among the various bones of pelvic limb the incidence was highest in femur (47.48 %) followed by tibia and fibula (42.67 %).

Maruf minar *et al.* (2013) made a retrospective study on 80 cases of canine fractures and reported that majority of fractures were seen in young dogs of less than 1 year age (50%). Small breed dogs has higher incidence of fractures Poodle (12%), Yorkshire terrier (12%) and Maltese (9%). Males (54%) were more commonly affected than females (46%). Automobile accidents (43%) and fall from height (28.5%) were prime causes of fractures in dogs. Among the long bones, incidence of fractures were highest in femur (25%), followed by tibia-fibula (19.5), radius-ulna (17%) and humerus (11%).

Piermattei *et al*. (2016a) stated that incidence of the femur fracture is about 20% to 25% of all fractures and represents 45% of all long bone fractures. Further, it was stated that diaphyseal fractures alone account for 56% of femur fractures.

Kallianpur *et al.* (2018) conducted a study on long bone fractures in 216 dogs and stated that highest number of fractures were noticed in dogs less than 6 months (41.2%) followed by 6-12 months of age (18.5%). Automobile accidents (43.1) and fall from height (36.6%) are the leading causes of fractures in dogs. Among the long bones incidence of fractures were highest in femur (37%), followed by radius-ulna (28.7%), tibia-fibula (20.4%) and humerus (7.9%).

2.2.1 Etiology

Maala and Celo (1975) reported that, among femoral fracture of dogs, 75% were caused by automobile accidents, 25% by kicking, gunshots, fighting and jumping from a height.

Phillips (1979) surveyed 284 canine and 298 feline fractures over a period of 2 years. He observed that, automobile accidents were the main causes of fracture followed by falls and crush injuries in dogs.

Singh *et al.* (1983) reviewed 511 clinical cases of fractures in animals and observed vehicular accidents as major cause for femoral fractures.

Johnson *et al*. (1998) recorded that the highest incidence of femoral fractures was due to trauma caused by motor vehicle accidents.

Umarani *et al*. (2004) reported that the major exciting causes for hind limb fractures were automobile accidents (68.24%) and fall (31.76%) and the incidence was more when compared to fore limbs.

2.3 PRE-OPERATIVE CLINICAL EXAMINATION

Wong (1984) reported that most consistently noted clinical sign of femoral fractures was loss of function of the affected limb while crepitus was elicited in only 2% of fracture cases.

Johnson and Boone (1993) opined that dogs with femoral fractures usually did not bear weight on injured limb and have palpable swelling and crepitation at fracture site.

Braden *et al*. (1995) stated following a review of 1000 cases of femur fractures, that two thirds of the cases were presented with same sort of “pre surgical” complications which included contamination, infection, severe tissue damage, nerve impairment, treatment delay, multiple bone and limb fractures, respiratory and urinary problems.

Johnson (2013) stated that diagnosis of femoral diaphyseal fractures is done based upon history of trauma of jumping or falling or automobile accidents. Physical examination findings like palpation of the limb reveal swelling, pain, and crepitation.

Piermattei *et al*. (2016a) stated that pain, deformity or change in angulation, abnormal motility, local swelling, loss of function and crepitus were the main symptoms to be noted in clinical examination of fractures.

2.4 PRE-OPERATIVE RADIOGRAPHIC EXAMINATION

Newton (1985) opined that two radiographic orthogonal views of lateral and craniocaudal projections with stress view were important for diagnosis of any long bone fractures.

Smith (1998) stated that definitive radiography, in a minimum of two planes enabled full assessment of a fracture. The author opined that further damage to surrounding tissue while taking radiograph increased the risk to the patient.

Langley-Hobbs (2003) suggested taking of orthogonal radiographic views of the affected and contralateral bone to diagnose the fracture type. The author also opined that oblique views might be useful to confirm the presence of fissures in the bone around the fracture site.

Ayyappan *et al*. (2009) used pre-operative radiographs of mediolateral and craniocaudal orthogonal views to determine long bone fracture configuration in dogs.

Johnson (2013) stated that both craniocaudal and lateral radiographs of the femur are necessary to assess the extent of bone and soft tissue injury. The author also opined that radiographs of the contralateral limb are useful in assessing normal bone length and shape.

Piermattei *et al*. (2016b) opined that in cases of fractures, radiographs of at least two views at right angles to each other were essential for accurate diagnosis and selection of the best procedure for reduction and immobilization.

2.5 CLASSIFICATION OF FEMORAL FRACTURES

Unger *et al*. (1990) classified fractures of long bones in dogs and cats by giving an alpha numeric code with four digits, representing the fracture description in a defined order, in which the first two digits represented the localization of the fracture and the last two digits its morphology. The author classified femur fractures as Type 3 - 2A indicating diaphyseal, simple or incomplete; Type A1-incomplete, Type A2-simple oblique, Type A3-simple transverse femoral; Type 3-2B indicating diaphyseal femoral wedge, Type B1- one reducible wedge, Type B2- several reducible wedges, Type B3- non reducible wedge; Type 3-2C indicating diaphyseal complex, Type-C1-reducible wedges, Type C2- segmental, Type C3- non reducible wedges.

Aithal *et al.* (1999) reported that femoral diaphyseal fracture constituted 38.56% of total fractures, in which middle and distal third were commonly affected than the proximal third. Among different types of fractures recorded, oblique/spiral (54.86%) was most common followed by comminuted (16.57%), transverse (14.86 %), incomplete (6.57 %) and multiple (5.14%) types.

Kallianpur *et al.* (2018) conducted a study on long bone fractures in 216 dogs and reported that femoral fractures constituted 37% of total fractures. Among different types of fractures recorded, transverse (47.5%) was most common followed by communited and short oblique (23.8%), long oblique (3.8%) and multiple (1.3) types.

2.6 FRACTURE STABILIZATION TECHNIQUE

2.6.1 Pre-operative considerations

2.6.1.1 Anaesthesia

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

Hilbery (1992) stated that ketamine could be given intravenously at the dose rate of about 5mg per kg body weight followed by administration of diazepam at the dose rate of 0.2 mg per kg body weight which provided quite, smooth and slow induction of anaesthesia.

Thurmon *et al.* (1996) stated that atropine was an anticholinergic (parasympatholytic) drug frequently used to reduce the secretion in the respiratory tract and salivary glands and also to inhibit the vagal stimulation of the cardiovascular and respiratory system.

Mohinder Singh *et al.* (1999) reported that, the use of xylazine-ketamine combination along with atropine sulphate as premedicant proved to be the best for undertaking repair of fractures.

Pardeshi and Ranganath (2008) used atropine sulphate at the rate of 0.04 mg per kg body weight intramuscularly followed by xylazine hydrochloride at the rate of 0.5 mg per kg body weight intravenously as pre-anaesthetic medication. General anaesthesia was induced and maintained by intravenous injection of 2.5% thiopentone sodium given "to affect".

Fattahian *et al*. (2011) used pre-operative medication with atropine sulphate at the rate of 0.03 mg per kg body weight subcutaneously 30 minutes prior to anaesthesia. Cefazolin at the rate of 22mg per kg body weight was administered as a prophylactic antibiotic before operation. Diazepam and ketamine hydrochloride combination at the rate of 0.27 mg per kg body weight and 5.5 mg per kg body weight respectively, were administered as an induction and propofol at the rate of 7.5 mg per kg body weight intravenously for maintenance of anaesthesia.

2.6.1.2 Surgical Approach to Femur

Denny and Butterworth (2000) stated that, femur is exposed by a lateral skin incision extending from the greater trochanter to the stifle. The fascia lata is incised just cranial to the biceps femoris and blunt dissection between the vastus lateralis and biceps femoris will reveal the femoral diaphysis. Exposure of the proximal femur is achieved by subperiosteal elevation and cranial reflection of the origin of the vastus lateralis muscle. The bone plate (compression, neutralization or buttress) is usually applied to the lateral aspect of the femur.

Johnson *et al*. (2005) stated that, the tension surface of the femur is the craniolateral surface and is the position best suited for plate application. A craniolateral approach was commonly practiced with skin incision extending from greater trochanter to stifle and incising the tensor fascia lata muscle and retracting the biceps muscle caudally and the vastus lateralis muscle cranially to expose the femoral diaphysis.

Piermattei and Johnson (2014) stated that, femur is exposed by making a skin incision along the craniolateral border of the shaft of the bone from the level of greater trochanter to the level of patella. The tensor fascia lata muscle was incised along the cranial border of biceps femoris muscle. Caudal retraction of biceps femoris and cranial retraction of vastus lateralis muscles gave satisfactory exposure of the femoral diaphysis.

2.6.2 IMPLANTS

2.6.2.1 String of Pearls (SOP) Locking Plate

DeTora and Kraus (2008) conducted mechanical testing of 3.5 mm locking and non locking plates and stated that, SOP plates were stiffer and stronger even after bending than equivalent size bent LCP and LC-DCP. The authors further concluded that, SOP had a bending strength of 16% and 30% greater than the 3.5mm LCP and LC-DCP respectively. The greater area moment of inertia inherent to SOP provides greater implant strength and is therefore less likely to fail with use in buttress fixation. The profile of SOP, with prominent spherical screw components, can also potentially allow for minimally invasive surgeries with percutaneous osteotechniques like Less Invasive Stabilization System (LISS) techniques.

Downes *et al*. (2009) reported the management of triple thoracolumbar disc protrusion by selective hemilaminectomy, vertebral body stabilization with or without annulectomy in twenty eight dogs. Vertebral stabilization was achieved with bone plates in twenty six dogs, of which 24 plates were dynamic compression plates which were placed unilaterally and remaining two plates are string of pearl locking plates which were applied bilaterally. The authors further opined that, the locking screw design of SOP confers two key advantages compared to conventional plates. Firstly, the likelihood of damaging spinal nerves exiting the intervertebral foramina is reduced since the plate is not compressed against vertebrae and secondly, axially loaded locking screws subjected to cantilever bending are biomechanically superior to non locking screw, thus reducing risk of screw loosening.

Kowaleski (2009) reported that, the spherical screw holes of SOP plate provided greater stiffness than the inter node components so that SOP did not act as a stress riser as occurring with most other implant systems. The author reported that twisting of plate along its longitudinal axis decreased the plate stiffness and should be limited to 20^0 per internode to prevent plate weakening. The author also reported that, bending of SOP plate performed not only in orthogonal planes, but can be performed in angles between as well so that plate can be contoured in unique configurations such as for acetabular fracture application. The author also opined that, with locking plate systems such as SOP, efforts should be made to have three bicortical screws on either side of fracture.

Mills (2009) used String of Pearls locking plates for stabilization of a sacral fracture and an ilial fracture in dog and concluded that String of Pearls locking plates gave robust, safe stabilization of a sacral fracture luxation.

Ness (2009a) studied the effect of bending and twisting on the stiffness and strength of the 3.5mm SOP implant and concluded that, Untouched SOP was found to be significantly stiffer and stronger than uncontoured 3.5mm DCP. The author further opined that, bending, and to a lesser extent twisting diminished the SOP stiffness and strength but the contoured SOP remained at least as stiff and strong as the untouched DCP.

Ness (2009b) used String of Pearls locking plates for repair of Y-T humeral fractures via combined medial and lateral incisions in 13 dogs and reported excellent functional outcome in 10 dogs, good in two and poor in one. The author further opined that, SOP can be contoured with six degrees of freedom, so that the implant can be shaped and applied in the optimum position according to anatomical and biomechanical requirements.

Bufkin *et al.* (2010) biomechanically tested 3.5mm SOP bone plate using a delrin rod gap model with four different screw configurations and stated that construct stiffness decreased as screw holes adjacent to the fracture site are omitted in eccentric axial loading. The authors further stated that, the stiffness of the SOP construct can be increased in eccentric axial loading by filling the screw holes adjacent to the fracture.

Klein *et al*. (2010) described the Minimally Invasive Percutaneous osteosynthesis (MIPO) technique in eight dogs and one cat with non articular tibial fractures using the SOP plate system and concluded that, an SOP-rod construct used in a minimally invasive percutaneous technique was an acceptable option for non-articular tibial fracture repair.

Blake *et al.* (2011) conducted a study on the biomechanical properties like bending stiffness and bending strength, of the commonly used standard plates like DCP, SS LC-DCP, Ti LC-DCP to the newer locking plate systems like LCP, SOP, ALPS, FIXIN. The authors opined that, SOP had the highest mean bending stiffness, mean bending structural stiffness and mean bending strength.

Cabassu *et al.* (2011) conducted a study on the biomechanical properties like strength, deformation, stiffness of a number of locking veterinary bone plates like LCP, SOP, ALPS and Fixin system and compared these to the standard conventional plates like DCP, LC-DCP as applied to a bone model to stimulate a bridging osteosynthesis, and loaded to failure in torsion. Based on the material manufactured (Titanium or Stainless Steel) and physical characteristics of different plate designs, authors hypothesized that, the Titanium plate constructs (Ti LC-DCP, ALPS) would sustain the highest elastic deformation (yield angle), and the SOP had the strongest (yield torque) and stiffest construct.

Choate and Arnold (2011) stated that use of String of Pearls locking plate for elbow arthrodesis provided a satisfactory clinical outcome as a method of stabilization after unique polycystic humeral bone cysts caused a pathologic fracture of the humeral condyle in one dog. The authors further concluded that, use of String of Pearls locking plate imparted increased strength and stiffness compared to conventional elbow arthrodesis techniques.

Scrimgeour and Worth (2011) reported a satisfactory clinical outcome following application of String of Pearls (SOP) locking plate system in stabilization of a comminuted calcaneal fracture in a giant breed Pyrenean Mountain dog weighing 65 Kg. The authors concluded that, SOP plate was considered as an appropriate implant for repair of calcaneal fracture with addition of intramedullary pin support which provided greater stability and strength of the repair.

Fitzpatrick *et al*. (2012a) used string of pearls locking plate and cerclage wire stabilization of periprosthetic femoral fractures after total hip replacement in six dogs and found that use of a String of Pearls (SOP) locking plate and cerclage wire was effective for stabilizing periprosthetic femoral fractures after total hip replacement in dogs.

Fitzpatrick *et al.* (2012b) reported the clinical outcome and application of SOP in shoulder arthrodesis in 7 out of 14 dogs and concluded that, SOP plate might help to overcome several challenges associated with conventional implant systems like DCP or reconstruction plate. The authors further reported that, SOP was a locking plate which may theoretically reduce the risk of screw loosening and might help to distribute load evenly throughout the limited and poor quality bone stock of scapula. The authors further stated that, the narrow internode design and locking screw design of SOP plate had an advantage of applying over neurovascular structures like suprascapular nerves without compression or hindrance of movement.

Rutherford and Ness (2012) compared the bending structural stiffness (BSS) and bending strength (BS) of 3.5 titanium (Ti) String of Pearls (SOP) plate and 3.5 316LVM stainless steel String of Pearl plate *in vitro* experimental static 4-point bending materials testing and stated that, 3.5 Ti SOPs had lower BSS and similar BS to 3.5 316LVM SOPs. The authors also studied the effect of contouring on BSS and BS of 3.5 Ti SOP plate and reported that, bending the Ti SOP diminished its BSS and BS while twisting the Ti SOP slightly increased its BSS and slightly diminished its BS.

Hespel *et al*. (2013) reported successful management of a closed, complete transverse fracture of left tibial diaphysis in a common grey seal with string of pearl locking plate covered with polymethylmethacrylate impregnated with gentamicin.

Hurt *et al.* (2014) compared the biomechanical performance of two string of pearls (SOP) plate constructs in canine cadaveric humeral metaphyseal fracture gap model of which one group consisted of unilateral medially placed SOP plate with bicortical screws (UNI) and second group consisted of bilateral caudo-medial and caudo-lateral SOP plates applied with monocortical screws (BI). The authors stated that, a paired monocortical SOP plate construct (BI) had a significantly higher stiffness in compression and torsion than the single SOP construct with bicortical screws (UNI) in stabilizing distal humeral metaphyseal gap model. The authors further reported that in fixation of communited supra condylar humeral fractures with bilateral SOP plate, it was necessary to incorporate a transcondylar screw in the distal hole of medial plate when possible.

Kim and Lewis (2014) stated that corrective osteotomy stabilized with String of Pearls locking plates was a viable treatment option for improving limb function in two dogs with severe procurvatum deformities caused by distal femoral physeal fracture malunion. The authors further concluded that excellent functional outcomes were achieved in both the dogs.

Kraus and Ness (2014) stated that, SOP plate can be contoured in six degrees of freedom; medial to lateral bending, cranial to caudal bending and torsion. The contouring can be done by bending as well as twisting in and out of plane with a maximum of 40 degrees between the nodes which allowed the application of these plates to bones of any shape more easily than conventional bone plates. A second SOP plate can be applied on the contralateral side or orthogonal side of the bone, or two SOP's can be nested side by side.

Malenfant and Sod (2014) conducted a study on biomechanical properties like static loading and cyclic fatigue in 3.5mm SOP and 3.5mm LCP and stated that SOP construct was superior under bending static and cyclic testing than the LCP construct.

Benamou *et al*. (2015) conducted a study on the effect of bending direction on the mechanical behavior of 3.5mm SOP and 3.5mm LC-DCP plate constructs and opined that, mediolateral bending stiffness was significantly greater in the SOP than in LC-DCP constructs. The authors further stated that, SOP constructs had a more homogenous bending behavior in orthogonal bending directions.

Boucher and Zeiler (2015) used String of Pearls locking plate and intramedullary pin for femur fracture repair of tiger cub (Panthera tigris tigris) suffering from nutritional secondary hyperparathyroidism and osteopenia and opined that String of Pearls locking plate system was regarded as a better method of repair than that of conventional plating system.

Demianiuk *et al.* (2015) studied the effect of screw type (monocortical vs bicortical), number, and position on torsional stability of SOP locking plate constructs and stated that, a minimum of one (1) bicortical screw per fragment should be used to increase torsional stability of 3.5mm SOP constructs. The authors further stated that, positioning of the bicortical screw at the inner or outermost positions relative to fracture is preferred with the innermost position providing the greatest improvement in stability.

Hutcheson *et al.* (2015) evaluated biomechanical properties of single 3.5mm broad DCP and double 3.5mm SOP plate constructs in single-cycle bending and torsion and concluded that, double SOP constructs had significant greater bending stiffness, bending strength, bending structural stiffness, and torsional stiffness than the broad DCP constructs.

Sadan *et al*. (2015) used String of Pearls locking plate for repair of ilial fractures in dogs and cats and opined that String of Pearls locking plate permits good correction of ilial fractures with good return to function and with minimal post operative complications.

Grand (2016) used String of Pearls locking plates for the stabilization of acetabular and supra-acetabular fractures in three dogs and opined that String of Pearls locking plates are effective for stabilization of acetabular and supra-acetabular fractures in dogs.

Early *et al.* (2017) conducted a study to quantify stiffness of String of Pearls (SOP) interlocking plate system on the lumbosacral junction in 3D printed model dogs and opined that SOP locking plate system can significantly increase the stiffness of the lumbosacral junction of 3D printed canine vertebral models. The authors further stated that, greatest stiffness was achieved in models with two parallel SOP locking plates across the lumbosacral junction with two standard cortical screws engaged in the pedicle of L7 and two screws in the sacrum. The authors further concluded that, using two plates rather than one plate increase construct stiffness in vertebral bending when two screws engage the pedicle of L7.

Kumar *et al.* (2018a) used String of Pearls locking plate for distal femoral diaphyseal fractures in dogs and concluded that String of Pearls (SOP) locking plates were good for stabilization of distal femoral diaphyseal fractures for early limb ambulance and excellent healing.

Segal *et al.* (2018) used bilateral twisted String of Pearls locking plates for lumbosacral fracture-luxation in 4 dogs and 2 cats and concluded that bilateral twisted SOP locking plates were associated with a satisfactory outcome in treating lumbosacral fracture-luxation.

2.7. POST-OPERATIVE OUTCOME AND EVALUATION

2.7.1 Post-operative Coaptation

Tobias (1995) stated that Robert-Jones bandage was a variation of the padded bandage with a much thicker padding layer. As with padded bandages, the Robert-Jones type was constructed with contact, padding, compressive and outer layers. It provided more stability than a padded bandage because of its added thickness. Major advantages of Robert-Jones bandage included its increased stability over padded bandages and its tremendous absorbent capacity.

Gorse (1998) and Denny-Butterworth (2000) reported that Robert-Jones bandage could be used 5 to 10 days post-operatively to provide additional support and to control edema. The authors also recommended that a complete physical examination was mandatory in many patients who have sustained multiple traumatic injuries. They also stated that hair on fractured limb should be clipped to allow detection of subtle open injuries.

Denny and Butterworth (2000a) stated that Robert Jones bandage is a thick cotton-wool bandage which acts as a splint and controls oedema. For these reasons, it is useful not only as a first-aid measure for the temporary immobilization of fractures, but also as a postoperative bandage for fractures which have been treated surgically. The bandage is comfortable to wear and is generally well tolerated, despite its bulk.

De Camp (2003) stated that the bulk and mild compression of a Robert Jones bandage provide excellent temporary support for an injured extremity before or after surgical intervention and reduce swelling.

Johnson (2013b) stated that Robert Jones bandage and their modifications are the external splints most often used in veterinary patients. These bulky, cotton-gauge wrappings are typically used before or after surgery for temporary limb splintage. The thick cotton layer provides mild compression of soft tissue and immobilizes fractures without causing vascular compromise. Soft tissue and bone immobilization enhance patient comfort, prevent further soft tissue damage from sharp bone fragments and minimize swelling which enhances visualization and palpation of anatomic landmarks during surgery. Additionally, Robert Jones bandage help eliminate dead space after surgery.

2.7.2 Clinical Evaluation

Ness (2009b) reported good success following clinical application of SOP locking plates, placed via combined medial and lateral incisions in 13 dogs with Y-T humeral fractures and the functional outcome was considered excellent in 10 out of 13 cases.

Choate and Arnold (2011) reported a case of uneventful recovery with complete weight bearing in a 10 month old female Yorkshire terrier toy breed with bone cyst affecting the humeral condyle of both thoracic limbs simultaneously by using string of pearl locking plate for elbow arthrodesis as a method of stabilization.

Scrimgeour and Worth (2011) reported a case of uneventful recovery after treating with SOP locking plate along with intramedullary pin support for stabilization of comminuted calcaneal fracture in a giant breed Pyrenean Mountain dog.

Fitzpatrick *et al.* (2012b) reported the clinical outcome and application of SOP in shoulder arthrodesis in 7 out of 14 dogs and concluded that SOP plate might help to overcome several challenges associated with conventional implant systems like DCP or Reconstruction plate. The authors also reported that all the animals recovered uneventfully.

Kim and Lewis (2014) stated that, corrective osteotomy stabilized with string of pearl locking plates was a viable treatment option for improving limb function in two dogs with severe procurvatum deformities caused by distal femoral physeal fracture malunion. The authors further concluded that, excellent functional outcome was achieved in both the dogs.

Boucher and Zeiler (2015) used String of Pearls locking plate and intramedullary pin for femur fracture repair of tiger cub (Panthera tigris tigris) suffering from nutritional secondary hyperparathyroidism and osteopenia. The authors reported excellent functional outcome was achieved in this case.

Sadan *et al*. (2015) used String of Pearls locking plate for repair of ilial fractures in dogs and cats and opined that String of Pearls locking plate permits good correction of ilial fractures. The authors further concluded that, excellent functional outcome was achieved in 16 out of 20 cases and good results in 4 cases.

Grand (2016) used String of Pearls locking plates for the stabilization of acetabular and supra-acetabular fractures in three dogs and opined that String of Pearls locking plates are effective for stabilization of acetabular and supra-acetabular fractures in dogs. The author further concluded that, excellent functional outcome was noticed in all the three cases.

Kumar *et al.* (2018a) used String of Pearls locking plate for distal femoral diaphyseal fractures in dogs and concluded that String of Pearls (SOP) locking plates were good for stabilization of distal femoral diaphyseal fractures. The authors further concluded that, excellent functional outcome was achieved in 4 cases and good in 2 cases. The authors also stated that, overall healing time in all the cases was 7-11 weeks.

2.7.3 Radiographic Evaluation of Healing

Ackerman and Silverman (1978) reported that, formation of bony callus was first visible radiographically 7 to 14 days after fixation of fracture. The authors further reported that, rigid immobilization resulted in minimal callus formation whereas large callus was seen in cases of mobility between the fracture fragments.

Rand *et al.* (1981) evaluated the fracture healing fixed with intramedullary rod and compression plating in canine. The fracture treated with intramedullary rod showed more periosteal callus than those treated with rigid compression plate. They also observed that, the fracture healing was much faster with compression plating than those treated with intramedullary rod fixation technique.

Aron (1995) opined that fracture healing was a process of bone regeneration. It was divided in to well documented stages – inflammatory stage, connective tissue and fibrocartilage formation (soft callus) stage, bony bridging or mineralization (hard callus) stage and remodeling stage.

Gorse (1998) opined that while the patient remained anaesthetized post-operatively, radiographs should be taken to verify fracture reduction and joint alignment and follow-up radiographs should be taken every 4 weeks if possible.

Anderson *et al.* (2002) stated that the earliest follow-up in which the fracture gap was filled primarily with uniting endosteal callus was indication of radiographic union.

Henry (2007) stated that postoperative imaging is essential for proper evaluation of the reduction and alignment of the fracture as well as placement of orthopedic devices. At least two orthogonal views are required to interpret the location of bony structures and orthopedic devices accurately. An organized paradigm is required for evaluating radiographs of orthopedic procedures. One commonly used system goes by the mnemonic ABCDS, standing for alignment, bone, cartilage, devices, and soft tissues.

Ness (2009b) observed a circumferential radiolucency around the fracture site which is an evidence of bridging callus at the fracture site, and the author achieved radiographic bony union in 5 to 11 weeks with SOP plates in 9 out of 13 cases of Y-T humeral fractures in dogs.

Choate and Arnold (2011) concluded that, the functional and radiographic outcome of string of pearl (SOP) plate application was satisfactory in the cases treated for elbow arthrodesis. The authors observed satisfactory healing of arthrodesis after 10 weeks of surgery.

Scrimgeour and Worth (2011) observed the evidence of radiographic union after 9 weeks of surgery in a giant breed Pyrenean Mountain dog treated with SOP plate for stabilization of comminuted calcaneal fracture.

Fitzpatrick *et al.* (2012a) observed the evidence of bridging callus after 12 weeks of surgery in 6 dogs treated with string of pearls locking plate and cerclage wire for stabilization of periprosthetic femoral fractures after total hip replacement.

Fitzpatrick *et al.* (2012b) concluded that, the functional and radiographic outcome of string of pearl (SOP) plate application was satisfactory in the cases treated for shoulder arthrodesis. He observed that 11 out of 14 dogs had complete loss of the radiolucent line postoperatively at arthrodesis site by the time of 11 to 16 week reassessment.

Hespel *et al.* (2013) radiographically observed the signs of normal bone healing with development of bridging callus at the tibial fracture site and secondary bone healing at the fibular fracture site after 6 weeks of surgery in a grey seal treated with string of pearls (SOP) locking plate.

Boucher and Zeiler (2015) radiographically observed improved bone density, completely healed pelvic fractures and circumferential mature bridging callus across the femoral fracture site on post-operative 63rd day in a tiger cub treated with String of Pearls (SOP) locking plate.

Grand (2016) used String of Pearls locking plates for the stabilization of acetabular and supra-acetabular fractures in three dogs and radiographically observed complete bone healing in all the three cases at 8 weeks post-operatively with no loss of fracture reduction.

Piermattei *et al.* (2016b) refers clinical union to the period in the recovery process of a fracture when healing has progressed to the point that the bone is strong enough to remove the fixation. These healing times vary somewhat, depending on the type of fixation used. Radiographic evaluation of fracture healing should be routinely performed at the time of expected clinical union. The mnemonic “AAAA” Alignment, Apposition, Apparatus, Activity, has proved useful for evaluation of such radiographs.

Kumar *et al.* (2018a) radiographically observed excellent healing with absence of fracture lines with endosteal or bridging callus in all the cases of dogs with distal diaphyseal femoral fractures treated with String of Pearls locking plates.

2.7.4 Haemotological Evaluation

Umeshwori *et al.* (2015) evaluated closed and open intramedullary pinning for repair of tibial fractures in two groups of dogs and reported that the mean hemoglobin level in both groups increased significantly till day 30. Further the authors opined that a significant decrease in mean TLC and neutrophil count decreased on day 15, which was increased on day 30 in both groups. Mean lymphocyte count decreased gradually on day 15 and decreased subsequently by day 30.

Patil *et al.* (2017) reported that progressive increase of packed cell volume, hemoglobin and total erythrocyte count from immediately after operation to 90th day indicated erythropoisis. Physiological leucocytopenia, neutropenia with relative lymphocytosis on different post-operative days indicated resolution of inflammation and surgical stress. Monocyte and eosinophil counts were within physiological limits in all the groups of animals indicating free from anaphylactic reactions. Slight hypercalcemia, slight hyperphosphatemia and progressive decrease of serum alkaline phosphatase on different post-operative days indicated osteosynthesis of bone. Further, the authors opined that physiological and hemato-biochemical findings on different post-operative days helped in knowing the healing of fracture.

Singh *et al.* (2017) evaluated the haematological, radiographic and clinical outcome in the different time period and between the groups showed non-significant minor variation during the period of study in healing of femoral fracture with retrograde intramedullary pin in conjunction with demineralized bone matrix in dogs.

2.7.5 Serum Biochemical Evaluation

Siemesen (1970) reported that, serum inorganic phosphorus level elevated immediately after fracture fixation and significantly increased level was recorded on the 30th post-operative day and which thereafter decreased to reach normal level on 60th post-operative day.

Singh *et al. (*1976) observed a non significant difference in the level of serum calcium and inorganic phosphorus during the healing period of experimental ulnar defects in dogs. But, there was significant increase in the serum alkaline phosphatase levels at seventh and fourteenth post-operative days and returned to normal by sixth post-operative week. The authors opined that, increase in level of serum alkaline phosphatase was attributed to fibrous tissue formation and early stage of bone repair.

Guyton (1981) reported that, in most of the compression method of internal fixation, an increase in alkaline phosphatase due to osteoblastic activity was observed.

Bush (1991) reported that, serum calcium levels increased slightly on 5th post-operative day and then increased significantly to reach the peak level on the 15th post-operative day followed by gradual decline to near base value on 60th post-operative day but it remained above the normal value. The gradual decline in serum calcium level from 30th post-operative day might be due to more rapid calcification at fracture site.

Kumar *et al. (*1999) found that, there was a significant decline in serum calcium and inorganic phosphorus levels during the healing period of 21 days in dogs with fractures.

Maiti *et al.* (1999) reported that, an increase in serum alkaline phosphatase level was observed from 5^{th} post-operative day, reached its peak level at the 15^{th} post-operative day and thereafter a declining trend was followed up to the 60^{th} post-operative day and remained above the base line values. This increased alkaline phosphatase activity might be an indication of increased chondroblastic proliferation to cause bone formation during fracture repair.

Chandy (2000) analysed the serum calcium, phosphorus and alkaline phosphatase level post-operatively and reported that, there was no variation in the serum calcium and phosphorus levels. But, serum alkaline phosphatase level showed a significant increase from the pre-operative day to 28^{th} post-operative day.

Ghosh *et al.* (2003) studied the activity of serum alkaline phosphatase during repair of compound fracture in goats with autogenous cancellous and homogenous decalcified bone chip for six weeks. The authors concluded that, in cancellous bone group, serum alkaline phosphatase level was significantly higher for entire observation period than the base line value, whereas such an increase was observed during 1^{st} to 5^{th} week post-operatively in homogenous decalcified bone group.

Nagaraja *et al.* (2003) evaluated the feasibility of using plastic rods in the diaphyseal femur fracture based on serum biochemical changes, gross and histopathological changes. They reported that, the levels of calcium and phosphorous increased gradually up to 15^{th} post-operative day and rapidly returned to normal which was statistically nonsignificant and no significant variation were noticed in the serum alkaline phosphatase values from that of preoperative day values.

Rani and Ganesh (2003) estimated the concentration of serum calcium, phosphorous and serum alkaline phosphatase during fracture healing of femur in goats. They reported marked reduction in serum calcium level on 7^{th} post-operative day in both the groups and marked rise in the values from 1st day and reached the normal level as that of pre-operative values on 60th day in both the groups. They further reported significant elevation of alkaline phosphatase level in both the groups up to 15th post-operative day following surgery and thereafter the values were found to be declined.

Julie (2005) observed significant decrease in the serum calcium levels by the fourth week post-operatively, which remained same during the sixth week. The author observed a significant decrease in the serum phosphorus levels during fourth and sixth week post-operatively. A significant increase in the alkaline phosphatase level by the second week and significant decrease by fourth week was observed in dogs with radial and tibial fractures treated with external skeletal fixators.

Mahendra *et al*. (2007) reported no significant change in serum calcium and serum phosphorus levels post-operatively after treating femur fracture in dogs using intramedullary pinning and cerclage wiring. They observed significant increase in serum alkaline phosphatase levels throughout the study period, which might be due to the process of increased osteogenic activity and deposition of calcium salts at the site of fracture.

Hegade *et al.* (2007) reported that the significant increase in serum alkaline phosphatase on the day of surgery following fracture immobilization and was attributed to proliferation of osteogenic cells with maximum contribution from the periosteum of destructed bone, which was a rich source of serum alkaline phosphatase.

Phaneendra *et al.* (2016) reported that alkaline phosphatase and C-reactive protein can be used as useful biochemical markers in assessing the bone formation and pain respectively. Biochemical parameters along with clinical and radiographical examination provide sound knowledge on the degree of bone healing.

Kumar *et al.* (2018b) reported that serum calcium, inorganic phosphorus, alkaline phosphatase and C-reactive protein can be used as useful biochemical markers in assessing the bone formation and pain respectively. Biochemical parameters along with clinical and radiographical examination provide sound knowledge on the degree of bone healing.

2.8 POST-OPERATIVE COMPLICATIONS

2.8.1 Complications

Ness (2009a) mentioned that bending of SOP plate beyond the yield point showed initial plastic deformation at the internode region.

Kim and lewis (2014) reported that, the main disadvantage of using string of pearl bone plate was that, the prominent profile of implants created soft tissue irritation.

2.8.2 Loosening of Screws and breakage of plates

Fitzpatrick *et al.* (2012a) used string of pearls locking plate and cerclage wire stabilization of periprosthetic femoral fractures after total hip replacement in six dogs. Out of six dogs, in one dog, the plate failed adjacent to fracture line at 5 weeks, with failure occurring through the internode between 2 screw holes and the reason for plate failure was that the fracture was a comminuted distal diaphyseal fracture whereas all the fractures were of oblique or spiral configuration.

Fitzpatrick *et al.* (2012b) reported the clinical outcome and application of SOP in shoulder arthrodesis in 7 out of 14 dogs and observed a major complication of plate breakage 4 months postoperatively due to delayed arthrodesis in 1 dog and was managed by surgical revision of SOP application.

2.8.3 Osteomyelitis and Delayed Fracture Union

Vaughan (1975) stated that the most serious complication of internal fixation methods in fracture repair was osteomyelitis.

Hunt *et al.* (1980) stated that the complications of the diaphyseal fractures treated surgically in small dogs were chronic osteomyelitis and implant failures.

Nunmaker and Newton (1985) stated that the metals used for internal fixation techniques lower local tissue resistance to infection and delayed the bone healing process.

Boone *et al.* (1986) found that the time of bone union varied with age of the animal and method of fixation. Healing time was found to be longer in adults compared to young dogs. It also increased the stability of fracture fixation.

2.9 REMOVAL OF PLATES

Emmerson and Muir (1999) opined that the plate removal was not required in adult cases and also listed the various reasons of plate removal were instability, soft tissue irritation infection and chronic lameness.

Mills (2009) used 2.7 mm SOP locking plate for stabilization of sacral and ilial fracture in an adult Staffordshire bull terrier which showed uneventful healing of both fractures and implant was removed 15 weeks after surgery.

Ness (2009b) reported good success following clinical application of SOP locking plates, placed via combined medial and lateral incisions in 13 dogs with Y-T humeral fractures and the SOP implants were left in place unless complications prompted removal.

Kim and Lewis (2014) used SOP locking plate for stabilization severe procurvatum deformities caused by distal femoral physeal fracture malunion after corrective osteotomy. Functional outcome was excellent with complete weight bearing on affected limb and implants were removed 3 to 5 months after surgery.

Kumar *et al.* (2018a) used SOP locking plates for stabilization of distal femoral diaphyseal fractures. Functional outcome was excellent with complete weight bearing and implants were removed after 18 weeks in two cases.

CHAPTER III

MATERIALS AND METHODS

3.1 SELECTION OF CASES

The present clinical study on fixation of femoral fractures using String of Pearls (SOP) Locking plates was performed on 7 dogs presented for treatment at Department of Surgery and Radiology, College of Veterinary Science, Rajendranagar, Hyderabad. Routine clinical, orthopaedic and radiographic examinations were conducted to diagnose the fractures of femur. After confirming femoral fractures, 7 cases were selected for the study. Femur fractures in the dogs were immobilized by open and internal fixation by using either 2.7 mm or 3.5 mm String of Pearls (SOP) Locking plates and screws, depending on the fracture configuration and body weight of the dog.

3.2 ANAMNESIS

Information about the dogs presented with femur fracture was collected. Details regarding age, sex, breed, chief complaint, age of fracture, history of other illness, previous injury or other orthopaedic disease, the manner of onset of chief complaint, duration of signs and past treatment, if any, for the chief complaint were recorded.

3.3 PRE-OPERATIVE EXAMINATION

3.3.1 Pre-operative Clinical Examination

The dogs presented with fractures of femur were first subjected to routine clinical and orthopaedic examination. The dogs were examined for loss of function, abnormal motility, deformity or change in angulation of affected limb, pain and crepitation at the fracture site. Clinical signs such as local swelling, infection and exudation from the fracture site were recorded. The neurological status of the dogs was assessed. The dogs with neurological signs and the dogs with open wounds at the fracture site were excluded from the study. The femoral fractures were temporarily stabilized with Robert Jones bandage with or without the use of splints until the day of surgery.

3.3.2 Pre-operative Radiographic Examination

Following initial clinical assessment, the dogs were subjected to pre-operative radiographic examination in orthogonal views. Plain mediolateral and anteroposterior radiographs including the concerned joints were obtained (Langley-Hobbs, 2003). The type and site of the fracture on the femur were ascertained from the radiographs.

3.3.3 Planning of Surgery

Measurements of the fractured femur and contralateral normal femur were obtained from the pre-operative radiographs (Langley-Hobbs, 2003). These measurements from pre-operative radiographs were used to select the length of SOP plate and screws. The length of the screw needed for application of SOP plate in each patient was determined by measuring the mediolateral thickness of femur at different distances from the fracture site of the respective bones directly from the anteroposterior radiographs (Fig. 1).

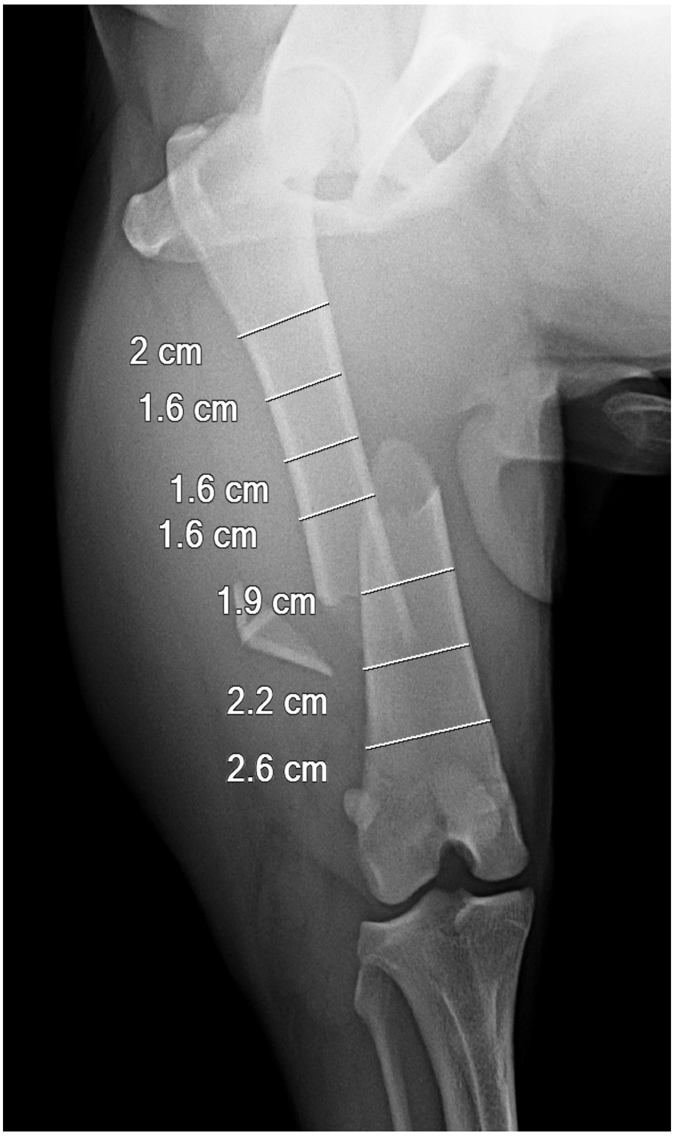

Fig.1. Radiograph showing mediolateral thickness of femur at different distances from fracture site in anteroposterior view

3.4 PATIENT PREPARATION, ANESTHESIA AND POSITIONING

3.4.1 Pre-operative Patient Preparation

The femoral fractures were temporarily stabilized as described earlier. The owners were advised to withhold food for about 12 hours and water for about 6 hours prior to surgery. The affected limb was aseptically prepared by clipping the hair from dorsal midline to the tarsal joint. The operative site was shaved and scrubbed using povidone-iodine surgical scrub[1], followed by application of surgical spirit. Similarly, the skin was also prepared over the cephalic vein on both fore limbs for intravenous injections. Normal saline was intravenously infused throughout the duration of surgery.

3.4.2 Anaesthesia

Atropine sulphate[2] at the rate of 0.04 mg/kg body weight was administered subcutaneously as pre-anaesthetic medication followed 10 minutes later by xylazine hydrochloride[3] at the rate of 1 mg/kg body weight intramuscularly. Ten minutes later, general anaesthesia was induced with intramuscular injection of ketamine hydrochloride[4] at the rate of 10 mg/kg body weight. Following induction, the dogs were intubated with endotracheal tubes of suitable size. Anaesthesia was maintained with intravenous infusion of propofol[5] at the rate of 4 mg/kg body weight. Additional doses of propofol were also administered whenever necessary during surgical procedure through the intravenous line.

3.4.3 Positioning of the Animal

The dogs were positioned in lateral recumbency with the fractured limb up. The distal extremity of the limb was covered with sterile gauze bandage. The prepared site

1. Betadine Surgical Scrub- Win-Medicare Pvt. Ltd., New Delhi, India.
2. Atropine sulphate Injection- Domesto Pvt. Ltd., Vijayawada, India.
3. Xylaxin Injection- Indian Immunologicals Ltd., Hyderabad, India.
4. Ketamax 50- Troikaa Pharmaceuticals Ltd., Dehradun, India.
5. Profol- Claris Injectables Ltd., Ahmedabad, India.

was again painted with 5 % povidone-iodine solution followed by application of spirit. Sterile drape was applied (Fig. 2).

3.5 MATERIALS USED

3.5.1 Orthopaedic Instruments

A general surgical instrument set and the required orthopaedic instruments were used. Orthopaedic instruments including Gelpi retractors, bone holding forceps, Hohmann's retractors, Senn retractors, orthopaedic hexagonal screw drivers, 2 mm and 2.7 mm drill bits, depth gauge and low speed high torque electric drill were used.

The general surgical and orthopaedic instruments including the implants were sterilized in an autoclave prior to surgery while low speed high torque drill was sterilized in a formaldehyde sterilizer.

3.5.2 Instruments for Plating

SOP plate benders, SOP bending tees or plugs, and a K - wire to act as template for plate contouring (Fig. 3) were used in the present study.

3.5.3 Implants

The String of Pearls Locking plates (SOP)[6] and screws were used for stabilization of femoral fractures viz., 3.5 mm SOP plate with 3.5 mm locking screws and 2.7 mm SOP plate with 2.7 mm locking screws (Fig. 4 and 5). The choice of plate was determined on the basis of weight of the dog and the diameter of the bone as measured from the pre-operative radiographs. The 2.7 mm SOP plate was used in dogs weighing less than 10 kg and 3.5 mm SOP plate was used in dogs weighing more than 10 kg. Due to implant failure observed in two dogs weighing more than 10 kg, 3.5 mm SOP plates were used in nested configuration in one dog weighing 27.2 kg.

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6. String of Pearls Locking plate (SOP) - Siora Surgicals, New Delhi, India.

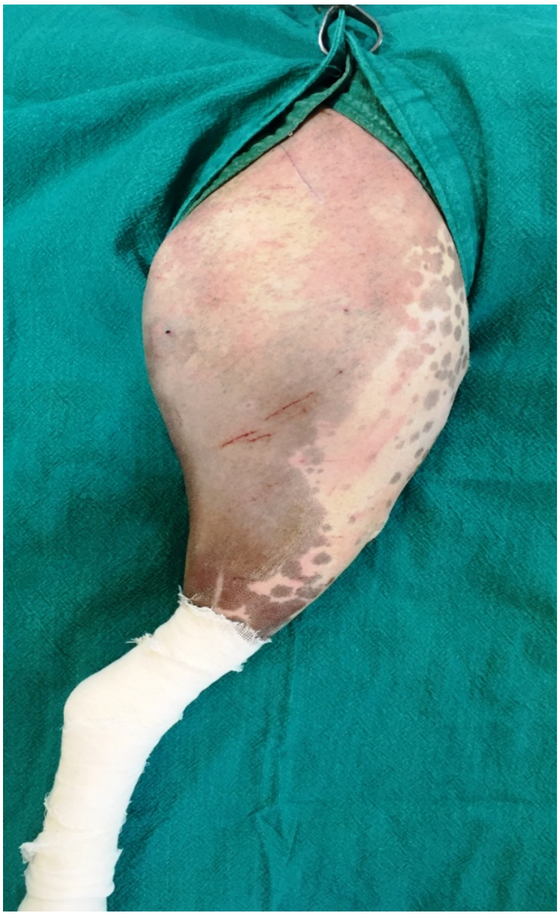

Fig.2. The dog with femoral fracture prepared, draped and positioned for surgery

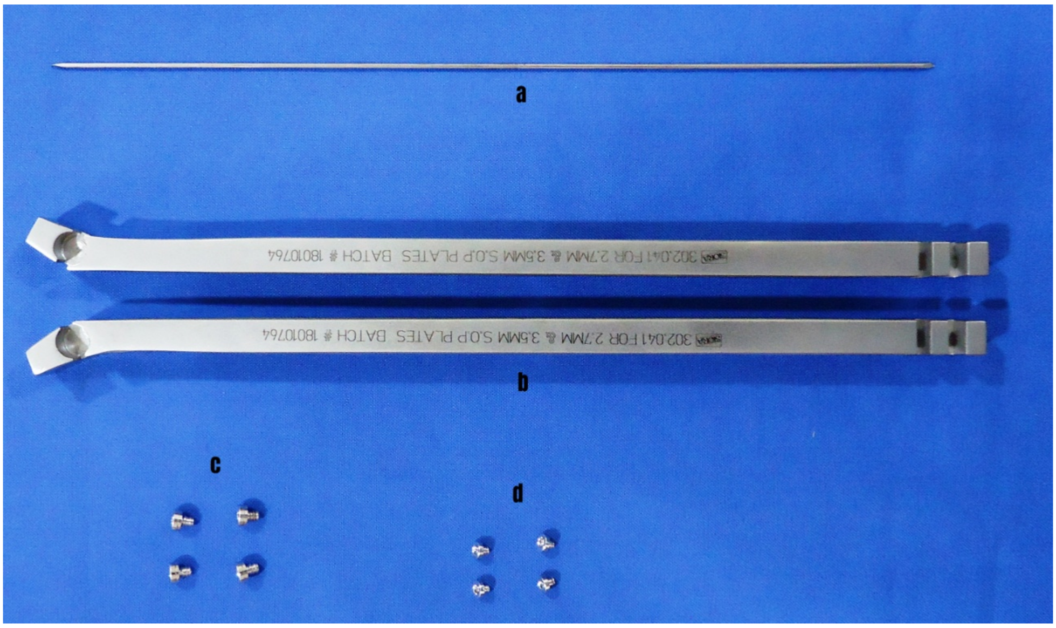

Fig.3. Instruments for SOP plating: a) K - wire, b) String of Pearls Plate Benders, c) 3.5 mm SOP bending tees and d) 2.7 mm SOP bending tees

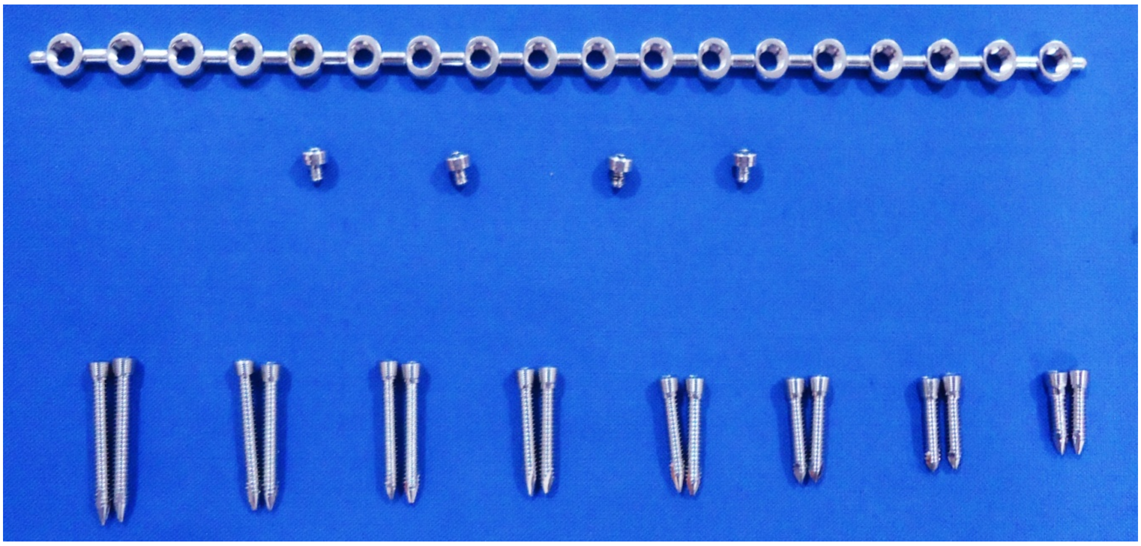

Fig.4. 3.5 mm String of Pearls Locking plate with 3.5 mm bending tees or plugs and 3.5 mm locking screws

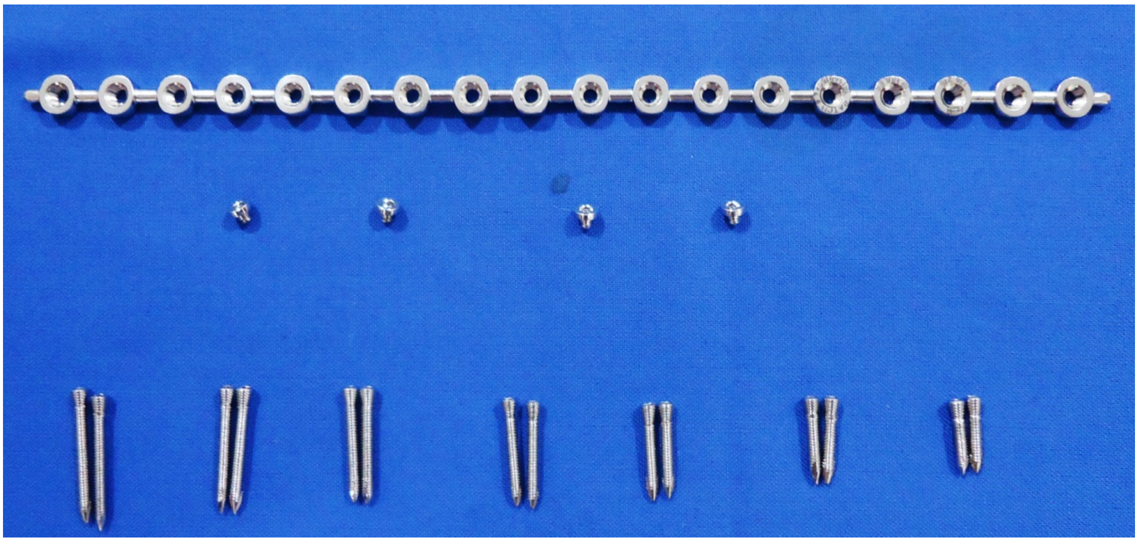

Fig.5. 2.7 mm String of Pearls Locking plate with 2.7 mm bending tees and 2.7 mm locking screws

3.6 SURGICAL PROCEDURE

3.6.1 Surgical Approach to the Femoral Diaphysis

A skin incision was made along the craniolateral border of the thigh extending from the trochanter major to the lateral condyle of femur (Fig. 6). Subcutaneous tissue was incised to expose the tensor fascia lata muscle. The tensor fascia lata was incised along its insertion to the cranial border of biceps femoris muscle (Fig. 7). Biceps femoris muscle was retracted caudally to expose the vastus lateralis muscle. These muscles were separated and retracted to expose the shaft (Fig. 8) of the femur (Johnson, 2013; Piermattei and Johnson, 2014).

3.6.2 Fracture Reduction and Plating

The fractures were reduced by manipulation and the fracture fragments were aligned and held in position using bone reduction forceps with speed lock (Fig. 9). After reduction, the fracture fragments were stabilized with precontoured 3.5 mm or 2.7 mm SOP plate with locking screws of corresponding size. Prior to bending of SOP plate, the holes in the SOP plate were loaded with SOP bending tees to protect the pearl integrity. The SOP plate was bent using the SOP plate benders by engaging the adjacent pearls (Fig. 10). The tees were then removed.

After contouring (Fig. 11), the SOP plate was placed on the bone and the contour was reviewed. The screws were directed perpendicular to the spherical component of SOP. A hole was drilled using either 2mm (for 2.7 mm SOP plate) or 2.7mm (for 3.5 mm SOP plate) drill bit across the femoral diaphysis using a low speed high torque electric drill (Fig 12) until the drill bit passed through both the near and far cortices. Screws were first placed at the proximal and distal holes of the SOP plate. The length of the screws was determined by measuring the thickness of femur from the pre-operative radiographs and was confirmed during the surgical procedure by using a depth gauge. A screw of suitable length was then placed at the drilled hole and tightened using

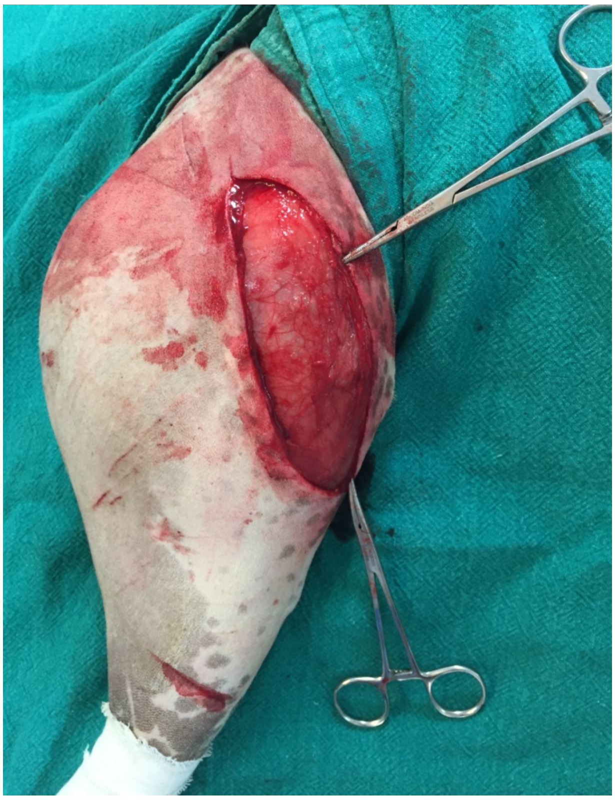

Fig.6. Skin incision made from trochanter major to lateral condyle of femur

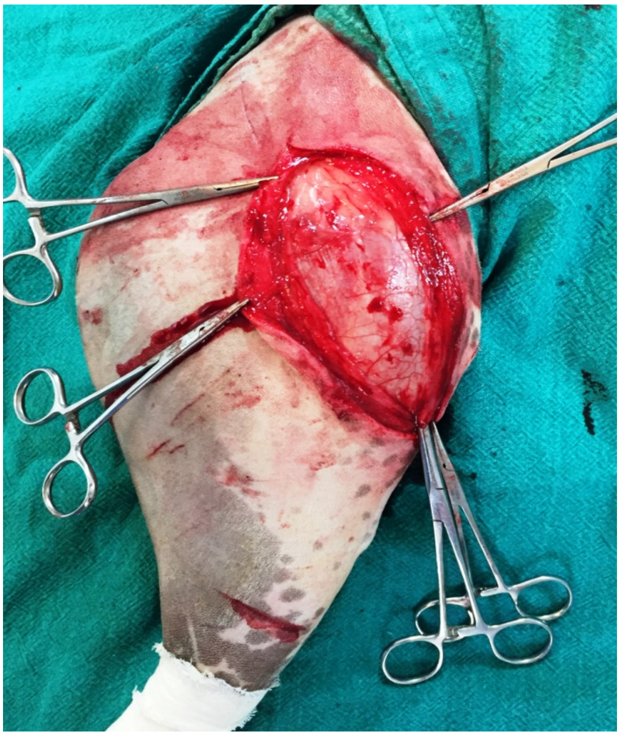

Fig.7. Incised tensor fascia lata muscle

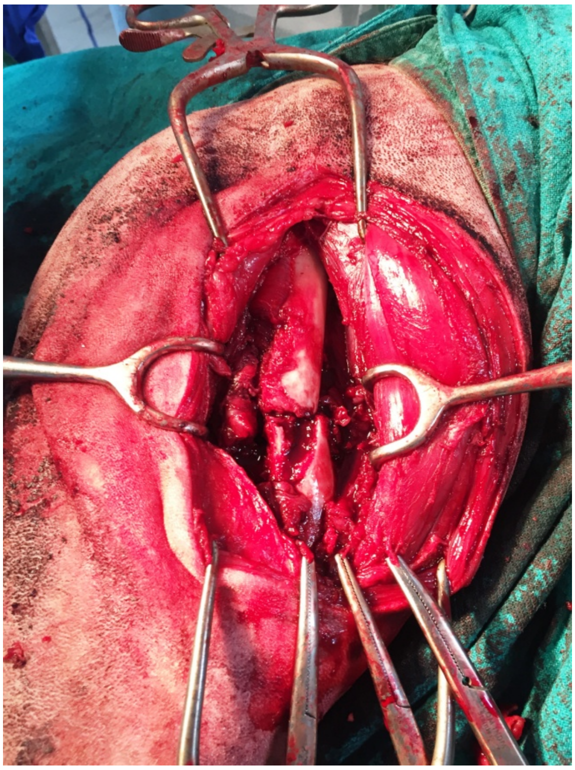

Fig.8. Femoral fracture fragments were exposed

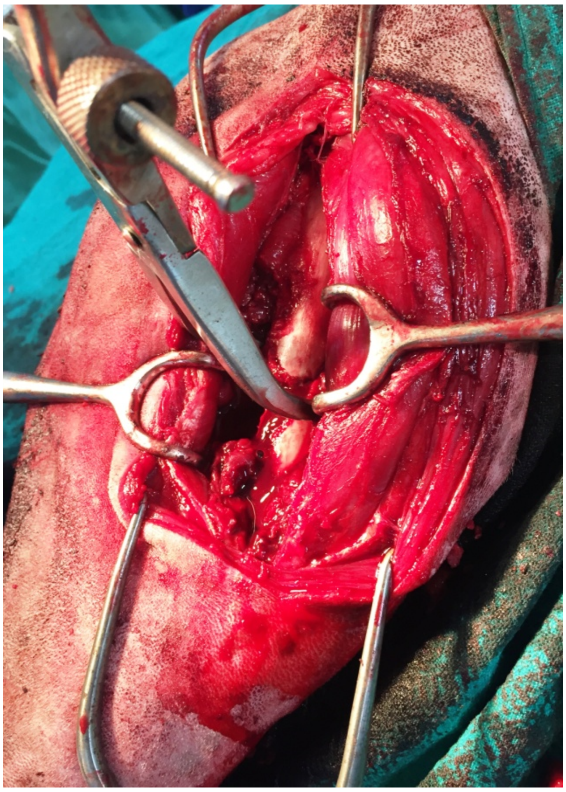

Fig.9. Reduced fracture fragments held in place using bone reduction forceps with speed lock

Fig.10. SOP plate with SOP bending tees is loaded into SOP plate benders for contouring

Fig.11. Contoured 3.5 mm SOP plate

a hexagonal orthopaedic screw driver until the taper end of screw exited the far cortex to secure the SOP plate to the bone. String of Pearls bone plating was accomplished by insertion of one to three screws in both proximal and distal fracture fragments (Fig. 13). In one dog weighing 27.2 kg, SOP plate nesting was performed; the surgical approach followed was as described earlier. Instead of one plate, two 3.5 mm SOP plates were contoured to match the topography of lateral aspect of femur (Fig. 14) and were nested side by side (Fig. 15).

3.6.3 Closure of the Incision

Following fracture repair, the incision on the tensor fascia lata was closed in a simple continuous pattern using 2-0 polyglactin 910[7] (Fig. 16). Subcuticular sutures were placed with 2-0 polyglactin 910. The skin incision was closed in a row of cruciate mattress suture using 2-0 polyamide[8] (Fig. 17).

3.7 POST-OPERATIVE CARE AND MANAGEMENT

The suture line was covered with a thin layer of sterile gauze bandage dipped in 5% povidone-iodine solution and a thick layer of cotton pad was overwrapped. It was then covered with gauze bandage and finally, a layer of surgical paper tape[9] was applied to provide additional protection (Fig. 18). The dressing was changed every alternate day until the sutures were removed on the 12th post-operative day.

Ceftriaxone sodium[10] was administered at the rate of 25 mg/kg body weight as intramuscular injection twice a day for 7 days post-operatively. Meloxicam[11] was administered once a day at the rate of 0.3 mg/kg by intramuscular injection for 3 days. Owners were advised to restrict the movement of the animal for the first 2 weeks of surgery and then to allow leash walking for next few days.

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7. Vicryl - Johnson & Johnson Pvt. Ltd., Aurangabad, India.
8. Ethilon - Johnson & Johnson Pvt. Ltd., Baddi, HP, India.
9. Micropore – 3M India Ltd., Shirur, Pune, India
10. Ceftriaxone- Intas Pharmaceuticals Ltd., Ahmedabad, India.
11. Melonex injection- Intas Pharmaceuticals Ltd., Ahmedabad, India.

Fig.12. Drilling the proximal-most hole

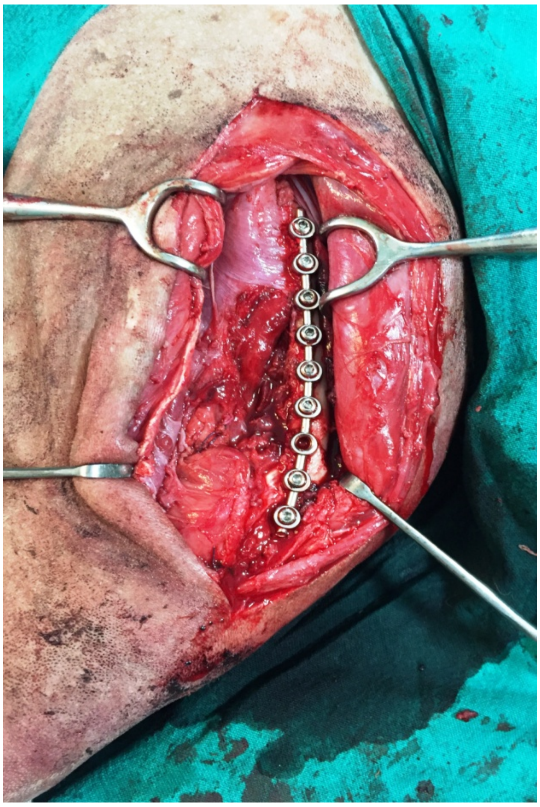

Fig.13. SOP bone plating completed

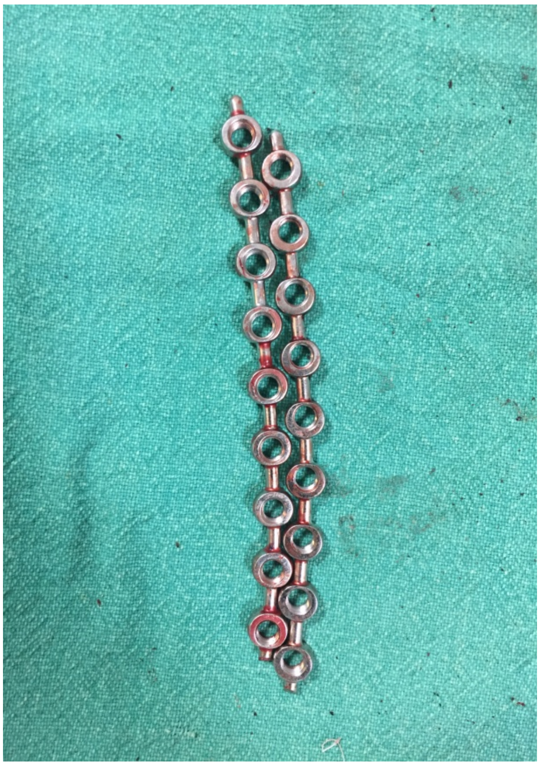

Fig. 14. Two 3.5 mm SOP plates contoured for plate nesting

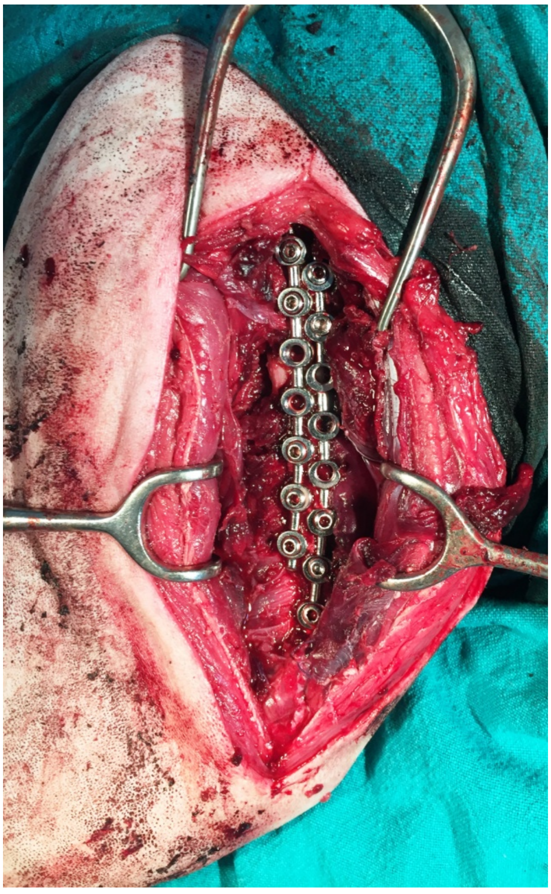

Fig.15. SOP plate nesting performed in a dog weighing 27.2 kg

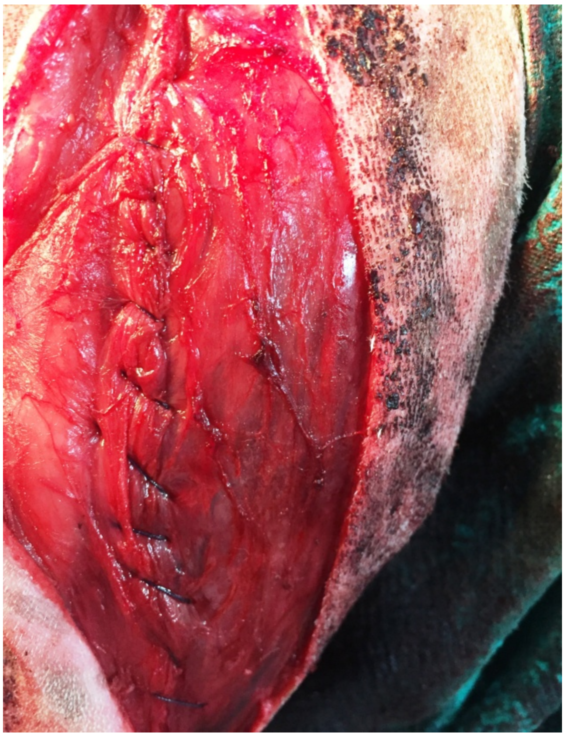

Fig.16. Tensor fascia lata muscle being closed with simple continuous suture of 2-0 polyglactin 910

Fig.17. Skin incision closed by cruciate mattress suture using 2-0 polyamide

Fig.18. Limb stabilized with Robert Jones bandage

3.8 EVALUATION OF FRACTURE HEALING

3.8.1 Clinical Evaluation

Clinical evaluation was carried out every alternate day to check for the presence of swelling, exudation and weight bearing in all the dogs. The appearance of suture line was also examined every alternate day until the sutures were removed. The post-operative day on which the dog started bearing weight was recorded and graded. After suture removal, the dogs were examined once in a week for the limb stability up to 45 days.

3.8.2 Lameness Grading

A lameness grade was assigned in all cases during pre and post-operative period based on the weight bearing nature during stance and while walking. Weight bearing was graded as follows (Vasseur *et al*. 1995).

Grade I- Normal weight bearing on all limbs at rest and while walking.

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

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

Grade IV- Partial weight bearing at rest; does not bear weight on affected limb while walking.

Grade V- Does not bear weight on limb at rest or while walking.

3.8.3 Radiographic Evaluation

Plain anteroposterior and mediolateral radiographs of the operated femur were obtained immediately after surgery and on the 7th, 15th, 30th and 45th post-operative days to assess the progress of bone healing.

3.8.4 Haematological Evaluation

Blood sample was collected in EDTA coated vials in all the cases on the day before surgery and on the 15th and 45th days of surgery. Haemoglobin (g/dl), packed cell volume (%), total erythrocyte count (x10^6/µl), total leucocyte count (x10^3/µl) and differential leucocyte count (cells/µl) were estimated on the said day as per the methods described by Jain (1993).

3.8.5 Serum Biochemical Evaluation

Blood sample was collected and serum was separated in all the cases on the day before surgery and on the 15th and 45th days of surgery. Serum alkaline phosphatase, calcium and phosphorous were estimated on the said day.

3.8.5.1 Serum Alkaline Phosphatase (U/L)

Serum alkaline phosphatase (U/L) was estimated by International Federation of Clinical Chemistry (IFCC) kinetic assay method (Young, 1997).

3.8.5.2 Serum Calcium (mg/dL)

The levels of calcium (mg/dL) in serum were determined by OCPC method (ortho-cresolphthalein complexone) (Lin *et al*. 1999).

3.8.5.3 Serum Phosphorus (mg/dL)

The levels of inorganic phosphorus (mg/dL) in serum were determined by Phosphomolybdate Method (Young, 2000).

3.8.6 Statistical analysis

The data regarding haematological and serum biochemical values were subjected to standard statistical analysis using one way ANOVA as described by Snedecor and Cochran (1994) using Statistical Package for the Social Sciences (SPSS) 15 software package.

CHAPTER IV

RESULTS

4.1 ANAMNESIS

4.1.1 Selection of Dogs with Femoral Fractures

A total of 68 cases of long bone fractures were recorded in dogs during the period of study. Out of these 68 cases, fractures involving femur were encountered in 32 cases. Out of these 32 cases, seven cases that were considered suitable for fixation using String of Pearls Locking plates (SOP) were selected for the study. Fracture fixation in these seven dogs was performed using String of Pearls Locking plates (SOP).

4.1.2 Age, Breed, Sex and Body Weight of the Dogs

The age of seven dogs ranged from 4 – 48 months with a mean of 24 ± 7.94 months. Out of these seven dogs, four were male and three were female. Five dogs belonged to non-descript breed, one dog belonged to spitz breed and one dog belonged to German shepherd breed. The body weight of the dogs ranged from 4.5 to 27.2 kg with a mean body weight of 12.15 ± 3.25 kg.

4.1.3 Etiology and Age of the Fracture

The main cause of fractures was found to be automobile accident in 4 (57.15%) dogs followed by fall from height in 3 (42.85%). The dogs were presented for treatment between 2 to 6 days with a mean of 3.85 ± 0.5 days after sustaining fracture. No other concurrent illness, orthopaedic or neurological conditions were found in any of the dogs. Details of the cases are represented in Table 1.

4.2 PRE-OPERATIVE OBSERVATIONS

4.2.1 Pre-operative Clinical Observations

All the seven dogs presented for treatment of femur fractures exhibited symptoms like sudden onset of pain and lameness immediately after a traumatic injury. There were symptoms like swelling, dangling of the limb, non-weight bearing and abnormal angulation of the limb at the fracture site (Fig. 19 a, b, c). In all the dogs, crepitation was noticed at the fracture site on physical manipulation. None of the dogs had either sciatic or femoral neurological defect since all of them responded at good or fair levels to pinching of lateral and medial digits. All the seven dogs had closed fractures.

4.2.2 Pre-operative Radiographic Observations

Plain mediolateral and anteroposterior radiographs of the femur including the proximal and distal joints confirmed femur fractures. Pre-operative radiographs revealed proximal diaphyseal fractures in two dogs, mid diaphyseal fractures in two dogs and distal diaphyseal fractures in three dogs. Pre-operative radiographs also revealed the type of femoral fractures as short-oblique in two dogs, transverse fractures in four dogs and comminuted diaphyseal fracture in one dog. In all the dogs, over-riding fractures were found. Pre-operative radiographs of dogs with femoral fractures were

Table 1 – Clinical History of the Dogs selected for SOP locking plate procedure

Case No.	Breed	Age (months)	Sex (M/F)	Body weight (KG)	Cause of fracture	Days since fracture
1	Non-Descript	16	M	18.2	Automobile accident	5
2	Non-Descript	4	M	4.5	Fall from height	4
3	Non-Descript	48	M	16.4	Automobile accident	3
4	German shepherd	4	F	5.6	Fall from height	2
5	Spitz	44	F	6.8	Fall from height	3
6	Non-Descript	6	F	6.4	Automobile accident	6
7	Non-Descript	46	M	27.2	Automobile accident	4
Mean		24 ± 7.94		12.15 ± 3.25		3.85 ± 0.5

Fig. 19 a, b, c – Dangling and non-weight bearing of the fractured limb presented in Fig. 20 (a, b, c, d, e, f, g). The details regarding the fractures encountered in all the dogs were presented in Table 2.

4.3 PATIENT PREPARATION, ANAESTHESIA AND POSITIONING

The patient preparation and anaesthetic protocol followed for the surgery was found adequate to carry out the surgical interventions. The dogs with fractures of femur were positioned in lateral recumbency with fractured limb up. Covering the distal extremity of the limb with sterile gauge bandage facilitated manipulation of the limb during surgery without compromising asepsis. Painting the surgical site with 5% povidone-iodine solution followed by application of surgical spirit and the draping was considered satisfactory since infection was not encountered in any of the seven dogs post-operatively.

4.4 PLANNING OF SURGERY

Measurements obtained from the pre-operative radiographs of the affected limb like the length of the bone and transcortical diameter at different regions proved vital in selecting the appropriate sized String of Pearls Locking plate (SOP) and the length of the screws.

4.5 MATERIALS USED

4.5.1 Implants

String of Pearls Locking plates (SOP) used for stabilization of femoral fractures resulted in good fracture fixation and immobilization. Selection of appropriate size of SOP plates was determined by the weight of the dog and length of the bone measured from radiographs. The 2.7 mm SOP plates were used in 4 dogs weighing less than 10 kg, 3.5 mm SOP plates were used in two dogs weighing greater than 10 kg and 3.5 mm SOP plates were used in nested configuration for one dog weighing 27.2 kg body weight. SOP plates of 2.7 mm size with 5 holes were used in two dogs and with 6 holes

Fig. 20 a, b, c, d - Pre-operative radiographs of the dogs with femoral fractures

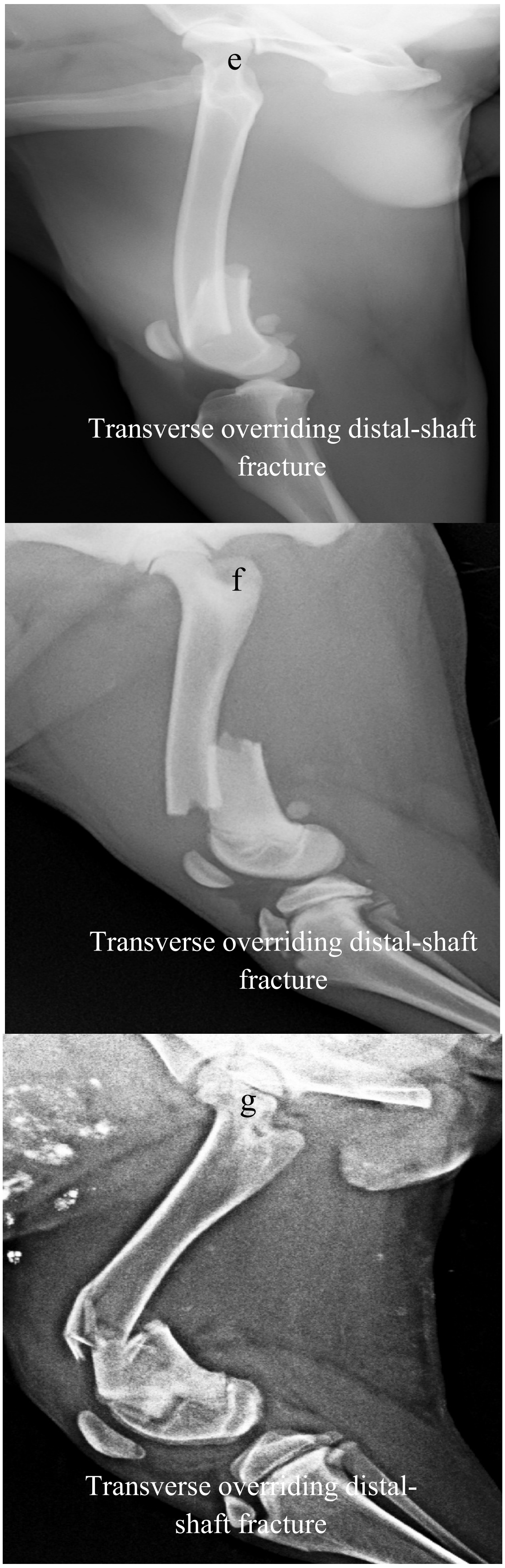

Fig. 20 e, f, g - Pre-operative radiographs of the dogs with femoral fractures

Table 2 – Pre-operative Radiographical Observations of the femoral fractures in dogs

S.No	Limb affected	Location of fracture	Type of fracture
1	Right	Mid diaphyseal	Closed Complete comminuted overriding
2	Left	Proximal diaphyseal	Closed Complete short oblique overriding
3	Right	Distal diaphyseal	Closed Complete transverse overriding
4	Right	Distal diaphyseal	Closed Complete transverse overriding
5	Right	Mid diaphyseal	Closed Complete short oblique overriding
6	Right	Proximal diaphyseal	Closed Complete transverse overriding
7	Left	Distal diaphyseal	Closed Complete transverse overriding

were used in two dogs. SOP plates of 3.5 mm size with 9 holes were used in two dogs. Since implant failure was observed in two dogs treated with 3.5 mm SOP plates each weighing 16.4 and 18.2 kg respectively, the seventh case was taken up for study weighing 27.2 kg, in which two 3.5 mm SOP plates were nested side by side (one with 8 holes and the other with 7 holes) to enhance the stiffness (Fig. 21).

4.5.2 Locking Screws

In the present study the 2.7 mm self tapping locking screws varying from 14 mm to 26 mm in length were used in four dogs and 3.5 mm self tapping locking screws varying from 16 mm to 34 mm were used in three dogs. The lengths of the screws were determined by measuring the transcortical diameter of the bone at different regions from the anteroposterior radiographs obtained pre-operatively.

4.6 SURGICAL PROCEDURE

4.6.1 Surgical Approach to the Femoral Diaphysis

The craniolateral border of thigh approach provided satisfactory exposure of fractured diaphyseal region of femur bone to perform bone plating with String of Pearls Locking plates (SOP).

4.6.2 Fracture Reduction and Plating

Following reduction of fracture, the SOP plate was contoured to match the lateral surface of femur and then secured to the bone using self tapping screws. The drill bit of 2.0 mm for 2.7 mm SOP plate and 2.7 mm drill bit for 3.5 mm SOP plate were found suitable for plate fixation. Screw positioning without involving growth plates and their application without tapping provided satisfactory fixation of the plate in all cases.

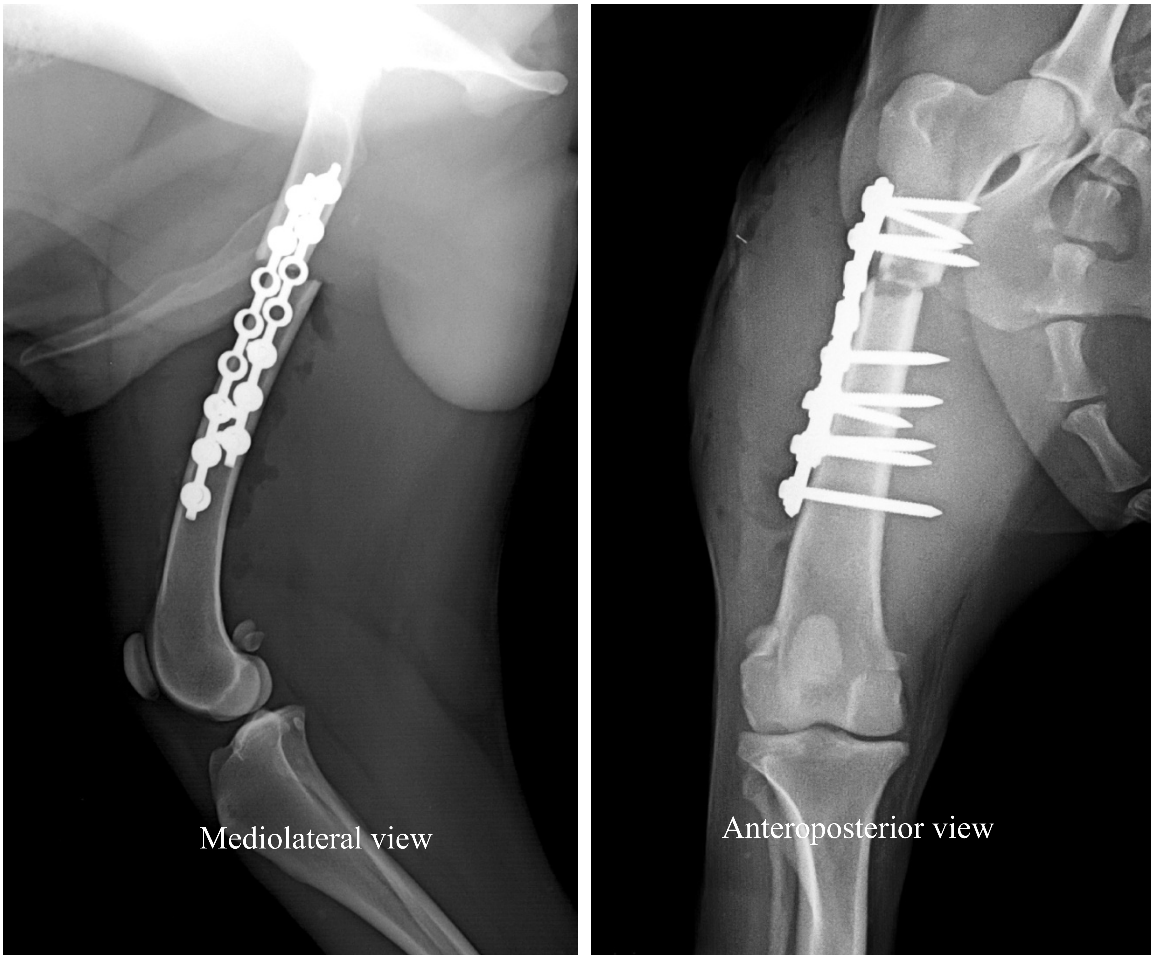

Fig. 21 – Immediate post-operative radiographs of SOP plate nesting in a dog

4.6.3 Closure of the Incision

Closure of the tensor fascia lata and application of a layer of subcuticular sutures using 2-0 polyglactin followed by closure of skin in a row of cruciate mattress sutures of polyamide resulted in uneventful healing of suture line in all the dogs.

4.7 POST-OPERATIVE OBSERVATIONS

Dressing the surgical wound with 5% povidone-iodine pads was found to be effective in keeping the site clean in all the dogs and application of Robert Jones bandage was found to be satisfactory for immobilization of the limb. The use of Ceftriaxone sodium effectively prevented post-operative infection. None of the dogs developed post-operative swelling. The surgical wounds healed well in all the dogs without any complications. The skin sutures were removed on the 12^{th} postoperative day in all the dogs (Fig. 22).

4.8 POST-OPERATIVE LAMNESS GRADING

All the dogs in present study showed partial weight bearing from the 1^{st} post-operative day. One dog achieved complete weight bearing by the 7^{th} post-operative day, four dogs by 15^{th} post-operative day and five dogs by 45^{th} post-operative day (Fig. 23 a, b, c). The mean lameness scores in animals was found to be 3.14 ± 0.14, 2.42 ± 0.29, 1.42 ± 0.20, 1.71 ± 0.35 and 1.28 ± 0.18 respectively by the end of 1^{st} day, 7^{th} day, 15^{th} day, 30^{th} day and 45^{th} day of surgery. The details of lameness grading are presented in Table 3.

Fig. 22 – Skin sutures removed on 12^{th} post-operative day

Fig. 23 a, b, c. Progressive weight bearing on different post-operative days

Table 3 – Post-operative Lameness Score in SOP plating for femoral fractures in dogs

Case No	Pre-operative	Post-operative weight bearing at the end of				
		Day 1	**Day 7**	**Day 15**	**Day 30**	**Day 45**
1	V	III	III	II	III	II
2	V	III	I	I	I	I
3	V	III	III	II	III	II
4	V	IV	III	II	II	I
5	V	III	III	I	I	I
6	V	III	II	I	I	I
7	V	III	III	I	I	I
Mean		3.14 ± 0.14	2.42 ± 0.29	1.42 ± 0.20	1.71 ± 0.35	1.28 ± 0.18

Grade I – Normal weight bearing on all limbs at rest and while walking.

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

Grade III – Partial weight bearing at rest and while at walking.

Grade IV – Partial weight bearing at rest; does not bear weight on affected limb while walking.

Grade V – Does not bear weight on limb at rest or while walking.

4.9 STABILITY OF IMPLANT

In the present study with 2.7 mm and 3.5 mm String of Pearls Locking plates (SOP) with locking screws produced rigid fixation and remarkable improvement with normal limb function. Good implant stability throughout the observation period without any complications was achieved in five dogs. In two dogs, plate breakage was observed at the fracture site by post-operative 30th day due to subsequent fall from height in both the dogs (Fig. 24 a and b). Revision of surgery was not performed due to owner's noncompliance. However, intermittent weight bearing was observed by 45th post-operative day in both the dogs.

4.10 POST-OPERATIVE RADIOGRAPHIC OBSERVATIONS

Immediate post-operative radiographic evaluation confirmed proper placement of the SOP plate and screws, good apposition and alignment of the fracture fragments in all the seven dogs (Fig. 25 a, b, c, d, e, f, g). Immobilization was considered satisfactory in all the cases. The plate length, size and position were appropriate in all cases. Screw length, size and position were considered appropriate in all cases. Sequential post-operative radiographs showed progressive bone healing. Post-operatively no screw loosening was observed in any of the cases.

Radiographs obtained on the 7th post-operative day revealed proper apposition and alignment of the fracture fragments in all the seven dogs. The radiolucent fracture line was observed.

Follow-up radiographs obtained on the 15th post-operative day depicted proper position and good alignment of the fracture fragments in all the dogs. The radiographs revealed good callus formation, bridging the fracture site in all the dogs. However the radiolucent fracture line was still discernible in all the cases.

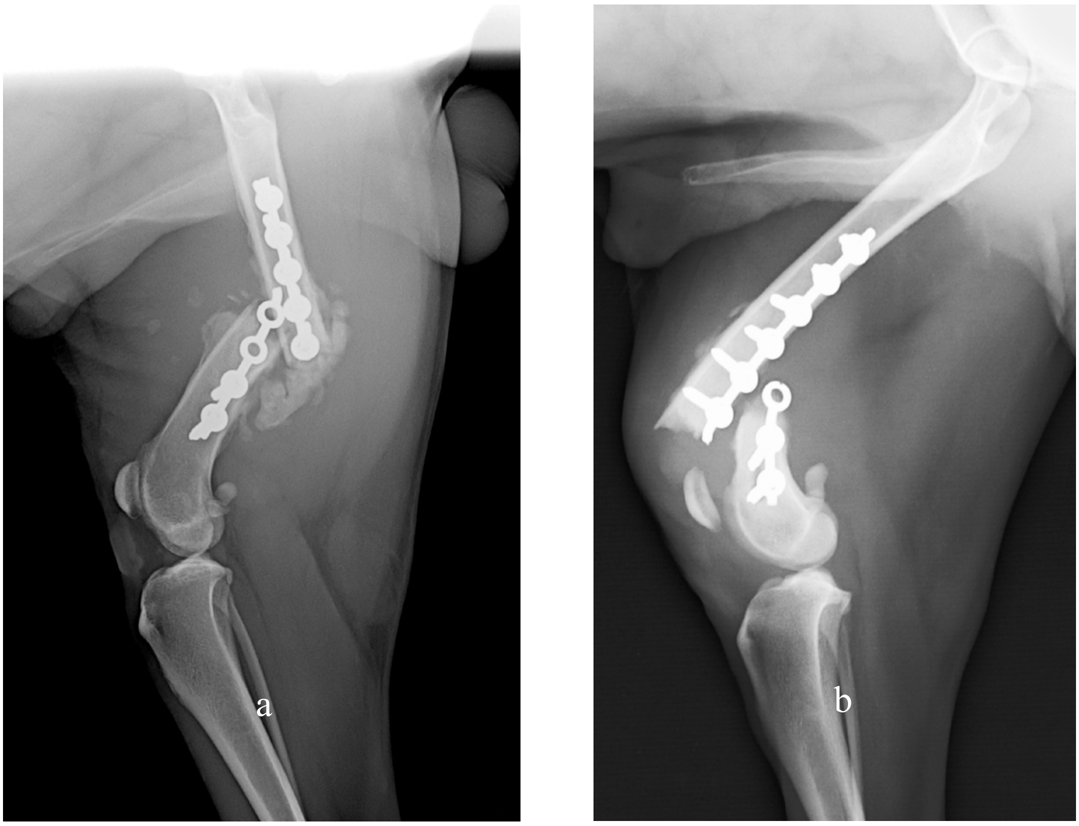

Fig. 24 a and b – Plate breakage in two dogs by 30th post-operative day

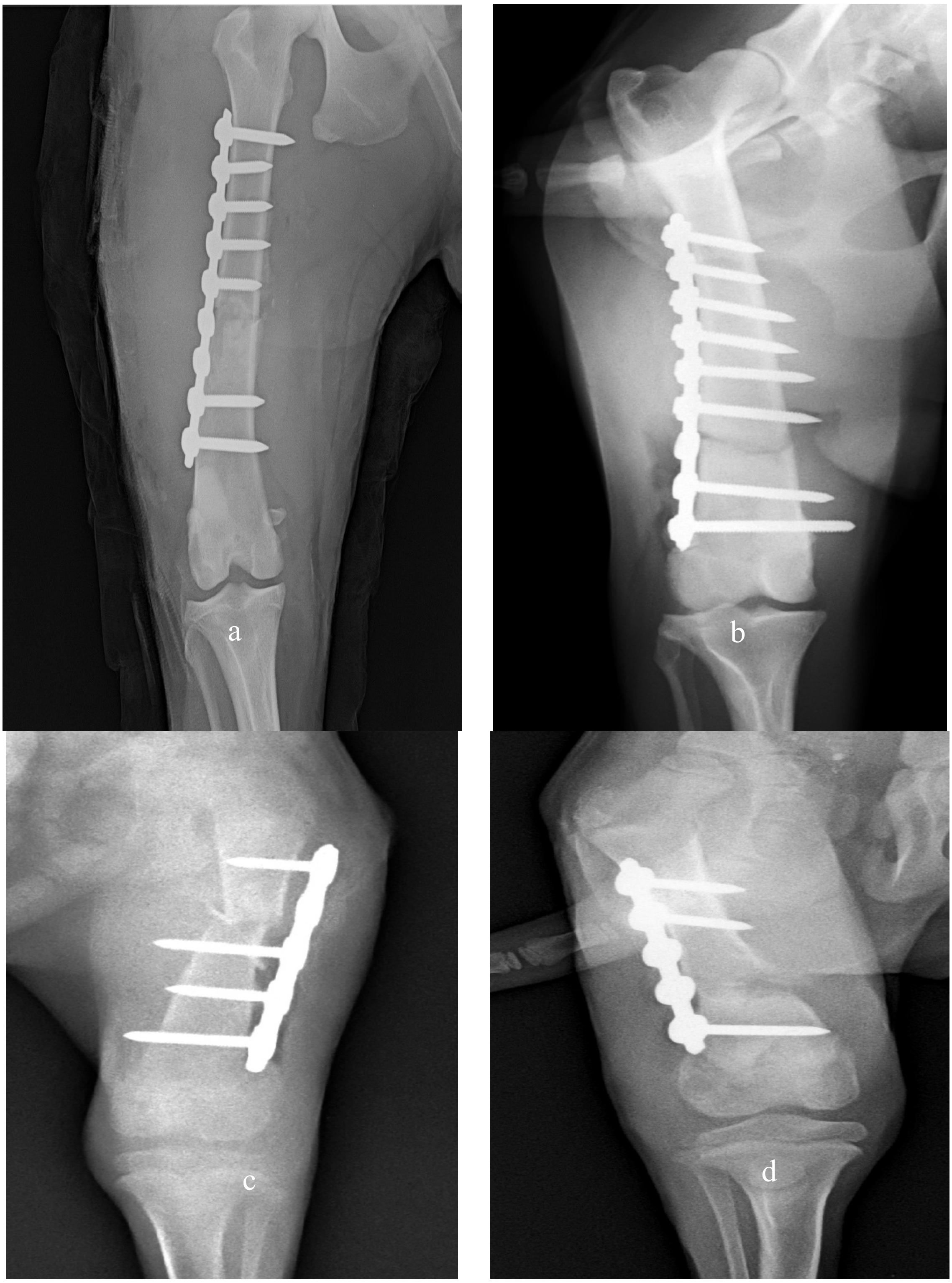

Fig. 25 a, b, c, d – Immediate Post-operative anteroposterior radiographs of the dogs with femoral fractures

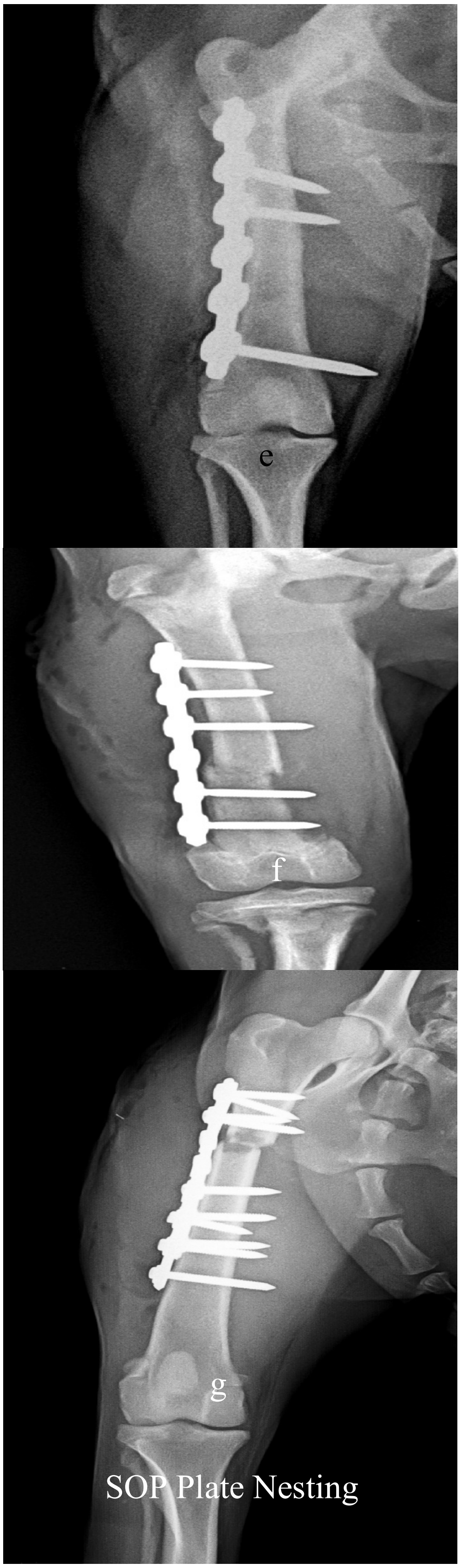

Fig. 25 e, f, g – Immediate Post-operative anteroposterior radiographs of the dogs with femoral fractures

Radiographs obtained on the 30^{th} post-operative day revealed bridging callus considerably reduced in size. In two dogs, radiographs revealed plate breakage at the fracture site. The callus was smoother and more opaque. The radiolucent fracture line was faintly visible.

On the 45^{th} post-operative day, the radiographs revealed, gradual obliteration of the bridging callus at the fracture area. Callus looked as opaque as the normal bone. The various stages of radiographic healing noted was depicted in Fig. 26.

4.11 HAEMATOLOGICAL OBSERVATIONS

The mean ± SE values of haematological parameters of haemoglobin, packed cell volume, total erythrocyte count, total leukocyte count and differential leukocyte count are presented in Table 4. Standard statistical analysis was done using one way ANOVA as described by Snedecor and Cochran (1994) using statistical package for the social sciences (SPSS) 15 software package.

4.11.1 Haemoglobin (g/dL)

The mean ± SE values of haemoglobin on day before surgery and on 15^{th} and 45^{th} day of surgery were found to be 8.98 ± 0.22, 10.27 ± 0.33 and 11.14 ± 0.24 g/dL respectively. Standard statistical analysis by one way ANOVA method revealed that there was significant difference ($P < 0.01$) among the three intervals. Highest value 11.14 ± 0.24 g/dL was observed at 45^{th} post-operative day, whereas the lowest value 8.98 ± 0.22 g/dL was observed on day before surgery.

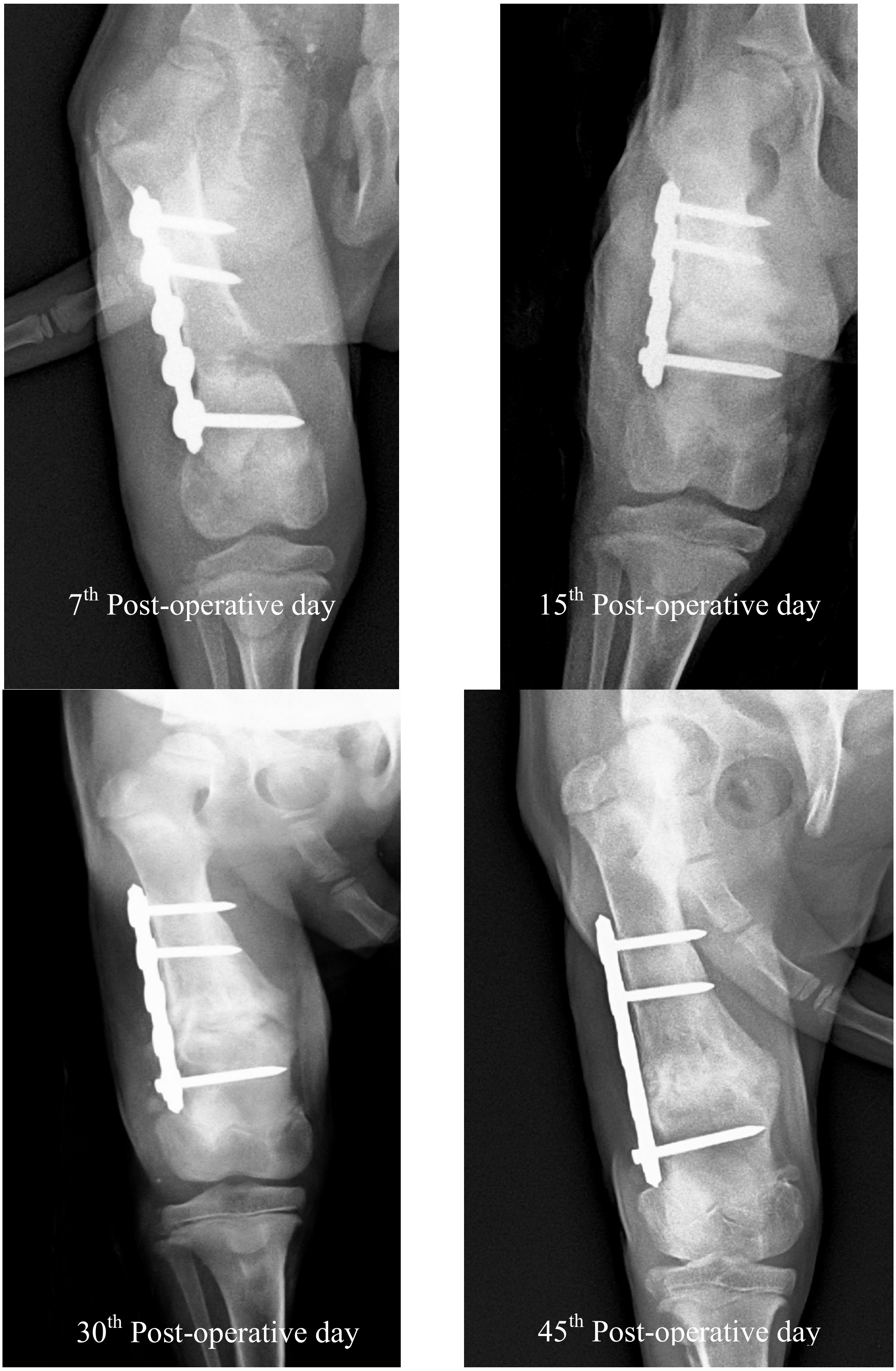

Fig. 26 - Progressive radiographic changes in a dog with femur fracture

Table 4 – Haematological Changes observed following SOP plating in dogs (Mean ± SE)

Parameter	Pre-operative	Post-operative	
	Day before surgery	15th day	45th day
Hb (g/dL)	$8.98^{a} \pm 0.22$	$10.27^{b} \pm 0.33$	$11.14^{c} \pm 0.24$
PCV (%)	$30.81^{a} \pm 0.85$	$37.44^{b} \pm 0.61$	$43.91^{c} \pm 0.23$
TEC ($\times 10^6$ /µL)	$5.01^{a} \pm 0.17$	$6.12^{b} \pm 0.09$	$7.09^{c} \pm 0.11$
TLC ($\times 10^3$ /µL)	$12.29^{a} \pm 0.19$	$11.65^{b} \pm 0.13$	$10.45^{c} \pm 0.14$
Neutrophils (cells/µL)	$9940^{a} \pm 0.53$	$8353^{b} \pm 0.11$	$7501^{c} \pm 0.56$
Lymphocytes (cells/µL)	$2267^{a} \pm 0.87$	$3230^{b} \pm 0.37$	$3815^{c} \pm 0.24$
Monocytes (cells/µL)	$261^{a} \pm 0.21$	$135^{b} \pm 0.83$	$85^{c} \pm 0.83$
Eosinophils (cells/µL)	$252^{a} \pm 0.51$	$151^{b} \pm 0.16$	$206^{c} \pm 0.45$

Means bearing different superscripts in the same row differ significantly ($P < 0.01$).

4.11.2 Packed Cell Volume (%)

The mean ± SE values of packed cell volume on day before surgery and on 15th and 45th day of surgery were found to be 30.81 ± 0.85, 37.44 ± 0.61 and 43.91 ± 0.23 % respectively. Significant difference ($P < 0.01$) was observed among the packed cell volumes between three intervals. Highest value of 43.91 ± 0.23 % was observed at 45th post-operative day, whereas the lowest value 30.81 ± 0.85 % was observed on day before surgery.

4.11.3 Total Erythrocyte Count (× 10^6 /µL)

The mean ± SE values of total erythrocyte count on day before surgery and on 15th and 45th day of surgery were found to be 5.01 ± 0.17, 6.12 ± 0.09 and 7.09 ± 0.11 × 10^6/µL respectively. Total erythrocyte count at the three intervals differed significantly ($P < 0.01$). Highest value of 7.09 ± 0.11 × 10^6/µL was observed at 45th post-operative day, whereas the lowest value 5.01 ± 0.17 × 10^6/µL was observed on day before surgery.

4.11.4 Total Leukocyte Count (× 10^3/µL)

The mean ± SE values of total leukocyte count on day before surgery and on 15th and 45th day of surgery were found to be 12.29 ± 0.19, 11.65 ± 0.13 and 10.45 ± 0.14 × 10^3/µL respectively. Total leukocyte count at the three intervals differed significantly ($P < 0.01$). Highest value of 12.29 ± 0.19 × 10^3/µL was observed on day before surgery, whereas the lowest value 10.45 ± 0.14 × 10^3/µL was observed on 45th post-operative day.

4.11.5 Neutrophil Count (cells/µL)

The mean ± SE values of neutrophil count on day before surgery and on 15th and 45th day of surgery were found to be 9940 ± 0.53, 8353 ± 0.11 and 7501 ± 0.56 cells

/µL respectively. Neutrophil count at the three intervals differed significantly ($P < 0.01$). Highest value of 9940 ± 0.53 cells/µL was observed on day before surgery, whereas the lowest value 7501 ± 0.56 cells /µL was observed on 45th post-operative day.

4.11.6 Lymphocyte Count (cells/µL)

The mean ± SE values of lymphocyte count on day before surgery and on 15th and 45th day of surgery were found to be 2267 ± 0.87, 3230 ± 0.37 and 3815 ± 0.24 cells /µL respectively. Neutrophil count at the three intervals differed significantly ($P < 0.01$). Highest value of 3815 ± 0.24 cells/µL was observed at 45th post-operative day, whereas the lowest value 2267 ± 0.87 was observed on day before surgery.

4.11.7 Monocyte Count (cells/µL)

The mean ± SE values of monocyte count on day before surgery and on 15th and 45th day of surgery were found to be 261 ± 0.21, 135 ± 0.83 and 85 ± 0.83 cells /µL respectively. Monocyte count at the three intervals differed significantly ($P < 0.01$). Highest value of 261 ± 0.21cells/µL was observed on day before surgery, whereas the lowest value 85 ± 0.83 cells /µL was observed on 45th post-operative day.

4.11.8 Eosinophil Count (cells/µL)

The mean ± SE values of eosinophil count on day before surgery and on 15th and 45th day of surgery were found to be 252 ± 0.51, 151 ± 0.16 and 206 ± 0.45 cells /µL respectively. Eosinophil count at the three intervals differed significantly ($P < 0.01$). Highest value of 252 ± 0.51 cells/µL was observed on day before surgery, whereas the lowest value 151 ± 0.16 cells /µL was observed on 15th post-operative day.

4.12 Serum Biochemical Observations

The mean ± SE values of serum biochemical parameters of serum alkaline phosphates, serum calcium and serum phosphorous are presented in Table. 5. Standard statistical analysis was done using one way ANOVA as described by Snedecor and Cochran (1994) using statistical package for the social sciences (SPSS) 15 software package.

4.12.1 Serum Alkaline Phosphatase (U/L)

The mean ± SE values of serum alkaline phosphatase on day before surgery and on 15^{th} and 45^{th} day of surgery were found to be 94.81 ± 0.47, 114.90 ± 0.33 and 81.50 ± 0.73 U/L respectively. Standard statistical analysis by one way ANOVA method revealed that there was significant difference ($P < 0.01$) among the three intervals. Highest value 114.90 ± 0.33 U/L was observed on 15^{th} post-operative day, whereas, the lowest value 81.50 ± 0.73 U/L was observed on 45^{th} post-operative day.

4.12.2 Serum Calcium (mg/dL)

The mean ± SE values of serum calcium on day before surgery and on 15^{th} and 45^{th} day of surgery were found to be 8.90 ± 0.14, 11.63 ± 0.30 and 10.35 ± 0.25 mg/dL respectively. Serum calcium levels differed significantly ($P < 0.01$) with the highest value 11.63 ± 0.30 mg/dL was observed on 15^{th} post-operative day.

4.12.3 Serum Phosphorous (mg/dL)

The mean ± SE values of serum phosphorous on day before surgery and on 15^{th} and 45^{th} day of surgery were found to be 5.02 ± 0.09, 5.18 ± 0.08 and 5.25 ± 0.11 mg/dL respectively. Statistical analysis revealed that there was no significant difference in serum phosphorous levels in three intervals. The serum phosphorous levels were within the normal range.

Table 5 – Serum Biochemical Changes observed following SOP plating in dogs (Mean ± SE)

Parameter	Pre-operative	Post-operative	
	Day before surgery	15^{th} day	45^{th} day
Alkaline Phosphatase (U/L)	$94.81^{a} \pm 0.47$	$114.90^{b} \pm 0.33$	$81.5^{c} \pm 0.73$
Calcium (mg/dL)	$8.90^{a} \pm 0.14$	$11.63^{b} \pm 0.30$	$10.35^{c} \pm 0.25$
Phosphorous (mg/dL)	5.02 ± 0.09	5.18 ± 0.08	5.25 ± 0.11

Means bearing different superscripts in the same row differ significantly (P < 0.01).

4.13 COMPLICATONS

In two dogs weighing above 10 kg, plate breakage at the fracture site was observed by 30th post-operative day, however intermittent weight bearing was noticed from 45th post-operative day in both the dogs. Since no other complications were clinically observed and since the owners also reported no discomfort in their pet dogs, these implants were left in place.

In none of the cases, implant removal was taken up since the owners were reluctant for the second surgery.

CHAPTER V

DISCUSSION

The goals of fracture treatment are to encourage healing, restore function of the affected bone and the soft tissue and to obtain a cosmetically acceptable appearance. Bone plates are ideal for accomplishing these goals because of their ability to restore rigid stability of the reconstructed bone when properly applied. Bone plates and screws offer a versatile method of fracture stabilization and can stabilize any long bone fracture. External coaptation methods, such as casts or splints are ineffective and contraindicated for repair of femur fractures in dogs due to anatomical orientation of the hind limb. Due to the disadvantages of intramedullary pins which include poor resistance to axial and rotational loads and external skeletal fixation technique which includes premature pin loosening, pin tract infections and pin breakage, plate osteosynthesis remains the treatment of choice for femoral fractures in dogs (Fossum, 2013). Bone plates when properly applied, effectively resist axial loading, bending and torsional forces acting on fractured bones. Bone plates like Dynamic Compression Plate (DCP), Limited Contact Dynamic Compression Plate (LC-DCP) and Locking Compression Plate (LCP) are commonly used in small animal practice for long bone fracture repair.

New plate designs like Unilock plate, Advanced Locking Plate System (ALPS), Fixin systems and String of Pearls Locking plates (SOP) have been introduced into small animal practice with several advantages over the other bone plates.

Among the currently developed locking bone plates, the SOP plate is a novel orthopaedic locking plate system designed for Veterinary and Human orthopaedic use to improve the biology of bone repair, mechanics of fracture stabilization and to decrease the rate of mechanical failure. As with all locking plate systems, the SOP can be thought of mechanically as internal-external fixator. The SOP consists of series of cylindrical sections (internodes) and spherical components (pearls). The cylindrical component, or internode, has an area moment of inertia greater than the corresponding DCP's. The SOP differs from other locking plate systems; in that the SOP can be contoured in six degrees of freedom; medial to lateral bending, cranial to caudal bending and torsion using specially designed bending irons without compromising the locking function. Properly performed, contouring results in bending or torsion at the internode, preserving the locking function of pearl absolutely. For securing the SOP plate to the bone, it should be ensured that screws are always directed perpendicular to the spherical component of the SOP and hence, it is essential that all planned screws engage the bone.

Search of the published literature revealed that there are only a few published studies on the clinical use of SOP Locking plate system for stabilization of femur fractures in dogs. Therefore, the present study entitled "Use of String of Pearls Locking Plate system for stabilization of femoral fractures in canines" was contemplated to study the clinical outcome of SOP locking plates for the treatment of femoral fractures in dogs.

5.1 ANAMNESIS

During the period of study a total of 68 cases of long bone fractures were recorded in dogs. Out of 68 cases, fractures involving femur were encountered in 32 cases. Unger *et al*. (1990), Johnson *et al*. (1994), Balagopalan *et al*. (1995), Aithal *et al*. (1999), Gahlod *et al*. (2004), Simon *et al*. (2010), Piermattei *et al*. (2016a) and Kallianpur *et al*. (2018) also stated that the femur was most commonly fractured bone than other long bones.

The results of present study showed the age of the dogs presented with the femoral fractures ranged from 4-48 months. Aithal *et al.* (1999) and Kumar *et al.* (2007) also stated that the fractures are common in young dogs because this age group is highly vulnerable to fractures. In the present study five dogs belonged to non-descript breed, one dog belonged to spitz breed and one dog belonged to Germen shepherd breed. This was due to more local population of non-descript breed dogs. The results of the present study are in conformity with the reports of Gahlod *et al.* (2004) and Simon *et al.* (2010). Four out of seven dogs were males indicating that fractures are more common in males than females. Similar findings were recorded by Aithal *et al.* (1999), Mohinder singh *et al.* (1999), Kumar *et al.* (2007) and Johnson (2013). The authors stated that this could be due to exploring nature of males with more curiosity to react to unfamiliar stimulus as compared to females. The body weight of dogs ranged from 4.5 kg to 27.2 kg with a mean body weight of 12.15 ± 3.25 kg.

Out of seven dogs the causes of fractures were found to be automobile accident in four dogs (57.15%), followed by fall from height in three dogs (42.85%). These findings are in accordance with Maala and Celo (1975), Phillips (1979), Aithal *et al.* (1999), Johnson (2013) and Piermattei *et al.* (2016a). The authors stated that fall from height and automobile accidents were major exciting causes of fractures in dogs. It was found in the present study that the dogs with fractures were presented for treatment between 2 to 6 days with a mean of 3.85 ± 0.5.

5.2 PRE-OPERATIVE OBSERVATIONS

In the present study, the clinical signs of fracture were noticed to be sudden onset of pain and lameness immediately after traumatic injury. The other symptoms included swelling, non-weight bearing and dangling of the limb and crepitation at the fracture on physical manipulation. Similar observations were recorded by Johnson (2013) and Piermattei *et al*. (2016a). All the fractures were closed fractures.

In the present study, the mediolateral and anteroposterior radiographs facilitated diagnosing the type of fracture encountered. Radiographs revealed transverse fractures in four dogs, short oblique fractures in two dogs and comminuted fracture in one dog. Langley-Hobbs (2003), Kumar *et al*. (2007) and Piermattei *et al*. (2016b) also recommended that at least two orthogonal views of the concerned bone and related joints should be obtained for proper treatment planning.

5.3 PATIENT PREPARATION, ANAESTHESIA AND POSITIONING

Atropine sulphate and xylazine hydrochloride as pre-anaesthetic medication, induction with ketamine hydrochloride and maintenance with propofol infusion was considered satisfactory. Pardeshi and Ranganath (2008) and Fattahian *et al*. (2011) also adapted similar anaesthetic protocol in their studies.

5.4 MATERIALS USED

In the present study, the use of String of Pearls Locking plates (SOP) provided good fracture stability. Kowaleski (2009) and Kraus and Ness (2014) studied biomechanical properties of SOP locking plate and stated that SOP plate can be contoured by twisting as well as bending in and out of plane with a maximum of 40 degrees between nodes which allows application of these plates to bones of any shape than conventional bone plates. Mills (2009) used SOP locking plates for stabilization of sacral and iliac fractures and Ness (2009b) used SOP locking plates for repair of Y-T humeral fractures after contouring the SOP plate. DeTora and Kraus (2008) studied the biomechanical properties of SOP locking plates, and stated that SOP locking plates were stiffer and stronger even after bending when compared to equivalent sized bent Locking Compression Plates (LCP) and Limited Contact Dynamic Compression Plates (LC-DCP). The authors further asseverated that SOP locking plates had a bending strength 16% and 30% greater than that of 3.5mm LCP and LC-DCP respectively. This asseveration was also supported by Ness (2009a), Blake *et al*. (2011), Cabassu *et al*. (2011), Malenfant and Sod (2014) and Benamou *et al*. (2015) who studied the biomechanical properties of SOP locking plates.

The application of SOP locking plates was found useful for stabilization of femoral fractures in dogs as the SOP plate could be contoured according to the shape of the bone. The contouring was done with help of SOP plate benders after addition of SOP bending tees or plugs into the pearls of plate which protected the functional integrity of pearls (Mills 2009, Ness 2009a, Scrimgeour and Worth 2011, Rutherford and Ness 2012, Kraus and Ness 2014, Malenfant and Sod 2014, Benamou *et al.* 2015, Grand 2016 and Kumar *et al.* 2018a).

In the present study, the SOP plate was contoured to match the topography of lateral surface of femur. This was done before application of plate to the bone. It was well ensured that, the most distal screws did not enter the physis or pattelofemoral or femerotibial joints. Fitzpatrick *et al*. (2012a) stated that the distal end of the plate was bent caudally and torqued in the supracondylar region to prevent interference with patellar motion and to ensure that the most distal screws were not directed into either the patellofemoral or femerotibial joints.

5.5 SURGICAL PROCEDURE

Craniolateral approach used for femoral fractures in the present study as suggested by Denny and Butterworth (2000), Johnson *et al*. (2005), Johnson (2013) and Piermattei and Johnson (2014) provided good access to the femoral diaphysis in all the seven dogs. In the present study, following reduction of the fracture, the SOP plate was applied on the lateral surface of femur and then secured using locking self-tapping screws. The same technique was reported by Fitzpatrick *et al.* (2012a). Since implant failure was observed in two dogs treated with 3.5 mm SOP plates each weighing 16.4 and 18.2 kg respectively, the seventh dog weighing 27.2 kg was taken up for study, in which two 3.5 mm SOP plates were nested side by side which enhanced the implant stability. Kraus and Ness (2014) also recommended that two SOP's can be nested side by side.

Kraus and Ness (2014) stated that a minimum of 4 screws should engage each segment to decrease the risk of failure. However Kowaleski (2009) stated that, with locking plates like SOP, efforts should be made to have 3 bicortical screws on either side of fracture. In the present study, 1-3 bicortical screws were employed in the distal segment according to the length of the fractured fragment which showed sufficient stability with good healing and complete weight bearing which is in agreement with the observations of Kim and Lewis (2014) and Kumar *et al.* (2018a).

In the present study, closure of tensor fascia lata in a simple continuous pattern using 2-0 polyglactin 910, subcuticular sutures using 2-0 polyglactin 910 and the skin incision with a row of cruciate mattress sutures using 2-0 polyamide resulted in uneventful healing of suture line.

5.6 POST-OPERATIVE OBSERVATIONS

In the present study, dressing the surgical wound with 5% povidone-iodine pads was found to be effective in keeping the site clean in all the dogs. Gorse (1998) opined that immediate post-operative care including bandaging of the limb and antibiotic administration for a week which ensured good outcome in orthopaedic surgery. Robert Jones bandage was applied for ten days after surgery for all the dogs in the present study as recommended by Tobias (1995) and Denny and Butterworth (2000a). In the present study, ceftriaxone was found satisfactory in preventing post-operative infection in all the dogs.

5.7 POST-OPERATIVE LAMENESS GRADING

Post-operatively, lameness grade showed gradual improvement to normal weight bearing over the period of study. The lameness grade was carried out in accordance with protocol developed by Vasseur *et al.* (1995). Lameness grading based on weight bearing was recorded in all animals pre-operatively showed grade V lameness before surgical stabilization of the fracture. Post-operatively, five dogs progressed to grade I lameness and two dogs progressed to grade II lameness by the end of 45th post-operative day.

5.8 STABILITY OF THE IMPLANT

In the present study, use of the String of Pearls locking plate (SOP) with locking screws showed remarkable improvement with normal limb function and maintaining good implant stability throughout the treatment period without any complications in five out of seven dogs. Similar findings were observed by Ness (2009b), Scrimgeour and Worth (2011), Kim and Lewis (2014), Sadan *et al.* (2015), Grand (2016) and Kumar *et al.* (2018a). However, in two dogs, plate breakage was observed adjacent to fracture line by 30th post-operative day with failure occurring through the internode between two screw holes. Fitzpatrick *et al.* (2012a) also reported plate breakage adjacent to fracture line in one dog which was stabilized with SOP Locking plate**.**

5.9 POST-OPERATIVE RADIOGRAPHIC OBSERVATIONS

Radiographic evaluation which was carried out on 1st, 7th, 15th, 30th and 45th post-operative days to assess the status and condition of fracture apposition and alignment showed good apposition of the fracture ends. Radiographic evaluation of fracture healing should be routinely performed at the time of expected clinical union. The mnemonic "AAAA" Alignment, Apposition, Apparatus, Activity, has proved useful for evaluation of such radiographs (Piermattei *et al.* 2016b). Henry (2007) also stated that postoperative imaging is essential for proper evaluation of the reduction and alignment of the fracture as well as placement of orthopaedic devices and at least two orthogonal views are required to interpret the location of bony structures and orthopaedic devices accurately.

Fracture healing is a process of bone regeneration. It is divided in to well documented stages: inflammatory, connective tissue and fibrocartilage formation (Aron, 1995). In the present study, all the fractures were healed by secondary bone healing with periosteal callus formation. Callus formation is the hallmark of secondary bone healing which occurs under conditions of stability of the implant-bone constructs (Claes *et al*. 1997). Radiographs obtained on the 7th post-operative day revealed proper apposition and alignment of the fracture fragments in all the six dogs. A radiolucent fracture line could still be discerned at this stage. On the 15th post-operative day, radiographic examination revealed good callus formation, bridging the fracture site with radiolucent fracture line still discernible. Radiographs obtained on the 30th post-operative day revealed a much smoother, smaller and opaque callus with faintly visible fracture line. In two dogs, plate breakage was observed adjacent to fracture line by 30th post-operative day with failure occurring through the internode between two screw holes. By the end of the 45th day, recheck radiographs showed, obliteration of the fracture line with the bony callus bridging the fractured area.

5.10 HAEMATOLOGICAL OBSERVATIONS

The Haemoglobin level and Packed cell volume on the 15th and 45th post-operative days were statistically higher when compared to day before surgery. The total erythrocyte count was significantly elevated on 45th post-operative day when compared to pre-operative day before surgery. This showed that progressive increase of haemoglobin, packed cell volume and total erythrocyte count on post-operative days indicating erythropoiesis. However, all the values were within the normal physiological limits throughout the course of the present study. This finding was in agreement with the findings of Singh *et al*. (2008). The total leukocyte count was higher on pre-operative day before surgery when compared to post-operative days. Physiological reduction in total leukocyte count was reported to be suggestive of gradual decrease in inflammatory reaction (Maiti *et al*. 1999). Leucocytosis occurred in conditions where there was corticosteroid release in state of stress, pain, anaesthesia, trauma and surgical manipulation.

The differential leukocyte count like neutrophil was significantly decreased on 15th and 45th post-operative days when compared to pre-operative day before surgery in all the cases. On the contrary, the lymphocyte count was statistically increased on 15th and 45th post-operative days when compared to pre-operative day before surgery. Neutropenia with relative lymphocytosis indicated gradual decrease of inflammatory reaction (Patil *et al*. 2017). The monocyte count was higher pre-operatively when compared to the post-operative observation period in all cases. However, it fluctuated within normal physiological limits. Also, eosinophil count between different post-operative days fluctuated within normal physiological limits. These findings were in agreement with the findings of Tembhurne *et al*. (2010) and Hansda *et al*. (2012).

5.11 SERUM BIOCHEMICAL OBSERVATIONS

The serum alkaline phosphatase values significantly increased from pre-operative day to 15th day indicating increased chondroblastic proliferation to cause bone formation during bone repair (Maiti *et al*. 1999). Increase in the serum alkaline phosphatase resulted from the periosteum of destructed bone which was a rich source of alkaline phosphatase. The findings were in concurrence with those of Singh *et al*. (1976), Guyton (1981), Rani and Ganesh (2003), Julie (2005), Hegade *et al*. (2007) and Mahendra *et al*. (2007). The serum alkaline phosphatase levels reached normal levels by the 45th post-operative day indicating quiescence at the fracture site.

The mean serum calcium values showed a significant rise on the 15th day followed by decrease in the value and reaching normal at 45 days of post-operative interval period. The serum calcium level in all the animals fluctuated within normal physiological range. This could be due to severe trauma associated with comminuted and unstable fractures. The present observations were in accordance with those of Bush (1991), Nagaraja *et al*. (2003) and Rani and Ganesh (2003).

The serum phosphorous mean values showed no significant variation post-operatively and the values were within the normal range. The present observations were in accordance with those of Singh *et al*. (1976), Chandy (2000) and Mahendra *et al*. (2007).

5.12 COMPLICATIONS

In the present study, in two dogs, plate breakage was observed adjacent to fracture line by 30th post-operative day. This was due to subsequent fall from height in both the dogs. However, intermittent weight bearing was observed by 45th post-operative day in both the dogs. Fitzpatrick *et al.* (2012a) also reported plate breakage adjacent to fracture line in one dog which was stabilized with SOP Locking plate. Since the owners of these two dogs were reluctant for corrective surgery and were unwilling for further examination at the end of the observation period, these dogs were lost to subsequent follow up.

5.13 CONCLUSIONS

Based on present study, it was concluded that String of Pearls Locking plates (SOP) was successful in the treatment of femoral fractures and offered good recompense and remarkable improvement in limb function in five out of seven dogs.

Although plate breakage was observed adjacent to fracture line by 30th post-operative day in two dogs, they showed intermittent weight bearing by the end of 45th post-operative day.

It was concluded from the results of the present study that SOP plates were found to be effective in treatment of femoral fractures since they are replete with features like their ability to lend themselves to contouring to any shape of bone, high bending strength and maintaining limited contact with bone. The implant used in this technique was light weight, versatile and economical making it amenable for use in veterinary practice. It was also felt that SOP plates, because of the features mentioned above, have a good potential for use in fractures of not only the long bones but also flat bones in dogs.

CHAPTER VI

SUMMARY

The present clinical study on fixation of femoral fractures using String of Pearls Locking plates (SOP) was conducted in seven dogs presented for treatment at Department of Surgery and Radiology at College of Veterinary Science Rajendranagar, Hyderabad. The cases were diagnosed by clinical examination and radiography.

The age of the seven dogs ranged from 4 - 48 months. Out of seven dogs, four were male and three were female. Among the seven dogs, five dogs belonged to non-descript breed, one dog belonged to spitz breed and one dog belonged to German shepherd. The body weight of the dogs ranged from 4.5 to 27.2 kg.

The symptoms observed in the dogs presented for treatment were pain on manipulation, abnormal angulation, and lameness immediately after traumatic injury, swelling, non-weight bearing and dangling of the limb and crepitation at the fracture site.

Pre-operative radiographic examination in orthogonal views i.e., anteroposterior and mediolateral radiographs revealed proximal diaphyseal fracture in two dogs, mid diaphyseal fractures in two dogs and distal diaphyseal fractures in three dogs. Pre-operative radiographs also showed the type of femoral fractures as transverse fracture in four dogs,

short oblique fracture in two dogs and comminuted diaphyseal fracture in one dog. All the seven dogs had closed fractures.

Out of seven dogs, four dogs were treated with 2.7 mm String of Pearls locking plates (SOP), two dogs with 3.5 mm String of Pearls locking plates (SOP) and in one dog two 3.5 mm SOP plates were used in nested configuration with compatible size of self-tapping locking screws. Selection of appropriate size of plate and screws according to body weight and type of fracture (2.7 mm plate for dogs weighing below 10 kg, 3.5 mm plate for dogs above 10 kg and 3.5 mm plate was used in nested configuration for dogs weighing more than 25 kg) provided good fracture stability. The length of the plates to be used was determined by the length of the bone as measured from the radiographs. The lengths of screws were determined by measuring the transcortical diameter of the bone at different regions from the anteroposterior radiographs obtained pre-operatively. Craniolateral approach used provided good exposure of the fracture site and enabled good fracture fixation.

Post-operative radiographs taken immediately after the surgery revealed satisfactory fracture reduction and good alignment of the fracture fragments in all the seven dogs. Follow-up radiographs taken on 7th, 15th, 30th and 45th post-operative days revealed secondary bone healing with periosteal callus formation. Slow obliteration of the fracture line with the bony callus bridging the fracture area was observed by the end of 45th post-operative day.

All the dogs which were diagnosed for femoral fractures showed grade V lameness before surgical management. Post-operatively, five dogs progressed to grade I lameness and two dogs progressed to grade II lameness by the end of 45th post-operative day.

Fracture fixation using 2.7 mm and 3.5 mm String of Pearls locking Plates (SOP) with locking screws resulted in remarkable improvement with normal limb function. Good implant stability throughout the treatment period without any complications could be achieved in five dogs. In two dogs, plate breakage was observed at the fracture site by 30th post-operative day. However, intermittent weight bearing was achieved by 45th post-operative day in both the dogs.

The Haemoglobin level and Packed cell volume on the 15th and 45th post-operative days were statistically higher when compared to pre-operative day before surgery. The total erythrocyte count was significantly elevated by the 45th post-operative day when compared to pre-operative day before surgery. The progressive increase of haemoglobin level, packed cell volume and total erythrocyte count post-operatively days indicated erythropoiesis. However, the values were within the normal range.

The total leukocyte count was higher on the day before surgery when compared to the post-operative period. Physiological leucocytopenia seen was suggestive of gradual decrease in inflammatory reaction. The differential leucocyte count like neutrophil was significantly decreased on 15th and 45th post-operative day when compared to the day before surgery in all the cases. Contrary to this, the lymphocyte count was statistically increased on 15th and 45th post-operative days. This indicated gradual decrease of inflammatory reaction. However, they were within normal physiological limits on different post-operative days in all the cases. The monocyte counts were higher on the pre-operative day when compared to post-operative days in all cases. However, it fluctuated within normal physiological limits. Also, eosinophil count between different post-operative days fluctuated within normal physiological limits.

The serum alkaline phosphatase and serum calcium values significantly increased from day before surgery to 15th day and thereafter reached to normal values by 45th post-operative day. The increased serum alkaline phosphatase levels during the first two weeks indicated increased chondroblastic proliferation to cause bone formation during fracture repair. The serum phosphorous values showed no significant variation and the values were within the normal range.

Based on present study, it was concluded that String of Pearls Locking plates (SOP) was successful in the treatment of femoral fractures and offered good recompense and remarkable improvement in limb function in five out of seven dogs. The application of SOP plates was found to be effective with features like being light in weight, versatile owing to its ability to contouring to any shape of bone, high bending strength and maintaining limited contact with bone. The implant used in this technique is economical, making it amenable to use in veterinary practice. In the opinion of the author, SOP locking plate has potential for application in other long and flat bones.

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