EVALUATION OF DIFFERENT LOCKING BONE PLATES FOR FRACTURE REPAIR IN GOATS

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CERTIFICATE

This is to certify that the thesis entitled **EVALUATION OF DIFFERENT LOCKING BONE PLATES FOR FRACTURE REPAIR IN GOATS** submitted by **Mr. DODDAMANI JAHANGIRBASHA,** I.D. No**. DVNK-1604** in partial fulfilment of the requirements for the award of **DOCTOR OF PHILOSOPHY** in **VETERINARY SURGERY AND RADIOLOGY** of the **KARNATAKA VETERINARY, ANIMAL AND FISHERIES SCIENCES UNIVERSITY, BIDAR** is a record of bonafide research work carried out by him during the period of his study in this University under my guidance and supervision, and the thesis has not previously formed the basis for the award of any degree, diploma, associationship, fellowship or other similar titles.

AUGUST, 2019

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Affectionately Dedicated to

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Bidar **DODDAMANI JAHANGIRBASHA**

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LIST OF ABBREVIATIONS AND SYMBOLS

Symbol	Description
%	Percentage
@	At the rate of
±	Plus, or Minus
<	Less than
>	Greater than
ºF	Degree Fahrenheit
dL	Decilitre
gm	Gram
Kg	Kilogram
mg	Milligram
ml	Millilitre
mm	Millimetre
No.	Number
Viz	Namely
SOP	String of pearls
LRP	Locking reconstruction plate
LCP	Locking Compression plate
SE	Standard Error
IU/L	International units/litre
et al.	Co-workers
/	Per
BID	Twice (two times) a day

Introduction

CHAPTER I

INTRODUCTION

Fractures have been described as the most common orthopaedic problem in goats (Singh and Nigam, 1981). People rear goats by letting them free for browsing in nearby grasslands and pastures, during which they meet with automobile accidents, attack by dogs and maliciously get hit by stones or sticks. Because of their curious and easily excited nature, they also attempt impossible jumps resulting in severe unpredictable forces on bone, leading to complex and comminuted fractures (Singh *et al*., 2006). The overall prognosis following fracture of the tibia in goats is generally good when appropriate treatment is applied.

Fractured tibia in goats have been immobilised more commonly using non-invasive external immobilisation techniques such as bandages, splints, plaster of Paris, fibreglass cast and various external fixation devices as these are economical and conservative in nature. However, these methods have various demerits like mal-union, delayed union and non-union (Singh *et al.,* 1984), large callus formation, weakening of tendons, muscle atrophy (Mbuiki and Byagagaire, 1984), delay in weight bearing, interference with radiographic evaluation, slippage of plasters, softening of plaster cast and wetting of cast due to faulty management which ultimately leads to increase in expenses because of reapplication.

The ultimate goal of the orthopaedic surgeon is to restore function through undisturbed bone healing, preserving the soft tissues, which allows safe and expeditious rehabilitation of the patient. Tan and Balogh, (2009) and Sirin *et al.* (2013) opined that biological osteosynthesis with bone plates is one of the most stable form of fracture fixation technique for veterinary orthopaedic surgeons. Bone plating improves the function of surrounding joints, decreases muscle atrophy by allowing early activity and provides an avenue for anatomic reduction of fracture, thus preventing “fracture disease” (Allgower and Speigel, 1979).

A refined understanding of bone healing biology, the role of tissue vascularity and gap strain and the biomechanics of fracture fixation in fracture healing has led to a significant evolution in plating techniques which has contributed to the development of the concept of bridging plate osteosynthesis and use of locked plate technology as opined by Gardner *et al.* (2004). Locked plates were developed in response to a need to adequately stabilize fractures where there was poor bone quality, mechanically weaker metaphyseal bone or bone affected by osteoporosis, osteomalacia or comminution where standard bicortical screws were unable to gain sufficient purchase for maintenance of the plate-bone relationship.

Locking plates function as “internal fixator” with multiple anchor points. They have a locking mechanism between the screw heads and the plate holes thereby producing a very sturdy mono-block effect, with all screws forcing at the same time. This interface creates a fixed angle, single beam construct which provides axial and angular stability, eliminates screw toggle (Egol *et al.*, 2004), increases their load carrying capacity, minimises the compressive forces between the bone and plate and avoids bone implant contact there by preserving the periosteal biology (Toro *et al.*, 2015). Since they cause less disruption of the soft tissues, do not exert pressure on the periosteal and endosteal blood supply, they do not hinder fracture healing. Hence early fracture healing is achieved indirectly by callus formation (Bhandari *et al.*, 2002; Gautier and Sommer, 2003; Wagner, 2003; Greiwe and Archdeacon, 2007 and Hoffmeier *et al.*, 2011). The secure feel of locked plates, ease of application, and the low incidence of complications noted in the early clinical reports have contributed to the proliferation of the locking plate technology.

The locking compression plate (LCP) features a uniquely designed combination hole that accepts standard bone screws as well as locking screws and allows the plate to be used as a conventional plate (compression), a locking plate (internal fixator principle) or as a combination of both principles. The LCP is a fixed angle construct that does not rely on friction at the plate-bone and screw-bone interfaces. Rather, the system relies on friction at the threaded screw-plate interface. The underside of the plate has scalloped undercut, which creates a uniform area moment of inertia to minimize stress concentration at the plate hole, as well as mitigate disruption of extra osseous blood supply. LCP brought the use of locking plate technology into routine fracture care (Frigg, 2001 and Kubiak *et al.*, 2006). For the first time in 1998, Prof. Dr. Micheal Wagner used threaded screws in combination with standard screws. Clinical use of LCP began in March 2000 and it was first used in Veterinary medicine in 2005.

The string of Pearls (SOP) is a newer, unique and versatile locking plate system developed specifically for veterinary use in 2006. The system was designed by a small group of veterinary surgeons and engineers to address the problems and limitations they had encountered using first-generation locking systems as reported by DeTora and Kraus (2008) and Ness (2009). The “plates” have a circular cross-section with a repeating pattern of series of cylindrical “internodes” and spheroid “pearls/ nodes” component. The holes in the spherical section of the plate have threads which correspond to those on the head of the screws. Each pearl is threaded in the base to accept a standard cortical bone screw, with a proximal aperture just wide enough to accept the screw’s head. The screw head impinges within the pearl, producing interference fit - a secondary lock between the plate and screw. As the screw is secured to the plate, it threads into the pearls to press fit into the spherical portion and thus allowing the screw to be properly torque while removing any compressive forces acting on the bone. As with all locking plate systems, the SOP can be thought of mechanically as an internal external fixator. Applying a SOP is similar to standard ORIF principles and procedures. The primary use of SOP is for communicated fractures where buttress or neutralization techniques are most appropriate.

The locking reconstruction plates are characterised by deep notches between the holes. These plates are very adaptable and are useful in complex anatomical sites (Colton and Orson 2013) and are especially useful to repair fractures of bones with complex 3-dimensional geometry. They are not as strong as compression plates and may be further weakened by heavy contouring.

Locked plating is a more recent technique available for fracture fixation. Locked plating technology has continued to progressively evolve since its introduction into fracture repair just over twenty years ago understanding the principles and limitations is essential to maximise its effectiveness. Research studies on comparison of different materials may improve the technique and help to adopt the most appropriate treatment, thus maximising benefits and minimising complications. A search of literature revealed dearth of literature regarding the evaluation of newer locking plates as internal fixator in goats; especially locking compression plate, locking string of pearls plate and locking reconstruction plate.

Hence, the present research work was undertaken with the following objectives.

1. To study the incidence of fracture in goats.
2. To evaluate the clinical efficacy of different locking bone plates for tibial fracture repair in goats based on clinical, radiological and biochemical observations.
3. To study the complications associated with different locking bone plates.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Research studies and clinical trials with different bone plates are often undertaken to evaluate their pros and cons and thus to design better methods for fracture fixation. Bone plating, when applied properly offers the most stable form of fixation of fractures by neutralising all the commonly acting forces on a fracture: compression; tension, shear, torsion and rotation. Over the years a variety of bone plates have evolved. Literature on comparison between the different locking plating techniques is scanty. Keeping in view of the above facts, the present study was under taken with the objective of comparing the efficacy of locking compression plate versus locking string of pearls plate and locking reconstruction plate for tibial fracture repair in goats. The available literatures are reviewed under the following headings.

1. Incidence of long bone fracture in goats
2. Pre-operative evaluation of tibial fracture
3. Bone-plating in goats
4. Bone plates under study
5. Physiological changes during fracture treatment
6. Post-operative evaluation of long bone fracture healing
7. Complications

2.1 Incidence of long bone fractures in goats

Singh and Nigam (1981) observed the incidence of fractures of long bones in sheep and goats to be as femur (32.0%) followed by tibia (21.7%) metacarpal (15.3%), phalanges (6.4%), humerus (5.1%), radius and ulna (3.8%) and pelvic bones (2.5%).

Singh *et al.* (1983) observed that fractures are more common in female goats than in males. A major proportion of fractures were recorded in the age group of one to three years. Hindlimbs were more often affected with a higher number of fractures involving femur and tibia.

Patil *et al*. (1991) reported that in goats hindlimbs were more commonly fractured. The frequency of tibial, metacarpal and metatarsal fractures was equal (23.2%). Most fractures involved shaft of bones and were either comminuted, oblique or transverse in nature.

Ganesh *et al.* (1994) stated that the incidence of fracture was higher in sheep and goats. They noticed that animals below one year of age were affected more.

Arora (1996) reported that the overall incidence of fractures in goats was 12.23%. Females (71.32%) and animals below one year of age (52.44%) sustained more fractures. Hindlimbs were found more often involved with a higher incidence in tibia (25.17%) and metacarpal (21.67%) bones. Most of the fractures were oblique (36.02%) or transverse (34.55%) or comminuted (18.24%) and diaphyseal in nature.

Philip *et al.* (1998) concluded that fractures were the most common orthopaedic problem in goats (11.2%). The incidence of fracture was more in males (55.7%) than in females (44.3%).

Aithal and Singh (1999) observed that road accidents and fall from height were the major causes for bovine and caprine fractures. They noticed that oblique fractures constituted the major proportion with femur sustaining highest number of fractures.

Virkar (1999) reported that fractures were more common in female goats than in males. The incidence was higher in animals below one year of age. Majority of the fractures (55.38%) were due to automobile accidents.

Kumar (2005) stated that long bone fractures were the most common musculoskeletal disorder in goats. Females sustained more fractures than male animals. Goats below one year of age were observed to have highest incidence of fractures. The forelimbs were more commonly affected with metacarpus being the commonly affected bone. Oblique and transverse fractures were the most common type.

Dandekar (2007) observed a higher incidence of fractures in goats below 1 year of age. He reported higher incidence of fractures in females (63.33%) than males (36.66%). He reported that fractures in hind limb (63.33%) were more than forelimb (36.66%) in goats.

Singh *et al*. (2008) recorded higher incidence of long bone fractures in female goats between one and three years and males below one year of age. Fractures were found more in hindlimbs (62.96%) than forelimbs. Metatarsal and metacarpal bones had the highest incidence of fractures, with transverse type being more common followed by oblique, multiple, epiphyseal, impacted and avulsion fractures. They suggested the fractures were mainly caused by trauma due to automobile accidents followed by fall from a height and external violence. They opined that the animals were hit from behind and therefore chance for hindlimb fracture was more.

Matthews (2009) reported that the most common cause of lameness in goat kids was trauma that led to fractures, bruises or sprain. The incidence was the highest for metacarpal followed by radius and ulna, then tibia and metatarsal bones.

According to Kushwaha *et al.* (2011) the major cause for fracture in goats was being hit by something, followed by fall from a height and external trauma and a higher incidence of fracture was recorded in goats below nine months of age. Most of the fractures were of closed type with higher incidence for midshaft fracture. This was followed by proximal and distal diaphyseal fractures with equal incidence rate. Regarding the type of fracture, higher incidence was recorded for oblique fractures.

According to Tambe *et al*. (2012) a retrospective study of fracture cases was done for past 10 years and found that 5.5% of the total presented fractures were of goats. A higher incidence of fracture was in female goats than in male goats. The incidence of fracture was 27.5% in tibia followed by radius and ulna, metatarsal and metacarpal bone. Midshaft diaphyseal fractures were more in goats. The majority of the animals were presented with the history of road accidents (51.5%), followed by other reasons like falling, dog bite and fighting.

Daron (2013) studied the incidence of long bone fractures in goats from 1995 -2013 in referral surgical hospital, Veterinary College, Bidar and found that the overall incidence of long bone fractures among all surgical problems in goats was 5.49%. Female goats were more commonly affected (68.1%) than males (31.9%). The incidence of fractures was most common in goats below 6 months of age (42.03%) followed by those of 6 months to one year (33.33%) and above one year (21.74%) of age. Majority of the animals had simple fractures (65%) of long bones. Hindlimbs were more involved (58%) than forelimbs. The most commonly affected bones were metatarsal (27.7%) and metacarpal (23.07%) followed by tibia (18.46%), femur (15.38%), humerus (7.7%) and radius- ulna (6.15%). Oblique fractures were more common (58%) than transverse type (40%). Majority of the long bone fractures in goats were maliciously induced (47.6%) or due to automobile accidents (32.3%). Dog bite and fall from height were the other reasons.

Gupta (2015) studied age wise distribution of fracture in goats and found that incidence of fracture was 50% in goats aged between six months to one year. Whereas, below six month and above one year it was 25%. Further the incidence of fracture was more in females compared to males. Highest incidence was found in tibial bones followed by humerus, radius ulna and femur.

2.2 Pre-operative evaluation of tibial fracture

2.2.1 Clinical signs and orthopaedic examination of tibial fractures in goats

Brinker *et al.* (1990) stated that pain, deformity or change in angulation, abnormal mobility, local swelling, loss of function and crepitus were the main symptoms to be noted in the clinical examination of fractures.

Kumar (2000) stated that the fracture could be diagnosed by pain at the site of fracture, dysfunction, local trauma, abnormal posture and crepitus and most of the cases have history of injury and sudden onset of symptoms.

Piermattei *et al.* (2006) described that in cases of fractures of the long bones, symptoms like swelling, dangling of the limb, non-weight bearing abnormal angulation of the limb at the fracture site and crepitation were generally apparent.

Singh *et al*. (2008) employed clinical signs such as swelling, pain, abnormal mobility, crepitation and dysfunction of the limb to evaluate long bone fractures in goats.

Smith and Sherman (2009) opined that long bone fractures in goats were usually identifiable by an acute onset of lameness and deviation of limbs, with or without palpable crepitus.

Venugopalan (2009) reported the major clinical signs exhibited by animals with fracture as loss of function of the affected limb, abnormal mobility at the fracture site, deformity due to displacement of fractured fragments, pain and crepitus on palpation. Affected animals deviated from their normal posture and position. Pain was usually absent in pathological fractures. Loss of function was mainly exhibited by inability of the animal to bear weight on the affected limb.

Reilly *et al*. (2012) remarked that the hallmark of long bone fractures in small ruminants was an acute non-weight bearing lameness. However, they suggested that a thorough clinical assessment for detection of instability and crepitation on palpation of the fracture site could rule out other causes of severe lameness such as septic arthritis and joint luxation.

2.2.2 Pre-operative radiological evaluation of fracture

Hickman (1957) opined that radiography was necessary to determine the exact site and type of fracture, the degree and extent of displacement of the segments. He suggested that radiographs taken in at least two planes gives an accurate picture of the injury, especially if closed reduction had to be adopted.

Hulse and Johnson (1997) stated that for adequate evaluation of affected bone, two radiographs are to be taken at 90-degree angle to each other. For evaluating fractures, radiographs of long bones must include the joints above and below the bone of interest.

Eisenberg and Johnson (2015) recommended at least two radiographic views at right angles to one another for proper evaluation of the status of a bone. Standard views for limb bones are cranio-caudal and medio-lateral. They opined that pre-operative radiographic examination helped to confirm the diagnosis of fracture, identify the bone involved, and understand the nature of fracture (number of fragments, direction of fracture line *etc*).

Guiot and Dejardin (2012) suggested that the goals of pre-operative imaging should include (1) identification of the nature, location and the extent of fracture; (2) determination of ideal mode of fixation; and (3) to allow templating and pre-selecting of the surgical implants.

2.3 Bone plating in goats

Singh *et al*. (1987) studied the efficacy of bone plate prepared from bovine horn for treatment of femoral fracture in goats and reported that it can be used successfully for immobilization of fracture segments without any sign of osteopenia and abnormal reaction. They concluded that horn plate was strong enough to hold fracture fragment in alignment till complete fracture healing without any adverse effect or reaction.

Shivaprakash and Singh (2003) evaluated bone plates made up of various materials such as nylon, teflon, stainless steel, horn and xenogenous bone for repair of femoral fracture in Black Bengal goats. Functional restoration of fractured limb in animals treated with nylon plates and stainless steel plates was much faster than the animals treated with other implant materials. They reported that steel plate resulted in less callus formation, whereas teflon plate resulted in excess callus due to slight movement at the fracture site. Nylon plate was comparable to stainless steel plate in terms of weight bearing and healing. Clinical union was observed in animals treated with nylon and stainless steel plates as early as day 35 and the animals were able to run without any evidence of lameness by day 60. The type of callus seen radiographically in animals of all the groups was 'external callus'. The reestablishment of medullary canal at the fracture site was seen as early as day 90 in animals treated with nylon and stainless steel plates

Da-cheng *et al.* (2010) compared limited contact-dynamic compression plates and locking plates in goats and recommended use of locking plate as it minimises impairment of blood supply to cortical bone due to significantly smaller bone contact area than LC-DCP, thus leading to early healing of fracture.

Gupta (2015) studied fracture healing using dynamic compression plate in goats and found it suitable for fracture of long bones. He recommended 2.7 mm system to be suitable for goats weighing less than 10 kg and 3.5 mm system for goats weighing between 10-20 kg. He observed that longer length of the implant provided more stable internal fixation in case of comminuted or multiple fractures.

Dharmendra (2016) studied fracture healing in goats using DCP for fracture repair in goats and found that complete weight bearing in goats started after 30 days.

Vinit (2017) evaluated fracture healing in goats using Veterinary cuttable plate and polypropylene mesh impregnated poly methyl methacrylate plate for long bone fracture repair in goats and opined that the Veterinary cuttable plate provided better stability at fracture site compared to polypropylene mesh impregnated PMMA plates.

2.4 Locking bone plates under study

2.4.1 Locking compression plating (LCP)

Frigg (2001) reported that locking compression plates were developed for the fracture fixation to overcome the lacunae observed in application of the conventional plating system. Locking compression plate has a combination hole that can accept both conventional screws and locking screws.

Bhandari *et al.* (2002) stated that the LCPs did not exert pressure on the periosteal blood flow and hence did not hinder the fracture healing and fracture haematoma.

Gautier and Sommer (2003) stated that when a LCP was used as an internal fixator, the exact adaptation of the implant to the bone surface was not mandatory because the load transfer occurred by locking. Once the fracture fragments were properly aligned, tightening of the screws into the conical threaded plate holes did not lead to a secondary displacement and hence no compression of the soft tissue in the plate-bone interface occurred. They stated that the angular stability provided by the locking screws mitigated the need for anatomic plate contouring and the limited plate-to-bone contact preserved the periosteal blood supply and reduced osteoporosis below the plate. Similar observations were made by Perren (2002) and Tong and Bavonratanavech (2007).

Wagner (2003) opined that the advantage of locking plates was the minimal contouring required for their application in comparison to standard plates. The locking plate acts as an internal fixator and therefore does not displace the fracture segments during locking screw tightening, regardless of the precision of contouring.

Egol *et al*. (2004) and Baroncelli *et al.* (2011) evaluated the clinical application of the LCP in treatment of the appendicular skeletal fractures in 25 dogs. They opined that it did not interfere with the biology of the fracture site, allowed buttress plate application and provided improved comfort to the patient in the post-operative period.

Niemeyer and Sudkamp (2006) opined that locking compression plate was a combination of two completely different anchoring technologies and two opposed principles of osteosynthesis. As a single implant, it combines the principles of conventional plate osteosynthesis for direct anatomical reduction with those of the bridging plate osteosynthesis.

Wagner and Frigg (2006) reported design and development of locking compression plate and its use in clinical cases as per AO/ASIF recommendations. The direction of combi hole is directed towards the centre of the plate. The combination hole allowed the insertion of either a conventional screw or a locking head screw with angular stability. The compression could be achieved by using conventional screws on non-locking plate holes and locking could be achieved by using locking screws on locking plate hole.

Ahmad *et al.* (2007) observed that when locking screw function was employed, the LCP functioned as an internal fixator and the plate need not be in contact with the cortical surface of the engaged bone segments in order to provide stable fixation.

Greiwe and Archdeacon (2007) reported that in the locking plate system secondary bone healing took place because the construct was less rigid than the conventional plate as it did not rely on the bone-to-bone stability. The lack of absolute stability did not impair early joint motion and rehabilitation. The bone to plate interface did not depend on the screw purchase in bone which was advantageous when the locking plate was used in osteopenic bone or highly comminuted fractures. Locking plates were designed to be single beam fixators which converted axial loads into a compression force rather than shear force as in conventional plating.

Miller and Goswami (2007) and Haaland *et al.* (2009) opined that the locking compression plate (LCP) is designed to limit the contact between the implant and the bone in order to minimise impairment of vascular supply to the bone. LCP did not press to the bone unlike the conventional plates and thus did not have to be contoured exactly to the bone. The LCP with combination holes can also be used, depending on the fracture situation, in either a conventional technique (compression principle), bridging technique (internal fixator principle), or a combination technique (compression and bridging principles).

Stoffel *et al*. (2007) reported that LCP have combination screw holes making it possible to use as a ‘‘locked system’’, a dynamic compression plate (DCP) system or a ‘‘combination’’ system. They compared these three systems and opined that the locking system results in less loss of reduction under axial compression with less plastic deformity and the DCP system provides better strength under torsion. The authors propose fixation using combination system.

Sengoz and Olcay (2008) reported that the LCP technology allowed the surgeon to use one implant system in different modes for the treatment of fractures having variable fracture type, bone quality and concurrent soft tissue trauma. They also reported that since the locking internal fixators depended on the screw purchase in bone, they were more advantageous in comminuted and osteoporotic fractures.

Haaland *et al.* (2009) treated 47 cases of appendicular fracture in dogs using the LCP system. The author used the implant in 3 different ways; as a pure internal fixator using locking head screws, as a conventional compression plate using compression screws and as a hybrid of the two. It was concluded that the LCP system in combination with a less invasive surgical approach was found advantageous in comminuted fractures where the LCP was used as a bridging plate, in situations where exact plate contouring was difficult and when other implants prevented the use of bi-cortical screws. LCP had several advantages as it allowed controlled flexibility of the fracture fragments to facilitate secondary bone healing with a callus. The plate did not compress to the bone and thereby not compressing the periosteal circulation as it was observed with a bone plate applied with conventional cortical screws.

Uhl *et al.* (2013) reported that the LCP enhanced the mechanical stability when compared to a non-locking plate. Stability was achieved by screws locking into the plate so that a fixed angle construct optimized the stress at the screw-bone interface. The LCP did not require a large area of contact between the plate and the bone to generate stability.

Dahlberg and Bruecker (2018) reported that the Synthes Locking Compression Plate (LCP) with its patented combination plate holes (combi-holes) was released in 2001 and could accommodate conventional or locking screws. As such, an LCP can be applied in two manners: as a compression plate or as a bridging “internal fixator” plate. Locking screws have a larger core diameter than conventional screws, allowing them to be stronger in bending and shear forces. Locking screws offer less risk of screw loosening than do conventional screws. Using only locking screws provides a buttress effect and produces no additional compression across a fracture. If using the plate as an internal fixator, precise contouring of the LCP is not required.

2.4.2 String of pearls (SOP) plate

Kraus and Ness (2007) reported good success following clinical application of SOP locking plates. The SOP plate 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.

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 opined that with locking plate systems such as SOP, efforts should be made to have three bicortical screws on either side of fracture.

Ness (2009) observed that the 3.5 SOP plate with screws was "taller". However, it was narrower than a comparable standard self-compressing plate and screws. He opined that, even in locations with minimal soft tissue coverage, this was rarely more than a minor cosmetic issue.

Klein *et al*. (2010) described the 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.

Cabassu *et al.* (2011) evaluated 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 and concluded that the SOP had the strongest (yield torque) and stiffest construct.

Miller *et al.* (2011) opined that, the greater holding strength imparted by locking nature of string of pearls (SOP) bone plate might prove advantageous in internal fixation of naturally occurring fractures involving thin cortical bone.

Fitzpatrick *et al.* (2012) reported that SOP was a locking plate which might reduce the risk of screw loosening and might help to distribute load evenly throughout the limited and poor-quality bone. The narrow inter-node design and locking screw design of SOP plate had an advantage of applying over neurovascular structures like supra scapular nerves without compression or hindrance of movement.

Manoj (2015) applied String of pearls (SOP) locking plates for management of distal femoral shaft fracture in dogs and opined that it could be applied satisfactorily and with good fracture stability.

2.4.3 Locking reconstruction plate

Lewis *et al*. (1993) used reconstruction plates to stabilize eight fractures involving supracondylar region in five dogs, two cats and a corrective osteotomy of the distal femur in one dog. All the fractures and the corrective osteotomy achieved clinical or radiographic union. Four animals had normal limb function and two animals had subtle lameness. The authors concluded that reconstruction plates were useful in dogs with chondrodystrophoid conformation, for animals with failed fixation and for animals with comminuted fractures. These plates were not useful to buttress large fracture gap because of the ductile properties of these plates.

Herford and Ellis (1998) used locking reconstruction bone plate/screw system for mandibular surgery in humans and concluded that the locking reconstruction plate was advantageous above the conventional bone plates as locking plate does not require to be compressed against the bone for stability while tightening the screws, the screw gets locked in the plate. This makes impractical for the screw insertion to alter the reduction. Other advantages of locking plate are that they do not disrupt the cortical blood supply below the plate. Loosening of screws from bone plate was questionable even if the screws were placed into the fracture gap. This attributed to decline in the incidence of inflammatory complication from loosening of the implant.

Lidbetter and Glyde (2000) and Glyde *et al.* (2003) reported that reconstruction plates were ideally suited for fractures of the distal femur because of their ability to be contoured in three planes especially in small and medium sized dogs, chondrodystrophic breeds and cats.

Harasen (2001) advocated the use of reconstruction plate for distal femur fractures, where conventional bone plates could not be used because of the anatomical peculiarities like caudal bowing, small distal fragment and high weight bearing region, as it was more malleable which allowed placement of one or two more screws in the distal fragment. The author further said that the bony column must be reconstructed to allow load sharing between the implant and bone.

Harasen (2002) stated that reconstruction plate was an alternative to the conventional bone plate especially for distal femur fracture repair which was more malleable and could be bent in three different planes due to the presence of notches between the screw holes.

Koch (2005) stated that the reconstruction plate provided a better contouring of the plate in an additional plane than the regular plates due to the presence of the deep notches between the holes. The strength of the plate got compromised when it was heavily contoured.

Tomlinson (2005) opined that supracondylar femur fractures, comminuted distal femur fractures and distal femur fractures in large dogs could be best stabilized with reconstruction plate. The reconstruction plate can be contoured to the caudal curvature of femur which allowed the distal placement of the plate and placement of additional screws.

Piermattei *et al*. (2006); Robertson *et al*. (2009) and Johnson (2013) opined that the traditional reconstruction plates designed with V-shaped grooves between the screw holes, to allow contour in three directions. However, these designs are less stiff and allow a better fit on more complex bony contours, or bones with irregular anatomic shapes and made it weaker when compared with DCPs of equivalent size.

Robertson *et al.* (2009) evaluated the biomechanical stability of locking and non locking reconstruction plates for treating midshaft, transverse fractures in human clavicle and concluded that locking reconstruction plate were significantly stiffer than the non locking reconstructive plates.

Cho *et al.* (2010) reported that reconstruction plates could be manipulated to fit the contour of the human clavicle and fracture pattern to obtain firm fixation, were lighter and thinner than dynamic compression plates and are durable to multidirectional mechanical stress imposed on the fracture site.

Harikrishna (2013) compared locking distal femoral head plate, locking L-plate and locking reconstructive plate for plate osteosynthesis of distal femoral fractures in dogs and opined that the locking reconstructive plate showed higher stiffness, yield load and ultimate load values compared to locking distal femoral head plate and locking L-plate.

Chandini (2018) comparatively evaluated locking reconstruction plate and locking compression plate and opined that locking reconstruction plate and locking compression plate were suitable for immobilization of long bone fractures in young and sub-adult dogs. Early ambulation with complete weight bearing could be obtained equally by both techniques. Locking plate did not require being intimate with the bone surface to provide stabilization as in conventional plate. Thus, it was found advantageous in preserving the periosteal layer during the study, which has an important role in fracture healing.

2.5 Physiological Changes

De'Souza (2012) recorded temperature, pulse rate and respiratory rate while evaluating fracture healing via internal fixation in dog. The author reported that there was an initial increase followed by decrease in these parameters.

Rajhans (2013) studied internal fixation in canine and recorded clinical parameters such as respiratory rate, pulse rate and temperature. The author reported non-significant decrease in temperature while non-significant increase in mean value of respiratory rate and pulse rate at different time intervals.

Gupta (2015) recorded respiratory rate, pulse rate and temperature during repair of fracture using dynamic compression plate in goats and reported that the value of these parameters fluctuated within normal range.

Singh (2015) recorded increase in rectal temperature pre and post-operatively at different time intervals. The author further discussed that increase in rectal temperature might be attributed to release of mediators of inflammation *viz.*, prostaglandins, bradykinins and interleukins followed by trauma and fracture. He also observed significant decrease in inflammation post-operatively as compared to 0-hour value.

Vinit (2017) recorded physiological parameters like respiratory rate, heart rate and rectal temperature on day 0, 15, 30 and 60 in both VCP and PMMA treated groups for fracture repair in goats and reported that there was decrease in the respiratory rate and heart rate on 15th day, 30th day and 60th day when compare to 0 day. The rectal temperature was fluctuated in normal physiological limits on all days of observation.

2.6 Fracture healing

2.6.1 Clinical evaluation of fracture healing

Boone *et al.* (1986) studied that the time of bone union varied with age of the animal and method of fixation. Healing time increased in mature animals and also increased as the stability of the fracture fixation increased.

Schwandt and Montavon (2005) reported a case of uneventful recovery with complete weight bearing on all 4 limbs after treating with LCP on both radius-ulna and tibia-fibula concomitant fractures in a dog.

Dharmendra (2016) studied fracture healing in goats using DCP as implant with various bone substitutes and found that complete weight bearing in goats was observed by 30th day onwards.

Vinit (2017) studied fracture healing in goats using Veterinary cuttable plate and polypropylene mesh impregnated poly methyl methacrylate plate and reported that the goats in both the groups showed weight bearing between 7^{th} to 30^{th} days.

2.6.2 Radiographic healing of fracture

Morgan (1972) described the radiographically visible periosteal callus as a faint hazy area developing adjacent to and directly overlapping the site of fracture. He opined that the callus formation was proportional to the rigidity of fracture fixation and suggested that fracture healing could be better studied clinically and radiographically.

Ackerman and Silverman (1978) advocated the use of radiography in the evaluation of fracture healing. They observed that fractures in young animals healed rapidly and that, the external callus formation was very minimal with rigid fixation techniques such as bone plating.

Chawla *et al.* (1983) radiographically evaluated tibial fracture healing in sheep and concluded that marked periosteal reaction and bigger callus were seen in fractures immobilized with external immobilization and intramedullary pinning than with bone plating.

Mukherjee and Sahay (1992) made clinico-radiographic evaluation of biological osteoinducers in the healing of compound metacarpal fractures in goats. They observed the obliteration of the fracture gap by osseous tissue in 4 weeks, with complete union and normal periosteal contour by 6 weeks.

Umarani and Ganesh (2002) evaluated the healing of mid shaft fracture of femur in goats by radiographical observations. They noticed a late periosteal reaction and callus with irregular borders in animals treated using Kuntschner nails. An early periosteal reaction and fusiform shaped smooth intense periosteal callus were observed with intramedullary pinning.

Langley-Hobbs (2003) suggested that the intervals at which follow-up radiographs were taken depends on the age of the patient, the severity of the fracture, the confidence of the clinician in the repair and the progress of the patient. According to him, radiograph would be taken every 2 to 3 weeks for immature animal and every 4 to 6 weeks for mature cases and that the follow-up radiographs would be evaluated both in isolation and in comparison, with the previous radiographs. He also found that immediate post-operative radiographic assessment was the 4 A's- apposition, alignment, angulations and apparatus and follow-up post-operative radiographic assessment was the 6 A's- apposition, alignment, angulations, apparatus, activity and architecture.

Reems *et al.* (2003) reported that the bridging callus was expected in 3 to 5 weeks in immature patients and 4 to 6 weeks in mature patients.

Griffen (2005) reported that unstable fractures healed by formation of intermediary callus prior to actual bone formation. Amount of callus formed depended on fracture stability. Less stable fractures had more callus formation. This was referred to indirect or secondary healing.

Pedrotii *et al.* (2006) proposed radiography as the most important technique among all for assessing healing of fracture in long bones. He consolidated the radiographic observations of a fracture at progressive stages of healing as appearance of demineralization and broadening of fracture line and shadow of fibrous callus in the first month, peripheral callus formation and little bone bridges in the second month and interfragmental trabecular bridging and complete mineralization in the third month.

Venugopalan (2009) reported that healing of fracture included four stages-haematoma formation, soft callus formation, primary bone callus formation and secondary bone callus formation. Within 24 hours of fracture a well-formed haematoma was formed. It took about one to two weeks for the complete formation of soft callus and less than four to eight weeks was taken for the formation of primary bone callus, which established clinical union between the fracture fragments. Primary bone callus was radiographically visible due to mineralization. Secondary bone callus or reconstruction of bone occurred from fourth to eighth week.

Da-cheng *et al.* (2010) studied interface contact profiles of a novel locking plate and its effect on fracture healing in goats. Radiographic studies at the fracture site revealed that the fracture line disappeared in the locking plate group on 8^{th} post-operative day.

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

2.6.3 Serum Biochemistry

2.6.3.1 Serum Alkaline phosphatase (SAP)

Robinson (1923) first reported the relation between the enzyme phosphatase and calcification of bone. He found that the enzyme hydrolysed phosphoric esters into phosphate ions, which trapped calcium to form osseous tissue at the fracture site.

Markowitz *et al*. (1959) remarked that the enzyme phosphatase decomposed the soluble salts of phosphoric esters into free phosphate ions, which trapped calcium resulting in calcium phosphate deposition on alkaline medium. They mentioned that the periosteum of bone contained a high amount of alkaline phosphatase.

Brinker (1965) noticed that alkaline phosphatase as being secreted by proliferating cartilage cells and osteoblasts. The level of the enzyme in fracture haematoma reached 6 to 8 times more than that in the serum. The excess enzyme persisted throughout the period of active growth of cartilage cells and osteoblasts.

Simensen (1970) observed that serum inorganic phosphorus level elevated immediately after fracture fixation and significant increased level was recorded on the 30^{th} post-operative day and which thereafter decreased to reach normal level on the 60^{th} post-operative day.

Guyton (1981) observed an increase in alkaline phosphatase activity during osteoblastic activity and the author also observed a high increase in alkaline phosphatase level in most of the compression methods of internal fixation.

Maiti *et al.* (1999) recorded a significant increase in serum alkaline phosphatase level from 5th post-operative day and reached its peak value at 15th day and thereafter a declining trend was noticed at the 60th post-operative day. However, it always remained significantly above the base line value. This increased alkaline phosphatase activity might be an indication of increased chondroblastic proliferation to cause bone formation during fracture repair.

Zama *et al*. (1999) observed a continuous increase in serum alkaline phosphatise levels throughout the period of fracture healing in goats treated with intramedullary pinning for femur fractures.

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. However, the serum alkaline phosphatase level showed a significant increase from the pre-operative day to 28th post-operative day.

Ghosh *et al.* (2003) observed an increase in serum alkaline phosphatase level from base value on 1st week, reaching peak on 3rd week, then declined towards normal level by 6th week post-operatively following repair of compound fractures with autogenous cancellous and homogenous decalcified bone chips in goats.

Komnenou *et al.* (2005) observed that within 10 days of fracture there was increase in the level of alkaline phosphatase and phosphorus to the peak level and followed by a gradual decrease. Whereas the serum calcium level decreased and reached to a minimum level by 10th day and subsequently it increased and returned to its initial level.

Hegade *et al.* (2007) reported that the serum alkaline phosphatase level was significantly higher on operative day than rest of the post-operative days in all the groups of after bone plating in dogs. This was associated with the osteogenic cells proliferation chiefly from the periosteum of fractured bone. Serum calcium and phosphorus values fluctuated within the normal physiological limit.

Mohamadnia *et al.* (2007) reported that bone alkaline phosphatase activity was significantly increased after surgery during bone formation.

Matthews (2009) published the normal reference serum biochemical values of alkaline phosphatase in goats was 0-300 IU/L. for determining the activity of the enzyme by reading the reaction and absorbance at 405nm.

Dias *et al.* (2010) evaluated serum alkaline phosphatase during fracture healing in goats and found an increase in these parameters between 2nd and 3rd week post-operatively, which reached peak between 3rd and 4th week and was followed by decrease reaching to base level at 12th week interval.

Joy (2013) reported an increase in the level of serum alkaline phosphatase by the 2nd week of fracture healing in goats and was considered as an indicator for the progress of bone healing.

Gupta (2015) studied biochemical parameters during fracture healing in goats and found significantly high individual variation in alkaline phosphatase during fracture healing at different time intervals.

Phaneendra *et al.* (2016) evaluated serum alkaline phosphatase on 0^{th}, 7^{th}, 14^{th}, 28^{th}, 45^{th} and 60^{th} post-operative day during fracture repair in dog. They recorded gradual increase in alkaline phosphatase upto 14^{th} day after surgery, followed by decrease with minimum value on 60^{th} post-operative day. They concluded that increase in serum alkaline phosphatase level was due to chondroblastic proliferation to cause bone formation during fractured bone repair with maximum contribution from the periosteum of destructed bone which is a rich source of serum alkaline phosphatase.

2.6.3.2 Serum Calcium (Ca)

Pandey and Udupa (1980) observed no significant change in the calcium level up to sixteenth day after tibial fractures immobilized by intramedullary nailing in dogs.

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

Komnenou *et al.* (2005) stated that the mean serum calcium concentration initially decreased and reached a minimum level on day 10 and subsequently the calcium concentration increased again and returned to initial values or higher.

Hegade *et al.* (2007) observed the rise in serum calcium level in all the post-operative periods of study i.e. on 15th day, 30th day, 45th day and 60th day in comparison to the operative day (0th day) however all the values were within normal physiological limit.

Dwivedi *et al.* (2009) reported non-significant changes in serum calcium, phosphorus and alkaline phosphatase during their observation period.

Venugopalan (2009) reported that during primary callus formation, there existed a variation in the pH from acidic to alkaline that favoured bone healing. During the initial stages, haematoma formation occurred which was acidic in nature. Also, the acid phosphatase enzyme released by osteoclasts favoured lowering of pH at the fracture site. Low pH led to mobilization of calcium from blood and bone to supersaturate the fracture site with calcium. However, the author reported that no appreciable variation could be detected in the level of calcium in blood during this stage. In later stages due to increased osteoblastic activity, alkaline phosphatase enzyme was released and facilitated calcium deposition in the area.

Daron (2013) reported that the serum calcium level increased from day 0 and attained maximum on day 30 in goats treated with fibre glass or plaster of paris as mode of external immobilization in goats. The levels declined thereafter and returned to normal by day 60.

2.6.3.3 Serum Phosphorus (P)

Pandey and Udupa (1980) recorded a significant rise in the serum phosphorus levels between 5 and 23 days after tibial fractures in dogs.

Singh and Nigam (1982) reported that there was no significant variation in levels of serum phosphorus during healing of metatarsal fractures in buffalo calves.

Kumar *et al.* (1999) evaluated biochemical changes in fracture repair in calves and observed a higher level of serum inorganic phosphorus up to day 60 of fracture healing.

Maiti *et al*. (1999) stated that serum phosphorus level showed an increase immediately after bone fixation in all animals and it remained slightly above normal level till the end of 60 days.

Umarani *et al.* (1999) reported that serum phosphorus levels increased significantly up to seventh post-operative day in goats treated with Steinmann pins and Kuntschner nails for midshaft fracture of femur.

Zama *et al*. (1999) observed that serum phosphorus level increased non-significantly during post-operative period in goats treated with intramedullary pinning for femur fractures.

Komnenou *et al*. (2005) stated that the mean serum concentration of serum phosphorus initially increased and reached a peak on day 10 and then decreased.

Hegade *et al.* (2007) observed that serum inorganic phosphorous levels were elevated in all the post-operative periods of study i.e. on 15^{th} day, 30^{th} day, 45^{th} day and 60^{th} day in comparison to the operative day (0^{th} day). However, all the values were within normal physiological limit.

Singh *et al*. (2008) observed that serum phosphorus concentration rose significantly up to day 15 of fracture healing and gradually declined to the normal by day 45 after application of plaster of paris and fibre glass for external immobilization of long bone fractures in goats.

Chandini (2018) evaluated biochemical parameters during fracture healing and observed that the serum calcium and serum phosphorus did not alter significantly; whereas serum alkaline phosphatase decreased during fracture healing.

2.7 Complications

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

Nunamaker (1985) stated that whenever internal fixation techniques (plates and screws) were used it was important to assess whether there was sufficient soft tissue to cover the wound on implant. He also opined that metals lowered local tissue resistance to infection and slowed bone healing.

Boone *et al*. (1986) opined that in addition to osteoblast, the periosteum and the bone marrow all contributed to bone repair and he recommended that the periosteum be protected during surgery as periosteal blood supply let to damage led to necrosis of the bone under the plate. They recommended the use of longer plates with fewer screws, which favoured faster healing with a mechanically strong callus.

Dudley *et al.* (1997) and Altunatmaz *et al.* (2007) opined that the early porosity observed underneath the plate was more likely the result of bone devascularisation and necrosis than the result of stress shielding. The porosity was therefore attributed to an intense bone remodelling following bone necrosis induced by cortical devascularisation.

Denny and Butterworth (2000) reported malunion, non-union of fracture ends, delayed union, fracture disease, fracture associated sarcoma, osteomyelitis and fat embolism as complications of fracture healing.

Bhandari *et al.* (2001) opined that plate/screw systems are rarely used in the management of open fractures because they can cause high rates of infection and other complications.

Schutz and Sudkamp (2003) observed that the orientation of the individual screws in locking plates is predetermined and cannot be changed. The reason for this is the angular-stable screw–plate connection, is achieved by an outer thread of the screw head and an inner thread of the plate hole and it does not permit a variable screw direction.

In a series of 169 fractures in 144 human patients treated with the LCP, Sommer *et al*. (2003) reported 27 complications (16.0% incidence), including 5 cases of implant loosening and 4 cases of implant breakage. The authors attributed these implant failures to intraoperative technical errors, including the use of plates that were too short and those that did not have adequate spanning segments (empty screw holes) over the fracture site.

Haidukewych (2004) observed that when tightening the screws, the surgeon has no tactile feedback as to the quality of screw purchase into the bone. Because the screws lock into the plate, all screws abruptly stop advancing when the threads are completely seated into the plate, regardless of bone quality. They also observed that the current locking plate designs can be used to maintain fracture reduction. Once a locked screw was placed above and below a fracture line, no further reduction adjustment was possible unless the screws were completely removed. They opined that the locked screws will not “pull” the plate down to bone.

Kowaleski (2009) opined that a concern with a locking plate system was bone slicing. They also observed that with locking screw systems the screws could not pullout, especially if there was some divergence or convergence of the screws. Instead, failure occurred through slow creep of the screw through the weak bone, known as “bone slicing”. Therefore, as locking plate systems are preferred in weak or osteoporotic bone, they may still exhibit this mode of failure if the bone/implant system used in not sufficiently robost.

Budsberg (2005) reported technical errors were the major reasons for the failure of implants used for fracture fixation. The most common mechanism that resulted in implant failure was ‘fatigue failure’ where the implant became unable to counteract the disruptive forces acting at the fracture site. It usually occurred few weeks after implant fixation, due to the repetitive loading stresses on account of increased weight bearing. According to the author a good implant has to counteract all the loading stresses acting on the bone till the healing process was complete.

Rovesti (2005) defined delayed union as a fracture that took longer time to heal than anticipated. Clinically it was diagnosed by the persistence of pain and non-usage of limb for a longer period after the occurrence of fracture. Radiographic appearance was often similar to normal healing with delayed appearance of callus with persistent fracture line.

Schwandt and Montavon (2005) reported a case of failure of locking compression plate stabilization on both radius and tibia concomitant fractures in a 6-month-old dog because of fixation breakdown.

Greiwe and Archdeacon (2007) opined that locking plates encourage secondary bone healing; therefore, recommended their use in cases of low strain motion and non-anatomic reduction.

Freeman *et al*. (2010) opined that the locking plates could inhibit the formation of fracture callus in secondary bone healing. Non-union rates as high as 19% have been reported with some periarticular locking plates. They also noted a paucity of callus formation on the lateral side of the femur near the plate where interfragmentary motion was most inhibited.

Cronier *et al.* (2010) and Scolaro and Ahn (2011) recommended to avoid an overly stiff construct in locking plates, because a lack of motion at the fracture site may prevent bone healing. They opined that some motion was desirable in order to stimulate secondary callus formation.

Fitzpatrick *et al.* (2012) 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.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The present study was conducted in two phases. In phase I, incidence of long bone fractures in goats was studied. In phase II, study was carried out on the clinical cases of goats to compare different locking bone plates for tibial fracture repair.

3.1 Phase I

3.1.1 Study of incidence of tibial fracture in goats

Incidence of long bone fractures in goats was evaluated by analysing the data of clinical cases of the last twelve years (2007 - 2018) presented to Veterinary College, Bidar. The incidence was studied in relation to the age and sex of the animal and type of fracture of long bones in goats.

3.2 Phase II

3.2.1 Clinical study

The study was conducted on 18 clinical cases of goats with tibial fracture presented to the Department of Veterinary Surgery and Radiology, Veterinary College, Bidar. The cases were randomly divided into 3 groups with 6 goats in each group. Diagnosis of tibial fracture was made based on clinical and radiographic examination. Three different techniques of open reduction and internal fixation using different locking bone plates (Table 1) applied as an “internal fixator” were evaluated with an objective to accomplish fracture repair for an early functional weight bearing. In group I, goats suffering from tibial fractures were treated using locking Compression plate (LCP). In group II, tibial fractures were treated using string of pearls (SOP) plate. In group III, tibial fractures were treated using locking reconstruction plate. The signalment of animals included in the clinical study and details of fractures are given in Table 2.

Table 1: Design of technical programme of clinical study

Sl. No.	Group	No. of Goats	Bone plate used for tibial fracture repair
01	I	06	3.5 mm Locking compression plate
02	II	06	3.5 mm Locking string of pearls plate
03	III	06	3.5 mm Locking reconstruction plate

3.2.1.1 History collection

The details regarding the age, sex, breed, chief complaint, the duration and manner of onset of clinical signs were recorded.

3.2.1.2 Clinical examination

The goats presented with fractures of tibia were first examined routinely and soft tissue injuries, if any, were attended to. Clinical signs (Plate 1) in relation to weight bearing, deformity of limb, site and type of fracture, pain and crepitation at the fracture site, signs of local swelling, infection and exudates from the fracture site were recorded.

3.2.1.3 Physiological parameters

3.2.1.3.1 Rectal temperature (°F)

Rectal temperature (°F) was recorded in all the animals of all the groups on day 0, 7, 15, 30, 60 and 120.

Table 2: Case details of the animals studied in phase II

(Group I - LCP)

Case No.	Age (m)	Sex	Body weight	Tibia affected	Etiology	Time since fracture	Type of fracture			Unger classification
LCP - 1	24 m	F	22kg	Left	Fall from building	One day	Simple	Mid-diaphyseal	Comminuted	42-B2
LCP - 2	7 m	F	10 kg	Left	Fall from bike	One day	Simple	Mid-diaphyseal	Comminuted	42-B1
LCP - 3	60 m	M	24 kg	Right	Infighting with buffalo	Three days	Simple	Distal diaphyseal	Oblique	42-A1
LCP - 4	8 m	M	12 kg	Left	Hit injury	One day	Simple	Mid-diaphyseal	Oblique	42-A2
LCP - 5	16 m	M	15 kg	Right	Automobile accident	One day	Simple	Mid-diaphyseal	Transverse	42-A1
LCP - 6	16 m	M	20 kg	Left	Automobile accident	One day	Simple	Mid-diaphyseal	Oblique	42-A2

Table 2 continued

(Group II - SOP)

Case No.	Age (m)	Sex	Body weight	Tibia affected	Etiology	Time since fracture	Type of fracture			Unger classification
SOP - 1	14 m	F	16 kg	Left	Fall in well	One day	Simple	Mid-diaphyseal	Oblique	42-A2
SOP - 2	18 m	F	22 kg	Left	Automobile accident	One day	Compound	Mid-diaphyseal	Oblique	42-A1
SOP - 3	22 m	F	25 kg	Right	Fall from wall	One day	Simple	Mid-diaphyseal	Oblique	42-A2
SOP - 4	12 m	M	15 kg	Left	Fall from wall	Five days	Simple	Mid-diaphyseal	Transverse	42-A1
SOP - 5	18 m	M	20 kg	Left	Automobile accident	One day	Compound	Mid-diaphyseal	Comminuted	42-C3
SOP - 6	18 m	F	15 kg	Right	Automobile accident	One day	Simple	Mid-diaphyseal	Transverse	42-A1

Table 2 continued

(Group III - Recon)

Case No.	Age (m)	Sex	Body weight	Tibia affected	Etiology	Time since fracture	Type of fracture			Unger classification
LRP - 1	7 m	M	10 kg	Left	Hit injury	Three days	Simple	Mid-diaphyseal	Transverse	42-A1
LRP - 2	13 m	F	14 kg	Left	Automobile accident	One day	Simple	Proximal diaphyseal	Oblique	42-A2
LRP - 3	9 m	M	12 kg	Right	Automobile accident	Two days	Simple	Distal-diaphyseal	Comminuted	42-C1
LRP – 4	13 m	M	15 kg	Left	Hit injury	Five days	Simple	Mid-diaphyseal	Transverse	42-A3
LRP - 5	11 m	M	13 kg	Right	Fall from building	One day	Simple	Mid-diaphyseal	Oblique	42-A3
LRP – 6	14 m	F	14 kg	Right	Hit injury	Two days	Simple	Mid-diaphyseal	Oblique	42-A2

Plate 1: Pre-operative presentation of goats with tibial fracture in all the groups

A) Pre-operative presentation of a female goat, 24 months (Case No. 1) of group I with left tibial fracture

B) Pre-operative presentation of a male goat, 60 months (Case No. 3) of group I with right tibial fracture

C) Pre-operative presentation of a female goat, 18 months (Case No. 2) of group II with left tibial fracture

D) Pre-operative presentation of a male goat, 18 months (Case No. 5) of group II with left tibial fracture

E) Pre-operative presentation of a male goat, 9 months (Case No. 3) of group III with right tibial fracture

F) Pre-operative presentation of a male goat, 11 months (Case No. 5) of group III with right tibial fracture

Group 1: Case 1

Group I: Case 3

Group II: Case 2

Group II: Case 5

Group III: Case 3

Group III: Case 5

Plate 1: Pre-operative presentation of goats with tibial fracture in all the groups

3.2.1.3.2 Heart rate (beats/minute)

Heart rate (beats per minute) was recorded in all the animals of all the groups on day 0, 7, 15, 30, 60 and 120.

3. 2.1.3.3 Respiratory rate (breaths/minute)

Respiratory rate (breaths per minute) was recorded in all the animals of all the groups on day 0, 7, 15, 30, 60 and 120.

3.2.1.4 Lameness Grade

A lameness grade was assigned in all the cases during pre-operative period based on the weight bearing nature during stance and while walking. Lameness was graded as recommended by Vasseur *et al.* (1995) as indicated in Table 3 as follows.

Table 3: Grading of lameness as recommended by Vasseur *et al.* (1995)

Lameness Grade	**Attribute**
I	Normal weight bearing on all limbs at rest and while walking
II	Normal weight bearing at rest, favours affected limb while walking
III	Partial weight bearing at rest and while walking
IV	Partial weight bearing at rest. Does not bear weight on affected limb while walking
V	Does not bear weight on limb at rest or while walking

3.2.1.5 Radiographic examination

Following initial clinical assessment, the fractured tibia was subjected to pre-operative radiographic examination in two orthogonal views (medio-lateral and cranio-caudal) including the stifle joint and hock joint (Plate 2 and 3). The fracture was classified based on the method recommended by Unger *et al.* (1990).

3.3 Patient Preparation and Anaesthesia

3.3.1 Materials Used

The requisite instrumentation, including a standard surgical pack, 3.5 mm stainless steel (316 LVM) locking bone plates under study along with 3.5 mm self-tapping locking screws (Plate 4) and locking drill guide, 2.7 mm drill bit, depth gauge, 3.2 mm bone tap and 3.5 mm hexagonal screw driver (Plate 5) were sterilized.

3.3.2 Pre-operative Patient Preparation

After initial evaluation of the patient the fractures were stabilized externally with bamboo splints until open reduction and internal fixation of bone plate was to be performed. The animals were fasted by withholding the food for 12 hours and water for 6 hours prior to surgery. Pre-operatively the affected limb was shaved and aseptically prepared using the standard pre-operative planning guide developed by the AO/ASIF group, taking care to include the upper and lower joints. Serum was collected for biochemical studies. A broad-spectrum antibiotic (inj. amoxicillin + cloxacillin[1] @ 10 mg/kg body weight) and an analgesic and anti-inflammatory drug (inj. meloxicam[2] @ 0.3 mg/kg body weight) was administered intra muscularly in all the animals of all the three groups. The animals were restrained in lateral recumbency with the affected limb placed below.

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[1] Injection Moxel, Alembic Ltd., Vadodra, Gujarat.
[2] Injection Melonex, Intas Pharmaceuticals., Ahmedabad, Gujarat

Group I: Case 6 **Group II: Case.5**

Plate 2: Pre-operative medio-lateral (A) and cranio-caudal (B) views of radiographs showing location and type of tibial fracture in goats

Plate 3: Medio-lateral (A) and cranio-caudal (B) views of radiographs showing pre-operative measurements of bone size for determination of bone plates and screw sizes

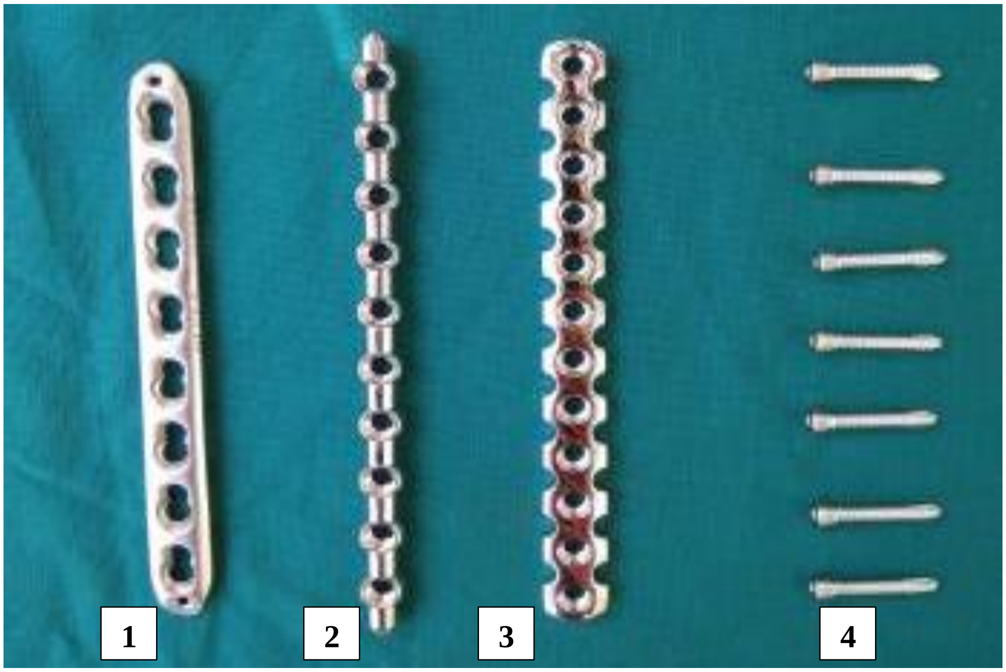

Plate 4: Locking bone plates under study:

1) Locking compression plate
2) Locking string of pearls plate
3) Locking reconstruction plate
4) Self-tapping locking head screws used for study

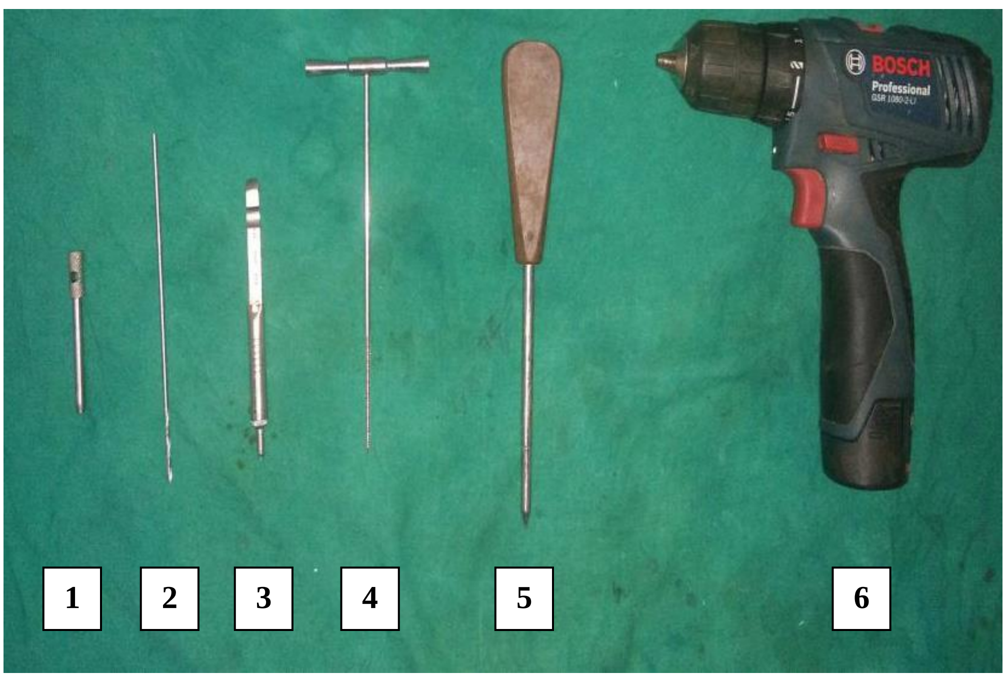

Plate 5: Orthopaedic set: 1) 3.5 mm locking drill guide, 2) 2.7mm drill bit, 3) Depth gauge, 4) 3.2mm bone tap, 5) 3.5 mm hexagonal screw driver, 6) Battery operated bone drilling machine

The operative site was scrubbed using povidone iodine surgical scrub[3], followed by application of surgical spirit[4]. The distal extremity of the limb was bandaged using sterile roll bandages and the entire operative site was covered with sterile drapes.

3.3.3 Anaesthesia

The surgery was performed under general anaesthesia using inj. xylazine hydrochloride[5] @ 0.1mg/kg b.wt. i/v for pre-anaesthesia immediately followed by inj. ketamine hydrochloride[6] @ 4mg/kg b.wt. i/v for induction. Additional anaesthetic maintenance was done using inj. ketamine hydrochloride @ 1 mg/ kg b.wt. i/v.

3.5 Surgical Procedure

A medial approach was used to repair fractures of tibia. An incision was made on the cranio-medial aspect of the leg region from the fracture site proximally towards the stifle and distally towards the hock. After incision on skin and fascia, the muscles were exposed. The bellies of tibialis anterior and flexor digitorum plofundis muscles were retracted cranially and caudally respectively to expose the fracture site. The fracture segments were identified and brought in apposition with each other. After satisfactory fracture reduction and limb alignment, the locking bone plates as per the grouping were applied along the medial surface of the tibia following AO/ASIF principles for plate fixation. A locking drill sleeve was inserted and locked in the hole immediately distal/proximal to the fracture site, followed by drilling of the hole using a low rotation

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[3] Betadine Surgical Scrub- Win-Medicare Pvt. Ltd., New Delhi
[4] Surgical spirit, Abbot Health Care Ltd., Hyderabad
[5] Injection Xylaxin, Indian Immunologicals Ltd., Gachibowli, Hyderabad
[6] Injection Aniket, Neon Laboratories Ltd., Mumbai, Maharashtra

battery operated drilling machine connected to a 2.7mm drill bit in order to perpendicularly drill the hole for screw insertion without any deviation of angulations. During the drilling procedure the drilling site was irrigated using normal saline solution. Both the bone cortexes were tapped using bone tap of 3.2 mm. The depth of the bone along with the bone plate was measured using depth gauze for selection of a screw of an appropriate length.

Self-tapping locking cortical screws (3.5 mm) were inserted and were locked at locking hole of the bone plates using a 3.5 mm hexagonal screw driver. Similar procedure was followed alternatively to the hole closer to the fractured site in the proximal/distal fragment until the last and the first hole of the plate. In order to pre-dynamize the fracture site, one to three screw holes at the fracture site were left unpurchased. A minimum of three screws in the proximal and three screws in the distal fragment were inserted. Finally, all the screws were tightened on the proximal and distal fragments alternately to provide a rigid fixation of the bone plate to the fractured bone. Similar procedure was performed for all cases of tibial fractures.

The muscles were sutured using with simple interrupted pattern using poliglecaprone[7] No. 1 suture material followed by the closure of the incisional wound on the skin with vertical mattress suture pattern using prolene[8] No. 2 (Plate 8).

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[7] Monoglyde, monofilament poliglecaprone, synthetic absorbable surgical suture, Sutures India Pvt Ltd, Bengaluru.

[8] Prolene, Sutures India Pvt Ltd, Bengaluru.

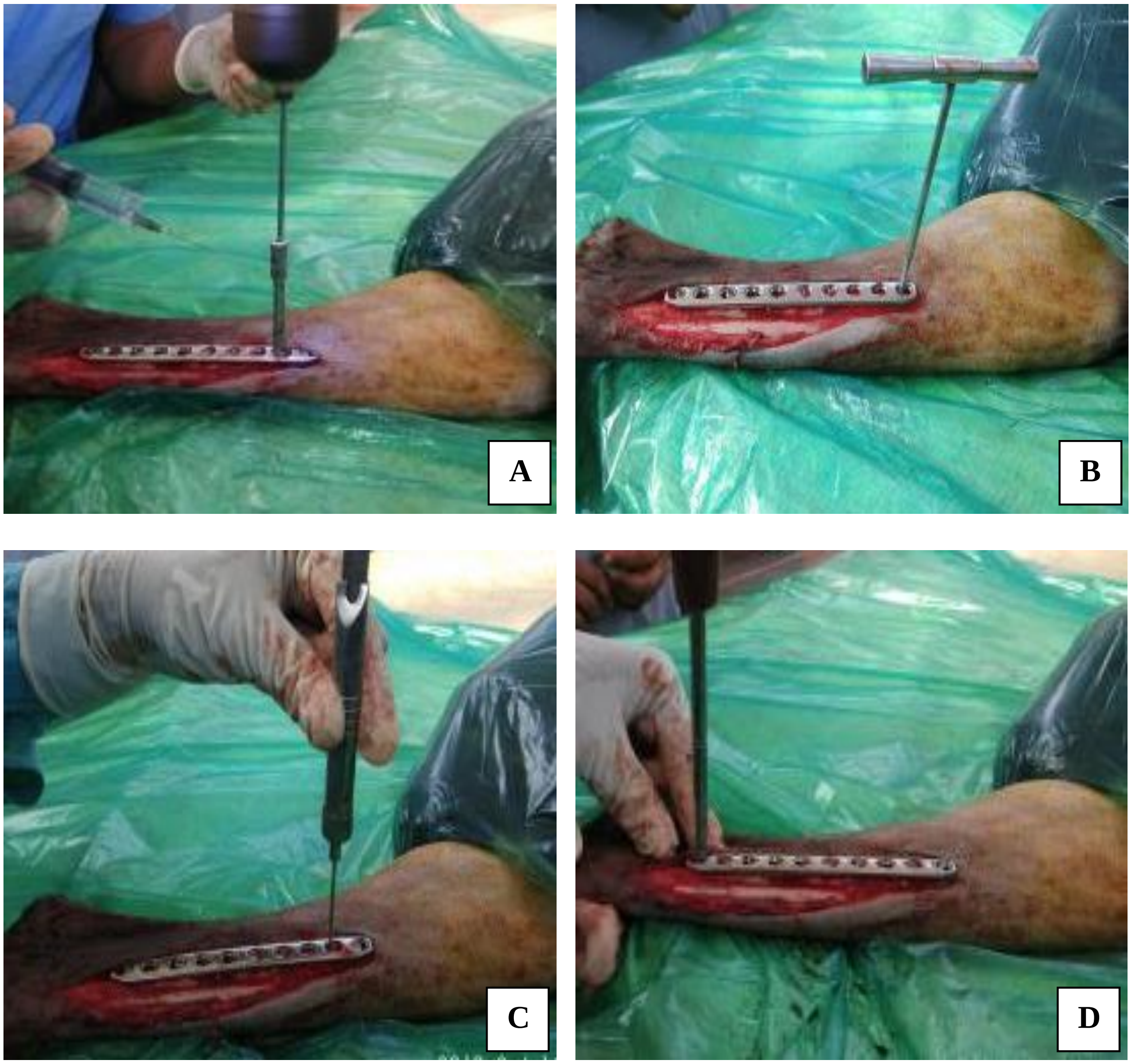

Plate 6: Application of bone plates

(Locking compression plate)

A) Application of locking drill sleeve and drilling of screw hole in bone

B) Tapping of the drilled hole using 3.2 mm bone tap

C) Measurement of screw hole depth using a depth gauge to determine the screw length

D) Application of locking head screws using hexagonal screw driver

Plate 7: Photographs after complete application of bone plates

A) Group I - Locking compression plate

B) Group II - Locking string of pearls plate

C) Group III - Locking reconstruction plate

A) Suturing of muscles

B) Closure of skin

Plate 8: Closure of incisional wound

Immediate post-operative radiographs were taken in cranio-caudal and medio-lateral views to assess the fracture apposition, limb alignment and status of the implant. The animals were kept under observation in a well-ventilated room with its neck in extended position, restricting its movements until complete recovery from anaesthesia. Post-operatively inj. amoxicillin + cloxacillin @ 10 mg/kg b.wt i/v BID, inj. meloxicam @ 0.2 mg/kg i/v BID and inj. pheniramine maleate[9] @ 0.5 mg/kg b.wt i/m BID were administered for seven days. The incisional wound was surgically dressed until healing. The skin sutures were removed after wound healing between post-operative day 7 to 10.

The owners were advised to restrict the movements of the animals for the first 2 weeks after surgery and then for short duration walk for 2-4 weeks. The cases were evaluated on day 15, 30, 60 and 120 for lameness grading and radiographic evaluation as per the methods recommended by Vasseur *et al.* (1995) and Hammer *et al.* (1985) respectively. The cases were examined during the study period for complications, if any.

3.6 Evaluation of Healing

3.6.1 Clinical Evaluation of incisional wound

Clinical evaluation was carried out to check for the progression of wound healing. After suture removal, the goats were kept under observation until the end of study period.

3.6.2 Lameness Grade

A lameness grade as recommended by Vasseur *et al.* (1995) was assigned in all the cases during the post-operative period based on the weight bearing nature during stance

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[9] Injection Avil, Intervet India Pvt Ltd., (MSD AH), Pune.

and while walking on the post-operative day 0, 7, 15, 30, 60 and 120. The post-operative day on which the goat started bearing weight was noted and graded.

3.6.3 Radiographic evaluation

Post-operatively radiographs were obtained immediately after plate fixation (day 0) and on day 15, 30, 60 and 120 to monitor bone healing. The evaluation of radiographic healing was done based on the modification done in the method of Hammer *et al*. (1985) as indicated in table 4.

Table 4: Evaluation of radiographic healing

Callus formation	Fracture line	Stage of union	Grade / Score
No callus	Distinct	Not achieved	0
Trace: No bridging of fracture line	Distinct	Not achieved	1
Apparent: Bridging of fracture line	Discernible	Uncertain	2
Massive: Bone trabeculae crossing fracture line	Barely discernible	Achieved	3
Homogenous bone structure	Obliterated	Achieved	4

3.6.4 Implant removal

The implant removal was performed under general anaesthesia using inj. xylazine hydrochloride @ 0.1mg/kg b.wt. i/v for pre-anaesthesia immediately followed by inj. ketamine hydrochloride @ 4mg/kg b.wt. i/v for induction. The implant was palpated below the skin and an incision was given over the plate at the cranio-medial aspect of the tibia. The fibrous tissue proliferation over the plate and the screw holes was cleared. Callus proliferation noticed at surrounding the plate was cleared and the locking head screws were unscrewed and removed. The plate was lifted and removed. The site was adequately lavaged with normal saline solution. The incisional skin wound was sutured with vertical mattress suture pattern using prolene No. 2. A broad-spectrum antibiotic (inj. amoxicillin + cloxacillin @ 10 mg/kg body weight) and an analgesic and anti-inflammatory drug (inj. meloxicam @ 0.3 mg/kg body weight) was administered intra muscularly for seven days in all the animals in which the implants were removed. The wound was surgically dressed until healing.

3.6.5 Complications

Intra-operative and post-operative complications related to wound (inflammation, discharge, wound dehiscence and limb swelling), complications related to bone/implant (due to reaction of bone to implant, implant status/ position such as hardware failure/loosening), complications during fracture healing (malunion/delayed union/non-union/osteomyelitis) and death, if any were observed and recorded in all the groups.

3.6.6 Biochemical Parameters

Serum samples were collected in vacutainer tubes on day 0, 15, 30, 60 and 120 in all the groups to evaluate the levels of serum alkaline phosphatase (unit/liter), serum calcium (mg/dL) and serum phosphorus (mg/dL) determined by using semi-automatic serum biochemical analyser (‘ERBA-Mannheim’ make, Germany) and standard kit supplied by Delta diagnostics, Bengaluru.

3.6.6.1 Serum alkaline Phosphatase

Serum alkaline phosphatase was estimated on day 0, 15, 30, 60 and 120 after fracture repair using P-nitrophenylphosphate method.

3.6.6.2 Serum calcium

Serum calcium was estimated on day 0, 15, 30, 60 and 120 after fracture repair Arsenazo method.

3.6.6.3 Serum phosphorus

Serum inorganic phosphorous was estimated on day 0, 15, 30, 60 and 120 after fracture repair using direct UV method.

3.6.7 Functional outcome

Functional outcome was evaluated on the 60th and 120th post-operative day and categorized as excellent, good, fair and poor in all the groups of animals (Clark, 1986) as indicated in table 5.

3.7 Statistical Analysis

The quantitative data like physiological and biochemical parameters were statistically analysed using R software freely available in the internet. Analysis of variance was done to determine the difference between the three groups studied and also to determine the difference between the time intervals within the groups. The qualitative parameters were analysed by arbitrary score card method (visual analog score).

Table 5: Evaluation of functional outcome as recommended by Clark (1986)

Grading	Attribute
Excellent	No lameness compared to the goat's opposite limb. No post-operative complications
Good	Moderate occasional lameness. No post-operative complications. Does not require treatment.
Fair	Moderate persistent lameness requiring treatment.
Poor	Persistent severe lameness may require revision surgery.

Results

CHAPTER IV

RESULTS

The present study was conducted in two phases. Phase I consisted of study of incidence of long bone fractures in goats. In phase II, clinical study was carried out on the cases of tibial fractures in goats brought for treatment to Department of Veterinary Surgery and Radiology, Veterinary College, Bidar. The results of the study are presented as follows.

4.1 Phase I

4.1.1 Incidence of long bone fractures in goats

The incidence of long bone fractures in goats was recorded by analysing the data of last twelve years (2007- 2018) of clinical cases presented to Veterinary College, Bidar and the results are shown in Table 6. A total number of 11,294 animals were treated for different surgical conditions during the period 2007-2018. Out of 1979 cases of goats treated for different surgical affections, 138 were of long bone fractures. Overall clinical incidence of long bone fractures among all surgical conditions treated in goats was 6.97%.

4.1.2 Sex wise incidence of long bone fractures in goats

The study showed that the incidence of long bone fractures in goats was more in females (66.66%) than in males (33.33%). Out of 138 goats, 92 were female and 46 were male goats as depicted in Table 7 and Fig.1.

4.1.3 Age wise incidence of long bone fractures in goats

Out of the 138 goats presented with long bone fractures, 35 goats were of less than 6 months of age (25.36%), 59 goats were between 6 months to 1 year of age (42.75%), and 44 goats above 1 year of age (31.88%) as depicted in Table 8 and Fig.2.

4.1.4 Bone affected

Fractures were found to be more common in hindlimbs (55.08%) than in forelimbs (44.98%). The incidence was 28.08% for metatarsal, 26.08% for metacarpal, 21.60% for tibia, 10.87% for radius-ulna, 7.97% for humerus, 5.07% for femur bone. Thus, the incidence of long bone fractures was found to be highest in metatarsal bone followed by metacarpal bone in goats as depicted in Table 9 and Fig.3.

4.1.5 Etiology wise incidence of long bone fractures in goats

Various causes for long bone fractures were recorded in the study. Most of the fractures reported in the study were due to automobile accidents 46 (33.33 %) followed by malicious/accidental hit injuries 29 (21.01 %), falling from height 22 (15.84 %) and dog bite 4 (2.88 %) as shown in Table 10 and Fig. 4. However, in 37 (26.64%) cases the owners were not sure of the exact cause of fracture.

4.1.6 Type of fracture

It was found that majority of the goats i.e. 102 out of 138 (73.91%) had simple fractures of long bones, whereas the rest had compound type as depicted in Fig 5. Oblique fractures (n=58) were more common (42.02%), followed by transverse type (n=51) with an incidence of 36.95% as depicted in Fig 6.

Table 6: Incidence of long bone fractures in goats treated at Veterinary College, Bidar during last 12 years (2007- 2018)

Sl. No.	Year (Jan – Dec)	Number of surgical cases treated	Number of surgical cases of goats treated	Number of long bone fractures in goats
1	2007	925	80	6
2	2008	1098	168	7
3	2009	762	130	12
4	2010	1532	184	7
5	2011	703	114	10
6	2012	849	133	6
7	2013	742	146	8
8	2014	921	179	12
9	2015	975	221	18
10	2016	918	241	12
11	2017	918	173	21
12	2018	951	210	19
Total		**11294**	**1979**	**138**

Table 7: Sex wise incidence of long bone fractures in goats

Sl. No.	Sex	Number of animals	Percentage of incidence (%)
1	Male	46	33.33 %
2	Female	92	66.66 %

Fig. 1: Pie diagram showing sex wise incidence of long bone fracture in goats

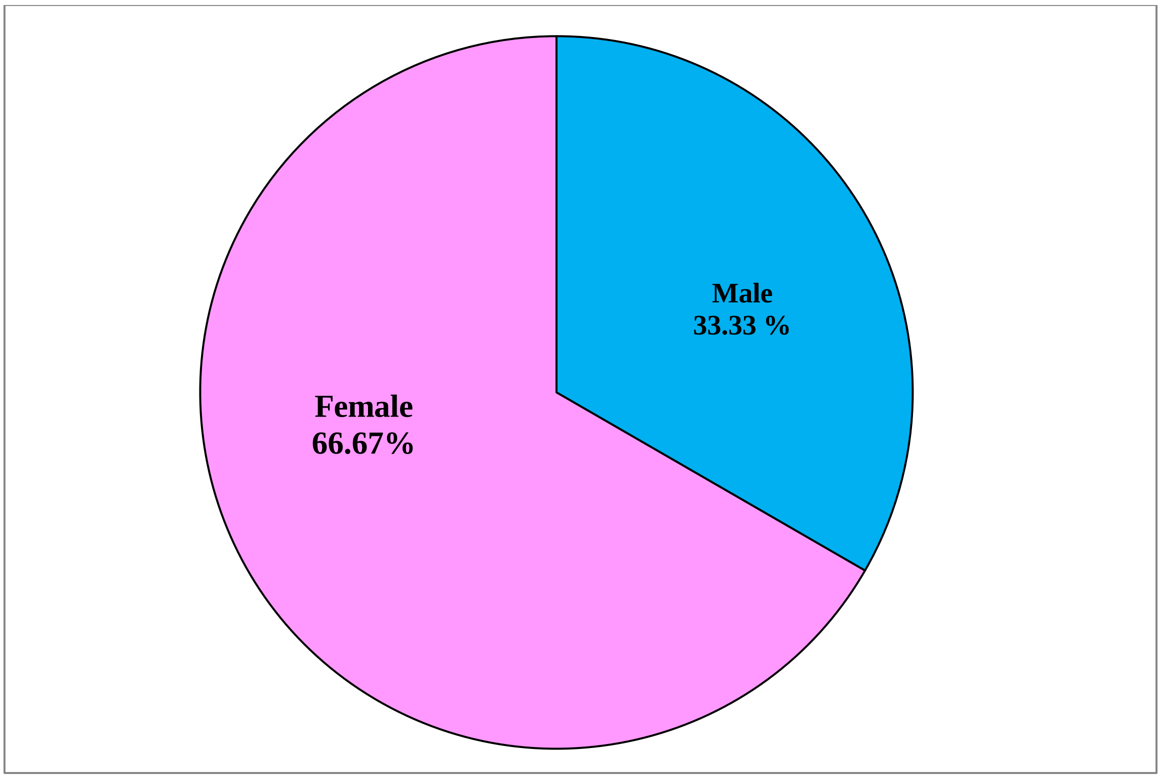


Table 8: Age wise incidence of long bone fractures in goats

Sl. No.	Age	Number of animals	Percentage of incidence (%)
1	Less than 6 months	35	25.36 %
2	6 months to one year	59	42.75 %
3	Above one year	44	31.88 %

Fig. 2: Pie diagram showing age wise incidence of long bone fractures in goats

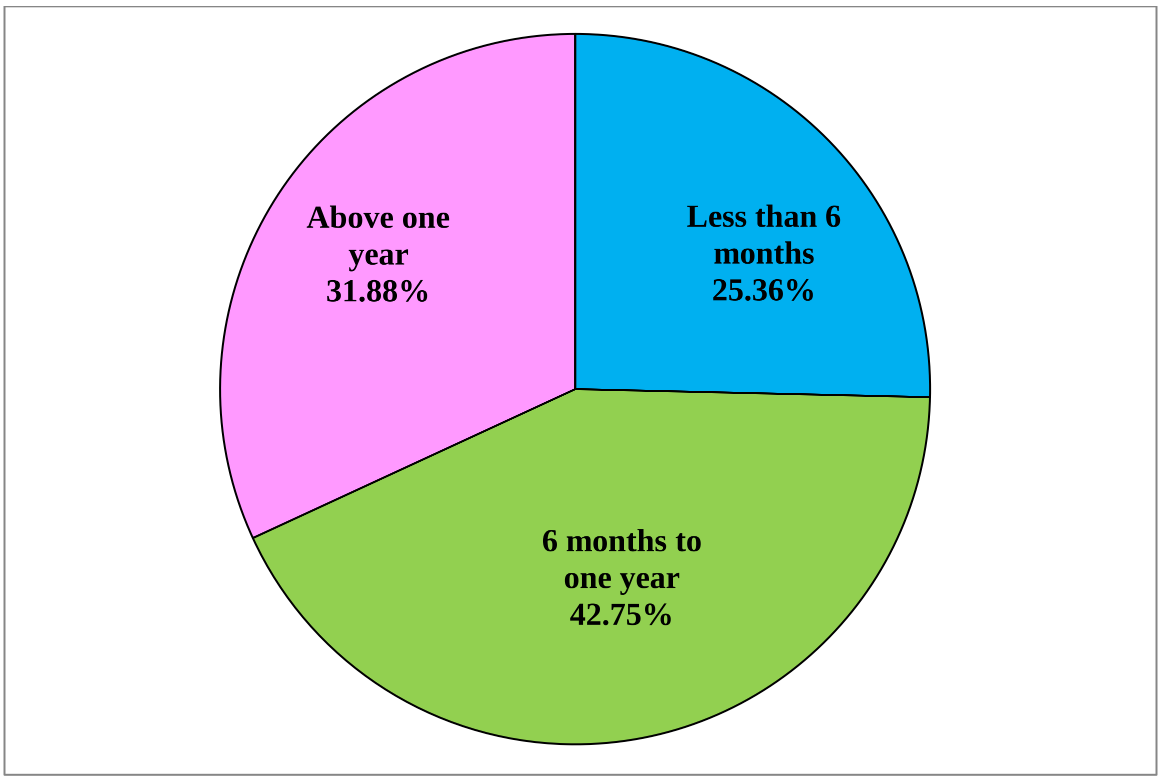


Table 9: Bone wise incidence of long bone fractures in goats

Sl. No.	Limb involved	Sl. No.	Bone involved	Number of animals	Percentage of incidence (%)
1	Hind limbs n=76 (55.08%)	1	Metatarsal	39	28.08 %
		2	Tibia	30	21.60 %
		3	Femur	07	05.07 %
2	Fore limbs n=62 (44.98 %)	4	Metacarpal	36	26.08 %
		5	Radius-ulna	15	10.87 %
		6	Humerus	11	07.97 %

Fig. 3: Pie diagram showing bone wise incidence of long bone fractures in goats

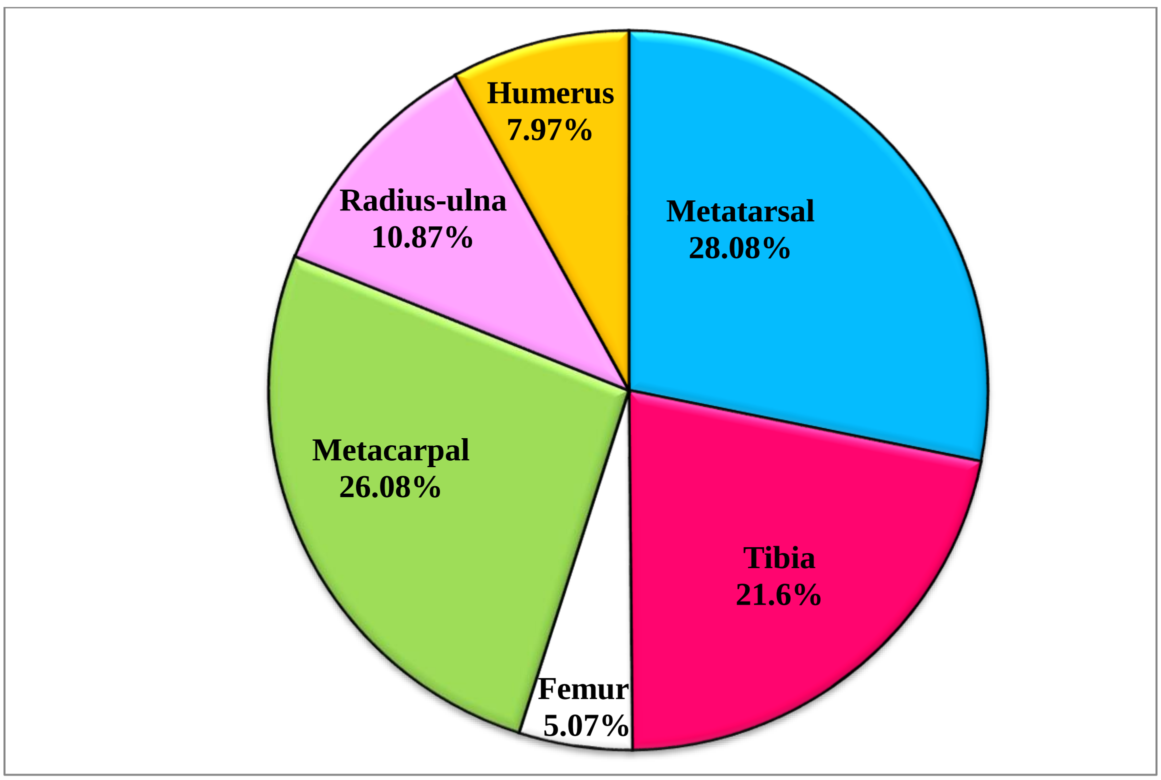


Table 10: Etiology wise incidence of long bone fractures in goats

Sl. No.	Cause	Number of animals	Percentage of incidence (%)
1	Automobile accidents	46	33.33 %
2	Hit injuries	29	21.01 %
3	Falling from height	22	15.84 %
4	Dog bite	04	02.88 %
5	Owner unaware of cause	37	26.64 %

Fig. 4: Pie diagram showing etiology of long bone fractures in goats

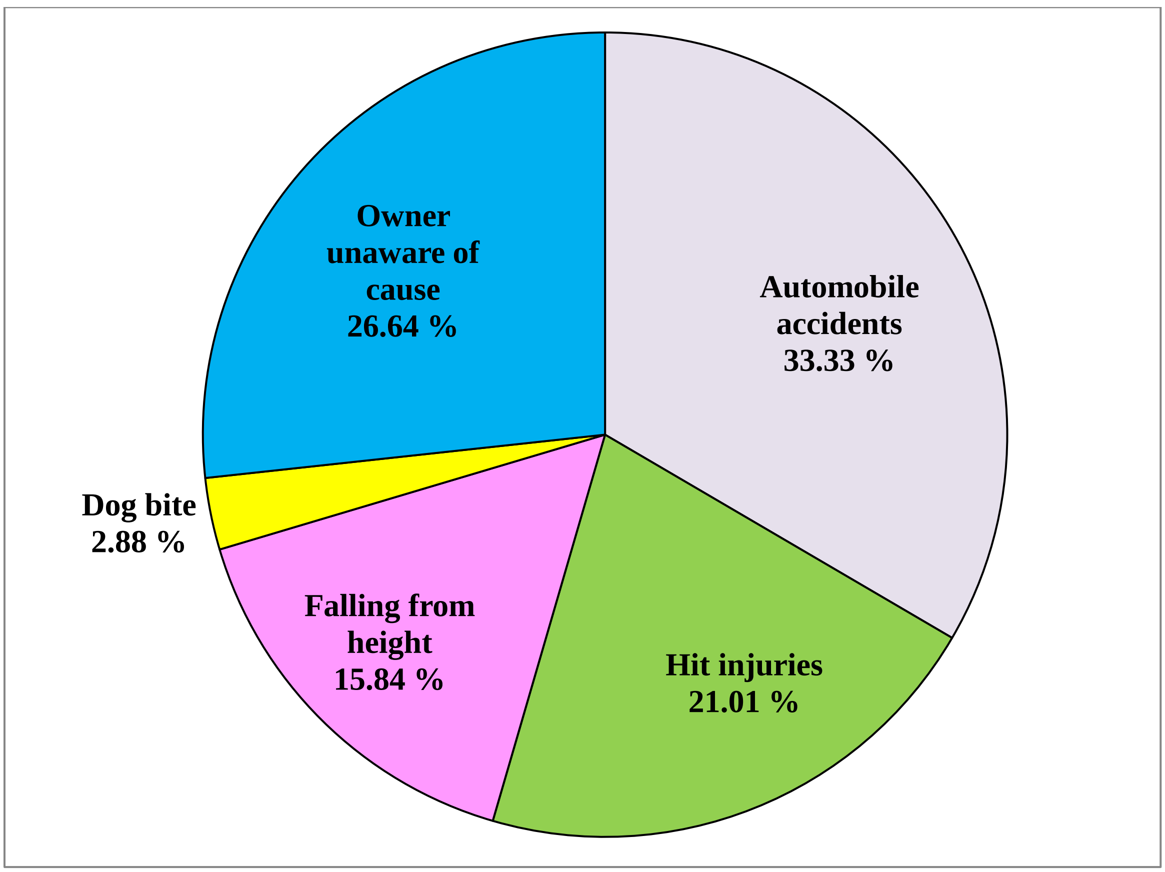


Fig. 5: Pie diagram showing type of long bone fractures in goats

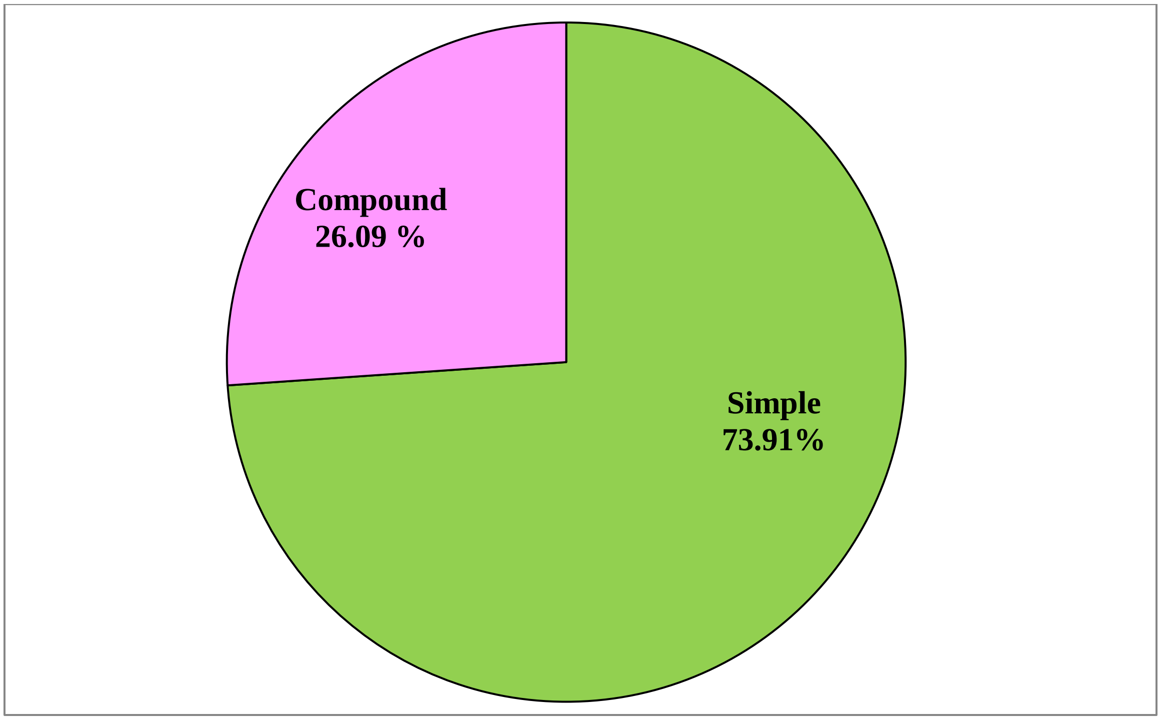
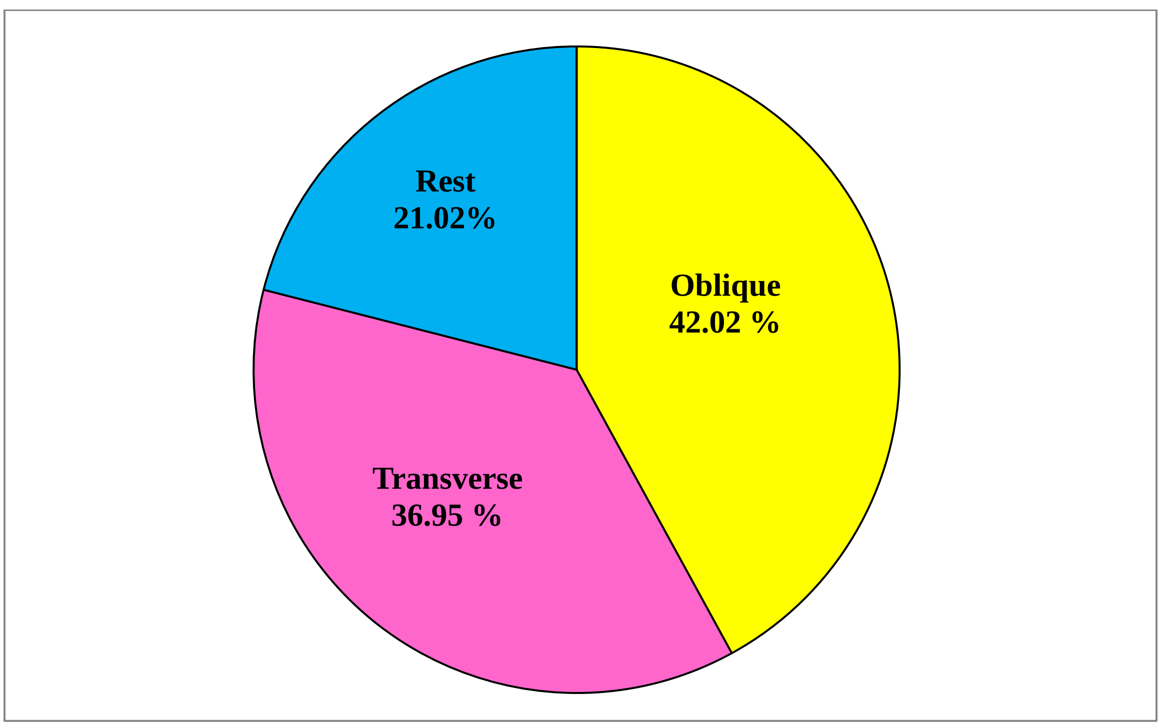


Fig. 6: Pie diagram showing incidence of different types of long bone fractures in goats



4.2 Phase II: Clinical study

The diagnosis of tibial fracture was based on the clinical signs of non weight bearing, dangling of the limb, reluctance to move the limb, crepitation of the fractured site and palpation of the fractured fragments of the tibia. Survey radiography of medio-lateral and cranio-caudal projections with stress view taken for determination and classification of the type of fracture of tibial diaphysis provided confirmatory diagnosis of fracture, enabled fracture classification, aided in pre-operative decision making, determination of the size of plates and length of the screws needed and also for post-operative evaluation of fracture healing.

4.2.1 Signalment of the animals and details of fractures

The signalment of all the 18 goats included in the clinical study, and the details of tibial fracture such as type and location of fracture are given in Table 2.

Seven out of 18 goats under study had a history of having met with an accident. Six goats had history of falling from a height. Four goats were presented with history of having sustained fracture due to hit injury and one goat was fractured due to infighting. The body weight in all goats ranged between 10 kg to 25 kg and they aged between seven months to 60 months. Eleven goats sustained fracture in left tibia and seven goats had fracture in right tibia.

4.2.1.1 Pre-operative clinical signs

Animals of all the three groups were assessed pre-operatively for weight bearing and lameness grading and a lameness grade of I to V was assigned based on the clinical signs as per the method recommended by Vassuer *et al.* (1995).

The goats on presentation were lifting the limb above the ground level or just touching the toe to the ground. The limb was dangling indicating a broken bone. Pain and swelling were present at the site of fracture. The fractured fragments could be palpated and the tentative location and type of fracture could be assessed. In 16/18 animals the fractures were simple type and two animals had compound fractures.

4.2.1.2 Type and location of fracture

In the present study, majority of the animals (9/18) had short oblique type (50.00%) of fractures. Five out of eighteen (27.78%) had transverse type of fracture and Four out of eighteen (22.22%) had comminuted fractures.

Majority of the fractures (15/18) were located in middle one third of diaphysis (83.33%), followed by distal one third (2/18) and proximal one third (1/18) contributing to 11.11% and 5.55% respectively.

4.2.2 Pre-operative plan for implant selection

The medio-lateral radiographic view was helpful in determining the length of the plate needed and to determine the diameter of the bone. The cranio-caudal view was useful in determining the length of the screws needed for the implant fixation and also in determining the length of the implant needed.

4.2.3 Premedication and anaesthesia

Pre-operative anaesthetic protocol using inj. xylazine hydrochloride and inj. ketamine hydrochloride produced smooth induction and provided satisfactory surgical plane of general anaesthesia throughout the bone plating procedure without any complications in all the animals.

4.2.4 Surgical approach to tibia

The cranio-medial approach from the site of fracture with extension of incision proximally towards the stifle joint and distally towards the hock joint provided satisfactory exposure of the fracture fragments with minimal soft tissue disruption, without causing injury to blood vessels and nerves for reduction. This approach facilitated adequate reduction, normal alignment and stabilization of the fracture fragments and placement of implants. This approach was found adequate for bone plating as the bone is present subcutaneously and has a flat surface for the application of bone plate.

4.2.5 Evaluation of the bone plates and technique of immobilization

The details of the bone plates and locking head screws used for the study are given in Table 11. The bone plates and locking screws necessary for the individual cases were selected based on AO preoperative plan and were found to be appropriate in the present study. A minimum of three locking screws were applied in the proximal and distal fragment in neutral position in all the cases and it provided adequate stability of the fracture site in all the animals of all the groups under study.

The foot-print of the 3.5mm locking compression plates were wider than the reconstruction plate. The foot-print of the string of pearls plate was narrowest among the three groups. However, plate thickness of the SOP plate was more in comparison to other two plates under study.

Intra-operative visualisation and assessment of the fracture site after placement of the LCP was comparatively less, as it did not permit adequate exposure of the fracture site due to broader profile. The narrow profile of the SOP plate especially at the internodes provided adequate visualisation of the fractured fragments during application of the bone plate. A better intra-operative assessment could be made with regard to the position of the plate, placement of the screws and in deciding as to which holes near the fractured site should be left un-purchased. The narrow profile of the reconstruction plate at notches between two holes provided good exposure of the fractured fragments during reduction and stabilization of the fractured fragments and application of the bone plate.

Ease of stabilization of the fracture fragments during plate application after fracture reduction was more with string of pearls plate followed by reconstruction plate and LCP as it did not move or slipped during application. Stabilization of the locking compression plate over the tibial bone surface was comparatively difficult than other bone plates in the study. Screw wobbling during screw application was more common in LCP than in other plates.

Stainless steel 3.5mm self-tapping locking head screws used in the present study provided a secure screw-plate construct. Despite the self-tapping flutes in the screws, the bone after drilling needed to be tapped.

Table 11: Details of implant studied in phase II

Group	Case No	Type of fracture		Implant size	Screw length	Screw placement sequence	Unpurchased holes at fracture site
I LCP	Case 1	Mid-diaphyseal	Comminuted	10 hole	18-26 mm	4-00-4	Two
	Case 2	Mid-diaphyseal	Comminuted	8 hole	16-22 mm	5-0-4	One
	Case 3	Distal diaphyseal	Oblique	8 hole	18-26 mm	4-4	zero
	Case 4	Mid-diaphyseal	Oblique	8 hole	16-22 mm	3-00-3	Two
	Case 5	Mid-diaphyseal	Transverse	8 hole	16-24 mm	1-0-2-0-3	One
	Case 6	Mid-diaphyseal	Oblique	10 hole	16-24 mm	2-0-2-00-3	Two
II SOP	Case 1	Mid-diaphyseal	Oblique	10 hole	18-22 mm	5-00-3	Two
	Case 2	Mid-diaphyseal	Oblique	10 hole	18-24 mm	4-00-4	Two
	Case 3	Mid-diaphyseal	Oblique	10 hole	18-24 mm	4-4	zero
	Case 4	Mid-diaphyseal	Transverse	10 hole	18-24 mm	5-00-3	Two
	Case 5	Mid-diaphyseal	Comminuted	10 hole	18-24 mm	102-0-3	One
	Case 6	Mid-diaphyseal	Transverse	10 hole	18-22 mm	202-00-3	Two
III Recon	Case 1	Mid-diaphyseal	Transverse	10 hole	18-22 mm	301-0-102	Two
	Case 2	Proximal diaphyseal	Oblique	10 hole	18-24 mm	4-00-4	Two
	Case 3	Distal-diaphyseal	Comminuted	10 hole	16-22 mm	4-000-3	Three
	Case 4	Mid-diaphyseal	Transverse	12 hole	18-24 mm	10101-00-10101	Two
	Case 5	Mid-diaphyseal	Oblique	12 hole	18-22 mm	102-000-202	Three
	Case 6	Mid-diaphyseal	Oblique	10 hole	18-24 mm	4-00-102	Two

The post-operative radiographic assessment of fracture healing in cranio-caudal view was clearly appreciable in all the groups. However, the post-operative radiographic assessment of fracture healing in medio-lateral view was difficult with LCP as the plate was wider and obstructed the fracture site and bone surface. Post-operative radiographic evaluation of fracture healing at the fracture site in medio-lateral view was most appreciable with the SOP plate as the fracture site was completely visible for assessment. The ease of observations with reconstruction plate were intermediate between SOP plate and LCP.

4.2.6 Post-operative evaluation of the patients

4.2.6.1 Evaluation of wound

Animals of all the three groups were assessed from next post-operative day to check for the progression of wound healing, evaluate weight bearing and lameness, radiographic evaluation and for complications, if any. The follow up was made for 120 days.

Post-operative oedema, inflammatory soft tissue swelling and warmth at the surgical site were noticed in all the animals immediately after surgery which lasted for two to five days. Lameness and pain persisted for eight to ten days. However, the animals were able to bare weight while standing. The animals were able to get up with caution. The joint mobility and function were normal. No complications were observed with regard to joint movement or wastage of musculature in all the cases. The incisional wound healed by day 10 after which the sutures were removed.

In four goats, serosanguinous discharge was evident on day seven, leading to infection of the surgical wound. By day ten, there was slight purulent discharge which was reduced by day 20, after prolonged course of antibiotic therapy and regular lavaging of the wound was carried out with diluted normal saline solution along with povidone iodine solution. However, the healing of the wound in these cases was prolonged to beyond 30 days as the animals regularly self-mutilated the wounds.

In group I (LCP case 4) and in group II (SOP case 2 and case 4), a soft swelling was noticed by day 15 at the distal tibial region. Aspiration of this swelling in both the cases revealed pus which was drained out after surgical incision. Wound lavaging along with prolonged antibiotic therapy resulted in recovery of these cases. Rest of the animals under study did not show any sort of infection during all the 120 days of post-operative care.

Mal-union, delayed union, non-union or osteomyelitis were not observed in any of the cases during the period of study.

4.2.6.2 Physiological parameters

The assessment of physiological parameters like rectal temperature (^{0}F), heart rate (beats/min) and respiratory rate (breaths/min) was carried out on post-operative day 0, 7, 15, 30, 60 and 120, in all the groups of animals.

4.2.6.2.1 Rectal temperature (º F)

The mean ± S.E. values of rectal temperature (º F) are given in Table 12 and Fig. 7.

The mean ± S.E. values of rectal temperature (º F) of group I animals on day 0, 7, 15, 30, 60 and 120 were 102.75 ± 0.30, 102.30 ± 0.10, 102.50 ± 0.21, 102.05 ± 0.28, 102.10 ± 0.13 and 102.50 ± 0.24, respectively.

The mean ± S.E. values of rectal temperature (º F) of group II animals on day 0, 7, 15 and 30 were 102.08 ± 0.40, 102.08 ± 0.44, 102.20 ± 0.58, 101.90 ± 0.24, 101.90 ± 0.39 and 102.58 ± 0.43, respectively.

The mean ± S.E. values of rectal temperature (º F) of group III animals on day 0, 7, 15 and 30 were 102.63 ± 0.25, 103.03 ± 0.35, 102.35 ± 0.20, 102.23 ± 0.17, 102.10 ± 0.21 and 101.48 ± 0.39, respectively.

The rectal temperature fluctuated within normal physiological limits on all the days of observation. Analysis of rectal temperature revealed that there was no significant difference between the groups and between the days of observation.

4.2.6.2.2 Heart rates (beats/minute)

The mean ± S.E. values of heart rate of all the three groups are given in table 13 and Fig. 8.

The mean ± S.E. values of heart rate (beats/minute) of group I animals on day 0, 7, 15, 30, 60 and 120 were 77.25 ± 1.89, 77.00 ± 0.41, 79.50 ± 2.22, 83.75 ± 2.84, 85.00 ± 6.01 and 90.25 ± 3.42, respectively.

The mean ± S.E. values of heart rate (beats/minute) of group II animals on day 0, 7, 15, 30, 60 and 120 were 80.25 ± 3.71, 78.25 ± 6.86, 80.25 ± 6.94, 85.25 ± 5.76, 79.75 ± 4.42 and 85.50 ± 2.63, respectively.

The mean ± S.E. values of heart rate (beats/minute) of group III animals on day 0, 7, 15, 30, 60 and 120 were 87.00 ± 3.39, 92.50 ± 1.26, 89.25 ± 7.43, 103.50 ± 5.56, 109.25 ± 9.34 and 97.00 ± 11.45, respectively.

In all the three groups there was a fluctuation in the heart rate within physiological limits through the different time intervals. There was no significant difference within the groups on different days of observation. There was no significant difference between the groups on all days except on day 60. On day 60, the heart rate in group I was non-significantly different from that of group II and group III. However, the heart rate of group II was significantly ($p<0.05$) differing from that of group III, at 60th post-operative day.

4.2.6.2.3 Respiratory rate (breaths/minute)

The mean ± S.E. values of respiratory rate (breaths/minute) are given in Table 14 and Fig. 9.

The mean ± S.E. values of respiratory rate (breaths/minute) of group I animals on day 0 day, 7, 15, 30, 60 and 120 day were 26.75 ± 1.03, 27.50 ± 0.65, 26.50 ± 2.10, 25.50 ± 1.89, 24.00 ± 1.96 and 26.25 ± 2.50 respectively.

The mean ± S.E. values of respiratory rate (breaths/minute) of group II animals on day 0 day, 7, 15, 30, 60 and 120 day were 28.50 ± 0.96, 26.50 ± 1.19, 25.75 ± 1.44, 27.50 ± 1.04, 25.50 ± 0.65 and 27.25 ± 2.93 respectively.

Table 12: Mean± S.E., values of rectal temperature (º F) on different post-operative days in all the groups of animals

Days	Group I	Group II	Group III
0	102.75 ± 0.30	102.08 ± 0.40	102.63 ± 0.25
7	102.30 ± 0.10	102.08 ± 0.44	103.03 ± 0.35
15	102.50 ± 0.21	102.20 ± 0.58	102.35 ± 0.20
30	102.05 ± 0.28	101.90 ± 0.24	102.23 ± 0.17
60	102.10 ± 0.13	101.90 ± 0.39	102.10 ± 0.21
120	102.50 ± 0.24	102.58 ± 0.43	101.48 ± 0.39

Fig. 7: Rectal temperatures (º F) on different post-operative days in all the groups of animals

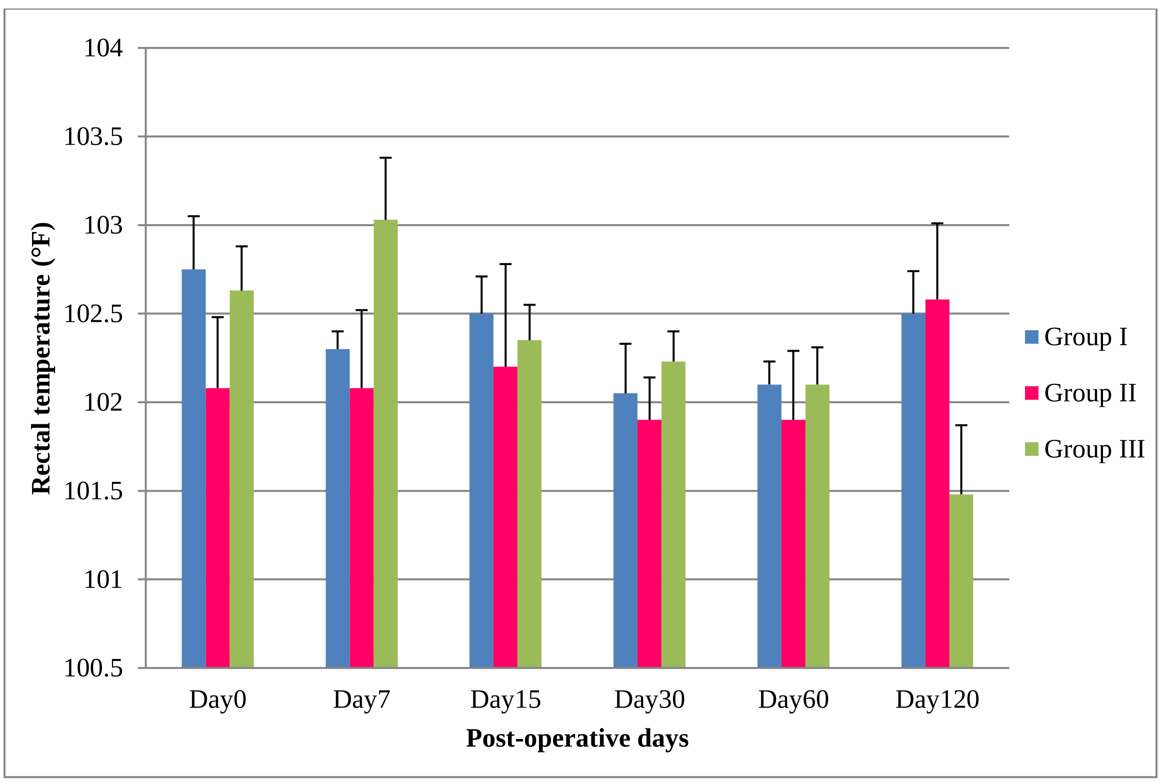


Table 13: Mean ± S.E., values of heart rate (beats/minute) on different post-operative days in all the groups of animals

Days	Group I	Group II	Group III
0	77.25 ± 1.89	80.25 ± 3.71	87.00 ± 3.39
7	77.00 ± 0.41	78.25 ± 6.86	92.50 ± 1.26
15	79.50 ± 2.22	80.25 ± 6.94	89.25 ± 7.43
30	83.75 ± 2.84	85.25 ± 5.76	103.50 ± 5.56
60	85.00 ± 6.01^{p}	79.75 ± 4.42^{p}	109.25 ± 9.34^{pq}
120	90.25 ± 3.42	85.50 ± 2.63	97.00 ± 11.45

Means with different superscripts (p, q...) indicate significant difference between groups within a time interval

Fig. 8: Heart rate (beats/minute) on different post-operative days in all the groups of animals

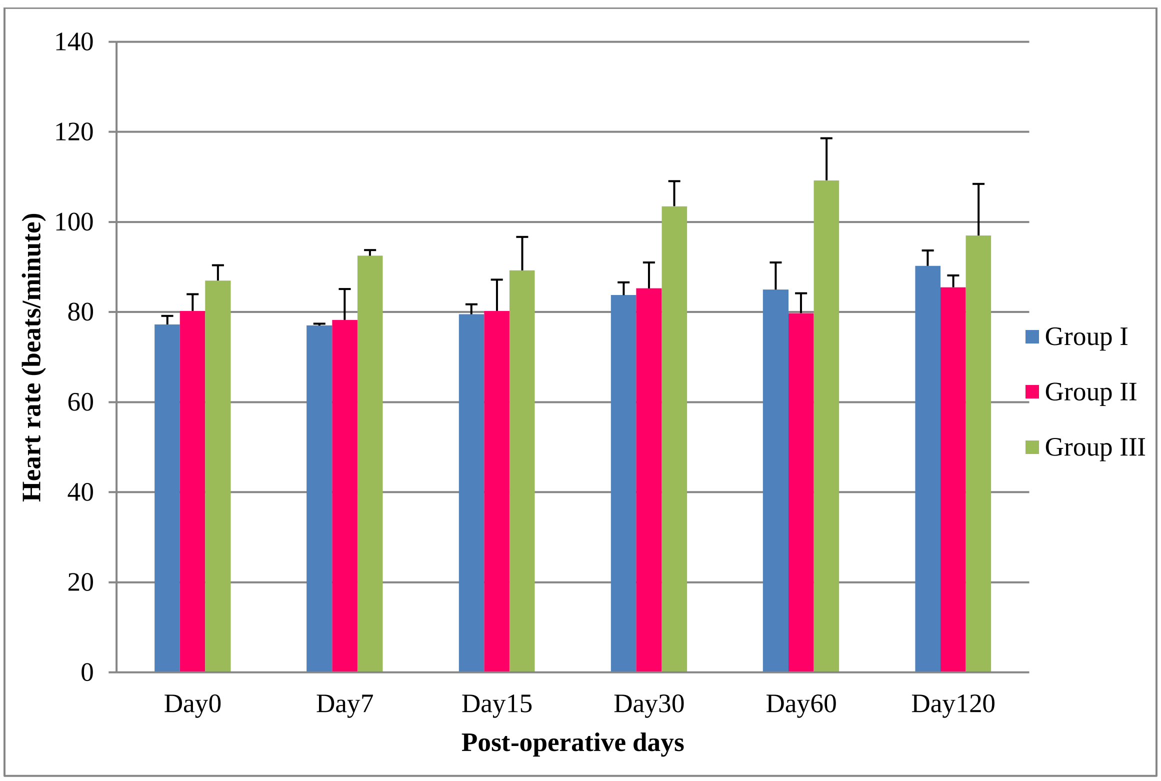
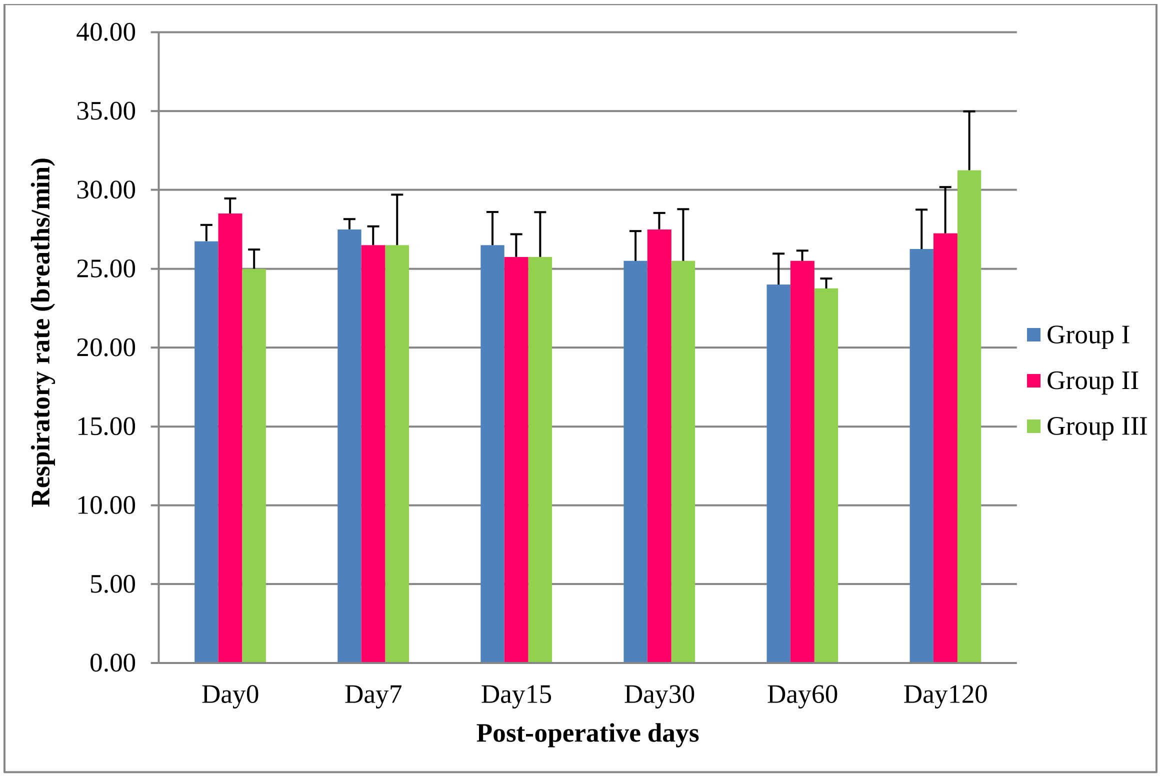


Table 14: Mean ± S.E., values of respiratory rates (breaths/minute) on different post-operative days in all the groups of animals

Days	Group I	Group II	Group III
0	26.75 ± 1.03	28.50 ± 0.96	25.00 ± 1.22
7	27.50 ± 0.65	26.50 ± 1.19	26.50 ± 3.20
15	26.50 ± 2.10	25.75 ± 1.44	25.75 ± 2.84
30	25.50 ± 1.89	27.50 ± 1.04	25.00 ± 3.28
60	24.00 ± 1.96	25.50 ± 0.65	23.75 ± 0.63
120	26.25 ± 2.50	27.25 ± 2.93	31.25 ± 3.73

Fig. 9: Respiratory rates (breaths/minute) on different post-operative days in all the groups of animals



The mean ± S.E. values of respiratory rate (breaths/minute) of group III animals on day 0 day, 7, 15, 30, 60 and 120 day were 25.00 ± 1.22, 26.50 ± 3.20, 25.75 ± 2.84, 25.00 ± 3.28, 23.75 ± 0.63 and 31.25 ± 3.73 respectively.

The respiratory rate fluctuated within normal physiological limits on all the days of observation. The statistical analysis of respiratory rate revealed that there was no significant difference between the groups and between the days of observation in each group.

4.2.6.3 Weight bearing and lameness grading

A lameness grade was assigned to each animal for better assessment of quality of weight bearing while standing and walking. All the animals were evaluated for weight bearing and lameness on the basis of gait on post-operative day 0, 7, 15, 30, 60 and 120 as per the technique recommended by Vasseur *et al*. (1995).

The lameness grades of all the animals are tabulated in Table 15a and 15b and Fig 10.

4.2.6.3.1 Group I (Locking compression plate)

The pre-operative evaluation of lameness in group 1 animals revealed complete non-weight bearing on the limb when at rest or while walking in three animals. This was graded as grade V lameness. Partial weight bearing when at rest, where the goats lifted their limb above the ground level or were just touching the toe to the ground and non weight bearing while walking was observed in three animals. The lameness was graded as grade IV in these goats.

Table 15a: Lameness score evaluation as per the method recommended by Vasseur *et al*. (1995)

Group	Case	Pre op	Post-operative					
			Day 0	Day 7	Day 15	Day 30	Day 60	Day 120
I (LCP)	**1**	5	4	4	4	2	1	1
	2	5	3	3	3	2	2	1
	3	4	3	3	3	2	1	1
	4	5	3	4	3	2	2	1
	5	5	3	3	2	3	2	1
	6	4	3	2	2	2	1	1
II (SOP)	**1**	5	4	4	3	3	2	1
	2	4	3	2	3	3	2	1
	3	5	4	3	3	2	2	1
	4	4	2	2	2	2	1	1
	5	5	4	3	3	3	1	1
	6	5	4	2	3	2	1	1
III (Recon)	**1**	4	3	3	2	2	2	1
	2	5	4	3	3	2	2	1
	3	4	3	3	3	3	2	1
	4	5	4	3	3	3	2	1
	5	5	3	3	2	2	1	1
	6	4	2	4	3	2	1	1

Grading of weight bearing as recommended by Vasseur *et al.* (1995)

Lameness Grade	Attribute
I	Normal weight bearing on all limbs at rest and while walking
II	Normal weight bearing at rest, favours affected limb while walking
III	Partial weight bearing at rest and while walking
IV	Partial weight bearing at rest; does not bear weight on affected limb while walking
V	Does not bear weight on limb at rest or while walking

On day 0, the lameness grade improved after stabilisation of fracture in comparison to pre-operative scores and the goats exhibited mild to moderate weight bearing. In two goats, lameness score improved from grade V to grade III. In these goats, partial weight bearing (touching the hoof to the ground) was observed when the animal was at rest and while walking. Normal weight bearing at rest was observed in one goat. This goat favoured the affected limb while walking. The lameness was graded as grade II. In one goat the lameness grade improved from grade V to grade IV. In one goat the lameness score improved from grade IV to grade III.

All the goats were very cautious during sitting, getting up and walking. Manipulation of the joints revealed discomfort in all the cases. The animals did not allow for the manipulation of the limbs and joints and exhibited pain. The lameness score remained the same up to day 7. However, improved activity and mobility were noticed in all the goats and the goats moved around more comfortably.

On day 15, the lameness grade improved to grade III in three out of six goats, where moderate weight bearing with slight limping was noticed. In two goats, normal weight bearing was observed at rest with slight limping when walking. The goats favoured the affected limb while walking. The lameness score in these goats was graded as grade II. However, case 5, did not completely bear weight when walking and lameness was graded as grade IV. In this goat lameness had increased due to infection and swelling at the distal extremity of the tibia. The lameness score in this goat improved gradually after treatment for infection. All the goats allowed for palpation of the limb and manipulation of the joints. However, slight discomfort and pain was expressed in all the cases.

By day 30, five out of six goats showed improvement in lameness to grade II. Normal weight bearing was noticed when at rest. The goats walked normally by favouring the affected limb while walking and sat and got up easily with pain free movements of the joints and limbs.

On day 60, the lameness grade had improved in four out of six goats. Three out of six goats showed grade II lameness. In three other goats, lameness grade had improved to grade I, in which there was complete weight bearing on all the limbs at rest as well as while walking. Full functional weight bearing was observed in these cases while standing and walking. No problems were noticed during sitting or getting up or during manipulation and movement of the joints.

By day 120, completely normal weight bearing on all the limbs when at rest and while walking was noticed in all the goats. Full functioning of the all the limbs and joints was noticed while standing, walking and running.

During the study of animals of this group, animals had mild to moderate weight bearing from day 0 to day 15 while good weight bearing was observed from day 30 to day 60. Complete functional recovery and normal weight bearing on all limbs while at rest and while walking, was observed from day 60 to day 120 (Plate 9 and Plate 10).

Statistical analysis of lameness score in the group I revealed that the lameness score on pre-operative day was significantly ($p<0.01$) differing from that of day 0, day 7, day 15, day 30, day 60 and day 120.

Plate 9: Group I, case 5

Sequential evaluation of weight bearing and lameness grading

A) Pre-operative, grade V lameness, showing non-weight bearing

B) Post-operative day 0, grade III lameness, showing partial weight bearing

C) Post-operative day 15, grade II lameness (arrow), showing complete weight bearing on the limb.

D) Post-operative day 30, grade III lameness, showing non-weight bearing on the limb.

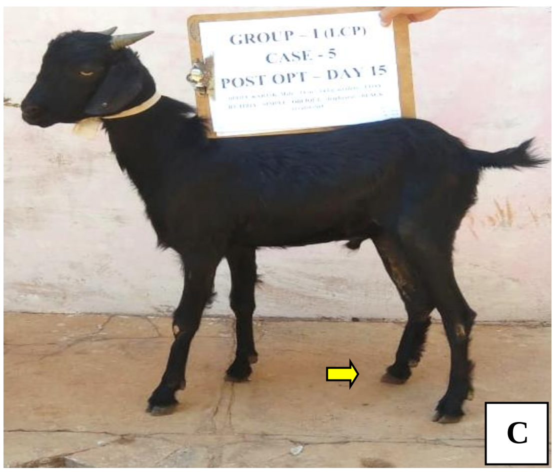
E) Post-operative day 60, grade II lameness, showing complete weight bearing on the limb.

F) Post-operative day 120, grade I lameness, showing normal weight bearing on the limb.

Sequential evaluation of weight bearing and lameness grading

Pre-operative - Grade V

Day 0 - Grade III



Day 15 - Grade II (arrow)

Day 30 - Grade III

Day 60- grade II

Day 120 - Grade I

Plate 9: Group 1, case 5

Plate 10: Group I, case 6

Sequential evaluation of weight bearing and lameness grading

A) Pre-operative grade IV lameness, showing non-weight bearing with hoof touching the ground

B) Post-operative day 0, grade III lameness, showing partial weight bearing

C) Post-operative day 15, grade II lameness, showing partial weight bearing

D) Post-operative day 30, grade II lameness, showing complete weight bearing

E) Post-operative day 60, grade I lameness, showing complete normal weight bearing

F) Post-operative day 120, grade I lameness, showing complete normal weight bearing

Sequential evaluation of weight bearing and lameness grading

Pre-operative - grade IV lameness

Day 0 - grade III lameness

Day 15 grade II lameness

Day 30 - grade II lameness

Day 60 - grade I lameness

Day 120 - grade I lameness

Plate 10: Group 1, case 6

The lameness score on day 0 was non-significantly differing from that of day 7, day 15 and day 30 and was significantly differing from that of day 60 ($p<0.01$) and day 120 ($p<0.01$).

Similarly, the lameness score on day 7 was non-significantly differing from that of day 15 and day 30 and significantly differing from that of day 60 ($p<0.01$) and day 120 ($p<0.01$).

The lameness score on day 15 was non-significantly differing from that of day 30 and significantly differing from that of day 60 ($p<0.01$) and day 120 ($p<0.01$).

The lameness score on day 30 was non-significantly differing from that of day 60 and day 120.

The lameness score on day 60 was non-significantly differing from that of day 120.

4.2.6.3.2 Group II (String of pearls plate)

The pre-operative evaluation of lameness in group II animals revealed grade V lameness in four out of six animals and grade IV lameness in two animals.

Post-operatively, the lameness score improved in all the goats and the goats exhibited mild to moderate weight bearing on day 0 after stabilisation of fracture. In four out of six goats, lameness score improved from grade V to grade IV where the goats lifted their limb above the ground level or were just touching the toe to the ground and non weight bearing on walking. Partial weight bearing at rest and while walking (grade III lameness) was noticed in one goat. While one goat exhibited normal weight bearing at rest and favoured the affected limb while walking (grade II). The goats were very cautious during sitting and getting up and exhibited signs of pain. Manipulation of the joints revealed slight discomfort in all the cases. The animals didn't allow for the manipulation of the limbs and joints. The lameness score improved in four out of six goats by day 7. However, though the goats were limping moderately, the level of comfort was more than day 0 in all the goats.

On day 15, grade III lameness was observed in five out of six goats, where mild to moderate weight bearing with slight limping was noticed in these animals. Of these, two goats (case 2 and case 4) exhibited partial weight bearing when at rest and. In these goats, lameness was severe due to infection and swelling at the distal extremity of the tibia. The lameness score in these goats improved gradually after treatment for infection. In one out of six goats, grade II lameness was observed. All the goats were relatively more comfortable while sitting and getting up. However, manipulation of the joints revealed slight discomfort and pain in all the cases. The lameness score in this goat improved gradually after treatment for infection.

By day 30, lameness scores improved to grade II in three out of six goats. All the goats sat and got up with ease and pain free movements of the joints and limbs were noticed.

On day 60, lameness scores had improved in five out of six goats. Three goats showed grade II lameness. In three other goats, lameness grade had improved to grade I, in which normal weight bearing was observed in all the limbs when at rest and while walking. Full functional weight bearing was observed in these cases while standing, walking and running. Pain free movements were observed while sitting and getting up or during manipulation of the joints.

On day 120, lameness scores had improved to grade I in all the cases and full functional weight bearing was observed in these cases while standing, walking and running. There was no difficulty in getting up and sitting down in any of the cases.

During the study of animals of this group, animals had mild to moderate weight bearing from 0 to 15 days while good weight bearing was observed from 30 to 60 days. Complete functional recovery and normal weight bearing on all limbs while at rest and while walking, was observed from day 60 to day 120 (Plate 11 and Plate12).

Statistical analysis of lameness score in the group II revealed that the lameness score on pre-operative day was non-significantly differing from that of day 0 and was significantly ($p<0.01$) differing from that of day 0, day 15, day 30, day 60 and day 120.

The lameness score on day 0 was non-significantly differing from that of day 7, day 15 and day 30 and significantly ($p<0.01$) differing from that of day 60 and day 120.

The lameness score on day 7 was non-significantly differing from that of day 15, day 30 and day 60 and significantly differing from that of day 120 ($p<0.01$).

The lameness score on day 15 was non-significantly differing from that of day30 and significantly ($p<0.01$) differing from that of day 60 and day 120.

Plate 11: Group II, case 2

Sequential evaluation of weight bearing and lameness grading

A) Pre-operative, grade V lameness, showing non weight bearing

B) Post-operative day 0, grade IV lameness, showing non-weight bearing with hoof touching the ground

C) Post-operative day 15, grade III lameness, showing partial weight bearing at rest and on walk

D) Post-operative day 30, grade II lameness, showing normal weight bearing at rest and on walk,

E) Post-operative day 60, grade I lameness, showing complete normal weight bearing at rest and on walk

F) Post-operative day 120, grade I lameness, showing complete normal weight bearing at rest and on walk

Sequential evaluation of weight bearing and lameness grading

Pre-operative -grade V lameness

Day 0 - grade IV lameness

Day 15 - grade III lameness

Day 30 - grade II lameness

Day 60 - grade I lameness

Day 120 - grade I lameness

Plate 11: Group II, case 2

Plate 12: Group II, case 5

Evaluation of weight bearing and lameness grading

A) Pre-operative, grade V lameness, showing non-weight bearing

B) Post-operative day 0, grade IV lameness, showing partial weight bearing

C) Post-operative day 15, grade III lameness, showing partial weight bearing

D) Post-operative day 30, grade III lameness, showing weight bearing

E) Post-operative day 60, grade I lameness showing complete weight bearing

F) Post-operative day 120, grade I lameness showing complete normal weight bearing

Sequential evaluation of weight bearing and lameness grading

Pre-operative - grade V lameness

Day 0 - grade IV lameness

Day 15 - grade III lameness

Day 30 - grade III lameness

Day 60 - grade I lameness

Day 120 - grade I lameness

Plate 12: Group II, case 5

The lameness score on day 30 was non-significantly differing from that of day 60 and significantly ($p<0.01$) differing from that of day 120.

The lameness score on day 60 was non-significantly differing from that of day 120.

4.2.6.3.3 Group III (Locking reconstruction plate)

The pre-operative evaluation of lameness in group III animals revealed grade V lameness in three out of six goats and grade IV lameness in three out of six goats.

Post operatively, the lameness grade improved in all the cases and the goats exhibited mild to moderate weight bearing on day 0 after stabilisation of fracture. In two out of six goats, lameness grade had improved from grade V to grade IV. In two out of six goats, lameness grade had improved from grade IV to grade III. In one goat lameness grade had improved from grade V to grade III and one goat exhibited improvement in lameness score from grade IV to grade II. All the goats exhibited signs of pain during sitting and while getting up. However, the signs were lesser than those of animals in group I and II. Though manipulation of the joints revealed slight discomfort in all the cases, the animals allowed for palpation of the limbs. On day 7, five out of six goats exhibited grade III lameness, in one goat early signs of infection were noticed due non presentation of the case during the early post-operative period which led to break in continuity of the post-operative antibiotic therapy. In this goat grade IV lameness was observed which improved to grade III by day 15.

On day 15, the lameness grade improved in three goats. Four out of six goats exhibited grade III lameness, where partial weight bearing when at rest and slight limping when walking was noticed in these animals. In two out of six goats, lameness score had improved to grade II. The goats exhibited pain free movement of the joints and did not show any discomfort while manipulation of the joints.

By day 30, lameness scores had improved in five out of six goats. In four out of six goats grade II lameness was observed. The goats sat and got up easily with pain free movements of the joints and limbs. One goat still exhibited grade III lameness. However, one goat (case 4) which exhibited grade II lameness on day 15 did not completely bear weight when walking (grade III lameness). This goat was re-presented with a history of being accidentally hit and lameness since then. In this goat lameness was seen due to inflammation and pain. The lameness score in this goat improved gradually after treatment with anti-inflammatory drugs and physiotherapy.

On day 60, all the goats showed improvement in lameness score and weight bearing. Four out of six goats exhibited grade II lameness. In other two goats, lameness grade had improved to grade I. Full functional weight bearing was observed in these cases while standing and walking. No problems were noticed during sitting or getting up or during manipulation and movement of the joints.

By day 120, complete normal weight bearing on all the limbs when at rest and while walking was noticed in all the six goats (grade I). Full functional recovery was noticed in all the cases while standing, walking and running.

During the study of animals of this group, animals had mild to moderate weight bearing from 0 to 15 days while good weight bearing was observed from 30 to 60 days.

Complete functional recovery and normal weight bearing on all limbs while at rest and while walking was observed from day 60 to day 120 (Plate 13 and Plate 14).

Statistical analysis of lameness score in the group III was revealed that the lameness score on pre-operative day was significantly ($p<0.01$) differing from that of day 0, day 7, day 15, day 30, day 60 and day 120.

The lameness score on day 0 was non-significantly differing from that of day 7, day 15 and day 30 and significantly ($p<0.01$) differing from that of day 60 and day 120.

The lameness score on day 7 was non-significantly differing from that of day 15 and day 30 and significantly ($p<0.01$) differing from that of day 60 and day 120.

The lameness score on day 15 was non-significantly differing from that of day 30 and day 60 and significantly ($p<0.01$) differing from that of only day 120.

The lameness score on day 30 was non-significantly differing from that of day 60 and significantly ($p<0.01$) differing from that of day 120.

The lameness score on day 60 was non-significantly differing from that of day 120.

The statistical analysis of the overall lameness score revealed non-significant difference among the three groups studied.

Plate 13: Group III, case 4

Sequential evaluation of weight bearing and lameness grading

A) Pre-operative, grade V lameness showing non-weight bearing

B) Post-operative day 0, grade IV lameness showing partial weight bearing at rest; non-weight bearing while walking

C) Post-operative day 15, grade III lameness showing partial weight bearing at rest and while walking

D) Post-operative day 30, grade III lameness showing partial weight bearing at rest and while walking

E) Post-operative day 60, grade II lameness, showing normal weight bearing

F) Post-operative day 120, grade I lameness showing complete normal weight bearing

Sequential evaluation of weight bearing and lameness grading

Pre-operative - grade V lameness

Day 0 - grade IV lameness

Day 15 grade III lameness

Day 30 - grade III lameness

Day 60 - grade II lameness

Day 120 - grade I lameness

Plate 13: Group III, case 4

Plate 14: Group III, case 5

Sequential evaluation of weight bearing and lameness grading

A) Pre-operative photo showing non-weight bearing of the affected limb grade V lameness

B) Post-operative day 0, grade III lameness, showing partial weight bearing

C) Post-operative day 15, grade II lameness, showing normal weight bearing at rest

D) Post-operative day 30, grade II lameness, showing normal weight bearing at rest

E) Post-operative day 60, grade I lameness, showing completely normal weight bearing,

F) Post-operative day 120, grade I lameness showing completely normal weight bearing

Sequential evaluation of weight bearing and lameness grading

Pre-operative - grade V lameness

Day 0 - grade III lameness

Day 15 - grade II lameness

Day 30 - grade II lameness

Day 60 - grade I lameness

Day 60 - grade I lameness

Plate 14: Group III, case 5

4.2.6.4 Radiographic evaluation of fracture healing

Sequential post-operative medio-lateral and cranio-caudal radiographs were taken immediately after surgery (day 0) and on day 15, 30, 60 and 120 to assess the progress of fracture healing, to determine the type of fracture healing and to evaluate the stability of the implants. In the present study, fracture healing was scored based on callus formation and/or elimination of the fracture line or gap as recommended by Hammer *et al.* (1985) as depicted in Table 16a, Table 16b and Fig 11.

The overall radiographic score of group I was non-significantly different from that of group II and that of group III. However, the overall radiographic score of group II was significantly ($p<0.01$) different from that of group III.

4.2.6.4.1 Group I (Locking compression plate)

Post-operative radiographic evaluation on day 0 revealed that the apposition and alignment of the fractured fragments was adequate in all the cases. The fracture line after alignment was clearly distinct with sharp and well-defined loss of radiographic density. The implants were stable and adequate in length. There was adequate contact between the bone plate and tibia.

The screw length, size, position and placement were appropriate in all cases except in case 4 where one screw was monocortical.

In case 5, iatrogenic hairline fracture had occurred.

Table 16a: Radiographic evaluation scores as per the method recommended by Hammer *et al*. (1985)

Group	Case No	Day 0	Day 15	Day 30	Day 60	Day 120
I (LCP)	1	0	1	2	3	4
	2	0	1	2	3	4
	3	0	1	2	3	4
	4	0	1	2	3	4
	5	0	0	2	3	4
	6	0	0	1	3	4
II (SOP)	1	0	1	2	3	4
	2	0	1	2	4	4
	3	0	1	2	3	4
	4	0	2	2	4	4
	5	0	1	2	3	4
	6	0	0	2	4	4
III (LRP)	1	0	1	0	2	4
	2	0	1	2	3	4
	3	0	0	1	2	4
	4	0	0	2	3	4
	5	0	1	2	4	4
	6	0	0	2	4	4

Evaluation of radiographic healing as per the modification in the method of Hammer *et al*. (1985)

Callus formation	Fracture line	Stage of union	Grade / Score
No callus	Distinct	Not achieved	0
Trace: No bridging of fracture line	Distinct	Not achieved	1
Apparent: Bridging of fracture line	Discernible	Uncertain	2
Massive: Bone trabeculae crossing fracture line	Barely discernible	Achieved	3
Homogenous bone structure	Obliterated	Achieved	4

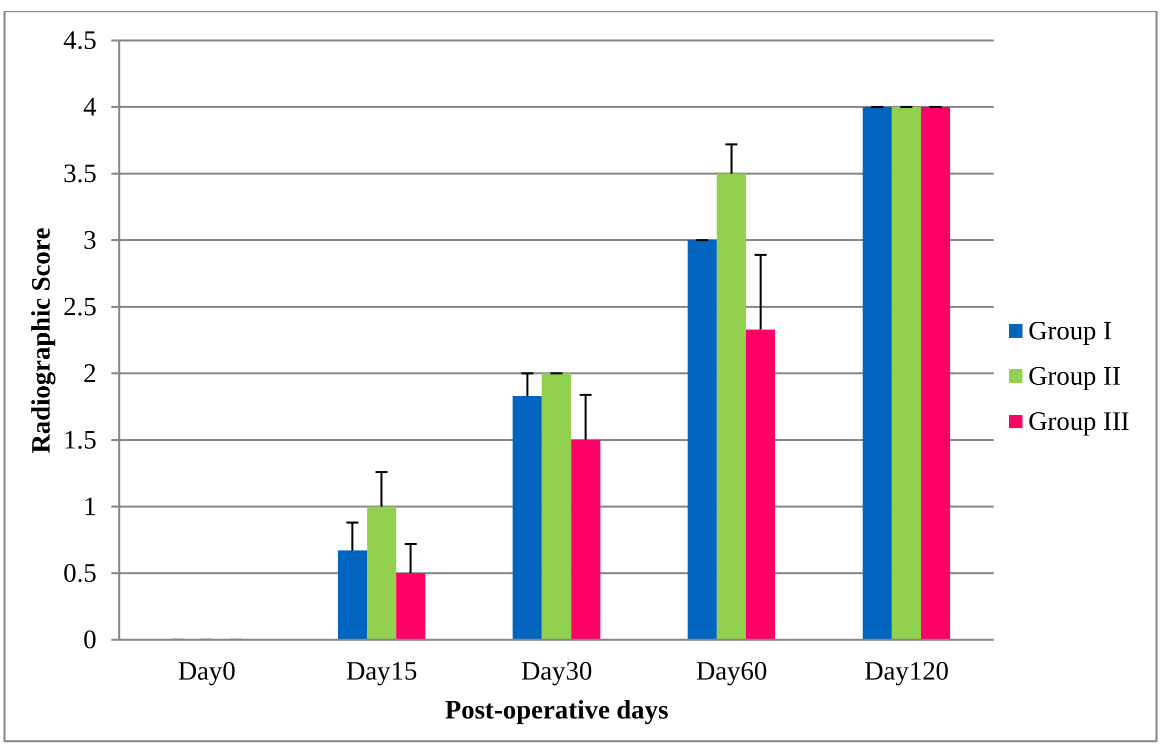
Table 16b: Mean ± S.E. of radiographic score on different post-operative days in all the groups of animals

Group	Group I	Group II	Group III
Day0	0.00±0.00[a]	0.00±0.00[a]	0.00±0.00[a]
Day15	0.67±0.21[a]	1.00±0.26[ab]	0.50±0.22[ab]
Day30	1.83±0.17[b]	2.00±0.00[b]	1.50±0.34[bc]
Day60	3.00±0.00[c p]	3.50±0.22[c p]	2.33±0.56[c pq]
Day120	4.00±0.00[c]	4.00±0.00[c]	4.00±0.00[d]
Overall	1.90±0.28[p]	2.10±0.29[p]	1.67±0.29[pq]

Means with different superscripts (a,b,c,d..) indicate significant difference ($p<0.01$) between time intervals within a group

Means with different superscripts (p,q,r,s..) indicate significant difference ($p<0.01$) between groups within a time interval

Fig. 11: Radiographic score on different post-operative days



Follow up radiographic evaluation on the 15th post-operative day, depicted proper apposition and alignment of fracture fragments with adequate cortical contact between fractured fragments in all cases. The fracture line was distinct with signs of bone resorption at the fracture line and traces of callus at far cortex in all the cases. Mild to exuberant periosteal callus was noticed at trans cortex along the length of the bone especially at the points where the screw were inserted.

Follow up radiographic evaluation on the 30th post-operative day revealed osteosynthesis and secondary healing characterised by apparent development of bridging callus filling the fracture gap. The radiolucent fracture line was faintly visible and there was patchy mineralization of the unstructured bridging callus. The fracture line was becoming hazy and was fading. The amount of periosteal callus appeared to be more extensive, dense and homogenous (soft callus) than on day 15. More callus formation was noticed on the far cortex than near cortex. Traces of callus infiltration over the bone plate was observed.

The iatrogenic fracture in case 5 had united.

The plates and screws were in position in all the cases and no cases showed any evidence of plate bending or screw loosening during the period of study.

On 60th post-operative day, the fracture line was obliterated with massive radio-dense callus completely filling the fracture site. The radiolucent fracture line was not visible indicating achievement of radiographic union. The periosteal callus had decreased in size and was more homogenous than on day 30. The callus was smoothening and becoming uniform in density. Cortico-medullary remodelling was evident indicating early clinical union.

On 120th post-operative day, the fracture site was bridged and the fracture line was not visible. The medullary canal had established. The periosteal callus had decreased in size and was more radiolucent indication that remodelling was taking place. Dense callus had begun to condense and remodel on periosteal and endo-osteal surface. Distinct cortico-medullary separation caused by remodelling was visible.

The plates and screws were in position in all the cases and no cases showed any evidence of plate bending or screw loosening during the period of study. In case 4, lateral deviation in angulation of the proximal fragment of tibia was noticed.

Radiographic union was achieved in all the cases and all the cases healed without any complications (Plate 15, Plate 16 and Plate 17). All the cases healed by secondary callus formation. Excess periosteal callus along the length of the bone in case 4 was noticed due to periosteal stripping.

All the animals were allotted a radiographic score and the mean score of this group on day 0, 15, 30, 60 and 120 was 0.00±0.00, 0.67±0.2, 1.83±0.17, 3.00± 0.00 and 4.00±0.00, respectively.

The statistical analysis revealed significant ($p<0.01$) difference of radiographic score on day 0 from that of day 30, day 60 and day 120. Similarly, the radiographic score on day 15 was significantly ($p<0.01$) differing from that of day 30, day 60 and day 120.

Plate 15: Group I case 4

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

A) Pre-operative medio-lateral and cranio-caudal radiographic views showing oblique transverse fracture at mid-diaphysis of tibia

B) Medio-lateral and cranio-caudal views of post-operative day 0 radiograph of same case showing proper alignment of tibial fracture and sharp fracture lines

C) Medio-lateral and cranio-caudal views of post-operative day 15 radiograph of same case showing traces of callus at tibial fracture site and initiation of periosteal callus

D) Medio-lateral and cranio-caudal views of post-operative day 30 radiograph of same case showing bridging of tibial fracture site and dense periosteal callus

E) Medio-lateral and cranio-caudal views of post-operative day 60 radiograph of same case showing bridging of tibial fracture.
Denser and homogenous periosteal callus is seen

F) Medio-lateral and cranio-caudal views of post-operative day 120 radiograph of same case showing remodeling of tibial fracture

a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120

Group I case 4: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120

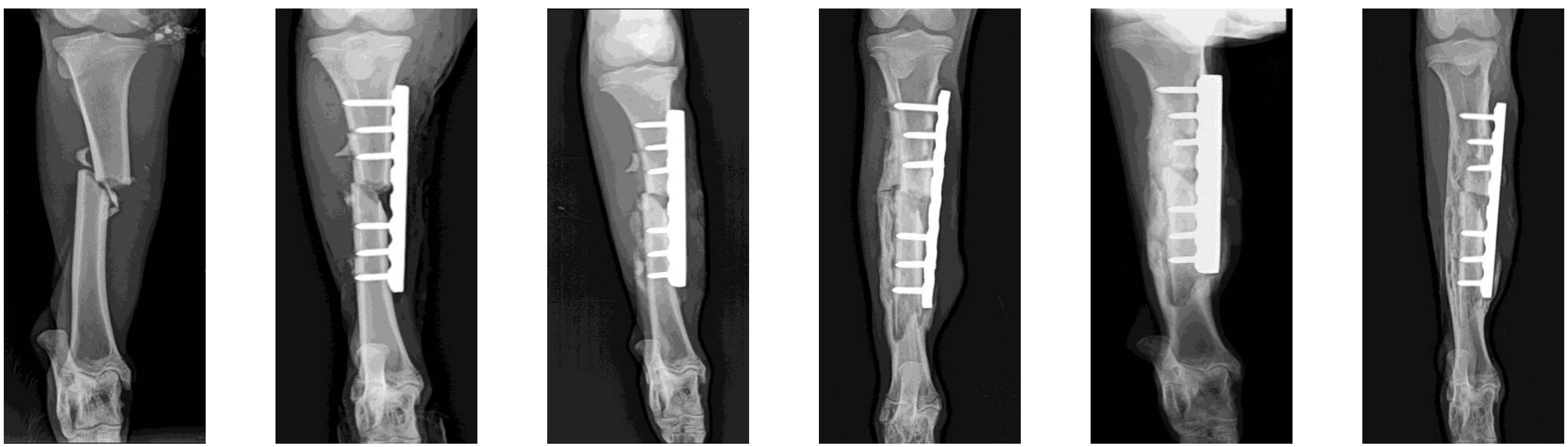


Plate 15: Group I, case 4- Sequential cranio-caudal radiographs showing fracture healing

Plate 16: Group I case 5

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

A) Pre-operative medio-lateral and cranio-caudal radiograph showing transverse tibial fracture at mid-diaphysis

B) Medio-lateral and cranio-caudal views of day 0^{th} radiograph of same case showing proper alignment of tibial fracture and sharp fracture lines

C) Medio-lateral and cranio-caudal views of post-operative day 15^{th} radiograph of same case showing hazy fracture line in tibia with increase in gap and periosteal callus initiation

D) Medio-lateral and cranio-caudal views of post-operative day 30^{th} radiograph of same case showing bridging of tibial fracture line (far cortex) with bone resorption (near cortex)

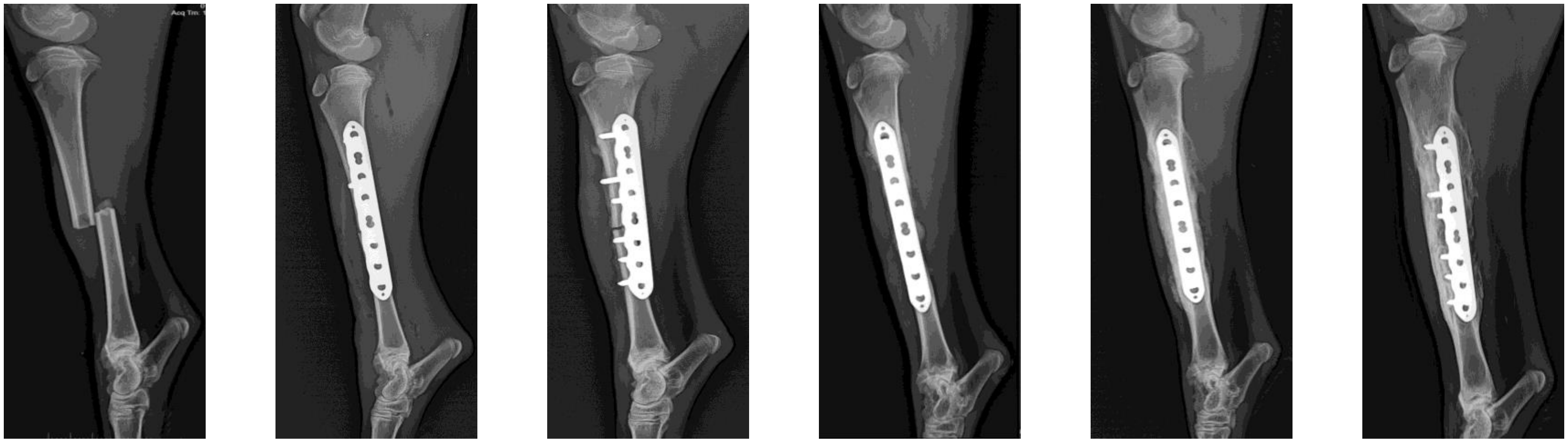
E) Medio-lateral and cranio-caudal views of post-operative day 60^{th} radiograph of same case showing bridging of tibial fracture.

F) Denser and homogenous periosteal callus is seen

G) Medio-lateral and cranio-caudal views of post-operative day 120^{th} radiograph of same case showing remodeling of tibial fracture.

H) Cortico-medullary union is achieved

a) Pre-operative | b) Day 0 | c) Day 15 | d) Day 30 | e) Day 60 | f) Day120



Group I case 5: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative | b) Day 0 | c) Day 15 | d) Day 30 | e) Day 60 | f) Day120

Plate 16: Group I case 5 - Sequential cranio-caudal radiographs showing fracture healing

Plate 17: Group I case 6

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

a) Pre-operative medio-lateral and cranio-caudal radiographic views showing transverse fracture at mid-diaphysis of tibia

b) Medio-lateral and cranio-caudal views of post-operative day 0 radiograph of same case showing proper alignment of tibial fracture fragments

c) Medio-lateral and cranio-caudal views of post-operative day 15 radiograph of same case showing hazy fracture line in tibia with increase in gap and periosteal callus initiation

d) Medio-lateral and cranio-caudal views of post-operative day 30 radiograph of same case showing bridging callus at tibial fracture site.
Denser periosteal callus is seen

e) Medio-lateral and cranio-caudal views of post-operative day 60 radiograph of same case showing union of tibial fracture site.
Homogenous periosteal callus is seen

f) Medio-lateral and cranio-caudal views of post-operative day 120 radiograph of same case showing remodeling of tibial fracture.
Cortico-medullary union is achieved

a) Pre-operative | b) Day 0 | c) Day 15 | d) Day 30 | e) Day 60 | f) Day120

Group I case 6: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative | b) Day 0 | c) Day 15 | d) Day 30 | e) Day 60 | f) Day120

Plate 17: Group I case 6- Sequential cranio-caudal radiographs showing fracture healing

Likewise, the radiographic score on day 30 was significantly ($p<0.01$) differing from that of day 60 and day 120. The radiographic score on day 60 were non-significantly differing from that of day 120.

4.2.6.4.2 Group II (String of pearls plate)

The apposition and alignment of the fractured fragments in all the cases was satisfactory and revealed adequate cortical contact between the fractured fragments. The fracture line was distinct with sharp and well-defined loss of radiographic density. The screw length, size, position and placement were appropriate in all cases except in case 4 where the plate was placed too proximal and one screw was monocortical. In case 4 and case 5, mal-alignment of 1 mm was noticed between the cortexes.

Follow up radiographs obtained on the 15th post-operative day, depicted proper apposition and alignment of fracture fragments with adequate cortical contact between fractured fragments in all cases. The fracture line was distinct in all the cases. However, traces of callus were noticed indicating initiation of callus formation. Mild to exuberant periosteal callus was noticed along the length of the bone trans cortex especially at the points where the screws were inserted.

By 30th post-operative day, the radiolucent fracture line was hazy and less visible and there was patchy mineralization of the unstructured bridging callus which could be appreciated in all the cases indicating that the complete bridging of the fracture fragments had not yet happened. More callus formation was noticed on the far cortex side of plate. The periosteal callus along the fracture was denser and homogenous.

On day 60, massive callus completely filling the fracture site was noticed and callus was smoother and radio-opaque. The fracture site was obliterated, radio-dense and barely discernible indicating that the bridging of the fracture fragments had happened. Early cortico-medullary remodelling was evident indicating early clinical union. The amount of periosteal callus appeared to be more homogenous and decreased in size than on day 30. The callus was smoothening and becoming uniform in density. Traces of callus were noticed over the plate in all the cases.

By day 120, the fracture line could not be appreciated in all the cases. The callus at the fracture site was homogenous and less dense indicating that the bridging and union of the fracture fragments had happened completely. The medullary canal was clearer and both the cortex could be easily appreciated indicating establishment of the canal. The periosteal callus had decreased in size and density indicating that remodelling phase had initiated.

The plates and screws were in position in all the cases and no cases showed any evidence of plate bending or screw loosening during the period of study.

Radiographic union was achieved in all the cases and all the cases healed without any complications (Plate 18, plate 19 and plate 20). All the cases healed through secondary callus formation.

All the animals were allotted a radiographic score and the mean score of this group on day 0, 15, 30, 60 and 120 was 0.00 ± 0.00, 0.50 ± 0.2, 1.50 ± 0.34, 2.33 ± 0.56 and 4.00 ± 0.00 respectively.

Plate 18: Group II case 4

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

a) Pre-operative medio-lateral and cranio-caudal radiographic views showing transverse fracture at mid-diaphysis of tibia

b) Medio-lateral and cranio-caudal views of post-operative day 0 radiograph of same case showing proper alignment of tibial fracture fragments

c) Medio-lateral and cranio-caudal views of post-operative day 15 radiograph of same case showing periosteal callus and hazy fracture line

d) Medio-lateral and cranio-caudal views of post-operative day 30 radiograph of same case showing bone resorption at tibial fracture site.
Denser periosteal callus is seen

e) Medio-lateral and cranio-caudal views of post-operative day 60 radiograph of same case showing union of fracture site of tibia.
Homogenous periosteal callus is seen

f) Medio-lateral and cranio-caudal views of post-operative day 120 radiograph of same case showing remodeling of tibial fracture.
Cortico-medullary union is achieved

a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120

Group II case 4: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120

Plate 18: Group II case 4: Sequential cranio-caudal radiographs showing fracture healing

Plate 19: Group II case 5

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

A) Pre-operative medio-lateral and cranio-caudal radiographic views showing comminuted fracture at mid-diaphysis of tibia

B) Medio-lateral and cranio-caudal views of post-operative day 0 radiograph of same case showing proper alignment of tibial fracture fragments

C) Medio-lateral and cranio-caudal views of post-operative day 15 radiograph of same case showing periosteal callus and traces of callus at fracture site is seen

D) Medio-lateral and cranio-caudal views of post-operative day 30 radiograph of same case showing bone apparent bridging of tibial fracture site.
Denser periosteal callus is seen

E) Medio-lateral and cranio-caudal views of post-operative day 60 radiograph of same case showing bridging of tibial fracture site. Homogenous periosteal callus is seen

F) Medio-lateral and cranio-caudal views of post-operative day 120 radiograph of same case showing remodeling of tibial fracture.
Cortico-medullary union is achieved

a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120

Group II case 5: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120

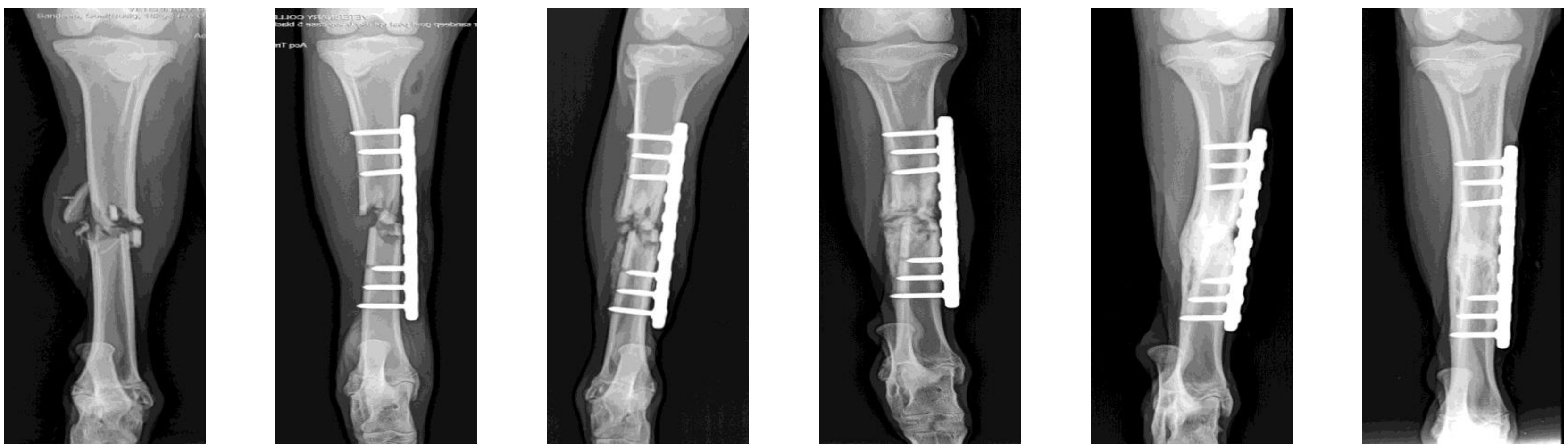


Plate 19: Group II case 5: Sequential cranio-caudal radiographs showing fracture healing

Plate 20: Group II case 6

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

A) Pre-operative medio-lateral and cranio-caudal radiographic views showing transverse fracture at mid-diaphysis of tibia

B) Medio-lateral and cranio-caudal views of post-operative day 0 radiograph of same case showing proper alignment of fracture fragments

C) Medio-lateral and cranio-caudal views of post-operative day 15 radiograph of same case showing slight periosteal callus and hazy fracture line in tibia

D) Medio-lateral and cranio-caudal views of post-operative day 30 radiograph of same case showing apparent bridging of tibial fracture site.
Denser periosteal callus is seen

E) Medio-lateral and cranio-caudal views of post-operative day 60 radiograph of same case showing bridging of tibial fracture site.
Homogenous periosteal callus is seen

F) Medio-lateral (A) and cranio-caudal (B) views of post-operative day 120 radiograph of same case showing remodeling of tibial fracture.
Cortico-medullary union is achieved

a) Pre-operative **b) Day 0** **c) Day 15** **d) Day 30** **e) Day 60** **f) Day120**

Group II case 6: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative **b) Day 0** **c) Day 15** **d) Day 30** **e) Day 60** **f) Day120**

Plate 20: Group II case 6: Sequential cranio-caudal radiographs showing fracture healing

Statistical analysis revealed significant ($p<0.01$) difference of radiographic scores on day 0 from that of day 30, day 60 and day 120. Similarly, the radiographic scores on day 15 was significantly ($p<0.01$) differing from that of day 60 and day 120. Likewise, the radiographic scores on day 30 was significantly ($p<0.01$) differing from that of day 60 and day 120. The radiographic score on day 60 was non-significantly differing from that of day 120.

4.2.6.4.3 Group III (Locking reconstruction plate)

The apposition and alignment of the fractured fragments in all the cases was satisfactory and revealed adequate cortical contact between the fractured fragments was observed in all the cases. The fracture line was distinct with sharp and well-defined loss of radiographic density. In case 3 and case 6, mal-alignment of 1 mm was noticed between the cortices. The screw length, size, position and placement were appropriate in all cases except in case 4 where the plate was placed too proximal and one screw was mono-cortical. The fracture line after alignment was distinct in all the cases and no callus was present.

The screw length, size, position and placement were appropriate in all cases except in case 1, case 3, case 5 and case 6. In case 1 and 6, the last screw in the proximal fragment had entered in the fracture line. In case 3, the last screw in the distal fragment was monocortical. In case 5, the first screw was cancellous type. Few screw heads in case 1 and case 3 projected slightly above the bone plate.

Follow up radiographs were obtained on the 15th post-operative day, depicted distinct fracture line. Early signs of bone resorption were noticed at the fracture site with the fracture margins being indistinct. Traces of periosteal callus were noticed along the trans-cortex especially at the points where the screws were place. The plates and screws were in position in all the cases and no cases showed any evidence of plate bending or screw loosening during the period of study.

On the 30^{th} post-operative day, the fracture line was distinct to discernible indicating apparent bridging of the fracture line with initiation of soft callus. However, the union was not complete and the bridging callus was not structured. The periosteal callus noticed on day 15 was denser and more homogenous in all the cases. In case 1, bone resorption had occurred around the screw that was placed in the fracture line.

By 60^{th} post-operative day, the fracture line was obliterated and apparent bridging of the fracture line had occurred indicating that the union had achieved. The bone structure and callus were of even density and homogenous the borders of the bridging callus were of even density.

The bone resorption evidenced by lytic changes at the fracture site in case 1 and case 3 was filled with callus and cortical establishment was evident. Callus proliferation over the plate was seen in case 4, 5 and 6.

By day 120, the fracture line could not be appreciated in all the cases, and the callus at the fracture site was homogenous and dense indicating that the bridging of the fracture fragments had happened completely. The periosteal callus had decreased in size and density indicating that remodelling phase was under process. Distinct cortico-medullary separation caused by remodelling was visible. Callus proliferation over the plates had decreased.

Radiographic union was achieved in all the cases and all the cases healed without any complications (Plate 21, Plate 22 and Plate 23). In this group all the cases healed through secondary callus formation. However, the quantity of callus was lesser than the other two groups. Delayed initiation of periosteal callus was observed in this group in comparison to the other two groups. Compared to the other two groups an earlier initiation of remodelling by day 60 was observed in this group.

All the animals were allotted a radiographic score and the mean score of this group on day 0, 15, 30, 60 and 120 was 0.00±0.00, 0.50±0.22, 1.50±0.34, 2.33±0.56 and 4.00±0.00 respectively.

The statistical analysis revealed significant ($p<0.01$) difference of radiographic score on day 0 from that of day 30, day 60 and day 120. Similarly, the radiographic score on day 15 was significantly ($p<0.01$) differing from that of day 60 and day 120. Likewise, the radiographic score on day 30 was significantly ($p<0.01$) differing from that of day 120. The radiographic score on day 60 was significantly ($p<0.01$) differing from that of day 120.

4.2.6.5 Biochemical parameters

Biochemical parameters such as alkaline phosphatase, serum calcium and serum inorganic phosphorous were estimated to assess course of fracture healing.

4.2.6.5. 1 Serum Alkaline Phosphatase (IU/L)

The mean ± S.E., values of serum alkaline phosphatase are given in table 17 and Fig. 12.

Plate 21: Group III case 1

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

a) Pre-operative medio-lateral and cranio-caudal radiographic views showing transverse fracture at mid-diaphysis of tibia

b) Medio-lateral and cranio-caudal views of post-operative day 0 radiograph of same case showing proper alignment of tibial fracture fragments

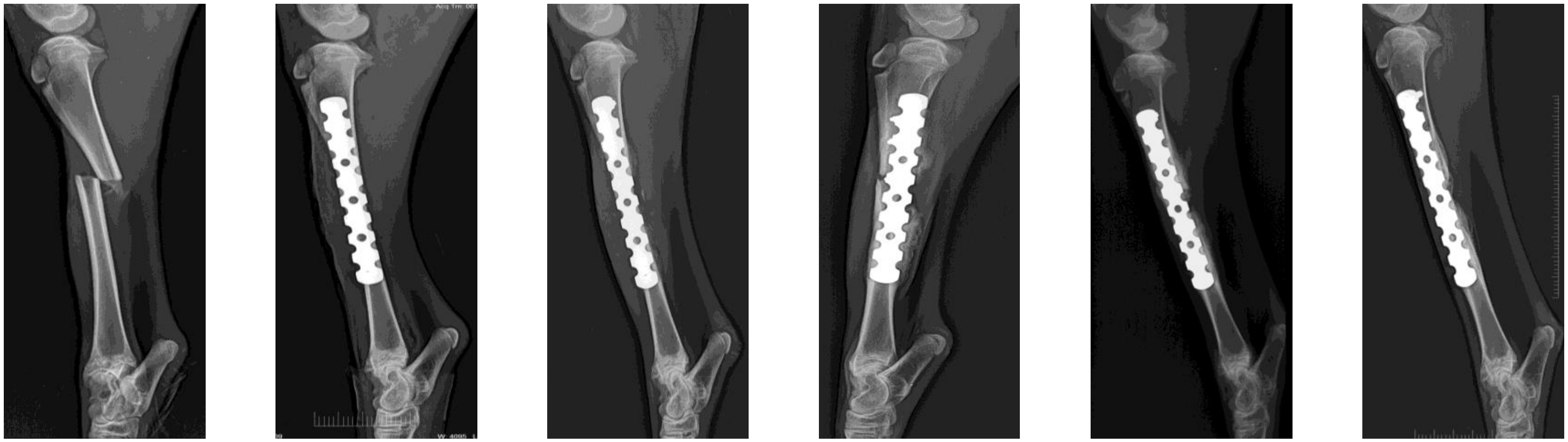
c) Medio-lateral and cranio-caudal views of post-operative day 15 radiographs of same case showing slight periosteal callus and hazy fracture line in tibia

d) Medio-lateral and cranio-caudal views of post-operative day 30 radiographs of same case showing resorption of bone at tibial fracture site. Denser periosteal callus is seen

e) Medio-lateral and cranio-caudal views of post-operative day 60 radiographs of same case showing bridging of tibial fracture site. Reduced periosteal callus is seen

f) Medio-lateral and cranio-caudal views of post-operative day 120 radiographs of same case showing remodeling of tibial fracture

a) Pre-operative **b) Day 0** **c) Day 15** **d) Day 30** **e) Day 60** **f) Day120**



Group III case 1: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative **b) Day 0** **c) Day 15** **d) Day 30** **e) Day 60** **f) Day120**

Plate 21: Group III case 1- Sequential cranio-caudal radiographs showing fracture healing

Plate 22: Group III case 5

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

a) Pre-operative medio-lateral and cranio-caudal radiographic views showing oblique fracture at mid-diaphysis of tibia

b) Medio-lateral and cranio-caudal views of post-operative day 0 radiographs of same case showing proper alignment of tibial fracture fragments

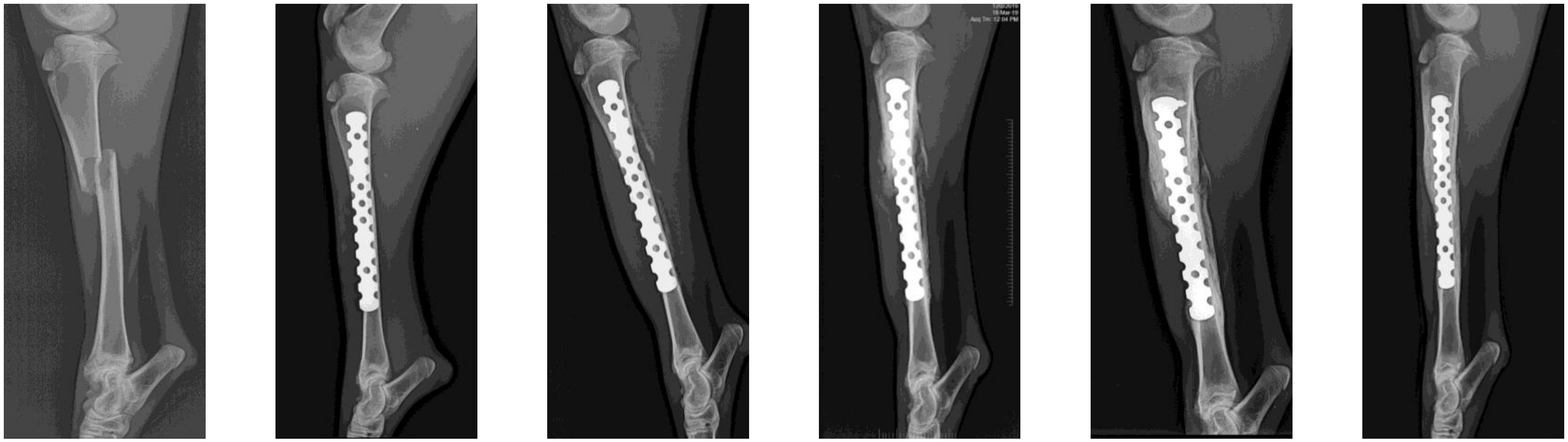
c) Medio-lateral and cranio-caudal views of post-operative day 15 radiographs of same case showing slight periosteal callus and hazy fracture line in tibia

d) Medio-lateral and cranio-caudal views of post-operative day 30 radiographs of same case showing apparent bridging of tibial fracture site.
Denser periosteal callus is seen

e) Medio-lateral and cranio-caudal views of post-operative day 60 radiographs of same case showing bridging of tibial fracture site.
Homogenous periosteal callus is seen

f) Medio-lateral and cranio-caudal views of post-operative day 120 radiographs of same case showing remodeling of tibial fracture

a) Pre-operative **b) Day 0** **c) Day 15** **d) Day 30** **e) Day 60** **f) Day120**



Group III case 5: Sequential medio-lateral radiographs showing fracture healing

a) Pre-operative **b) Day 0** **c) Day 15** **d) Day 30** **e) Day 60** **f) Day120**

Plate 22: Group III case 5- Sequential cranio-caudal radiographs showing fracture healing

Plate 23: Group III case 6

Sequential medio-lateral and cranio-caudal radiographs showing fracture healing

a) Pre-operative medio-lateral and cranio-caudal radiographic views showing oblique fracture at mid-diaphysis of tibia in

b) Medio-lateral and cranio-caudal views of post-operative day 0 radiographs of same case showing proper alignment of tibial fracture fragments

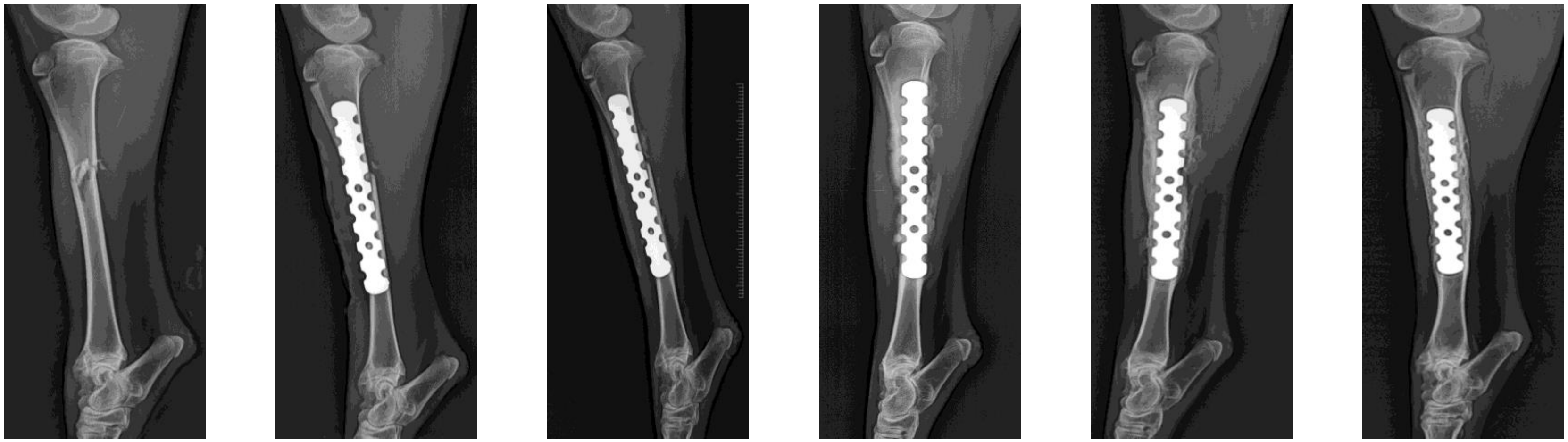
c) Medio-lateral and cranio-caudal views of post-operative day 15 radiographs of same case showing slight periosteal callus and hazy fracture line in tibia

d) Medio-lateral and cranio-caudal views of post-operative day 30 radiographs of same case showing apparent bridging of tibial fracture site. Denser periosteal callus is seen

e) Medio-lateral and cranio-caudal views of post-operative day 60 radiographs of same case showing bridging of tibial fracture site. Homogenous periosteal callus is seen

f) Medio-lateral and cranio-caudal views of post-operative day 120 radiographs of same case showing remodeling of tibial fracture

a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120



Group III case 6: Sequential medio-lateral radiographs showing fracture healing

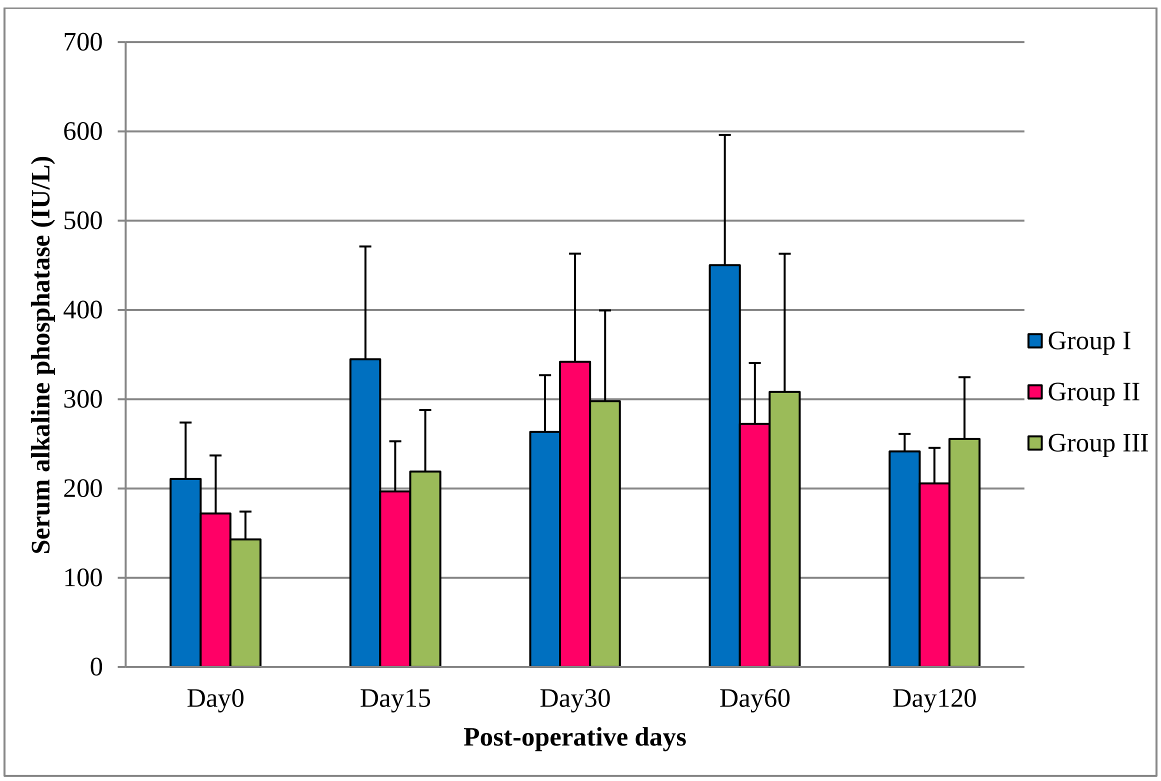
a) Pre-operative b) Day 0 c) Day 15 d) Day 30 e) Day 60 f) Day120

Plate 23: Group III case 6- Sequential cranio-caudal radiographs showing fracture healing

Table 17: Mean ± S.E., of serum alkaline phosphatase (IU/L) on different post-operative days in all the groups of animals

Days	Group I	Group II	Group III
0	210.78±63.00	171.95±64.98	142.95±31.09
15	344.53±126.52	196.83±56.00	218.83±68.96
30	263.37±63.48	341.80±121.18	297.78±101.61
60	450.17±145.85	272.13±68.40	308.11±154.79
120	241.63±19.44	205.65±39.80	255.55±69.03

Fig. 12: Serum alkaline phosphatase levels (IU/L) on different post-operative days in all the groups of animals



The mean ± S.E., values of serum alkaline phosphatase (IU/L) of group I animals on day 0, 15, 30, 60 and 120 were 210.78±63.00, 344.53±126.52, 263.37±63.48, 450.17±145.85 and 241.63±19.44 respectively.

The mean ± S.E., values of serum alkaline phosphatase (IU/L) of group II animals on day 0, 15, 30, 60 and 120 were 171.95±64.98, 196.83±56.00, 341.80±121.18, 272.13±68.40 and 205.65±39.80 respectively.

The mean ± S.E., values of serum alkaline phosphatase (IU/L) of group III animals on day 0, 15, 30, 60 and 120 were 142.95±31.09, 218.83±68.96, 297.78±101.61, 308.11±154.79 and 255.55±69.03, respectively.

There was no significant difference in serum alkaline phosphatase levels between the groups and between the days of observation.

4.2.6.5.2 Serum Calcium (mg/dL)

The Mean ± S.E., values of serum calcium (mg/dL) are given in table 18 and Fig. 13.

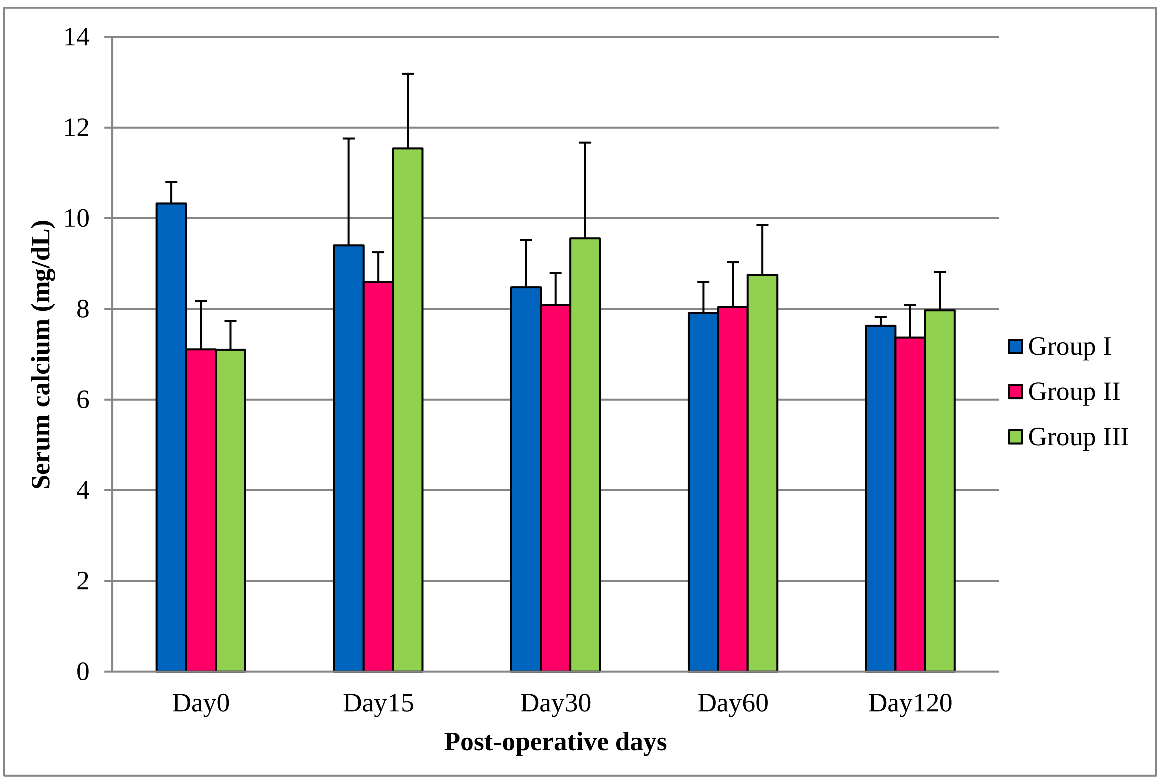
The mean ± S.E., values of serum calcium (mg/dL) of group I animals on day 0, 15, 30, 60 and 120 were 10.33±0.47, 9.40±2.36, 8.48±1.04, 7.91±0.68 and 7.63±0.19 respectively.

The mean ± S.E., values of serum calcium (mg/dL) of groups II animals on day 0, 15, 30, 60 and 120 were 7.11±1.06, 8.60±0.65, 8.08±0.71, 8.04±0.99 and 7.37±0.72 respectively.

Table 18: Mean ± S.E., of serum calcium (mg/dL) on different post-operative days in all the three groups of animals

Days	Group I	Group II	Group III
0	10.33±0.47	7.11±1.06	7.10±0.64
15	9.40±2.36	8.60±0.65	11.54±1.65
30	8.48±1.04	8.08±0.71	9.56±2.11
60	7.91±0.68	8.04±0.99	8.75±1.10
120	7.63±0.19	7.37±0.72	7.97±0.84

Fig. 13: Serum calcium (mg/dL) on different post-operative days in all the groups of animals



The mean ± S.E., values of serum calcium (mg/dL) of groups III animals on day 0, 15, 30, 60 and 120 were 7.10±0.64, 11.54±1.65, 9.56±2.11, 8.75±1.10 and 7.97±0.84 respectively.

The serum calcium (mg/dL) levels were non-significantly differing at different time intervals studied in each group. Also, the difference between the groups at each time interval was non-significant.

4.2.6.5.3 Serum Inorganic Phosphorous (mg/dL)

The mean ± S.E., values of serum inorganic phosphorous (mg/dL) are given in table 19 and Fig. 14.

The mean ± S.E., values of serum inorganic phosphorous (mg/dL) of group I animals on day 0, 15, 30, 60 and 120 were 6.67±0.23, 7.31±0.22, 7.94±1.08, 7.69±0.56 and 7.51±0.57 respectively.

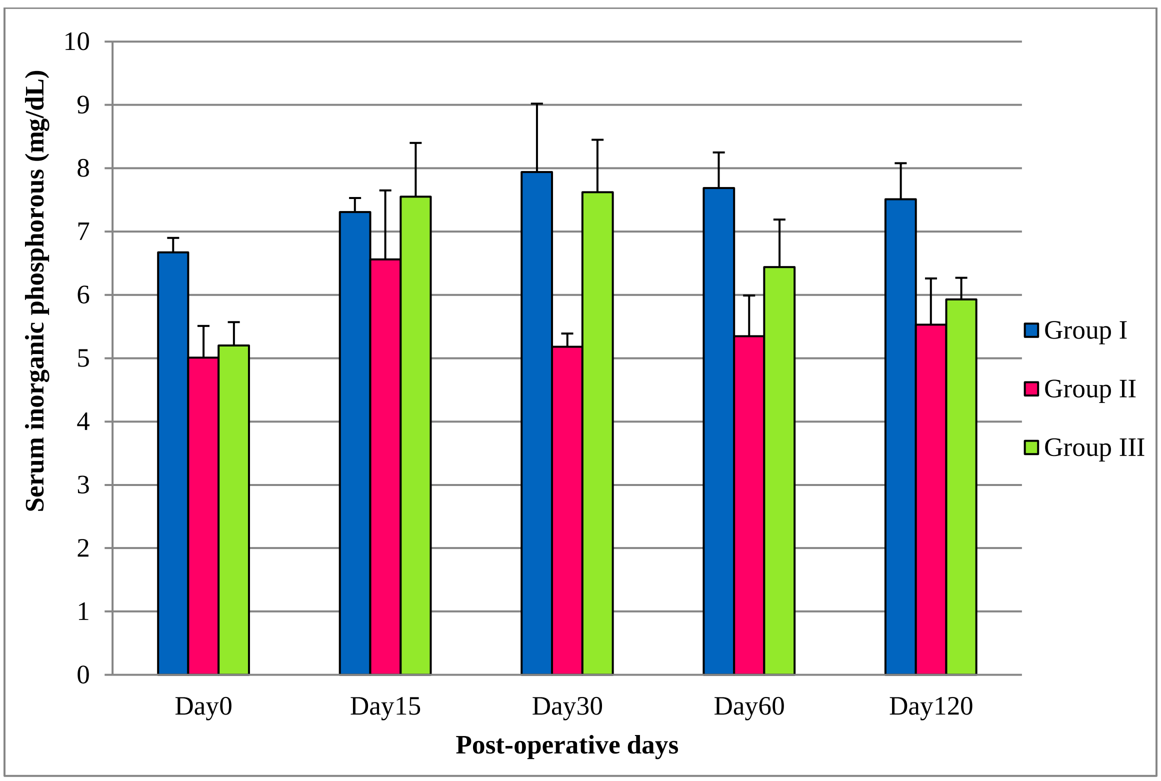
The mean ± S.E., values of serum inorganic phosphorous (mg/dL) of group II animals on day 0, 15, 30, 60 and 120 were 5.01±0.50, 6.56±1.09, 5.18±0.21, 5.35±0.64 and 5.53±0.73 respectively.

The mean ± S.E., values of serum inorganic phosphorous (mg/dL) of group III animals on day 0, 15, 30, 60 and 120 were 5.20±0.37, 7.55±0.85, 7.62±0.83, 6.44±0.75 and 5.93±0.34 respectively.

Table 19: Mean ± S.E., of serum inorganic phosphorous (mg/dL) on different post-operative days in all groups of animals

Days	Group I	Group II	Group II
0	6.67±0.23	5.01±0.50	5.20±0.37
15	7.31±0.22	6.56±1.09	7.55±0.85
30	7.94±1.08	5.18±0.21	7.62±0.83
60	7.69±0.56	5.35±0.64	6.44±0.75
120	7.51±0.57	5.53±0.73	5.93±0.34

Fig. 14: Serum inorganic phosphorous (mg/dL) on different post-operative days in all the groups



In each group, the serum inorganic phosphorous (mg/dL) levels were non-significantly differing among the different days of observation. Similarly, in each time interval, the serum inorganic phosphorous (mg/dL) levels were non-significantly differing among the three groups studied.

4.2.6.6 Implant removal

The details of the goats in which the implants were removed in all the three group of animals after the end of study are listed in table 20. The implants were removed under general anaesthesia using inj. xylazine hydrochloride and inj. ketamine hydrochloride. The anaesthetic combination was found to be sufficient for plate removal in all the cases.

No major complications were noticed during the plate removal. The implants could be easily palpated below the skin. In all the cases copious amounts of fibrous tissue had grown through the holes encircling the entire plate and snugly holding the plate to the bone where screws were not inserted. There was some difficulty encountered during plate removal in six goats in which the plates were removed on day 120. In these goats, proliferation of the callus over the plate or surrounding the plates was present. In four goats the plates were removed on day 150. The amount of callus surrounding the plate in these goats had decreased in comparison to those goats in which the plates were removed on day 120.

Difficulty was observed while removing of five screws due to proliferation of fibrous tissue over the screw head.

Table 20: Details of cases in which implants were removed

Group	Case No.	Implant removal time after surgery and observations	
I	LCP - 1	Owner sold the animal after end of study period as the animal was pregnant. Hence, the implant could not be retrieved.	
	LCP - 2	Owner presented the goat at 9 months after the end of the study period. The plate was exposed and soft tissue infection was present.	
	LCP - 3	Animal fell in the well, drowned and died near the end of the study period. Bone along with plate was recovered. Excess secondary callus around the plate was noticed.	
	LCP - 4	120 days	No complications noticed - Callus and fibrous tissue growth
	LCP - 5	120 days	No complications noticed- Callus and fibrous tissue growth
	LCP - 6	150 days	Difficult to remove three screws around fracture site.
II	SOP - 1	Owner did not consent for second surgery.	
	SOP - 2	120 days	Plate removed due to exposure of skin. No complications noticed during removal of plate.
	SOP - 3	Owner did not consent for second surgery.	
	SOP - 4	120 days	Difficult to remove two screws around fracture site. Callus around the plate.
	SOP - 5	150 days	No complications noticed-easy plate removal
	SOP - 6	Owner did not consent for second surgery as the animal was pregnant during post-operative period	
III	LRP - 1	120 days	No complications noticed- Callus and fibrous tissue growth
	LRP - 2	On presentation at 18 months, the proximal part of bone plate was exposed and soft tissue infection was present. No complications with regard to screw breakage or jamming were noticed. Callus was present over the plate.	
	LRP - 3	Owner did not consent for second surgery.	
	LRP - 4	120 days	No complications noticed- Callus and fibrous tissue growth
	LRP - 5	150 days	Neck of screw was broken. Hence only screw head could be removed and the shaft was left inside the bone.
	LRP - 6	150 days	No complications noticed

In one screw there was screw breakage at the neck and only the head could be removed and the implant was left in-situ.

No jamming of the screws was noticed in any of the screws. The plates could be easily lifted after removal of all the screws (Plate 24, Plate 25 and Plate 26).

The incisional would was sutured after thoroughly lavaging the operative site. Post-operatively, a course of antibiotic and anti-inflammatory therapy was given. The goats were restricted in their movement in-order to avoid occurrence of re-fracture. The sutures were removed after healing of the incisional wounds. All the cases recovered uneventfully.

Radiographs taken at one month post implant removal revealed that all the screw holes were filled with callus and the bone was in remodelling phase (Plate 27).

4.2.6.7 Complications

The results of the present clinical study revealed no serious intra-operative and post-operative complications in any of the groups. In the present study, animals in all the three groups showed a remarkable improvement with normal limb function and maintaining good implant stability throughout the treatment period without any complications. The post-operative complications were limited to wound infection and wound dehiscence. Since these complications resulted in uneventful recovery, they were considered trivial.

Major intra-operative complications were not observed in any of the cases except creation of iatrogenic fractures while drilling or tapping the bone or tightening of the screws.

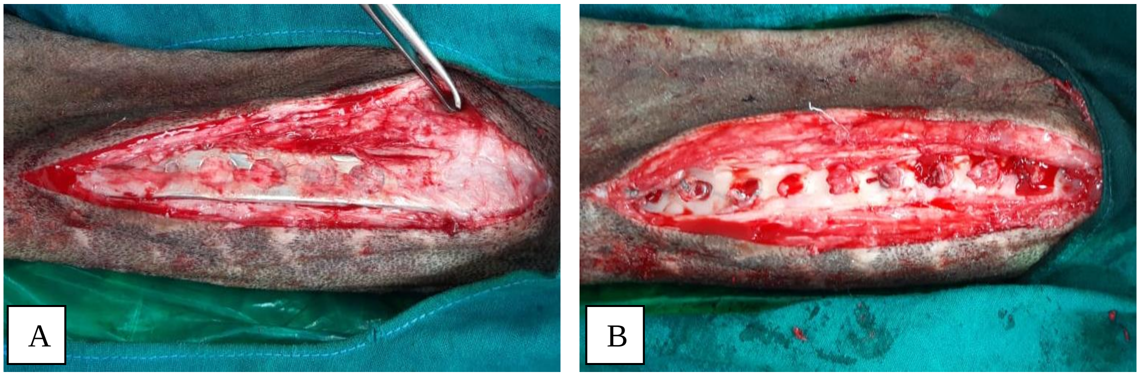


Plate 24: Plate removal after end of study period in group I

- **A) Exposure of the bone plate before removal of the LCP plate**
- **B) Bone after removal of the LCP plate**

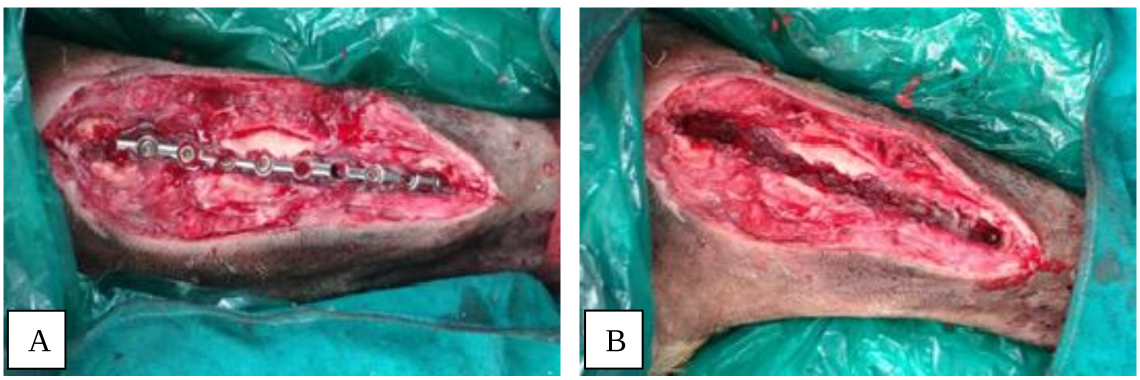


Plate 25: Plate removal after end of study period in group II

- **A) Exposure of the bone plate before removal of the SOP plate**
- **B) Bone after removal of the SOP plate**

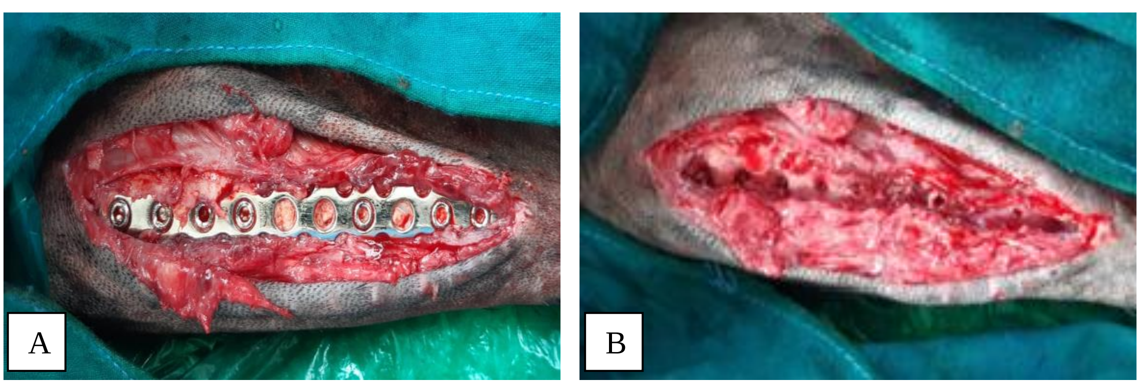


Plate 26: Plate removal after end of study period in group III

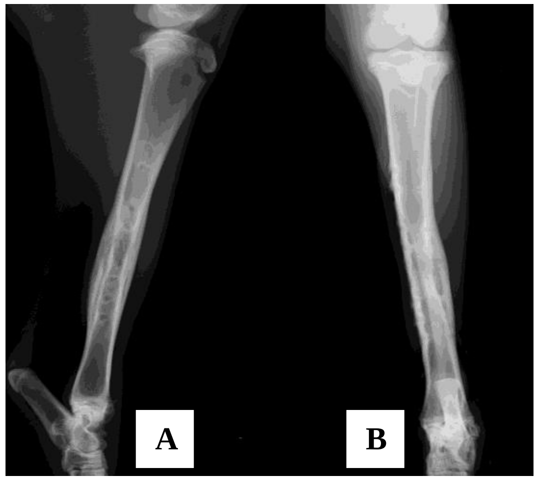
- **A) Exposure of the bone plate before removal of the LRP**
- **B) Bone after removal of the LRP plate**

Plate 27: Medio-lateral and cranio-caudal radiographs one month after implant removal showing remodelling and cortico-medullary reunion of bone

Group I, case 6: Medio-lateral (A) and cranio-caudal (B) radiographs one month after implant removal showing remodelling and cortico-medullary reunion of bone

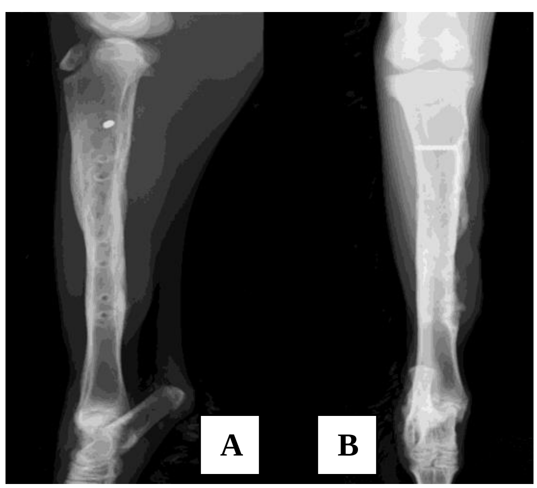
Group II, case 5: Medio-lateral (A) and cranio-caudal (B) radiographs one month after implant removal showing remodelling and cortico-medullary reunion of bone

Group III, case 5: Medio-lateral (A) and cranio-caudal (B) radiographs one month after implant removal showing remodelling and cortico-medullary reunion of bone



Group 1, case 6

Group II, case 5



Group III, case 5

Plate 27: Medio-lateral and cranio-caudal radiographs one month after implant removal showing remodelling and cortico-medullary reunion of bone

This was not felt intra-operatively but was observed in immediate post-operative radiographic evaluation in case 5 of group I and case 1 and case 4 in group III. The gap created with these hairline fractures was filled by callus and healed through primary union by day 30 (Plate 28).

The day 0, post-operative radiographic evaluation revealed slight mal-alignment in one cortex in four cases (LCP case 4, SOP case 5, recon case 3 and recon case 6). In these cases, exact cortex to cortex alignment could not be achieved due to the fractures being comminuted type, oblique type or transverse fractures with gap between the fragments. However, these cases with one cortex mal-alignment had a positive outcome and this did not affect the ambulation of the limb or fracture healing (Plate 15, Plate 19 and Plate 23).

In group II, case 4 the plate was placed too proximal. However, it did not interfere with the function of the limb (Plate 18).

The day 0, post-operative radiographic evaluation revealed that one screw each in group I case 4 and group II case 5 and two screws in group II case 4 and group III case 3 had not crossed the far cortex. However, there were no complications leading to implant failure in these cases due to the screws being monocortical (Plate 15, Plate 18 and Plate 19).

The day 0, post-operative radiographic evaluation revealed that, one screw each in case no 1 and case no 3 of group III (Plate 29) had been placed at the fracture line. In these cases, initial resorption of the bone was noticed between days 15 to 30. In both these cases the fracture line united by day 120.

In the present study, four animals; group 1 (LCP case no 4 and 5), group II (SOP case 4) and group III (recon plate case no 4) showed infection between days 7 to 12 due to break in continuity of the post-operative antibiotic therapy and wound management as the owners did not come properly for follow-up.

In group I (case 4) and in group II (case 2 and case 4) swelling due to chronic inflammation induced by the distal portion of the bone plates and infection was noticed in the distal tibial region between day 15 to 30 (Plate 30).

All the cases, in which infection was noticed, healed after prolonged wound management and antibiotic therapy.

In group II (case no 2) resulted in exposure of a portion of the bone plate on presentation at 120 days after surgery (Plate 31). Hence, in this goat the plate was removed at four months leading to uneventful healing of the surgical site after plate removal.

In the present study, animals in all the three groups showed a remarkable improvement with normal limb function and maintaining good implant stability throughout the treatment period without any complications. There were no implant failures such as plate breakage, bending or dislodgement and screw loosening encountered in any of the goats in the present study. Screw breakage was not noticed in any of the cortical type of the screws in any of the cases throughout the period of study. However, in one case (group III case 5) as cancellous type of locking screw was used in metaphyseal region, screw breakage was noticed in this screw at the head-shaft interface on day 30 post-operative evaluation (Plate 16). However, the plate was intact until the end of the study period. No complications such as implant pull-out or loosening were observed in this case.

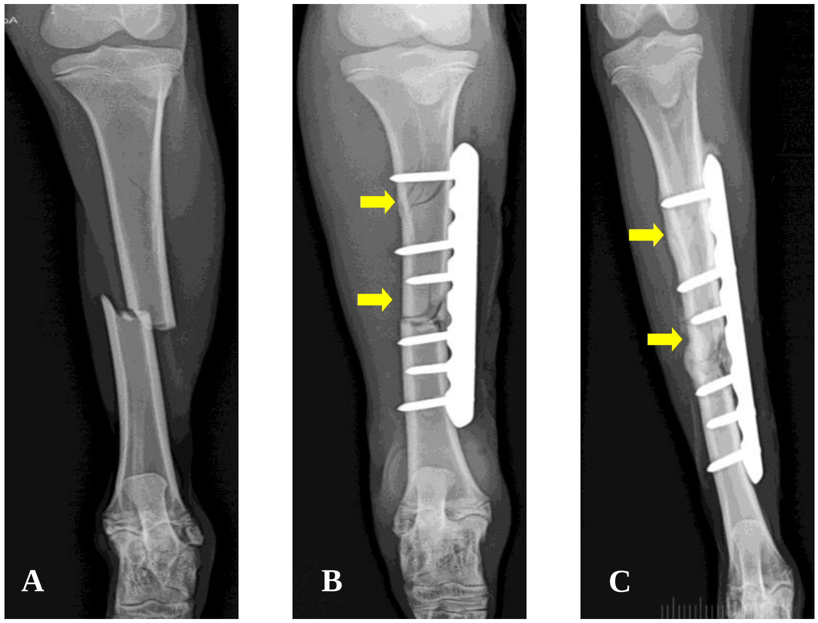


Plate 28: Sequential cranio-caudal radiographs of group I (case 5) showing iatrogenic fracture lines

A) Pre-operative radiograph

B) Post-operative day 0 radiograph showing iatrogenic fracture lines

C) Bridging of fracture lines on postoperative day 60 (indicated by arrows)

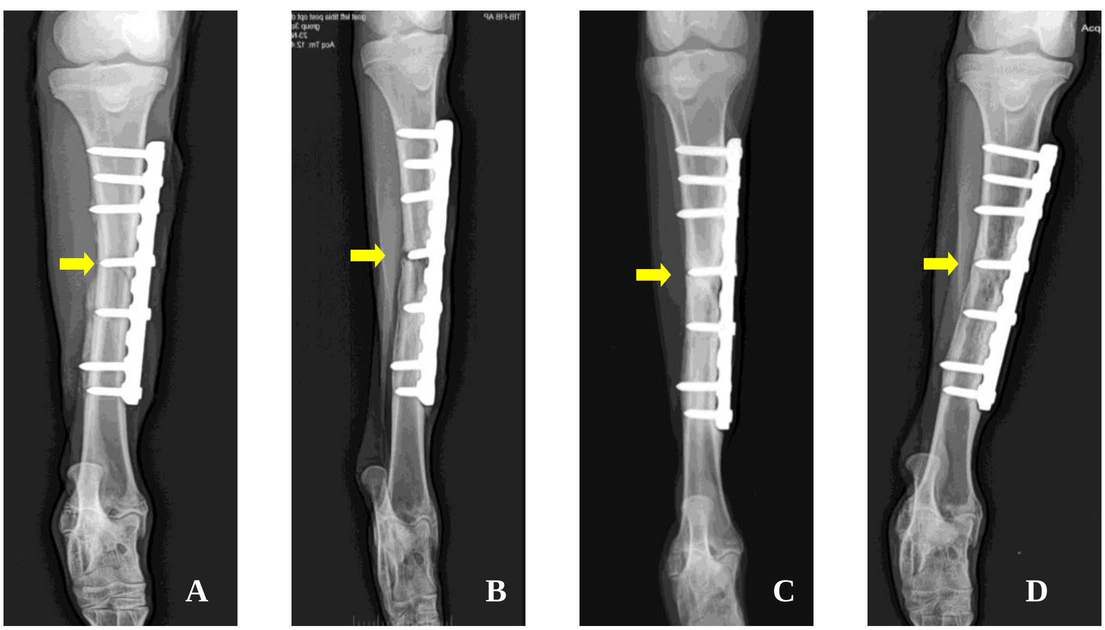


Plate 29: Sequential cranio-caudal radiographs of group I (case 4) showing fracture union with screw at fracture site (indicated by arrows)

A) Post-operative day 15, B) day 30, C) day 60 and D) day 120

Plate 30: **Swelling at distal extremity between day 15 and day 30**

Plate 31: **Group II case 2, exposure of the SOP plate on presentation at 120 days**

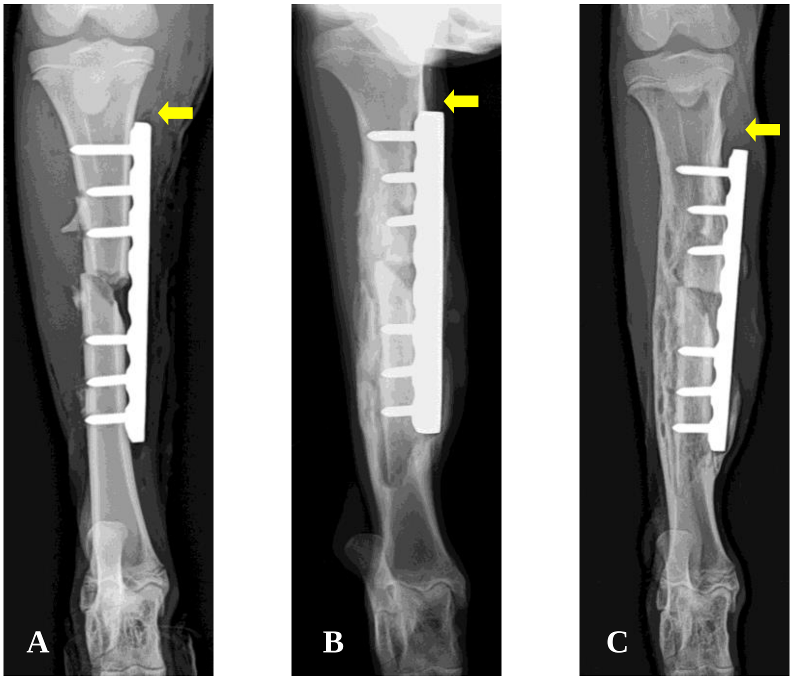


Plate 32: **Sequential cranio-caudal radiographs of group I (case 4) showing deviation of the bone on day 120 (indicated by arrows)**

A) Post-operative day 0 radiograph **B) Post-operative day 60 radiograph**

C) Post-operative day 120 radiograph showing gap between bone and plate

In LCP case 4, lateral deviation of the proximal tibia was observed radiographically on day 120, which gave an impression of plate elevation (Plate 32). The implant was stable and could not be palpated per-cutaneously. There was no associated inflammation or pain and weight bearing was excellent. Radiographic union was achieved. As the study period was completed the implant was removed.

4.2.6.8 Functional Outcome

All the animals were evaluated for functional outcome at 60th and 120th post-operative day and grouped as excellent, good, fair and poor. On day 60, 50% of the animals under study had good functional limb outcome and 50% of the animals had excellent functional outcome. On 120th post-operative day 83.33% of animals were graded as excellent and 16.66% of the animals were graded as good functional outcome.

At 60th day, out of six fractures treated in group 1, two (33.33%) goats were graded as excellent and four (66.66%) goats were graded as good. Out of 6 fractures treated in group II, three (50.00%) were excellent and three (50.00%) were good. In group III, four (66.66%) goats were graded as excellent and two (33.33%) goats were graded as good (Table 21 and table 22).

In animals graded as good, no post-operative complications were noticed on 60th day. Occasionally, moderate lameness was noticed. However, these cases did not require treatment for lameness. None of the animals required a revision surgery. In animals graded as excellent, no lameness was noticed when compared to the goat's opposite limb. There were no post-operative complications.

At 120th day, five out of six goats (83.33%) in each group were excellent. One (16.66%) goat in each group was graded as having good functional outcome. There was fully functional range of motion without any joint stiffness (Plate 33).

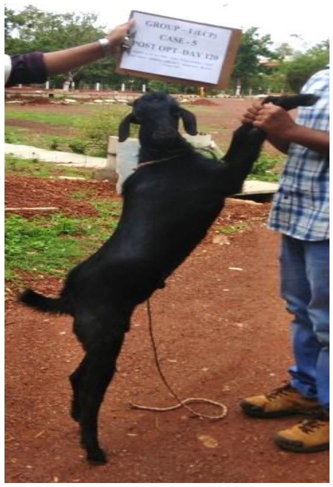
Open reduction and internal fixation of tibial fractures was technically demanding requiring appropriate plane of dissection, minimal trauma to the soft tissue and preserving the fragments with soft tissue attachment. Locking plating system with locking head screws provided rigid and stable diaphyseal fixation in tibial fractures. The principles of biological osteosynthesis together with the rigid stability provided by the plates resulted in good to excellent functional outcome in the present study

Table 21: Evaluation of functional outcome on day 60

Group	Cases treated	Excellent	%	Good	%	Fair	%	Poor	%
I	06	2	33.33	4	66.66	0	0	0	0
II	06	3	50.00	3	50.00	0	0	0	0
III	06	4	66.66	2	33.33	0	0	0	0
Total	18	9	50.00	9	50.00	0	0	0	0

Table 22: Evaluation of functional outcome on day 120

Group	Cases treated	Excellent	%	Good	%	Fair	%	Poor	%
I	06	5	83.33	1	16.66	0	0	0	0
II	06	5	83.33	1	16.66	0	0	0	0
III	06	5	83.33	1	16.66	0	0	0	0
Total	18	15	83.33	3	16.66	0	0	0	0



Group 1 - case 5

Group 1 - case 6

Group II - case 2

Group II - case 5

Group III - case 4

Group III - case 5

Plate 33: Complete functional weight bearing in goats on day 120

Discussion

CHAPTER V

DISCUSSION

The present study was carried out on eighteen clinical cases of tibial fractures in goats presented to Department of Veterinary Surgery and Radiology, Veterinary College, Bidar. A study on incidence of long bone fractures in goats presented to Veterinary College, Bidar and open reduction and internal fixation of fracture fragments was undertaken using locking compression plate in six goats (group I), string of pearls plate in six goats (group II) and locking reconstruction plate in six goats (group III). The results of the study are discussed under the following headings.

5.1 Phase I

5.1.1 Incidence of long bone fractures in goats

The study on surgical cases of goats brought for treatment during the last 12 years revealed that the overall clinical incidence of long bone fractures among all surgical conditions treated in goats was 6.97%. Thus, the incidence of long bone fractures was quite significant in goats. This may be attributed to the free grazing system of goat rearing in urban areas, which makes them predisposed to accidents, trauma by fall from walls, accidental or malicious hitting of animals and dog bites.

Arora (1996) reported that the overall incidence of fractures in goats was 12.23%. Philip *et al.* (1998) concluded that fractures are the most common orthopaedic problem in goats (11.2%). Tambe *et al*. (2012) in a retrospective study of fracture cases done for past 10 years and found 5.5% of the total presented fractures were of goats. Daron (2013) studied the incidence of long bone fractures in goats for a period of 18 years and found that the overall incidence of long bone fractures among all surgical problems in goats was 5.49%.

5.1.2 Sex wise incidence

The results of the present study revealed that the incidence of long bone fractures in goats was more commonly seen in female goats (66.66%) when compared to their male counterparts (33.33%). Higher incidence of fractures in females may be due to the fact that female goats are kept for longer period in the herd for production of offsprings and males are generally more commonly sold for meat purpose.

Similarly, Singh *et al.* (1983), Arora (1996), Virkar (1999), Kumar (2005), Dandekar (2007), Singh *et al*. (2008), Tambe *et al*. (2012), Daron (2013) and Gupta (2015) have also made similar observations.

This is in variance with the observations of Philip *et al.* (1998), Kushwaha *et al*. (2011) and Singh (2015) who found fractures more commonly in male sheep and goats. The difference in their findings may be due to small sample size, variation in place and time of study.

5.1.3 Age wise incidence

Out of the 138 goats presented with long bone fractures, 35 animals were aged less than 6 months (25.36%), 59 goats between 6 months and 1 year (42.75%), and 44 cases above 1 year (31.88%). The study revealed that incidence of fracture is more common in younger animals. The higher incidence in young goats may be due to their delicate body and inquisitive nature, which predisposes them to malicious insults or automobile accidents resulting in fracture. Also, a greater number of fractures in younger animals may be due to the fact that younger goats are more active and have the habit of wandering in free spaces more than that of adult goats. Another reason could be due to the fact that generally the male goats are slaughtered for meat purpose by age of one year. Hence the incidence of fracture in goats more than one year decreases due to their comparatively decreased population.

This is in consonance with the observations of Singh *et al.* (1983), Arora (1996), Aithal *et al.* (1998), Dandekar (2007), Thilagar *et al.* (2002), Kushwaha *et al*. (2011), Daron (2013), Gupta (2015) and Patel (2014) who observed a higher frequency of long bone fractures in goats below one year of age and stated that fractures are more common in young animals.

In contrast, Singh *et al.* (1983) observed that a major proportion of fractures were recorded in the age group of one to three years in goats and Singh *et al*. (2008) reported that fractures in female goats are more common between one to three years and in males below one year of age.

5.1.4 Bone affected

In the present study, fractures were found more commonly in hindlimbs (55.08%) than in forelimbs (44.98%). The incidence was 28.08% for metatarsal, 26.08% for metacarpal, 21.60% for tibia, 10.87% for radius-ulna, 7.97% for humerus and 5.07% for femur bone. Thus, the incidence of long bone fractures was found to be highest in metatarsal bone followed by metacarpal bone in goats.

The chance of hindlimbs getting traumatised with automobile accidents, malicious insults and fall from height is always more which resulted in majority of the fractures. Lack of protective musculature around metatarsal and metacarpal bones can be well correlated with higher incidence of fractures involving these bones.

Patil *et al*. (1991) noticed that hindlimbs were more commonly involved in long bone fractures. Singh *et al.* (1983), Arora (1996), Singh *et al*. (2008) and Daron (2013). Singh *et al.* (2017) recorded that fractures were found more in hindlimbs (63%) than forelimbs. Tambe *et al*. (2012) opined that as the animals were hit from behind and therefore chance for hindlimb fracture was more. Singh *et al*. (1983) opined that most of the fractures were caused by automobile accidents, where the animals were most likely to get injury from behind as the animals were slow to react from their hind quarters.

Dass *et al.* (1985) observed that metacarpal and metatarsal bones were more commonly affected in case of long bone fractures in goats. Patil *et al*. (1991) observed that the frequency of tibial, metacarpal and metatarsal fractures was almost equal in goats. Dandekar (2007), Singh *et al*. (2008) and Daron (2013) recorded that metatarsal and metacarpal bones had the highest incidence of fractures.

On the other hand, Singh and Nigam (1981) observed that the incidence of fractures in goats were more common in femur and tibia. Singh *et al.* (1983) reported that a higher number of fractures involved the femur and tibia in goats. Aithal and Singh (1999) observed that femur sustained highest number of fractures in sheep and goats. Seaman and

Boone *et al.* (1986), Arora (1996), Tambe *et al*. (2012), Gupta (2015) and Singh *et al.* (2017) found that the incidence of fracture in long bones in goats revealed to be highest in tibia.

Contrarily, Kumar (2005) noticed that forelimbs were more commonly involved in long bone fractures in goats, metacarpus being the commonly affected bone. Matthews (2009) opined that the incidence of fracture was highest for metacarpus, followed by radius–ulna and then tibia and metatarsals. The higher incidence of metacarpal bone fracture can be attributed to the fact that the goats often support body weight on their forelimbs during jumping, climbing and running etc. Thus, the forelimbs of goats are obviously prone for trauma and fracture.

5.1.5 Etiology of fracture

It was observed from the results of the present clinical study that automobile accidents (33.33%) were the most common cause of fractures in small ruminants followed by physical trauma/hit injuries (21.01%) and fall from a height (15.84%). Physical trauma, in this context is referred to the goats being maliciously or accidentally beaten either by the owners or strangers. The inquisitive nature of goats and free grazing system of rearing in the densely populated areas might have contributed to the higher incidence of fractures.

However, in 26.64% cases the owners were not sure of the exact cause of fracture as the animals were left for grazing and the owners noticed signs of lameness only after the goats returned home. An acceptable reason behind as higher incidence of fracture due to accidents may be congregation of nomadic, semi-nomadic and rural population keeping goats towards the urban periphery with availability of least grazing area due to which movement of the animals takes place in the urban areas and because of presence of large number of automobiles in the city, the goats get exposed to automobile accident, leading to fracture of long bones. The sheep and goats in our country are generally kept as small holdings by the rural and urban poor and the landless. These animals are generally fed by grazing and are let into barren lands or forest lands for grazing. Therefore, these animals are constantly at danger of trauma due to attacks by other animals like dogs, or trauma due to the terrain of the land in which they graze. In the urban areas, automobile accidents also pose a threat to sheep and goats. Small ruminants endure all these hostile factors regularly and hence, fractures are commonly seen in sheep and goats.

Nunamaker and Newton (1985), Aithal and Singh (1999), Virkar (1999), Singh *et al*. (2008) and Tambe *et al*. (2012) found that automobile accidents were the major cause of long bone fractures in goats followed by fall from a height and external violence.

However, these findings were not in accordance with the findings of Kushwaha *et al.* (2011) who reported that fall or jump from height (33.37%) was the major exiting cause of fractures in different animals. It could be due to the habitat of goat in the vicinity of densely populated urban areas.

Daron (2013) opined that the major cause for fracture in goats was being hit by something or due to automobile accidents followed by fall or jumping from a height.

5.1.6 Type of fracture

It was found that majority of the goats i.e. 102 out of 138 (73.91%) had simple fractures of long bones, whereas the rest had compound type. Oblique fractures were more common (42.02%), followed by transverse type with an incidence of 36.95%. Long bone fractures other than those of cannon bones constituted a significant proportion (45.84%) and this can be attributed to higher incidence of oblique fractures, where the bones are oriented at an angle.

The higher incidence of oblique fracture may also be attributed to the fact that jumping of the animal from a height leads to mechanical compression of the bone which mostly results in oblique fracture.

A possible explanation for the cause of oblique fracture might be, when a force which is less than optimal breaking force of the bone acts tangentially on any object, it gets distributed un-proportionately with more force on the near cortex and less force on the far cortex which is away, thus creating an oblique fracture. Similarly, when the bending force acts on the bone, due to abnormal landings of the limb in pits or hole, the cortex opposite to the forces breaks obliquely.

Patil *et al*. (1991) studied 471 clinical cases of fractures and reported that most of them were diaphyseal and either comminuted oblique or transverse in nature. Arora (1996) found that most of the long bones fractures in goats were oblique (36.02%) or transverse (34.55%), and diaphyseal in nature. Aithal and Singh (1999) noticed that oblique type constituted the major proportion of long bone fractures in sheep and goats. Kumar (2005), Patel (2014) and Singh *et al*. (2017) opined that oblique and transverse fractures were the most common type in goats.

However, Singh *et al*. (2008) reported higher incidence of transverse type of long bone fractures in goats.

The perpendicular orientation of metatarsal and metacarpal bones might be a contributing factor to a significant fraction of transverse type of fractures.

Kushwaha *et al.* (2011) and Daron (2013) opined that most of the fractures were simple fractures.

Patil *et al*. (1991), Arora (1996), Kushwaha *et al.* (2011), Tambe *et al*. (2012) and Daron (2013) reported a higher incidence for mid shaft diaphyseal fractures in goats. This may be due to reason of narrow shaft of long bone as compare to proximal and distal ends. It is more brittle than spongy ends which make them flexible and bone breaks mostly from the mid shaft.

5.2 Phase II

5.2.1 Clinical study

5.2.1.1 Clinical presentation

In the present study, the diagnosis of fracture was based on the clinical signs of non weight bearing and reluctance to move the limb, lifting the limb above the ground level or just touching the toe to the ground. The limb was dangling indicating a broken bone.

Palpation of the fractured fragments of the tibia revealed crepitation of the fractured site and pain and swelling were present at the site of fracture.

Reilly *et al*. (2012) remarked that the hallmark of long bone fractures in small ruminants was an acute non-weight bearing lameness. Smith and Sherman (2009) opined that long bone fractures in goats were usually identifiable by an acute onset of lameness and deviation of limbs, with or without palpable crepitus. Singh *et al*. (2008) employed clinical signs such as swelling, pain, abnormal mobility, crepitation and dysfunction of the limb to evaluate long bone fractures in goats. Venugopalan (2009) indicated that the major clinical signs exhibited by animals with fracture as loss of function of the affected limb, abnormal mobility at the fracture site, deformity due to displacement of fractured fragments, pain and crepitus on palpation. Affected animals deviated from their normal posture and position. Pain was usually absent in pathological fractures. Loss of function was mainly exhibited by inability of the animal to bear weight on the affected limb.

5.2.1.2 Radiographic diagnosis

In the present study the medio-lateral and cranio-caudal radiographs served well in diagnosing the type of fracture encountered, determining the size of implants needed, fracture healing at different time interval, status of the implants and complications if any. Langley-Hobbs (2003) and Kumar *et al.* (2007) also recommended that at least two orthogonal views of the concerned bones should be obtained to plan proper treatment.

5.2.1.3 Surgical technique

All the goats were operated under lateral recumbency with the affected limb down. A cranio-medial approach was followed in all the cases and was found adequate for bone plating as the tibia is present subcutaneously and has a flat surface for the application of plate. The medial aspect of the tibia presents a safe corridor along its entire length. The corresponding surface on the lateral side is classified as hazardous as is the cranial surface. Cantu and Koval (2006) opined that the proper plate position and location were important to ensure that the screws did not engage any neurovascular structures. Kaab *et al.* (2004) recommended that an aiming device should be used in every case during drilling for the locking head screws, since axial deviation of the direction of drilling by more than 5° leads to significantly impaired stability.

In the present study, the fractured fragments were adequately reduced and aligned before application of the bone plates in all the animals of all the three groups. Sommer (2003) opined that the fractured bone must be appropriately aligned before the LCP is applied. He observed that the locking plates do not displace the fragment during screw tightening regardless of the precision of contouring. Once a locking screw has been placed through the plate into bone, this particular bone segment can no longer be manipulated by insertion of additional screws or by using compression devices. The length of plates selected for the present study was decided based on the length of the bone. The locking plates used for all the cases in the present study irrespective of the age, sex and body weight were of 3.5 mm size. A minimum of three bicortical screws were placed in the proximal and distal segment in all the cases and were found to be adequate. The accidental placement of few screws monocortically in a few cases did not cause screw loosening, plate pull-out or any other complications related to implant failure. A minimum of one to three screw holes were left open over the fracture site in order to pre-dynamize the plates and allow for stimulation of callus formation.

The locking bone plates in all the cases in the present study were used as an internal fixator (bridging plate). The plates were not pre-stressed or contoured to the bone. Gautier and Sommer (2003), Ahmad *et al.* (2007), Miller and Goswami, (2007) and Cronier *et al*. (2010) opined that the locking plates do not require perfect contouring to the bone surface to maintain fracture reduction. Aguila *et al.* (2005) stated that LCP enabled stable fixation without the need for compressing the plate directly onto the bony surface or plate contouring. Perren (2002), Schutz and Sudkamp (2003), Wagner (2003) and Cronier *et al*. (2010) observed that in locking systems, the screw head is securely fixed to the plate, removing the need for the plate to be compressed to the bone. Due to the robust screw-plate junction and the fixed angle nature of the screw, perfect plate contouring becomes unnecessary. This reduces insult to the periosteum and its vascularisation. Kowaleski (2009) observed that the SOP does not need to lie directly on the outer cortical surface. He opined that it should be placed close to the bone to keep its profile as low as possible, but should contact the bone in a few locations or not at all as this preserves the blood supply of the bone and healing callus.

Perren, (2002); Gautier and Sommer, (2003); Sommer *et al*. (2004) and Kowaleski (2009) opined that when a fracture is bridged with a locking plate, the bridge plates must be longer and fewer screws are needed. They recommended that in general, the length of the plate should be more than two times the length of the fracture zone. Screws should be spread evenly. Ideally there should be at least one empty hole between each pair of holes filled with screws. They recommended to pre-dynamize the locked plates when they are used in a bridging mode by allowing atleast two empty screw holes over the fracture gap in order to increase the working length and decrease the strain and stress concentration on the plate which may lead to breakage of the plate. In contrast, if a locking construct is made too stiff with too many screws at the level of the fracture can lead to non-union. Cronier *et al.* (2010) and Scolaro and Ahn (2011) recommended to avoid an overly stiff construct in locking plates, because a lack of motion at the fracture site may prevent bone healing. They opined that some motion was desirable in order to stimulate secondary callus formation. Bottlang *et al.* (2016) concluded that an overly rigid locked plating constructs suppress callus formation and healing. They hypothesized that by providing axial dynamization, active locking plates deliver faster callus formation, consistent and circumferential bridging and stronger healing compared with standard non-locking plates.

Ehlinger *et al*. (2011) suggested use of at least three bicortical screws at each side of fracture. The bicortical screws should be systematically used to provide three points of fixation (2 cortical + the plate) to limit breakage. They opined that the position of the screw in relation to the fracture line depends on the type of fracture. If the fracture is unstable (long fracture line, comminutive fracture) locking screws should be placed near the fracture line to stabilize the fracture site. If it is a simple fracture, locking screws should be placed further away with an open hole on each side of the fracture to create elasticity in the system, which will promote union. Ellis (1985) stated that the use of three screws on each side of the fracture with AO reconstruction bone plate is claimed to provide adequate neutralization of functional forces in absence of compression. Lewis *et al*. (1993) stated that the use of reconstruction plate to buttress large fracture gaps was not recommended because of the ductile properties of the plate.

Schutz and Sudkamp (2003) recommended that at least three monocortical locking head screws (LHSs) should be securely anchored in each main fragment.

5.2.1.4 Physiological Parameters

The physiological parameters were within normal limits on all days of observation in all the groups.

The rectal temperature and respiratory rate fluctuated within normal physiological limits on all the days of observation. Statistical analysis of rectal temperature and respiratory rate revealed there was no significant difference between the groups and between the days of observation.

In all the three groups there was a fluctuation in the heart rate within physiological limits through the different time intervals. There was no significant difference within the groups on different days of observation. There was no significant difference between the groups on all days except on day 60. On day 60, the heart rate in group I was non-significantly different from that of group II and group III. However, the heart rate of group II was significantly ($p<0.05$) differing from that of group III.

Kelly, (1984) opined that physiological parameters are elevated when animals are under stress due to trauma, anaesthesia and surgery. The increase in physiological parameters might be attributed to release of mediators of inflammation *viz.*, prostaglandins, bradykinins and interleukins and stress due to fracture, anaesthesia and surgery and change of environment. Agnihotri (2007) recorded clinical parameters such as respiratory rate, pulse rate and rectal temperature pre and post-operatively and reported an increase in rectal temperature on 1st post-operative day followed by its decrease. However, the author did not find any significant variation in respiratory and pulse rate. Jawre (2012) evaluated different techniques of internal fixation during fracture healing in calves and reported non-significant difference in temperature, pulse rate and respiratory rate at different time intervals.

Daron (2013) compared the physiological parameters while comparing POP and fibreglass for treatment of long bone fractures in goats and found decrease in the values of physiological parameters compared to day 0. Gupta (2015) and Dharmendra (2016) found decrease in physiological parameters on subsequent days compared to day 0 during fracture repair using DCP in goats.

5.2.1.5 Weight bearing and lameness grading

Post-operatively, lameness grade showed gradual improvement to normal weight bearing over the period of study. All the goats showed complete functional recovery at the end of the study. Locking of the screws into the plate formed a single beam construct and thereby provided axial and angular stability to the construct. The principles of biological osteosynthesis together with the rigid stability provided by the plates resulted in good to excellent functional outcome in the present study.

The lameness grade was carried out in accordance with the protocol developed by Vasseur *et al.* (1995). Normal weight bearing on all the limbs at rest and while walking was graded as I (as seen between 60-120 days) and this was attributed to adequate fracture reduction with locking bone plates, load sharing between implant and bone and minimal disruption of the soft tissue. Statistical analysis of the overall lameness score on pre-operative and post-operative days in the groups at different intervals revealed significant ($p<0.01$) difference among the different time intervals and non-significant difference among the three groups studied.

Pre-operatively, none of the animals had weight bearing on the fractured limb. Semi-flexed joints above the fracture site with the toe touching the ground while standing, was consistently seen in all the animals. Non-weight bearing lameness was seen in all the cases. Dangling of distal part of hind limb below the fracture line in a case of multiple fracture of tibia, swelling at the fracture site and crepitation was seen in all the cases of fractures.

Reilly *et al*. (2012) remarked that the hallmark of long bone fractures in small ruminants was an acute non-weight bearing lameness. Venugopalan (2009) reported the major clinical signs exhibited by animals with fracture as loss of function of the affected limb, abnormal mobility at the fracture site, deformity due to displacement of fractured fragments.

On day 0, out of eighteen goats, nine were able to get up with ease and without assistance. Six goats were able to get up with ease after some assistance and remaining three goats could get up only with support and move slowly by using their three legs. Poor weight bearing along with pain may be due to moderate inflammatory reaction. Intermittent weight bearing with moderate pain in immediate post-operative period may be attributed to rigidity of locking plate construct which provide better immobilization of fracture fragments to better.

The weight bearing was better in group I and group III. This may be attributed to better bone to plate contact giving a rigid fixation. In group II, the higher profile and more proximal placement of the plate might have caused pain, irritation and inflammation while walking. By day 7, the lameness scores of group II had improved which might be attributed to decrease in inflammation and monoblock effect of the locking plate screw construct leading to axial load transfer. Nayak *et al*. (2011) concluded that the locking plate system using LCP allows early mobility, rapid functional recovery and good radiological results with low morbidity. Kim and Lewis (2014) applied SOP in dogs and concluded that, excellent functional outcome was achieved with complete weight bearing on affected limb within 3 days of surgery and remained weight bearing throughout the post-operative convalescent period.

At 15th day interval, the lameness grades had improved and mild to intermittent lameness with partial weight bearing at rest and while walking was observed. Mild initiation of bridging between the fractured segments as evident radiographically with hazy fracture line, traces of callus at the fracture site, initiation of periosteal callus and the decrease in inflammation at the fracture site may be the factor for better weight bearing. In group III, better weight bearing in comparison to group I and group II was observed which could be attributed to the close contour of the bone and the plate.

On 30th day, consistent weight bearing with mild lameness was noticed which might be due to increased periosteal callus and apparent bridging of the fracture fragments, evidenced radiographically, which contributed to consistent weight bearing. Group I and group III animals showed consistent improvement. However, in group II the infection and inflammation at distal end of tibia in two cases could be the reason for an increased lameness score.

On day 60, the lameness scores in all the cases of all the groups had improved and the animals exhibited normal weight bearing at rest and while walking. The bridging callus formation between the fractured fragments had obliterated the fracture site as evident radiographically. Radiographic union was achieved. This could have led to complete weight bearing without lameness and may be the reason for the animal to favour the limb while walking.

By day 120, all the goats of all the groups had resumed complete normal weight bearing and no signs of lameness were present. The goats moved about without any discomfort during walking and running. This could be attributed to the establishment of the cortico-medullary union, decreased size of periosteal callus and remodelling of the fractured bone. Butterworth (1993) reported that as healing progressed, the animal begins to use the limb more.

Jackson and Cockroft (2002) reported that a healthy alert goat will rise when approached and bear weight equally on all four limbs and passes dry faecal pellets. Lameness in goat led to wasting of muscles of affected limb. The authors also noticed reluctance to move when forced as an indication of pain by goats. Shivaprakash and Singh (2003) observed that the functional restoration of fractured limb in animals treated with nylon plates and stainless steel plates was much faster than the animals treated with other implant materials. Clinical union was observed in animals treated with nylon and stainless steel plates as early as day 35 and the animals were able to run without any evidence of lameness by day 60. Corr (2005) stated that clinical union often occurred before radiographic union was evident. Dharmendra (2016) studied fracture healing in goats using DCP and found that complete weight bearing in goats was observed by 30^{th} day onwards. Vinit (2017) studied fracture healing in goats using Veterinary cuttable plate and polypropylene mesh impregnated poly methyl methacrylate plate and reported that the goats in both the groups showed weight bearing between 7^{th} to 30^{th}days.

5.2.1.6 Radiographic evaluation

Fracture healing is a process of bone regeneration. It is divided into well documented stages: inflammatory, connective tissue and fibro-cartilage formation (soft callus), bony bridging or mineralization (hard callus) and remodelling (Aron, 1995). Ackerman and Silverman (1978) advocated the use of radiography in the evaluation of fracture healing. Whittick (1974) mentioned four important observations for radiographic union of fracture. They included continuity of cortex, continuity of medullary canal, mineralized callus and absence of gap between the fractured segments. Whelan *et al.* (2002) recommended antero-posterior and lateral radiography of the tibia at each follow-up visit, with measurement of the number of cortices (0 to 4) bridged by callus, as the most reliable method for assessing the progression of the healing of fractures.

In the present study, fracture healing was scored based on callus formation and/or elimination of the fracture gap as recommended by Hammer *et al.* (1985). Post-operative radiographic evaluation was carried out on day 0, 15, 30, 60 and 120 to assess the fracture healing.

In all the cases with comminution and non reducible wedge, all the fragments with soft tissue attachments were retained thus promoting biological osteosynthesis which was in agreement with Beale (2004). In addition, the intact periosteal vascularity promoted osteogenesis and bone healing in all the cases which was in concurrence with Egol *et al.* (2004).

At 0 day, the fracture line after alignment was clearly distinct with sharp and well-defined loss of radiographic density in all the 18 cases. The implants were stable and adequate in length. Excellent stability of the fracture fragment was observed in all cases.

On day 15, radiographic healing through bone resorption and initiation of periosteal callus and presence of traces of callus at the fracture site were noticed. The fracture line was distinct in all the cases. Mild to exuberant periosteal callus was observed all along the length of the bone at trans cortex especially at the points where the screws were fixed. Singh *et al.* (2006) reported that first evidence for increased rate of osteoblastic proliferation was detected about eight hours after occurrence of fracture and reached a peak by 24 hours. Initially the increased periosteal activity had generalized nature extending to the whole bone and later it got localized to the fracture site. Morgan (1972) described the radiographically visible periosteal callus as a faint hazy area developing adjacent to and directly overlapping the site of fracture. He opined that the callus formation was proportional to the rigidity of fracture fixation. The callus was more in group II and least in group III, indicating that recon plate was more rigid. The extent of secondary callus with recon plate was much less than with SOP plate and LCP. Bartels (1970) studied fracture healing in canine long bones radiographically. He observed that periosteal activity was evident from 9 to 21 days. The total bone regeneration occurred by 12 to 18 weeks.

30th post-operative day revealed that the fracture line was less visible and it was becoming hazy and was fading in all the cases. Apparent bridging of the fracture line could be observed. The amount of periosteal callus appeared to be more extensive, dense and homogenous. Traces of callus infiltration on the bone plate were observed. These cranio-caudal findings correlate with report of Umarani and Ganesh (2002) and Singh *et al.* (2008), who reported complete union of the fracture site with obliteration of fracture line, ossification and bridging of cortex from 4th - 8th week, post casting. Chaudhary (1982) reported radiographically visible periosteal reaction on the twenty-first day of fracture healing in sheep and goats. He noticed the presence of a translucent shadow in the callus and the still evident fracture gap in the radiographs. Guiot and Dejardin (2011) defined clinical union as the presence of a bridging callus or a callus >50% of the tibial diameter at the level of the fracture site on 3 of 4 cortices on 2 orthogonal views. Reems *et al.* (2003) reported that the bridging callus was expected in 3 to 5 weeks in immature patients and 4 to 6 weeks in mature patients.

By 60th post-operative day, the fracture line was completely obliterated with massive radio-dense callus completely filling the fracture site. The radiolucent fracture line was not visible indicating achievement of radiographic union. The periosteal callus had decreased in size and was more homogenous. The callus was smoothening and becoming uniform in density. Early cortico-medullary remodelling was evident indicating early clinical union. Anderson *et al.* (1995) stated that the earliest follow-up in which fracture gap was filled primarily with uniting endosteal callus was indication of radiographic union. Denny and Butterworth (2000) reported that callus formation started within two weeks and in ideal condition it was completed within six weeks with the establishment of clinical healing. Da-cheng *et al.* (2010) studied interface contact profiles of a novel locking plate and its effect on fracture healing in goats and observed that the fracture line disappeared in the locking plate group on 8^{th} post-operative week. Vinit (2017) used VCP and PMMA plates for fracture repair in goats and reported that radiographs on 15^{th} day depicted initiation of periosteal reactions, on day 30 there was development of minimal radio-dense callus with visible fracture line and by day 60 showed complete union of fractured fragments was achieved. Claes *et al*. (2002) observed that during fracture repair the intra-membranous and endochondral ossification initiates callus formation and growth towards the fracture gap until bridging callus is formed. During the remodelling process, newly formed soft bone is replaced by laminar bone, thus restoring the original bone structure and stability.

Shivaprakash and Singh (2003) evaluated bone plates made up of various materials such as nylon, teflon, stainless steel, horn and xenogenous bone for repair of femoral fracture in Black Bengal goats and reported that the type of callus seen radiographically in animals of all the groups was ‘external callus’. The re-establishment of medullary canal at the fracture site was seen as early as day 90 in animals treated with nylon and stainless steel plates. They reported that steel plate and nylon plate resulted in less callus formation, whereas Teflon plate resulted in excess callus due to slight movement at the fracture site.

The extent of callus formation on day 15 and day 30 was earlier in group II, followed by group I. In group III the quantity of periosteal and endosteal callus noticed was lesser. However, by day 60, the rate of union in group I and group II were same. In group III, remodelling had initiated by day 60. By day 120 the rate of fracture union was complete in all the cases of all the three groups. The cases in all the three groups healed by secondary callus formation. Comparative evaluation of animals depicted a higher extensive periosteal and endosteal reaction, callus formation with bridging and calcification in group II followed by group I. However, in group III the extent of periosteal callus was lesser and the cortico-medullary union was established and callus resorption could be appreciated by day 60 where as in other two groups it was noticed by day 120.

Excellent healing was noticed radiographically with absence of fracture lines with endosteal and bridging callus. The average time for bridging of the fracture site in all the groups was around 60 days. The medullary canal was established and remodelling was visible by day 120. Distinct calcification, bridging of the cortex and obliteration of the fracture gap in almost all the goats might be attributed to the fact that locking bone plates exhibited higher degree of grip and immobilization. Frandson *et al.,* (2009) reported that the fractures receiving good blood supply, good apposition and absence of infection healed better and faster. The callus observed in the fractures stabilized using locked plating technique suggested that this method provided both an appropriate vascular and mechanical environment to stimulate external callus formation as observed by Claes *et al.* (2002). Pandiya *et al*. (1977) made radiological observations of canine tibial fracture healing and opined that the fracture healing and remodelling of the osseous callus were influenced by the blood supply to the bone. They noticed complete healing by eighth week.

Maritato (2018) opined that clinically, a decrease in plate footprint and better preservation of bone vascularity should be associated with better healing and a smaller risk of refracture following removal. Hence, as the narrow profile of SOP plate has a decreased plate footprint, it could have led to better preservation of bone vascularity thereby resulting in earlier and extensive secondary callus as per the principles of internal fixators.

Perren (2002) opined that a bridging fixator allows a small amount of elastic motion and stimulation of callus formation at the fracture site leading to indirect healing, (sequential tissue differentiation). Sommer (2003) reported that a “pure” internal fixator provides relative stability by bridging the fracture zone and opined that this allowed rapid indirect fracture healing with external callus formation. Greiwe and Archdeacon (2007) opined that locking plates encourage secondary bone healing. Similar observations were made in present study where healing occurred in all the groups under study by bridging of fracture site by secondary callus.

Goodship and Kenwright (1985) stated that weight bearing led to micro motion at the fracture site which acted as a mechanical stimulus to the secondary bone healing. The strain theory demonstrates that anatomic reduction is not required for bone healing, and that tolerable strain (2%-10%) can promote secondary bone healing. Callus formation is further promoted when biologically friendly surgical approaches are combined with locking plate “internal fixators”.

Schwandt and Montavon (2005) reported that complete bridging and callus remodelling was observed at 53 days after LCP application in tibial fracture in a young dog. Haaland *et al.* (2009) reported that mean healing time of the fractures repaired with the LCP in a study of 47 cases of appendicular fracture repair in dogs was seven weeks. Sengoz-Sirin *et al.* (2013) assessed the clinical and radiological outcomes of the LCP system in 32 dogs with diaphyseal fractures. It was recorded that 27 of the 32 cases healed with primary bone healing while others healed with little callus formation. Yadav *et al.* (2016) treated long bone fractures with LCP and reported radiographic evidence of complete healing of fracture by 60 days. Chandini (2018) stated that the locking compression plate and locking reconstruction plate provided sufficient stability to the fractured fragments in dogs which helped in proper healing of the fracture at scheduled interval as was evident from the radiographic findings during the study.

Ness (2009a) 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. 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.* (2012) 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. 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.

5.2.1.7 Biochemical parameters

5.2.1.7.1 Serum alkaline phosphatase (IU/L)

The serum alkaline phosphatase level was above normal levels on day 0 in all the groups. This might be due to surgical trauma and initiation of the inflammatory phase of the healing process.

The serum alkaline phosphatase increased from day 0 to 30th post-operative day and then declined on day 120. However, all the values remained above the normal physiological limits at the end of study. In each group, alkaline phosphatase levels were non-significantly differing among different time intervals. Comparison between the groups showed non-significant difference between them in each time interval.

The findings in the present study were similar to the earlier findings of Akhare (1997) who remarked that no significant change in serum alkaline phosphatase levels could be found during the healing process of long bone fractures in goats. However, the concentration of the enzyme in the serum increased initially and then decreased gradually. Singh *et al*. (2008) and Daron (2013) reported that there was no significant difference in alkaline phosphatase levels when fibre glass and plaster of paris were used for external immobilization of long bone fractures in goats.

Aithal *et al*. (1995) Zama *et al*. (1999) Manjulkar (2000) Umarani and Ganesh (2003) Singh *et al.* (2008) Dias *et al*. (2010) Vinit (2017) analysed the serum alkaline phosphatase activity during fracture repair in goats and observed there was an increase level of alkaline phosphatase from 0th to 30th post-operative day which indicated the higher osteoblastic activity and enhanced fracture repair followed by gradual decrease from 30th to 60th day after surgery. The values reached its normal physiological limit on day 60 indicating the completion of repair process.

Zama *et al*. (1999) observed a continuous increase in serum alkaline phosphatase levels throughout the period of fracture healing in goats treated with intramedullary pinning for femur fractures. A significant rise in serum levels of the enzyme was evident on day 10 after fracture repair in goats.

In the present study, the rise in the alkaline phosphatase levels on day 15 and 30 might be due to increased osteoblastic activity. Pritchard, (1952) opined that the significant increase in the alkaline phosphatase level may be attributed to proliferation of osteogenic cells in the early stages of fracture repair. Panteghini *et al.* (2006) reported that alkaline phosphatase was produced by osteoblasts and was an excellent indicator for bone formation. Activity of the enzyme was found to increase with increased osteoblastic activity. Osteoblast secretes large quantity of alkaline phosphatase which is involved in the bone matrix formation and its mineralization. Singh *et al. (*1976) opined that increase in level of serum alkaline phosphatase was attributed to fibrous tissue formation and early stage of bone repair.

Umashankar and Ranganath (2008) observed significant increase in serum alkaline phosphatase level from 1st post-operative day to 21st post-operative day during tibial fracture healing in dogs. They opined that the marked elevation in early post-operative period could be attributed to adrenal hyperfunction, stress, skin and muscle trauma and later increase might be due to increased osteogenic activity and deposition of calcium salts at the site of the fracture.

The decrease in the levels of alkaline phosphatase might be indicative of cessation of osteoblastic activity and receding of the values towards its base value due to ossification and consolidation of fractured bone.

5.2.1.7.2 Serum calcium (mg/dL)

In the present study, the serum calcium levels were within the physiological limits. Statistically, no significant difference was observed in the serum calcium levels on different post-operative time intervals in each group studied and also between the three groups in each time interval.

Increased levels of serum calcium in the initial post-operative period could be attributed to increased osteoclastic activity, leading to resorption of dead bone. Also, mild elevation in serum calcium levels might be due to mineralization process at the fracture site which was in agreement with Bush (1991). Newton and Nunamaker (1985) were of the opinion that acid phosphatase released by the osteoclast first cause demineralisation and removal of organic matrix, which may be responsible for increased level of calcium in serum. A gradual decrease in the serum calcium levels from 60th day could be due to deposition of excess calcium at the fracture site.

The results in the present study are similar to the finding of Akhare (1997) and Zama *et al*. (1999) noticed no significant change in serum calcium levels during healing process of long bone fractures in goats.

Singh *et al.* (2008); Dias *et al*. (2010) and Daron (2013) noticed a significant rise in serum calcium level from day 15 after fracture repair in goats. The values returned to normal by day 120. Manjulkar (2000) studied the biochemical changes during healing of long bone fracture in goats and observed a gradual increase in the level of calcium up to day 30, after which it declined till 45th day and reached the normal value. Dharmendra (2016) used DCP for fracture in goats and observed rise in serum calcium levels by 3rd week onwards, that return to normal levels by 7th week onwards. Vinit (2017) observed that the serum calcium levels raised on 15th and 30th postoperative days after fracture treatment in goats treated with VCP and PMMA bone plates. The serum calcium levels then declined gradually to day 0 levels by 60th postoperative day.

Umarani and Ganesh (2003) noticed reduction in calcium level on seventh day after internal fixation of femur fracture in goats, followed by a significant rise in concentration from day 15 to reach the normal level gradually by day 60 of fracture healing.

5.2.1.7.3 Serum inorganic phosphorous (mg/dL)

The serum phosphorous levels showed an increase from day 15 to day 30 after fracture repair in all the groups. The levels declined gradually thereafter to reach normal values by day 120. However, the concentration was within normal limits on all the days of observation.

In each group, the serum inorganic phosphorous (mg/dL) levels were non-significantly differing among the different days of observations. Similarly, in each time interval, the serum inorganic phosphorous (mg/dL) levels were non-significantly differing among the three groups studied.

Higher levels of serum phosphorous levels at initial levels can be attributed to osteoclastic activity leading to the resorption of dead bone thereby increase in the levels of serum phosphorous. Singh and Nigam (1976) observed early rise in serum phosphorus level up to first two weeks of fracture healing and opined that it might be due to the necrotic disintegration of cells at the site of fracture.

Umarani *et al.* (1999); Zama *et al*. (1999); Manjulkar (2000); Umarani and Ganesh (2003); Singh *et al.* (2008); Dias *et al*. (2010); Daron (2013) and Vinit (2017) noticed that serum phosphorus levels were increased up to day 15, after which it declined till day 60 to reach normal values during healing of long bone fractures in goats.

5.2.1.8 Implant removal

After radiographical union of the fractured bone was seen at the end of the study period, the bone plates were removed as recommended by ASIF, since by leaving the plate in place even after the bone healing would lead to stress protection, osteomyelitis and osteopenia (Conzemius and Swainson, 1999 and DeCamp *et al*., 2016). Butterworth (1993) was of the opinion that the clinical union was more important compared to radiographic union when considering fixator removal. DeYoung and Probst (1993) advised plate removal after bone union, not only because of possible corrosion but also because the bone under a plate never becomes physiologically normal. They stressed that implants should not be removed before the architecture of the bone becomes radiologically normal.

Emmerson and Muir (1999) listed out that the various reasons of plate removal were instability, soft tissue irritation, infection and chronic lameness. In two cases of group II the plates were removed due to soft tissue exposure and infection. The exposure of the plates could have been due to the thick profile of the bone plates as the soft tissue covering in the distal extremity of the tibia is less. Johnson (2013) recommended plate removal when the plates have been applied in areas with limited soft tissue covering, such as tibia because cold conduction may cause discomfort.

Ehlinger *et al.* (2009); Cronier *et al.* (2010) and Suzuki *et al.* (2010) opined that although locking plate systems have become a gold standard in the treatment of many fractures their removal can be quite laborious and challenging. They observed that difficulties in removal of locking screw implants can be as frequent as 38% due to two major factors frequently encountered during removal of locking plates. 1) Destruction of the recess of the screw head during vigorous removal of ingrown bone tissue and 2) Cross-threading of the screw head threads with the threads in the plate hole by off-axis insertion of the screw. They opined that this resulted in jamming of the screw head into the plate which was due not using a target device or due to poor drilling orientation and poor positioning of the target device or drill sleeve. The quality of the screw placement depended on how accurately the targeting device was placed. Forceful insertion of the screw without using torque controlling screw driver could lead to threading lesion on the screw head and plate hole. Tacvorian, (2012) recommended that the screws must be inserted into the plate at a precise perpendicular angle to achieve a locked coupling. Failure to achieve this can result in ineffective locking between the screw and plate and cross threading between the plate hole and screw head threads resulting in incomplete insertion and challenging screw removal.

In the present study no incidence of jamming of screw head or screw loosening was noticed as the screws were perpendicular to the screw hole. Hence no cross threading would have occurred thereby preventing jamming of the screws. No complications noticed with regard to the jamming of the screws may be attributed to the fact that in all the cases locking drill guide was used for drilling the bone for screw placement. This had prevented cross threading of the screw with the plate holes. All screws could be removed easily except five screws in which difficulty was encountered during removal due to copious amount of fibrous tissue and excess periosteal callus infiltration over the screws. The fibrous tissue and callus over these screws had to be cleared before removal of the screw.

Van Nortwick *et al.* (2012) and Fujita *et al.* (2014) opined that intra-operative difficulties during screw removal appear to be increased with longer time periods from implant insertion to removal.

In the present study, there was some difficulty encountered during plate removal in plates which were removed after day 120 as callus was surrounding the plate especially at the distal end or proximal end in all the cases. Copious amounts of fibrous tissue had grown through the holes encircling the entire plate and snugly holding the plate to the bone. In cases where the plates were removed after day 150 the callus and fibrous tissue were decreased and the plate could be removed easily. Suzuki *et al.* (2010) opined that although locking plate systems had become a gold standard in the treatment of many fractures their removal could be quite laborious and challenging. They observed that difficulties in removal of locking screw implants could be as frequent as 38%.

5.2.1.9 Complications

In the present study, the fractures treated with the three different locking plates showed remarkable improvement with normal limb function and maintaining good implant stability throughout the treatment period without any complications in all the goats. Similar findings were observed by Aguila *et al.* (2005), Florin *et al.* (2005), Sod *et al.* (2008), Uhl *et al.* (2008) and Uhl *et al.* (2013).

Proper alignment of the fracture fragments was observed on post-operative radiograph taken immediately in all the animals of three groups. In four goats mal-alignment of one mm was seen at one cortex was due to bone loss due to comminuted fracture or in cases with oblique fracture, the bone happened to straighten and align out during the process of fracture healing. These cases with slight mal-alignment had a positive outcome and this did not affect the ambulation of the limb or fracture healing. Shales (2008) stated that good fracture healing will follow if the fracture fragments are in apposition for the extent of at least 50 percent.

In group I cases 4 and group II case 4, a large periosteal callus extending above and below the fracture line was noticed from day 15 onwards. This could be due to stripping of periosteum during surgery resulting in periosteal lipping and subsequent periosteal callus formation.

In two cases of group III, where the screws were inserted at fracture site healed uneventfully. Herford and Ellis (1998) opined that in locking bone plate/screw system even if a screw is inserted into a fracture gap, loosening of the screw will not occur. The possible advantage to this property of a locking plate/ screw system is a decreased incidence of inflammatory complications from loosening of the hardware as a loose hardware propagated on inflammatory response and promotes infection.

The occurrence of post-operative infection in few cases could be attributed to irregular follow up by the owners which led to break in continuity of the antibiotic therapy. The wound healed after a prolonged course of antibiotic therapy and regular lavaging of the wound with normal saline solution diluted with povidone iodine solution. Redfern *et al.* (2004) opined that the traditional open reduction and internal fixation results in extensive soft tissue dissection and periosteal injury and may be associated with high rates of infection, delayed union, and non-union.

In cases where infection was noticed at the distal tibial region, the thick profiles of LCP and SOP plate might have led to chronic irritation to the skin during ambulation and limb movements as there in no soft tissue covering in this region. This might have led to inflammation, seroma formation and infection in these cases. Exposure of a portion of SOP plate four months after surgery may be due to the thick profile of the SOP plate which might have caused pressure necrosis of the skin in the region. Tan and Balogh, (2009) reported that the locking plates used in the offset position from the periosteal surface might cause tendon and soft tissue irritation, if the plate was too prominent. 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.

Common post-operative complications encountered after bone plating included mild to severe plate bending (Das *et al.*, 2012), apparatus instability and loosening of screws and breakage of plates (Schwandt and Montavon, 2005), and osteomyelitis

(Vaughan, 1975 and Nunamaker, 1985). Tan and Balogh, (2009) observed that LCP has its implant specific complications such as plate breakage, locking screw breakage and soft tissue complications. They concluded that most of the complications and failures can be prevented with careful planning, application of the principles and good knowledge of the indications and the limitations of the implants and the technique. Tong and Bavonratanavech (2007) reported that if the proximal and distal screws were not inserted into the centre of the bone, because of the plate being offset, or if their direction was not perpendicular to the cortical surface, segment rotation and translation would occur at the fracture site. Sirin *et al.* (2013) reported no complications such as soft tissue and/or bone infection, delayed union or non-union, plate torsion or breakage were observed. This was considered to be related to the right choice of antibiotic, implant, surgical technique and postoperative case.

No breakage of screw was seen in any of the cortical type of locking head screws. Breakage of one screw was seen at the interface of the screw head and shaft. In this case the screw type was cancellous screw.

Sirin *et al.* (2013) reported that the locking screw head in one case was broken, could be a defective screw which in controls showed no secondary reduction loss post-operatively. Riemer *et al.* (1992) reported implant failure (plate failure or breakage of the screw) in 7% of plate fixations. Egol *et al.* (2004); Frigg, (2001) and (Sommer *et al*, 2004) opined that the interface of the locking head screw with the threaded locking hole is the strongest part of the locking plate system. They opined that the locking screws are less likely to break since the difference between the core diameters of the screw shaft and head is much smaller than it is with conventional screws. Locking screw heads can break in cases of chronic instability and increased strain as a result of rotational forces. Ness (2009) reported that no screw loosening, backing out, or breakage was observed in 115 SOP screws used for fracture fixation and the functional outcome was excellent in most cases.

No cases of implant pullout were noticed in cases where screws were monocortical or in the case where screw breakage was seen. Egol *et al*. (2004) and Frigg, (2001) opined that because the screws are locked to the plate, it is difficult for one screw to pull out or fail unless all adjacent screws fail. DeTora and Kraus (2008) opined that greater area moment of inertia inherent to the SOP provides greater implant strength and therefore less likely to fail with use in buttress fixation.

Lateral deviation of the proximal tibia observed in group I, case 4 might be attributed to the fact that the length of the proximal fragment increased over time. As a result of bone growth, the screw placed through the metaphysis were displaced slightly, leading to elevation of bone surface. Gupta (2015) opined that the stress forces acting on the bone during limb usage could have contributed to the deviation of the bone.

The locking plate technology does not protect from failures due to poor indication, disrespecting of fixation principles and region-specific considerations. The surgeon working with locking plates must be well aware of the indications and contraindications, technical tricks, advantages and limitations, and typical pitfalls and adverse events associated with these new implants (Wagner, 2003; and Cantu and Koval, 2006). The surgeon must keep in mind that, despite the “advanced technology” of expensive locking plates, they do not improve the fracture reduction and cannot help a poorly reduced fracture to heal. Patient behaviour is also impossible to control for and can lead to failure despite the best technical result.

Sommer *et al*. (2004) concluded that the techniques of locking plates demand very careful preoperative planning, especially in the sequence of applying the different types of screws, since this process requires a clear understanding of the principles governing each technique. They opined that most of the pitfalls encountered by surgeons have nothing to do with the implants and must be attributed to non-observation of important basic principles of the concept of biological osteosynthesis.

Locked plating has revolutionised plate fixation. The biomechanical and biological advantages of locking plate systems have led to a widespread use of these new implants in recent years. However, the effective and successful use of locking plates remains highly challenging and is associated with a substantial learning curve. Presently, there are no approved guidelines for the use of locking plates in animals. The basic tenets of plate fixation proposed for human orthopedics by the AO group was extrapolated in the present study. Although, the procedure was technically demanding in some cases, technique of application based on principles used in human orthopedics was found applicable for internal fixation of tibial diaphyseal fractures in all the cases.

Summary

CHAPTER VI

SUMMARY

The present study was conducted in two phases. In phase I, incidence of long bone fractures in goats presented to Veterinary College, Bidar from 2007- 2018 was analysed. It was found that the overall incidence of long bone fractures among all surgical problems in goats was 6.97%. Female goats were more commonly affected (66.66%) than males (33.33%). The incidence of fractures was most common in goats between six months to one year of age (42.75%) followed by those above one year of age (31.88%) and those below six months of age (25.36%). Majority of the animals had simple fractures (73.91%) of long bones. Hindlimbs were more commonly involved (55.08%) than forelimbs (44.98%). The most commonly affected bones were metatarsal (28.08%) and metacarpal (26.08%) followed by tibia (21.60%), radius- ulna (10.87%), humerus (7.97%) and femur (5.07%). Oblique fractures were more common (42.02%) than transverse type (36.95%). Long bone fractures in goats were mostly due to automobile accidents (33.33%) followed by malicious/accidental hit injuries (21.01%) and falling from height (15.84%).

In phase II, the clinical study was conducted in 18 clinical cases of goats presented with tibial fracture. The goats were randomly divided into 3 groups with 6 goats in each group. Three different techniques of open reduction and internal fixation using different locking plates applied as an “internal fixator” were evaluated with an objective to accomplish fracture repair for an early functional weight bearing. In group I, goats having tibial fractures were treated using 3.5mm locking compression plate (LCP). In group II, tibial fractures were treated using 3.5mm locking string of pearls (SOP) plate. In group III, tibial fractures were treated using 3.5mm locking reconstruction plate. The feasibility of using LCP, SOP plate and locking reconstruction plate for treatment of tibial fractures in goats was evaluated using clinical, radiological and biochemical changes. The goats were observed up to 120 days after fracture repair.

Clinical signs of non weight bearing, reluctance to move, lifting the limb above the ground level or just touching the toe to the ground, dangling of the limb indicated a broken bone. Palpation of the tibia revealed pain, swelling and crepitation at the fractured site. The broken bones at the fractured site could be palpated. The medio-lateral and antero-posterior radiographs provided confirmatory diagnosis of the type of fracture and aided in assessment of fracture healing after repair with locking bone plates on post-operative day 0, 15, 30, 60 and 120.

Open reduction and internal fixation technique was followed to apply the locking bone plates as internal fixators in all the cases. The plates were not pre-stressed or contoured to the bone. The plates were pre-dynamized by leaving one to three holes near the fracture site empty.

The physiological parameters, viz., rectal temperature, heart rate and respiratory rate were within normal limits at all intervals in all the three groups. No significant difference was observed within the group or between the group. However, on day 60, the heart rate in group I was non-significantly different from that of group II and group III. The heart rate of group II was significantly ($p<0.05$) differing from that of group III.

All the goats were assigned a lameness grade as per the recommendations of Vasseur *et al*., (1995). On day 0, Out of eighteen goats, nine were able to get up with ease and without assistance. Six goats were able to get up with ease after some assistance and remaining three goats could get up only with support and move slowly by using their three legs. All the goats were unable to completely support weight on the affected limb. The goats in group I and group III showed better weight bearing than the goats in group II. By day 7th the weight bearing in all the goats of all the groups had improved.

On 15th day interval, all the animals were able to bare weight on the limb while at rest and while walking. The lameness grades had improved and mild to intermittent lameness with partial weight bearing at rest and while walking However, the goats in group III exhibited better weight bearing in comparison to group I and group II.

On 30th day, group I and group III animals showed improvement with consistent weight bearing. On day 60, normal weight bearing when at rest and while walking was noticed in all the goats. The goats in all the groups showed similar weight bearing. By day 120, all the goats of all the groups had resumed complete normal weight bearing and no signs of lameness were present. The goats moved about without any discomfort during walking and running. There was no significant difference among the groups with regard to weight bearing.

In the present study, fracture healing was scored based on callus formation and elimination of the fracture line or gap as recommended by Hammer *et al.* (1985). Post-operative radiographic evaluation was carried out on day 0, 15, 30, 60 and 120 to assess the fracture healing. At 0 day, the fracture line was distinct with sharp and well-defined loss of radiographic density in all the 18 cases. The implants were stable and adequate in length. Excellent stability of the fracture fragment was observed in all cases.

On day 15, radiographic healing through initiation of periosteal callus and presence of traces of callus at the fracture site were noticed. The fracture line was distinct in all the cases. Mild to exuberant periosteal callus was observed along the length of the bone at trans cortex and mainly at the points where the screws were fixed. The callus was more in group II and least in group III, indicating that recon plate was more rigid. The extent of secondary callus with recon plate was much less than with SOP plate and LCP.

30th post-operative day radiographs revealed that the fracture line was less visible and was becoming hazy in all the cases. Apparent bridging of the fracture line could be observed. The amount of periosteal callus appeared to be more extensive, dense and homogenous. Traces of callus infiltration on the bone plate were observed. In group II, the extent of callus formation on day 15 and day 30 was earlier, followed by group I. In group III, the quantity of periosteal and endosteal callus noticed was lesser.

By 60th post-operative day, the fracture line was completely obliterated with massive radio-dense callus filling the fracture site indicating achievement of radiographic union. The amount of periosteal callus was decreased and more homogenous in nature. The callus was smoothening and becoming uniform in density. Cortico-medullary remodelling was evident indicating early clinical union. In group II and group I the periosteal and endosteal reaction was extensive and the bridging callus was denser. However, in group III callus resorption could be observed indicating initiation of remodelling.

The fracture union through secondary callus formation was complete in all the cases of all the three groups by day 120. Excellent healing was noticed radiographically with absence of fracture lines. The medullary canal was established and remodelling was appreciable.

The 3.5mm locking compression plates were wider than the reconstruction plate. The foot-print of the string of pearls plate was narrowest among the three groups. However, thickness of the SOP plate was more in comparison to other two plates under study. Intra-operative visualization and assessment of the fracture site and post-operative evaluation of the fracture healing in medio-lateral view was feasible with the SOP plate followed by the reconstruction plate. LCP did not permit adequate exposure of the fracture site due to broader profile. Radiographic assessment of fracture healing in medio-lateral view was difficult with LCP, as the plate was wider and obstructed the fracture site.

Analysis of the biochemical parameters revealed no significant difference in the levels of serum alkaline phosphatase, serum calcium and serum inorganic phosphorus at different time intervals within the group and between the groups. The serum alkaline phosphatase, increased from day 0 to 30th post-operative day and then gradually declined thereafter till day 120. However, all the values remained above the normal physiological limits at the end of study. Elevation of calcium levels above normal values from 15th to 60th post-operative day was observed which gradually declined towards normal by day 120. The serum phosphorous levels showed an increase from day 15 to day 30 after fracture repair in all the groups. The levels declined gradually thereafter to reach normal values by day 120. However, the concentration was within normal limits on all the days of observation.

Intra-operative complications included iatrogenic fractures, monocortical placement of screws and accidental placement of screw at the fracture site in two cases. Post-operative complications were limited to wound infection due to irregular follow-up in early post-operative period by the owners. Infection was noticed at the distal tibial region which might have been caused due to chronic irritation to the skin during ambulation due to the thick profiles of LCP and SOP plate. Implant related failures were not noticed in any of the cases except for breakage of one cancellous type of screw. No complications were noticed during implant removal.

Based on the above findings the following conclusions were derived

1. Incidence of long bone fracture among all surgical conditions in goats presented to Veterinary College, Bidar was 6.97%. Female goats were more commonly affected. The incidence of fractures was most common in goats between six months to one year of age. The most commonly affected bones were metatarsal and metacarpal. Oblique fractures were more common. Majority of the long bone fractures in goats were due to automobile accidents.

2. All the bone plates (LCP, SOP plate and reconstruction plate) evaluated in the study applied as internal fixators were found to be effective in repair of diaphyseal tibial fractures in goats.

3. In all the groups, normal weight bearing was achieved by day 30. Functional weight bearing was observed in all the groups by day 60. The weight bearing was similar in

all the cases. Group I (LCP) showed slightly better weight bearing throughout the period of study compared to group II and group III.

4. Initiation of periosteal callus was noticed by day 15 in all the groups. Apparent bridging of the fracture site was noticed in all the groups by day 30. Cortico-medullary union was established by day 60 and initiation of remodelling was observed by day 120. The complete union and initiation of remodelling of fracture was observed to be earlier in group III, followed by group II and group I.

5. Fracture healing in all the groups was through secondary callus formation. However, in group I and II a larger periosteal callus was noticed. Whereas, in group III the periosteal callus was lesser in quantity.

6. The physiological and biochemical parameters fluctuated within normal limits and no significant alterations were noticed.

7. The intra-operative and post-operative complications noticed were trivial and resulted in uneventful recovery in all the cases.

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CHAPTER VII

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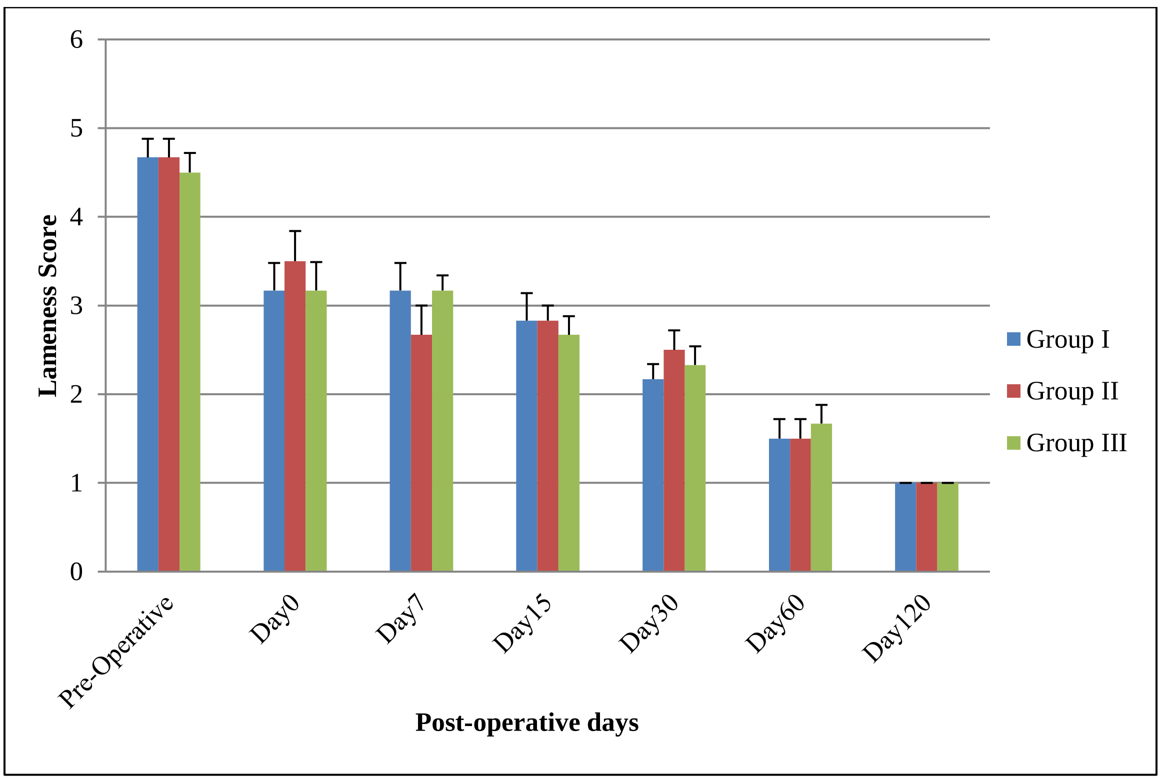
Table 15b: Mean ± S.E., values of lameness score on pre-operative and post-operative days in all the groups of animals

Days	Group I	Group II	Group III
Pre-operative	4.67±0.21[a]	4.67±0.21[a]	4.50±0.22[a]
Day 0	3.17±0.31[b]	3.50±0.34[ab]	3.17±0.32[b]
Day 7	3.17±0.31[b]	2.67±0.33[bd]	3.17±0.17[b]
Day 15	2.83±0.31[b]	2.83±017[b]	2.67±0.21[bd]
Day 30	2.17±0.17[bc]	2.50±0.22[be]	2.33±0.21[bd]
Day 60	1.50±0.22[c]	1.50±0.22[cde]	1.67±0.21[cd]
Day 120	1.00±0.00[c]	1.00±0.00[c]	1.00±0.00[c]

Means with different superscripts (a,b,c,d,e..) indicate significant difference ($p<0.01$) between time intervals within a group

Fig. 10: Lameness score on pre-operative and post-operative days



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Abstract

VIII. ABSTRACT

EVALUATION OF DIFFERENT LOCKING BONE PLATES FOR FRACTURE REPAIR IN GOATS

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The present study was conducted in two phases. In phase I, incidence study of long bone fractures in goats was undertaken. The incidence of long bone fractures among all surgical conditions in goats was 6.97%. Female goats were more commonly affected. Higher incidence of fractures was noticed in hindlimbs and in young goats between six months to one year of age. The most commonly affected bones were metatarsal and metacarpal. Majority of the goats had simple fractures; oblique fractures being more common. Majority of the long bone fractures in goats were due to automobile accidents. In phase II, the research was conducted in 18 clinical cases of goats affected with tibial fractures. The goats were randomly divided into three groups with six goats in each group. The feasibility of three different techniques of ORIF using 3.5mm locking plates applied as an “internal fixator” were evaluated using clinical, radiological and biochemical changes on pre-operative day, post-operative day 0, 15, 30, 60 and 120. In group I, LCP, in group II, locking SOP plate and in group III, locking reconstruction plates were applied. In all the groups, normal weight bearing was achieved by day 30. Functional weight bearing was observed in all the groups by day 60. Group I (LCP) showed slightly better weight bearing throughout the period of study compared to group II and group III. Radiological evaluation revealed that fracture healing in all the groups was through secondary callus formation. Initiation of periosteal callus was noticed on day 15 in all the groups. Apparent bridging of the fracture site was noticed in all the groups on day 30. Cortico-medullary union was established on day 60 and initiation of remodelling was observed on day 120. The complete union and initiation of remodelling of fracture was observed to be earlier in group III, followed by group II and group I. The physiological and biochemical parameters fluctuated within normal limits and no significant alterations were noticed. Intra-operative complications included iatrogenic fractures, monocortical placement of screws and accidental placement of screw at the fracture site. The post-operative complications noticed were limited to infection of operative site resulted in uneventful recovery of the cases. Implant related failures were not observed in any of the groups. The implants were removed between day 120 to 150 and no complications were noticed during implant removal.