CLINICAL EVALUATION OF END THREADED INTRAMEDULLARY PINNING FOR MANAGEMENT OF LONG BONE FRACTURES IN CANINES

THESIS

By

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Place: Palampur (Mitin Chanana)

Dated:

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LIST OF ABBREVIATIONS USED AND THEIR MEANINGS

Abbreviations	**Meaning**
%	Per cent
<	Less than
>	Greater than
@	At the rate of
&	And
ºF	Degree Fahrenheit
AMI	Area moment of inertia
AO/ASIF	Association for the Study of Internal Fixation
ASTM	American Society for Testing and Materials
B.I.D	Twice a day
B.Wt.	Body weight
Cm	Centimeters
DCP	Dynamic compression plate
et al.	And others
Fig.	Figure
Gm	Gram (s)
i.e.	That is
I.M.	Intramuscular
I.V.	Intravenous
IM	Intramedullary
Kg	Kilogram (s)
Kpa	Kilopascal
K-Wire	Kirschner wire
LC-DCP	Limited contact dynamic compression plate
LCP	Limited contact locking (threaded) auto compression plate
M.D.	Major diameter
mg	Milligram
min	Minute
ml	Milliliter
mm	Millimeter
Mpa	Megapascal
n	Number of cases
O.D	Once a day
P.D.	Pitch diameter
Pa	Pascal
Post-Op	Postoperatively
Pre-Op	Preoperatively
S.C.	Subcutaneous
Syrp.	Syrup
Viz.	Namely

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ABSTRACT

The present investigation was undertaken to evaluate the clinical efficacy of end-threaded intramedullary pinning for management of various long bone fractures in canines. The study was carried out in two phases, managing 25 client owned dogs presented with different fractures. Initially, the technique of application of end threaded intramedullary pinning in long bone fractures was standardized in 6 clinical patients presented with long bone fractures. In this phase, end threaded pins of different profiles i.e. positive and negative, were used as the internal fixation technique. These patients, allocated randomly in two groups, when evaluated postoperatively revealed slight pin migration in group-I (negative profile), which resulted in disruption of callus site causing delayed union in one case and large callus formation in other two cases whereas no pin migration was observed in group-II (positive profile). Other observations in group-I was reduced muscle girth and delayed healing time as compared to group-II. In clinical application phase, on the basis of results obtained from standardization phase, 19 client-owned dogs clinically presented with different fracture, implanted with end threaded intramedullary positive profile screw ended self tapping pin. Immediate post-operative radiograph revealed anatomical reduction, good cortical contact and stable implant fixation whereas muscle girth showed an initial decrease followed by a gradual increase over time. The 21st and 42nd day post-op radiographical follow-up revealed no pin migration in any of the cases and there was no bone shortening or fragment collapse. Based upon the above observations, it was concluded that the end threaded intramedullary positive profile screw ended self-tapping pin used for fixation of long bone fractures in canines can resist pin migration, pin breakage and all loads acting on the bone i.e. compression, tension, bending, rotation and shearing to an extent with no post-operative complications. The implant was found economical and can be easily used in field conditions in managing long bone fractures in canines, as compared to other orthopaedic implants.

(Signature of student with date)

(Signature of Major Advisor)

Head of Department

Chapter-1 INTRODUCTION

Trauma, the most common cause of fractures in small animals, is usually due to automobile injury or falling from a height. The amount and direction of force varies from accident to accident. Most fractures resulting from violent direct trauma are either comminuted or multiple.

The aims of fracture treatment are; early healing of the bone, rapid return to full function of the injured leg, and prevention of damage to the soft tissues and bone. Provided pin application principles are strictly adhered to, intramedullary pinning is a method that can easily be applied.

Treatment of fractures via intramedullary fixation is regularly used in Veterinary orthopaedics. For this treatment method, the Steinmann pin appears to be the most often used material, either on its own or in combination, while the Rush pin, Kirschner wire, Kuntscher pin and interlocking pin have all been employed.

Comminuted diaphyseal fractures are frequently encountered in Veterinary practice. Realignment of fracture fragments is achieved using lag screws and cerclage wires providing anatomical reduction, after which rigid fixation is established with a neutralisation plate. In comminuted fractures, although there are factors such as difficulties with reduction and stabilisation, time consumption, and a necessity for technical precision, the neutralisation plate becomes the most viable option. Long periods of anatomical reduction attempts frequently cause damage to soft tissues connected to the bone. Reduction of comminuted fractures is difficult due to surrounding soft tissues and even experienced surgeons may fail to achieve complete anatomical reduction. Prolonged duration of surgery, damage to soft tissues surrounding the bone and incomplete reconstruction of the bone diaphysis all play an important role in the failure of the fixation.

Unthreaded intramedullary pins alone cannot provide adequate traction and rotational stability as they are weak against rotational and shearing forces (DeYoung and Probst 1993). Stack pin application partially prevents these disadvantages by opposing the horizontal crossing and bending forces (Lidbetter and Glyde 2000) and it has been reported that combined plate-intramedullary pin application is successful in increasing axial and rotational stability (Hulse *et al.* 2000). Rotational stability can also be increased by cerclage wire, external fixation, interlocking pins and trilam nails (Hach 2000), or by using a C-clamp on the plate (Coetzee 2002). Lanz *et al.* (1999) reported that stabilisation of a Salter Harris type

IV physeal fracture of the humeral condyle in a miniature pinscher was simplified by using orthofix partially threaded Kirschner wire, with excellent clinical results. Partially threaded pins, having a negative profile ending creates a weak point in the pin-thread junction, so if these pins are to be used, the junction must not be near the fracture line (Olmstead *et al.* 1995; Denny and Butterworth 2000).

Maximum stability is required in intramedullary fixation to enable secondary bone healing, and a stable implant and strong callus formation consequently enables reliable and fast weight bearing (Brinker *et al.* 1985). While pin migration may occur when using unthreaded intramedullary pins, threaded pins prevent migration by gripping the cancellous bone.

The incidence of fractures in animals form a major part of the referral practice of Teaching Veterinary Clinical Complex of CSKHPKV. The fractures are managed with different techniques having their own pros and cons. A slight innovation and modification has been made with provision of threads at one end of the existing Steinman pin, and has been found to be one of the promising techniques in management of fractures in animals during our preliminary trials. As the intramedullary implant is easy to apply and remove without any post operative complication, it can be proved advantageous in animals with appalling temperament.

Many veterinary practitioners in field do not have access to the specialized and costly equipment to undertake complex orthopaedic procedures, or lack the technical assistance required to perform such operations. However, many of them have access to, and are skilled in using the simpler, more affordable equipment necessary to place an intramedullary pin and cerclage wires.

The aims of this study were:

1. To standardize the technique of application of end threaded intramedullary pin for management of long bone fractures in canines.
2. To evaluate the efficacy of end threaded intramedullary pin in management of long bone fractures in canines.

Chapter-2 REVIEW OF LITERATURE

Depending on the anatomical part of the bone there are: diaphyseal, metaphyseal and epiphyseal fractures. A classification on bone fractures, on the basis of fracture line includes transverse, oblique, spiral and impacted fractures. A fracture distribution depending on the degree of bone fragmentation consists of simple, comminuted and segmental fractures (Baadet *et al.* 1983; DeYoung and Probst 1985).

On the basis of a retrospective study on incidences of long bone fractures in canines over a period of five years, it was recorded that out of 5931 number of cases presented for long bone fractures; 34.69% were femur fractures, 33.62% tibia and fibula fractures, 17.88% radius and ulna and 13.79% of humerus bone. Considering fracture localisation, 73.06% diaphyseal fractures, 5.17% metaphyseal fractures and 21.76% epiphyseal fractures were recorded (Mosneang and Igna 2012).

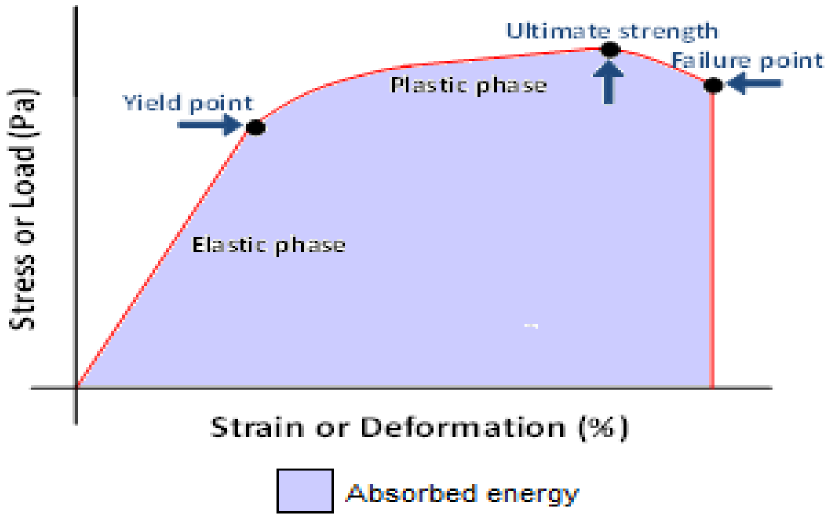
2.1 Biomechanical consideration of bone

Consideration of mechanical influences on bone during normal physiologic and nonphysiologic use is important since excessive load may result in failure (fracture) of the bone and implant (Schwarz 1993).

Bone as a biological material can absorb large amounts of load associated with normal physiologic activity, e.g. walking or running, but is less capable of tolerating a nonphysiologic load, e.g. bending (Kraus 1993).

Bone is not totally rigid and can deform due to loads applied to it. When mild deforming loads are removed from bone, it resumes its original shape. This is called elastic deformation. Large loads will deform bone permanently, i.e. to a point where it cannot resume its original shape. This is called plastic deformation. Even larger loads will result in failure of bone and will cause a fracture. This relationship between load (force) and bone deformation is described in graphic form (Plate-2.1) as a force-deformation curve (Kraus 1993; Schwarz 1993; Hulse and Hyman 2003).The structural strength of an object can be determined from such a graph by the load the structure can withstand, the deformation the structure undergoes, and the amount of energy the structure absorbs before falling (Schwarz 1993).

Plate 2.1: A classical stress-strain graph (Kraus 1993)



The material properties of bone tend to differ depending on the rate at which a specific load is applied to it. If a load is applied rapidly, bone tends to absorb more energy and will behave with more stiffness and higher ultimate strength. Any material with such a load-rate dependent property is referred to as viscoelastic. Furthermore, bone is also anisotropic, i.e. exhibiting different mechanical properties in different directions (Kraus 1993; Schwarz 1993; Hulse and Hyman 2003).

Every bone is a complex structure with a collection of components each having different material properties. For example, the metaphysis of tibia has different material properties than its diaphysis. A single bone is composed of both cortical and cancellous bone, with porosity ranging from 3% to 90%. The material properties of cortical and cancellous bone are different and reflect their general biomechanical purposes.

The metaphysis is composed of mostly of cancellous bone (Kraus 1993; Schwarz 1993; Hulse and Hyman 2003) which is made up of individual trabeculae, each with its own stiffness, together forming a structure that has its own unique stiffness. Cancellous bone therefore has a material stiffness, which is the stiffness of each trabeculae and a structural stiffness, which represents the stiffness of entire trabeculae structure. The majority of biomechanical studies of cancellous bone concentrate on its structural properties because the material properties of different trabeculae are difficult to measure individually. These structural properties vary in different anatomical regions depending upon the cancellous bone density and trabecular orientation (Turner and Burr 1993). When a large compressive load is applied to bone, the fine trabeculae of the bone will collapse. The wide metaphysis, though early to deform, will continue to deform without complete collapse. This material property is helpful in absorbing loads across joints and preventing direct damage to the joint cartilage (Kraus 1993; Hulse and Hyman 2003).

The diaphysis, on the other hand is composed of cortical bone where large loads are needed to deform the bone (Schwarz 1993; Hulse and Hyman 2003). Nearly 80% of the skeletal mass is represented by cortical bone. It provides strength in areas where bending or any other load would be undesirable, such as in diaphysis of long bones (Turner and Burr 1993). Cortical bone is normally rigid, yet brittle, with little plasticity, resulting in a long elastic phase of the stress strain graph and a very short plastic phase. Once enough strain has occurred, the diaphysis will fracture (Kraus 1993; Schwarz 1993; Hulse and Hyman 2003).

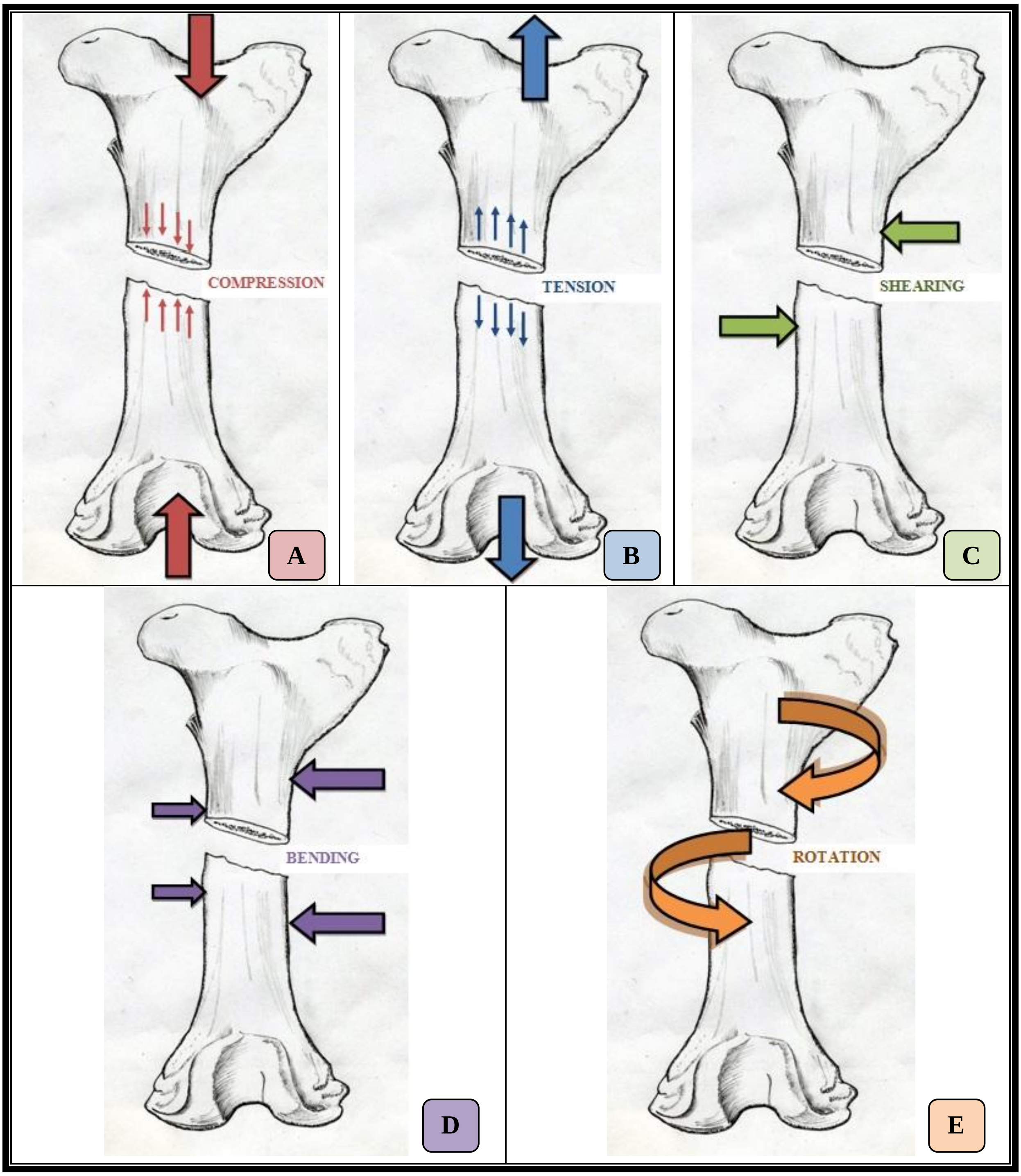
2.2 Forces acting on bone

Long bones exhibit specific fracture patterns as a result of different modes of loading. Several internally and externally generated forces can act on bone in vivo, arising either individually or in combination with one another (Rhinelander and Wilson 1982). Five individual forces acting on long bones are usually recognized i.e. compression, tension, shearing, bending and torsion (Sinibaldi 1983; Eaton-Wells *et al.* 1990; Schwarz 1993; Coetzee 1999; Hulse and Hyman 2003; Pope 2003; Roe 2003; Piermattei *et al.* 2006).

Axial forces, either compression or tension, occur along the long axis of the bone, while shearing occurs transversely, bending in a craniocaudal or mediolateral plane, and torsion in either direction around the long axis of the bone (Schwarz 1993).

Compression (Plate-2.2.A) occurs when two opposing forces act on a long bone along a single axis (Kraus 1993; Hulse and Hyman 2003; Piermattei *et al.* 2006) and is a primary disruptive force present in along bone diaphyseal fractures, owing to load generated by weight bearing and muscle contractions surrounding the bone. Compressive load can be beneficial in transverse and short oblique diaphyseal fractures where the fragment ends interdigitate and axial alignment is maintained, or detrimental in short oblique diaphyseal fractures where the fragment ends do not interdigitate, long oblique fractures and comminuted fractures in which anatomical reconstruction is not possible (Schwarz 1993).

Plate-2.2 Pictorial representation of different biomechanical forces acting on the bone



Resistance against compression is directly related to bone's mineral content. Pure compressive forces seldom cause fractures in animals because bone is under normal circumstances quite resistant to this normal physiologic type of load. However, when larger than normal compressive forces that exceed absorption are applied, most of the energy is released into the adjacent bony tissue, disrupting the structure of the bone, often leading to short oblique fractures (Kraus 1993; Schwarz 1993).

Tension (Plate-2.2.B), the opposite of compression, occurs when two opposing forces pull the bone apart (Kraus 1993; Hulse and Hyman 2003; Piermattei *et al.* 2006). Pure tensile forces are not seen in the diaphysis of long bones, but generally at the end of long bones where tendons and ligaments insert, and on the convex surface of bones undergoing bending deformation (Schwarz 1993). Resistance against tension is mainly related to the arrangement and properties of collagen. Tensile forces generally result in failure perpendicular to their direction. These forces are generally not physiologic and therefore, bone is inherently weaker against them. Avulsion fractures are examples of the result of tensile forces (Kraus 1993; Schwarz 1993).

Shearing (Plate-2.2.C) occurs when the forces in opposite directions at different level act on a bone. The opposing forces are due to the inherent resistance of constituents of bone to slide across one another. The bone fractures when bonds between the constituent parts fail, as in tension. Shear forces are also generally not physiologic, therefore long oblique fractures usually occur easily secondary to these forces (Kraus 1993; Schwarz 1993; Hulse and Hyman 2003; Piermattei *et al.* 2006).

Bending (Plate-2.2.D) results, when tensile and compressive forces act simultaneously on bone (Kraus 1993; Hulse and Hyman 2003; Piermattei *et al.* 2006). Bending forces are the result of eccentric loading of long bones, their normal curvature, and the spanning of these bones by large muscle masses (Schwarz 1993).

Because bending and tensile forces are opposing forces, the plane within the bone between bending and tensile forces contains no load and is called the neutral plane. The opposing forces are the bone's strength against compression and the bonding of its constituent parts. The bone will fracture first on the tension side. Since many long bones, have some curvature, forces acting from each end of the bone result in bending loads as well as compressive and tension loads. The greatest tensile load is found on the convex side of the curved bone, whereas the greatest compressive load is on the concave side. The fracture line will progress across the bone transversely or slightly obliquely, resulting in transverse, short oblique and/or comminuted fractures of the concave aspect, often with some butterfly fragments and greenstick fractures (Kraus 1993; Schwarz 1993; Hulse and Hyman 2003; Piermattei *et al.* 2006).

Torsion (Plate-2.2.E) occurs when rotating loads in opposite direction act on the ends of a bone structure. The opposing loads tend to be complex and depend on the geometry of the bone. Shear and tensile forces are the major constituent forces; therefore, the bonding substances of the bone act as the opposing forces (Kraus 1993; Hulse and Hyman 2003; Piermattei *et al.* 2006).

Shear forces are distributed about the neutral axis along the entire cross-sectional area of the bone and roughly at 45 degree to the axis of rotation (Schwarz 1993). Since strong torsional forces are not generally physiologic in nature and an angled distal limb easily acts as a rotational lever arm, fractures due to torsion are common and usually result in spiral oblique fractures (Kraus 1993; Hulse and Hyman 2003; Piermattei *et al.*2006).

The metaphysis of long bones are comprised of trabecular bone that is able to absorb and transmit energy and compressive loads generated by normal weight bearing. Because the resistance of trabecular bone is less than that of cortical bone, the metaphyseal region has to be wider than other regions of long bones (Carter and Spengler 1982; Audekercke and Martens 1984; Piekarski 1984; Meade 1989). The fact that long bones are thinner in the diaphyseal area than in the metaphyseal or epiphyseal areas, but still maintain adequate strength is due to the compact nature of their bone material and their strain behaviour. The compressive load of diaphyseal bone reduces the strain in bending and thus increases its capability for elastic and plastic bending without a brittle fracture (Carter and Spengler 1982; Piekarski 1984; Meade 1989).

The shape of the diaphysis of most long bones is cylindrical with a compromise between a square and triangle in cross section. Its shape is dependent on the type of forces it is designed to resist. A cylindrical shape is best for resisting torsional forces and a square shape for resisting bending forces that are applied parallel to its sides. The diaphysis of long bones is also tubular. This shape is better able to resist torsional and bending forces than a solid cylinder, since it distributes its mass at a distance from the neutral axis of the bone (Nordin and Frankel 1980; Audekercke and Martens 1984; Piekarski 1984).

In addition, the heterogenous nature of the bone as a material allows for different areas of bone to have different strengths in response to different loads. Loads will tend to concentrate and propagate along the weak areas of bone (Kraus 1993).

A bone fractures when a load greater than its tolerance is applied to it. The resultant fracture pattern is a function of the type of load, the amount of energy applied, the viscoelastic properties of the bone and to a lesser extent, the amount of tissue covering the area.

2.3 Blood supply

All physiological processes within bone, including the ability to heal, are dependent on its blood supply. In the diaphysis of mature long bones, the afferent blood supply, which is of frequent concern in orthopaedics, is derived mainly from the principal nutrient artery and supplemented through anastomoses with the metaphyseal arteries (Gothman 1962; Wilson 1991). In areas where the medullary circulation is intact, the cortex is mainly supplied by these medullary blood vessels, except in areas of ligamentous, fascial or strong muscular attachments (Gothman 1962; Hinko and Rhinelander 1975; Wilson 1991). In these areas, a minor component of the afferent system, the periosteal arterioles, run perpendicularly to the cortex and supply its outer layers (Gothman 1962; Wilson 1991). According to research by Gothman (1962), there are no longitudinal periosteal blood vessels. Under normal circumstances the direction of blood flow through the cortex is centrifugal, i.e. from medulla to periosteum, with venous drainage from the periosteal surface. Blood flow in immature bone is greater than in mature bone and is centered around areas of active growth. Here, the epiphysis and metaphysis are supplied separately and the periosteum has an extensive longitudinal system of blood vessels. At maturity, the metaphyseal and epiphyseal blood supply become one and the periosteal supply atrophies to only a vestige (Wilson 1991). With bone fractures, the afferent blood supply increases at the sites of healing. When needed, a variable and transitory supplemental extraosseus blood supply can be derived from the periosseous soft tissues. The function of this new extraosseous system is to supply blood to detached bone fragments, periosteal callus and the cortex when devascularized by trauma or surgical intervention. This transient extraosseous blood supply subsides as soon as the normal components of the bone’s blood supply are re-established (Gothman 1962; Hinko and Rhinelander 1975; Wilson 1991). To some degree, every method available to stabilize fractures has the potential to compromise the local blood supply to the bone. For example, the insertion of an intramedullary pin will disrupt the medullary blood flow, the extent thereof depends on the size of the pin – the larger the pin in relation to the medullary cavity, the greater the vascular damage (Wilson 1991).

2.4 Procedures commonly used in fracture repair

The goal of any fracture treatment is early ambulation and complete return to full function (Brinker *et al.* 1985). The surgeon must always aim to obtain a load-sharing system between the bony column and the implant that is mechanically stable and to maintain axial and rotation alignment throughout the entire healing period (Schwarz 1993; Coetzee 1999). Stability of a fixation depends on the stiffness of the fixation device, the stiffness of the device-bone interface and the effectiveness of the device to specifically neutralize disruptive forces acting on the fracture (Schwarz 1993).

Various methods of fixation can be used successfully depending on the nature and location of the fracture and signalment of the patient (Johnson and Boone 2003; Pope 2003; Harari 2004). Familiarity of the surgeon with different techniques and equipments is important in determining the selected method of repair. Methods of fixation currently in use in veterinary orthopaedics are; bone plates, screws, intramedullary pins, cerclage wires, external skeletal fixation, interlocking nails, and various combinations of the above (Alexander 1982; Sinibaldi 1983; Nunamaker 1985; Boone *et al.* 1986; Aron *et al.* 1991; Bouvy *et al.* 1993; Boudrieau 2003; Durall *et al.* 2003; Durall *et al.* 2004; Johnson and Boone 2003; Roe 2003; Harari 2004; Seaman and Simpson 2004; Ness 2006; Roe 2006; Johnson 2009; McCartney *et al.* 2009; Ting *et al.* 2009).

Intramedullary pins and orthopaedic wires are widely available and relatively inexpensive and many surgeons are skilled in their use. Hence intramedullary pins and cerclage wires are commonly used for fixation of long bone fractures, usually with fairly good results (Rhinelander 1974; Boone *et al.* 1986; Dixon *et al.* 1994; Lipowitz *et al.* 1996; Boudrieau 2003; Johnson and Boone 2003; Piermattei *et al.* 2006).

2.4.1 Cerclage wiring

The use of cerclage wiring as ancillary treatment with IM pins refers to a flexible stainless steel wire that completely (full cerclage) or partially (hemicerclage) passes around the circumference of a bone and is then tightened to provide static interfragmentary compression of the different loose bone fragments (Roe 2003; Roe 2006; Piermattei *et al.* 2006)

Cerclage wires effectively counteract bending, shear and rotational loads, and also provide interfragmentary compression of the fracture fragments (Sinibaldi 1983; Nunamaker 1985; Eaton-Wells *et al*. 1990; Boudrieau 2003; Hulse and Hyman 2003; Roe 2003; Piermattei *et al.* 2006). Because of the stresses produced by early weight bearing, it is not recommended to use full cerclage or hemicerclage wires as the only method of fixation in any type of oblique diaphyseal fracture. In addition, wires are often stressed during placement and tying, and are therefore susceptible to fatigue failure. Small nicks and notches in the wire also weaken a wire's resistance to repetitive loading (Roe 2006). Cerclage wires are used primarily as ancillary fixation devices with IM pins and bone plates on long oblique, spiral and certain comminuted or multiple diaphyseal fractures.

In addition, cerclage wires are used intraoperatively to aid in holding fracture fragments together while the primary fixation is applied (Piermattei *et al.* 2006; Roe 2006). Cerclage wire fixation should be restricted to those oblique diaphyseal fractures where the length of the fracture line is at least twice the diameter of the bone (or longer), ensuring that tensioning of the wire produces stable interfragmentary compression rather than shearing (Rooks and Tarvin 1982; Piermattei *et al.* 2006; Roe 2006). At least two wires should be used, but more than two cerclage wires are recommended. They should be spaced about half a bone diameter apart (Roe 2006) starting and ending approximately 0.5 cm from the tips of the fragments and be perpendicular to the long axis of the bone Coetzee (1999). Rooks and Tarvin (1982) and Blass and Piermattei (1986) independently recommend the use of monofilament stainless steel wire of 0.8 to 1.0mm (20 to 18 gauge) for use in small to medium sized dogs. Roe (2006) supports this and concludes that there are no rules for the appropriate size for a particular situation other than to use the biggest diameter of wire that seems appropriate to the size and strength of the bone. The effects of cerclage wiring on fracture healing have been reported (Rhinelander 1974; Rhinelander and Wilson 1982; Wilson 1987; Tomlinson and Payne 1993). Failure of fracture healing is usually not due to vascular compromise by the cerclage wire, but due to failure to apply cerclage wires correctly

(Gothman 1962). Due to the fact that the actual contact area of the cerclage wire with the underlying bone is less than the diameter of the wire, it minimally interferes with cortical blood flow (Gothman 1962; Hinko and Rhinelander 1975) even when parts of the bone surface are grooved for anchoring of the wires. The key in preserving the cortical blood supply is that all cerclage wires must be tight around the bone, since a moving wire will disrupt the periosteal capillary network, devascularizing the underlying bone and disrupting periosteal callus formation (Rhinelander 1974; Rhinelander and Wilson 1982; Piermattei *et al.* 2006). If a wire is loose or broken, the fracture may be unstable at the fracture line, which can lead to excessive bone movement with a resultant delayed or nonunion. Movement of the wire can interfere with bone vascularization by shearing off capillaries arising from the soft tissues that form the transient extra-osseous blood supply (Gothman 1962; Wilson 1991).

2.4.2 Bone plates and screws

Bone plates and screws are considered as the most sophisticated and reliable form of internal fixation currently available. Stable internal bone plate and screw fixation allows for early joint mobilization, full weight bearing, and union of the fracture (Coetzee 2002; Piermattei *et al.* 2006; Roe 2006).

i. Bone plates

When applied correctly, bone plates produce excellent stability of the fracture site (Piermattei *et al.* 2006; Roe 2006). They are effective in resisting all loads that are needed to be counteracted – compression, tension, and rotation, and if the bone is anatomically reconstructed, also bending and shearing loads (Ness 2006; Piermattei *et al.* 2006; Roe 2006). Bone plates are most susceptible to bending loads because of their eccentric placement relative to the central axis of a bone. When fractures are anatomically reduced with fragments compressed by the plate, the bone and plate share the load, their AMI is large, and the construct is strong. When it is not possible to reconstruct the bone, the plate alone has to resist all the bending forces. A screw hole, especially when located within the area of the fracture, is the weakest point on a plate due to stress concentration and greatly reduced AMI at that point (Muir 1995; Little 2001; Roe 2006). Various types of bone plates are available, which are primarily copies of the original system developed by the Association for the Study of Internal Fixation (AO/ASIF). Based on their function and modes of application, three main groups of bone plates are recognised in veterinary orthopaedic surgery, i.e. dynamic compression plate (DCP), neutralization plate and buttress plate (Piermattei *et al.* 2006; Roe

2006). Due to its versatility, DCPs can be used in all three modes of application (Coetzee 2002; Piermattei *et al.* 2006; Roe 2006). DCPs have oval, sloped screw holes whereas true neutralization plates have round holes; other plates can have either oval or round screw holes or combinations thereof incorporated in their design (Coetzee 2002; Roe 2006).

The principle of the DCP is to stabilize and compress a fracture with good bone contact between the major fragments, e.g. transverse or slightly oblique fractures, by driving the bone ends together by means of tightening of eccentrically placed screws in the oval, sloped screw holes. This causes the bone fragment that the screw engages, to move with it relative to the plate, so that the fracture gap is narrowed (Coetzee 2002).

A neutralization plate (either a DCP applied in neutralization mode or a true neutralization plate) refers to the application of the plate without compression. The plate splints the bone to support and neutralize the different forces acting on the reconstructed cylinder of bone. It is used when the fracture plane is oblique, because applying compression in a dynamic compression mode will cause the fragments to overlap one another. In these cases, compression of the fracture line and holding the fragments together is best achieved with lag screws or cerclage wires. However, they are never able to resist the bending forces on a weight-bearing bone on their own and therefore the additional application of a neutralization plate is imperative (Piermattei *et al.* 2006; Roe 2006). When a bone cannot be reconstructed in the area of the fracture, the plate is applied in buttress mode to maintain axial alignment. No compression is afforded to the fracture and the plate acts as a bridge. The plate is securely attached to the major proximal and distal bone fragments and must bear the entire load on the bone until the callus bridges the gap and matures. In some situations, a lengthening plate may be used so that a solid portion of plate spans the comminuted section of bone (Coetzee 2002; Piermattei *et al.* 2006; Roe 2006). Other plate types were developed to address certain deficiencies in the standard bone plate systems during specific applications (Roe 2003; Piermattei *et al.* 2006). An example of these, is the limited contact dynamic compression plate (LC-DCP), where stress concentration in the area of the screw holes is reduced, the AMI is similar over the length of the plate, the amount of devitalized cortical bone due to interference with periosteal blood supply is reduced, and which has superior fatigue resistance compared to DCPs (Muir 1995; Little 2001; Roe 2006). Another recent development is the limited contact locking (threaded) auto compression plate (LCP) which allows the surgeon to use locking screws, compression screws or both at any location (Florin *et al.* 2005; Securos Catalogue of Products 2008). Biodegradable, self-reinforced polylactide bone plates are increasingly being used in human orthopaedics and are also available for use in veterinary patients, notably in toy breed dogs, in combination with metal screws. However, these plates are usually not strong enough when used as a single plate and clinical use in veterinary patients has been limited due to their relatively high cost. Semitubular plates are standard plates in the AO/ASIF system, but due to its relative weakness compared to DCPs, are not often used in veterinary orthopaedic surgery (Zahn and Matis 2004; Florin *et al.* 2005; Saikku-Backstrom *et al.* 2005; Sod *et al.* 2005; Piermattei *et al.* 2006; Roe 2006; Ness 2009). The AO/ASIF group has developed guidelines for selection of the plate size for various bones based on the weight of the patient (Piermattei *et al.* 2006).

ii. Bone screws

Screws in orthopaedic surgery are used to hold a plate to the bone in a lag fashion (Roe 2003; Roe 2006) and to compress or hold bone fragments together. In most instances of individual use, they are applied in lag fashion so that fragments are compressed (Brinker *et al.* 1984; Schatzker 1991; Roe 2003; Roe 2006). Two basic types of bone screws are used in orthopaedic surgery i.e. cortical and cancellous (Brinker *et al.*1984; Schatzker 1991; Coetzee 2002; Roe 2006). Cortical screws are always fully threaded. Their core diameter is relatively thick and the pitch of the threads relatively shallow. Cortical screws are designed for primary use in the dense diaphyseal bone. Cancellous screws are either fully threaded or partially threaded, but with relatively few threads per unit length. Their core diameter is relatively thin and the pitch of the threads relatively high with deep threads. Cancellous screws are designed for use mainly in the metaphysis or epiphysis where the cortex is thin with an abundant amount of cancellous bone present, in very young animals with soft cortical bone, or in cases where threads for cortical screws have been stripped (Brinker *et al.* 1984; Nunamaker 1985; Schatzker 1991; Coetzee 2002; Roe 2006). Cortical screws are frequently used in a lag fashion by overdrilling the cis-cortex. The hole in the trans-cortex is determined by the core size of the screw and tapped with a tap that corresponds to the thread of the screw (Brinker *et al.*1984; Schatzker 1991; Roe 2003). A lag screw's thread purchases only the trans cortex. Lag screws, or the use of the lag screw technique, are the most efficient way of achieving interfragmental compression and stability (Brinker *et al.* 1984). Static interfragmental compression is achieved by tightening the screw. Maximal interfragmental compression is achieved when the screw is inserted through the middle of the fracture line equidistant from the fracture edges and directed more or less at right angles to the fracture plane. When a screw in lag fashion is inserted in any other direction, shearing loads will be introduced and the fragments will shift (Brinker *et al.* 1984; Schatzker 1991; Roe 2006). In oblique, spiral or multiple diaphyseal fractures, the bone fragments should be held in place by lag screws, or using the lag technique with a gliding hole. However, lag screws do not provide a great deal of strength. They are therefore protected from weight-bearing by a bone plate applied in a neutralization mode (Brinker *et al.* 1984).

2.4.3 Intramedullary pinning

Steinmann pins are the most commonly used intramedullary devices in Veterinary medicine. It is often used in combination with hemicerclage or full cerclage wiring to effect greater stabilization. The devices used in veterinary medicine include only the Steinmann pin, Kirschner wire, Rush pin and Kuntscher nail, and of these, the Rush pin and Kuntscher nail are not used extensively.

i. Single Steinmann Pinning

Intramedullary pinning with a single Steinmann pin is indicated in fractures throughout the length of a long bone. It is best for transverse and short oblique fractures of the middle third of long bones. It can be applied in conjunction with cerclage and hemicerclage wiring, which will extend its indications considerably. Single or multiple Steinmann pins together with cerclage and hemicerclage wiring may be adapted for all types of fracture fixation.

ii. Multiple Steinmann Pinning

Multiple Steinmann pinning is useful in transverse and short oblique fractures in the middle half of the long bone. The technique is especially useful when trying to optimise torsional stability of the fracture site with round pins in large medullary cavities. The concept of multiple pinning is to fill the medullary cavity with an implant so that strong frictional forces between the pins and the inner cortical surface of the medullary cavity will prevent rotation. Multiple Steinmann pinning can be used in comminuted fractures along with cerclage wiring (Nunamaker 1985).

The goal of IM pinning is to fill the area of the fracture with the pin (or pins), as this gives rigidity to the pin-bone unit (Piermattei *et al.* 2006). As long as the tubular nature of the fractured bone is restored, IM pins can be used in most long bone fracture types, including highly comminuted fractures (Sinibaldi 1983). Bending loads, that are present in most fractures, regardless of the fracture type, are well counteracted when a round pin of adequate diameter is well anchored both proximally and distally into the cancellous bone (Dixon *et al.* 1994; Boudrieau 2003; Piermattei *et al.* 2006; Roe 2006). Its ability to resist bending loads is directly proportional to its diameter and to the ratio of its diameter to the medullary diameter (Perren 1989; Muir 1995; Ness 2006; Roe 2006). As the medullary diameter becomes larger in comparison to the pin diameter, it becomes mechanically more difficult for the pin to control any bending loads (Rudy 1975). Transverse shearing loads, together with bending loads, are furthermore best neutralised when it also possible to have intimate contact between the pin and the inner cortical surface. This allows for effective load transfer across the fracture site, owing to the development of adequate shear resistance between the pin and the bone (Perren 1989), but does compromise some of the medullary supply (Gothman 1962; Hinko and Rhinelander 1975; Wilson 1991).

Single IM pin lack the ability to resist rotational and axial (compression and tension) loads and need ancillary support to stop axial and rotational collapse. Rotational and axial loads are counteracted only by frictional forces between the bone and the pin, which is too small to be effective in most clinical situations (Eaton-Wells *et al.* 1990; Boudrieau 2003) and to some degree by fragment interdigitation (Vasseur *et al.* 1984). Tension loads are not present in most diaphyseal fractures.

Because of these deficiencies, IM pinning as the only method of fixation is only indicated in simple transverse diaphyseal fractures in which there is good interdigitation of the bone fragments (Rhinelander 1974; Vasseur *et al.* 1984; Eaton-Wells *et al.* 1990; Dixon *et al.* 1994; Boudrieau 2003; Johnson and Boone 2003; Pope 2003; Roe 2003).

iii. Contraindications and Complications

Single Steinmann pins are usually contraindicated in severely comminuted fractures except when cerclage or hemicerclage is added. Steinmann pinning should be attempted only when the fracture can be made stable. Inadequate technique of Steinmann pinning placement with improper seating in the distal fragment or instability of the fracture will lead to the complication of pin migration, the most common problem associated with intramedullary pinning. It is seen in animals where there is instability at the fracture site, allowing the fracture to collapse over the pin, or where there is sufficient motion to cause loosening of the pin at its distal aspect. If the pin loosens, the fracture will usually distract or collapse and angulate. The pin may penetrate the skin through the site of initial insertion and create a tract for infection. As with single Steinmann pinning, pin loosening or migration is a complication but it can be minimised by using many pins. In general, when fixation has been accomplished with multiple Steinmann pins, only one or two pins will start to migrate, thereby saving the integrity of the fracture (Nunamaker 1985).

iv. Effect of IM pinning on medullary blood supply

The effect of IM pinning on the healing of fractures is important (Wilson 1991). Except in cases where active reaming for seating of the tips has taken place, total destruction of the medullary blood supply does not occur. Temporary disruption of the medullary blood supply occurs with any displaced fracture. The use of an IM Steinmann pin will reduce this supply initially, but will by no means completely destroy it. Hypertrophy of the medullary blood vessels will take place around the pin within the first 14 days after pin placement, unless the pin completely fills the medullary cavity, or if the inner cortex has been reamed out (Coetzee 1999).

2.5 Historical background of intramedullary pinning

Flynn (1949) reported intramedullary pinning of a complete transverse fracture of femur in left hind limb of a 6 year old male dog with a history of having suffered an injury of the left rear leg when struck by a car, the dog was unable to bear weight on that limb, which was swollen from a point below femoro-tibial articulation upto the pelvic region. Under general anesthesia, a sharp stainless steel pin with a three-sided short tip, was aligned parallel with the length of the femur, then driven into the medullary cavity of the bone at the selected site, and tapped downwards through it until its distal end was at a point just short of the fracture. Gradually the patient made satisfactory progress and the pin was removed after 26 days and within five days, the dog began making gradual use of the affected limb.

Hurov and Seer (1968) experimentally conducted intramedullary Steinmann pinning of the radius in radial-ulnar fractures in dogs and reported that reductions of overriding fractures were accomplished with good callus formation when an intramedullary Steinmann pin and a 0.035 inch Kirschner wire were placed in fractures of the radius and ulna.

Parker and Bloomberg (1984) used modified intramedullary pin technique for repair of distal femoral physeal fractures in dogs and cats and reported that it provided stability at the fracture site and allowed early range of motion.

Perren (1989) studied the biomechanics and biology of internal fixation using plates and nails and concluded that the mechanics of the medullary nail fixation are, in many aspects, different from those of compression fixation using screws and plates.

Pardo (1994) studied the relationship of tibial intramedullary pins to canine stifle joint structures: a comparison of normograde and retrograde insertion in dogs.

Dixon *et al.* (1994) reported the effects of three intramedullary pinning techniques on proximal pin location and evaluated the incidence of stifle joint injury using 70 cadaver canine tibiae after mid-disphyseal osteotomy and concluded that retrograde pins directed craniomedially may be an acceptable technique for the repair of proximal to mid-diaphysealtibial fractures.

Stigen (1999) treated supracondylar femoral fractures in 159 dogs and cats using a normograde intramedullary pinning technique and reported that 79.5 per cent dogs and 82.1 per cent cats were found to be free of lameness after the completion of treatment.

Guille *et al.* (2004) evaluated the surgical repair of humeral condylar fractures using self-compressing orthofix pins in 23 dogs and reported that these implants are suitable and should be considered for the repair of humeral condylar fractures in small breed dogs.

Ozsoy (2004) conducted an experimental study on the use of intramedullary threaded Steinmann pins for fixation of femur, humerus and tibia fractures in cats. In this study negative, full-threaded and trocar-pointed Steinmann pins, produced from stainless steel, were used; they were 3, 3.5, 4, 4.5 and 5 mm in diameter and 20 cm long. The pins were used alone or in conjunction with auxiliary fixation methods. He concluded that full-threaded

Steinmann pin application provided good axial stability when used alone in fractures of the femur, humerus and tibia in cats. Its advantages over other means of fracture repair using intramedullary pins included its practical application and fast return to full function.

Sissener *et al*. (2005) studied the effects of three intramedullary pinning techniques on pin location and articular damage in the canine humerus and suggested that either normograde or retrograde pins directed craniolaterally provide acceptable techniques for insertion of IM pins during distal humeral fracture repair.

Siraj *et al.* (2011) studied the comparative efficacy of intramedullary pinning with full cerclage wires and screwing for the repair of mid shaft tibial fracture in dogs and reported that intramedullary pinning with multiple full cerclage wires is the better internal approach to repair said tibial fractures in dogs.

Orfaly (2011) performed and claimed fixation of a bone, such as the clavicle, using an intramedullary pin which is threaded in a leading region and may define one or more transverse apertures in the trailing region to receive one or more fasteners.

Rani *et al.* (2012) experimentally studied immobilisation and treatment of femoral diaphyseal oblique fractures in dogs using double intramedullary pinning and cerclage wiring and evaluated its efficacy based on clinical, radiological and biochemical studies during post-operative period of 60 days.

Altunatmaz *et al*. (2012) used intramedullary fully-threaded pins manufactured from an alloy of titanium, aluminium and vanadium in a fully-threaded style. Pins were produced in various diameters and the proximal end of the pins was designed to fit into a hexagonal screwdriver, while the distal end was slightly tapered to allow for ease of entry into cancellous bone. Treatment using the fully-threaded intramedullary pin was carried out in a total of 175 fractures of the humerus, femur, and tibia in 95 cats (bilateral femur in 1 case) and 77 dogs (bilateral femur in 2 cases). Radiographic follow-up for the cases was performed at monthly intervals. Non-union developed in one dog with a femoral fracture in which cerclage wire had also been used. Delayed healing and lameness were observed in two other dogs. Healing with excessive callus formation was observed in 16 dogs. However, there were not any problems noted in these dogs in regards to limb usage. Normal, complete fracture healing occurred between 4 to 14 weeks in dogs, and between 4 to12 weeks in cats.

Chapter-3 Materials and Methods

3.1 Invention hypothesis

"Intramedullary compression and fixation device with a threaded end will overcome the potential post-operative complications of intramedullary pinning and will be an efficient and cost-effective technique in managing various long bone fractures in canines encountered by veterinarians in field conditions (Plate-3.1)."

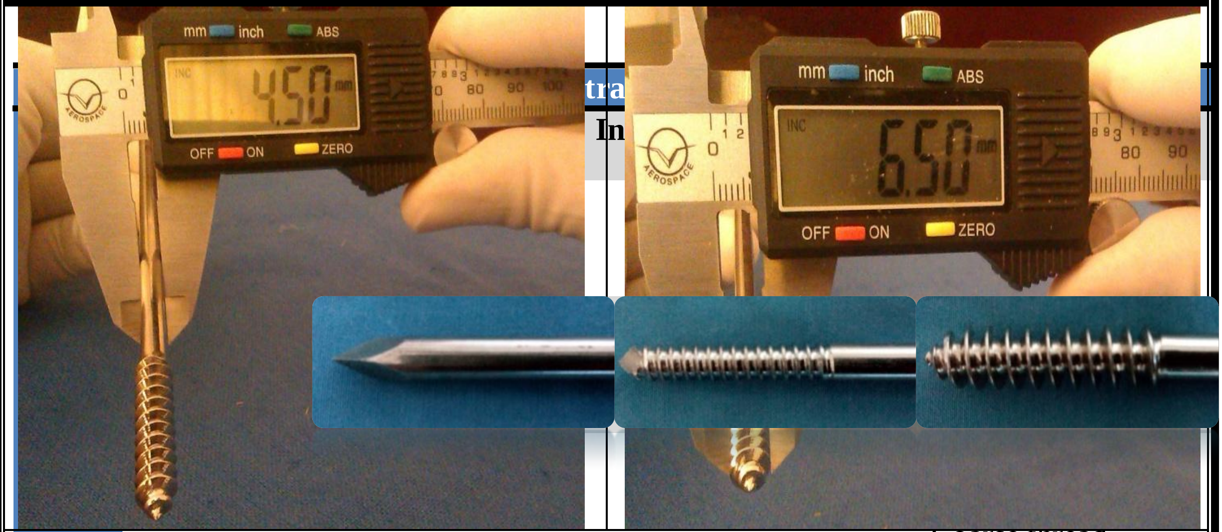
Plate-3.1: End-threaded intramedullary pin

The present study was carried out to assess the feasibility of using end threaded intramedullary pins which provides axial stability and resist bending, rotational & shear forces to an extent; but devoid of some complications like accurate proficiency as in plate application and its contouring with bone interface, as well as easy affordability.

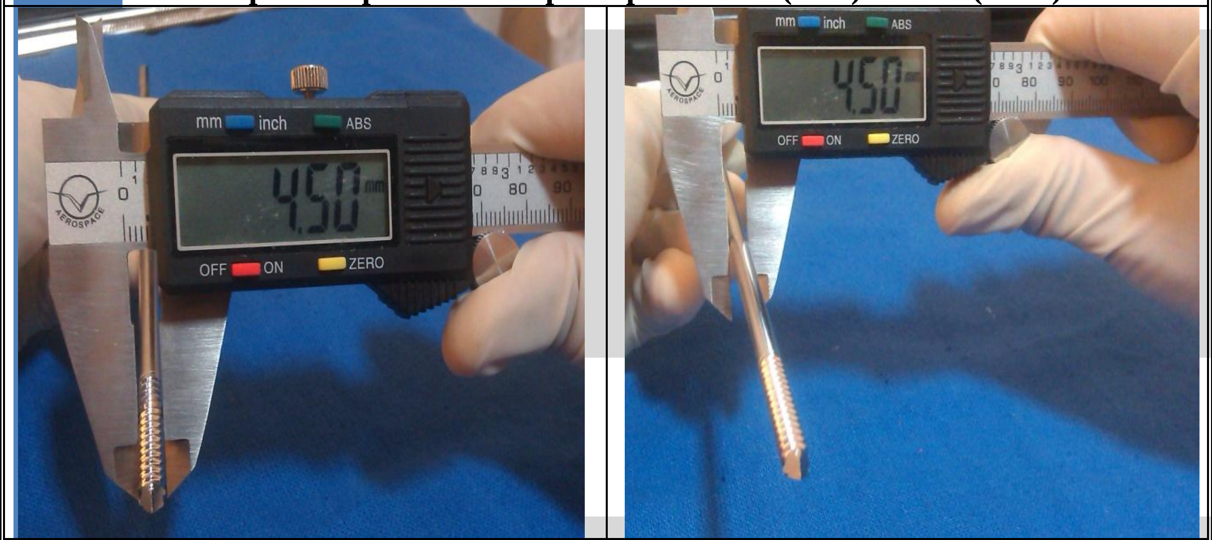
For this purpose we invented an intramedullary compression and fixation device which has been designed and customised specifically for field conditions for compressing a long bone which got fractured forming proximal and distal segments as in case of simple fracture or multiple fragments as in case of comminuted fracture.

The compression and fixation device includes an elongated intramedullary stainless steel rod of sufficient length to project from one end of the bone past the fracture site and which is formed with a diameter of sufficient size to substantially occupy the medullary cavity of the bone. Differences of the implant under study were enlisted in Table-3.1 and measurements of the implant using a vernier calliper were shown in Plate-3.2.

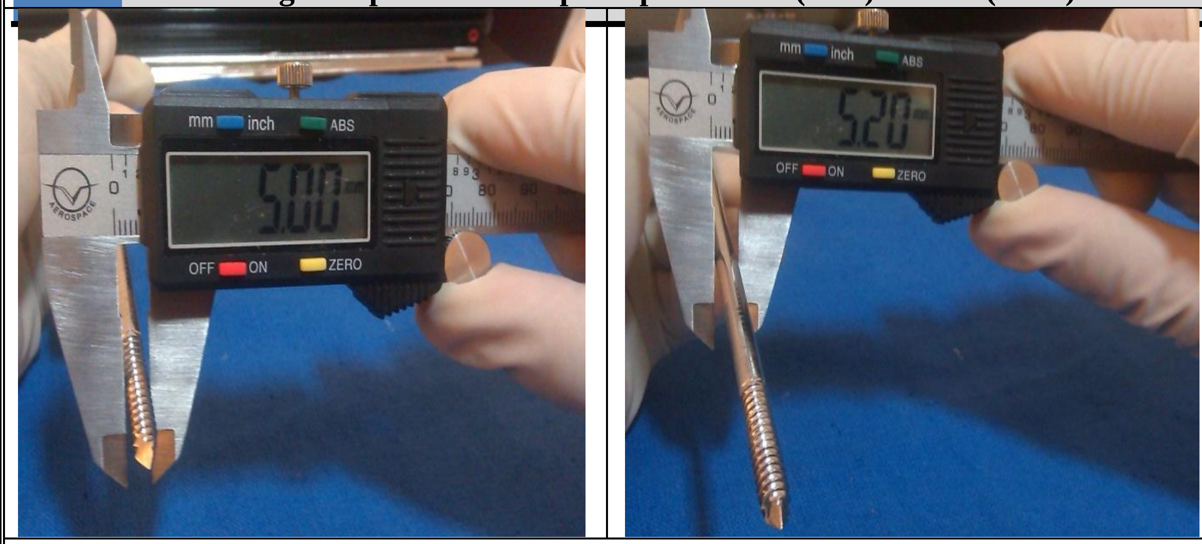
Plate3.2: Measurement of Intramedullary pins using Vernier Calliper during technique standardization phase.



A. End threaded positive profile screw point pin: 4.5mm(P.D.) /6.5mm(M.D.)



B. End threaded negative profile trocar point pin: 4.5mm(P.D.) /4.5mm(M.D.)



C. End threaded negative profile trocar point pin : 5.2mm (P.D.) / 5.0mm (M.D)

3.2 Methods

3.2.1 Preparation of Metal implant

Implants used in fracture repair bear all or part of the load normally carried by the bone (Coetzee 2002; Ness 2006). The implant used over here, in the management of long bone fractures in small animals was manufactured from iron-based alloys, especially 316L stainless steel (Schatzker 1991; Muir 1995; Little 2001; Ness 2006; Roe 2006) known for its superior corrosion resistance in different sizes as shown in Plate 3.2 (both negative and positive profile). Specifications for iron-based alloys have been laid down by the ASTM. Alloys used in the manufacturing of orthopaedic implants have to comply with ASTM standards F138 and F13940.

3.2.2 Composition of 316L stainless steel (Mears and Rothwell 1982)

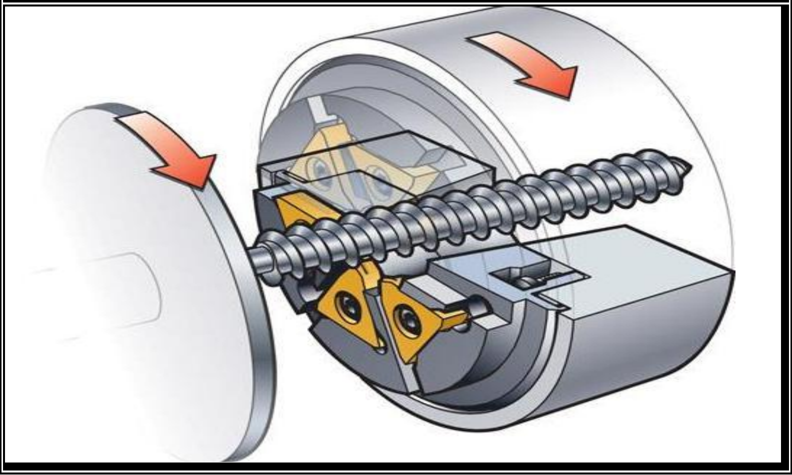
Chemical Composition (%)

1. Iron : 55-60
2. Chromium : 17-20
3. Nickel : 10-14
4. Molybdenum : 2.8
5. Manganese : 1.7
6. Silicon : 0.57
7. Copper : 0.1
8. Nitrogen : 0.095
9. Phosphorous : 0.025
10. Carbon : 0.024
11. Sulphur : 0.003

316L stainless steel is a relatively strong material, being able to withstand ultimate loads of up to 700 MPa during tension. This compares well to cortical bone, which is able to withstand loads of 150 MPa during compression, and a little less during tension (Ness 2006). The inherent strength of 316L allows implants to be made small enough to allow implantation, while remaining strong enough to resist most of the biomechanical forces acting on the bone-implant composite during the process of fracture healing (Little 2001; Muir 1995; Ness 2006).

3.2.3 Thread Production

Plate-3.3: Pictorial representation of Thread whirling



Threads were produced by cutting operations or thread whirling technique (Plate-3.3). The shank of a positive profile blank designed with a positive pitch dye for cut threading will be 3-4 cm extending from one end of the Steinmann pin which has a screw point, towards the other end of the pin. Further coarse cut threads were produced by removing the material from the positively pitched blank with a cutting dye or lathe. In these pins, the pitch diameter of the blank to be threaded was kept more than the major diameter of the intramedullary pin to give it a positive profile.

3.3 Plan of work

The present study was carried out in 25 client owned dogs of different breeds, sex and age with various long bone fractures presented in the Teaching Veterinary Clinical Complex of DGCN College of Veterinary and Animal Sciences, Palampur. The period of study was from January 2013 to April 2014.The study was planned to be conducted in two phases;

- **Phase I**: Technique standardization phase:

  6 out of 25 dogs were used for technique standardization phase.

- **Phase II**: Clinical application phase:

  19 out of 25 dogs were used for clinical application phase.

3.3.1 Phase I: Technique standardization phase (Test hypothesis)

The phase was divided in two groups;

- **Group I:** End-threaded intramedullary negative profile trocar point pin was used (Plate-3.4A)
- **Group II:** End-threaded intramedullary positive profile screw ended self tapping pin was used (Plate-3.4B)

A. Group I: 3 adult, clinical cases of femur fracture; average sized dogs (age- 1, 3 and 8 years, weight- 18kg, 20kg and 26kg) were clinically assessed and implanted with a negative profile end threaded intramedullary pin.

B. Group II: 3 adult average sized dogs presented with femur fracture (age- 18 months, 3 years and 10 years; weight- 16kg, 20.5kg and 30kg) were clinically assessed and implanted with a positive profile self tapping end threaded intramedullary pin.

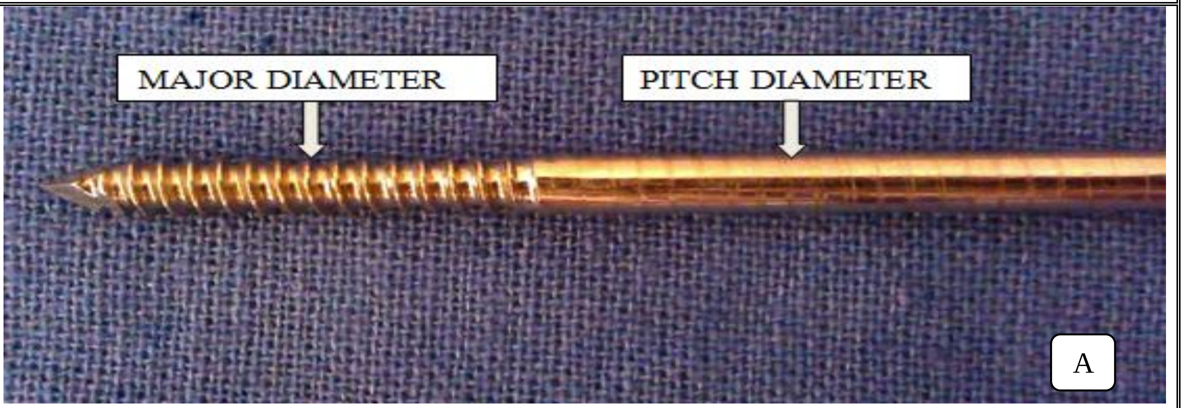
Radiographs of the fractured limb of all these six patients were taken and muscle girth was measured, pre- and post-operatively. Post operatively these patients were regularly observed for weight bearing and fracture healing. The findings of the first two patients in terms of early healing and other post operative complications were compared with the findings of the other two patients for standardizing the technique of application of end threaded intramedullary pinning in long bone fractures of canines.

3.3.2 Phase II: Clinical application phase

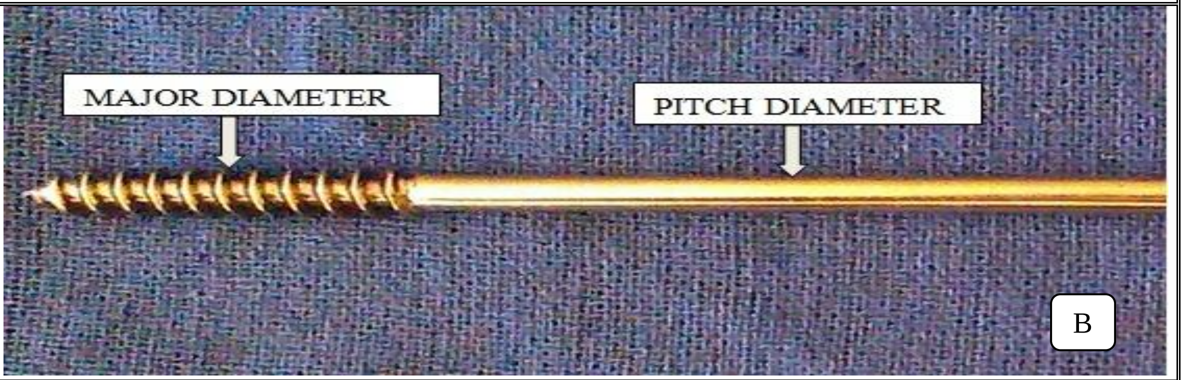
The results of test hypothesis were used to conduct the clinical application phase. History, age, breed, sex and body weight of all the patients were recorded at the time of presentation. Ancillary physical examination and clinical parameters were recorded as per the need in each patient.

Radiographic or fluoroscopic images of all the 19 patients (Age; 1.5 month – 9 years and body weight; 3.40kg - 21kg) were obtained prior to surgery and also postoperatively. End threaded positive profile intramedullary pin of different diameter as per the size of animal, were used for intramedullary fixation in all the patients with different long bone fractures. Healing assessment was performed via radiography on 21 and 42 days post-operatively to assess and evaluate the fracture healing and implant removal.

Plate-3.4: Positive & Negative profile pins used for standardization



Negative profile: Major diameter < Pitch diameter



Positive profile: Major diameter > Pitch diameter

3.4 Protocol followed during technique standardization and clinical application phase

3.4.1 Surgical Approach

I. Method of insertion

The pin was inserted by using a Jacob’s chuck. It was introduced at the end of the bone by rotating in clockwise direction, allowed to cross the fracture site and embedded in the distal metaphysis of the bone. Retrograde insertion technique of the end threaded positive profile pin was applied in femur and humerus fractures whereas normograde insertion technique in tibial fractures. The site for introducing the pin in dog’s femur was through the fracture site when done in retrograde manner whereas in some cases it was also introduced distally in the femur through the intercondylar fossa (In supracondylar fractures), when done in normograde manner. In the humerus, it was introduced through the proximal lateral aspect. The point of introduction was determined by the curvature of the humerus of the individual patient. In the tibia the pin was introduced just medial and slightly behind the straight patellar ligament. In this position, the pin entered the medullary cavity in front of the joint without invading it.

II. Seating of implant

The seating of end threaded intramedullary pin was a very important part of its placement. After the pin was introduced in clockwise rotating motion, crossed the fracture site, and reduced the fracture, it was seated firmly in the distal fragment. The distance travelled by the pin was measured and planned before introduction into the distal fragment. This was done easily by adjusting the chuck on the pin so that an adequate amount of pin appeared between the chuck and the surface of the skin; this distance was equivalent to the length of the pin that needs to be introduced into the distal fragment. The seating was achieved, by rotating the positive profile end threaded pin so that it may interdigitate with the cancellous bone. In some patients, fluoroscopic confirmation was also done intra-operatively just to assure adequate seating of the pin in the cancellous bone.

The self tapping screw end was used for drilling and allowed adequate seating of the pin in the distal aspect of the bone. When placed properly, the pin had three points of contact: proximally at its entry point, against the lateral cortex of the diaphysis and seated in the cancellous bone distally.

3.4.2 Postoperative Care

All operated dogs received;

- Antibiotics course of Amoxirum Forte 300mg at a dose of 15-20 mg/kg b.wt. I.V immediate post-operatively and continued every 12 hours I.M for 5 days postoperatively.

- Anti-inflammatory course of Meloxicam (Melonex) 5mg/ml at the dose rate of 0.2-0.5mg/kg b.wt. S/C immediate post-operatively and continued every 24 hours for 3 days post-operatively.

- Oral supplements included, Syrp. Osteopet (Calcium supplement) @ 5ml b.i.d for two months and Syrp. Sharkoferol or Multistar pet @ 5ml b.i.d for two months.

The owner was strictly advised to provide complete rest to the animal and its restrained movement till 1 month post-operatively. Skin sutures were removed 10 days post-operatively.

3.4.3 Pin removal

The pin was generally removed under general anaesthesia after radiographic evidence of periosteal bridging with some degree of bone remodeling on the callus. The site of insertion of pin over the bone i.e. proximally over subtrochantric fossa in case of femur or proximal lateral aspect of humerus or proximal medial aspect of tibia; was felt, shaved and scrubbed thoroughly with an antiseptic solution.

The removal of the implant was accomplished with a pair of pliers and a Jacob's chuck by means of a stab incision through the skin. The pin was then gently pulled out by rotating in anti-clockwise direction followed by suturing the incision given over the skin.

3.4.4 Post pin removal

Evaluation of complete recovery was done through telephonic follow-up for a period of three months post implant removal and was graded on the basis of different parameters observed (Table-3.2).

Table 3.2 Post implant removal, rehabilitation evaluation (Graded out of 100, excellent result when 100 points obtained)

S.no.	Parameters	Situation	Score
1	**Pain**	None	25
		When walking on irregular surface	20
		When walking on metalled road	10
		When walking on indoor cemented floor	5
		Constant and severe	0
2	**Stiffness**	None	10
		Stiff	0
3	**Swelling**	None	10
		Mild	5
		Constant	0
4	**Climbing stairs**	Not a problem	10
		Asymmetrically	5
		Impossible	0
5	**Running**	Possible	5
		Impossible	0
6	**Jumping**	Possible	5
		Impossible	0
7	**Squatting while defecation**	Possible	5
		Impossible	0
8	**Walking assistance**	None	25
		Manual support by owner	0
9	**Physiotherapeutic assistance**	None	15
		Needed	0

3.4.5 Parameters evaluated

a) **Type of fracture**- As per the radiographic observations the type of fractures were classified.

b) **Immediate weight bearing after operation**- The immediate response of carrying the limb and bearing the weight just after the operation was recorded.

c) **Assessment of healing**

1. Clinical findings

- Functional limb usage- It was scored as per Table 3.3.

Table 3.3 Scoring system used to assess functional limb usage

Grades	0	1	2	3	4
Limb use description	Non-use	Slight use	limping	Slight limping	Normal
Weight bearing and gait	No weight bearing; carrying the limb while walking	Slight weight bearing; touching the toe while walking	Moderate weight bearing; touching the sole while walking with limping	Good weight bearing; with slight limping	Complete weight bearing; with no sign of limping

- Muscle girth- It was recorded pre-operatively, post-operatively, 21st day and 42nd day of healing using a measuring tape.

2. Radiographic / Fluoroscopic findings

Radiographic projections of the fracture site were made before, immediately after fixation and during post operative period. The pin was maintained until there was a radiographic evidence of healing. Radiographs were observed for monitoring the bone fragments, bone reduction and alignment, amount of callus and degree of bone healing.

- Callus was graded as per the scoring system mentioned in Table 3.4

Table 3.4 Scoring system used to assess amount of callus formation

Grades	0	1	2	3
Amount of Callus formation	None(no visible callus)	Small (<10% increase in the bone diameter)	Moderate (10-20% increase in the bone diameter)	Large (>20% increase in the bone diameter)

- Healing was assessed by obliteration of the fractured gap and continuation of the cortical line between bone fragments, as mentioned in Table 3.5.

Table 3.5 Classification of healing according to the time taken by fracture to heal

Type of healing	Time of fracture healing
Normal	Healing<60 days without complication
Delayed	Healing >60 days
Malunion	Union with angulation
Failure of healing	Due to fixation failure

d) **Post-fixation physiotherapeutic technique used for early recovery**

In some patients as per the need and after assessing post operative recovery, physiotherapy was done to resolve the muscle contracture/fibrosis involving flexing and extending the knee 5 times in three sessions a day. Also leash walking several times but initially for just 5 min, the goal being to walk slowly, so that animal touches its operated leg to the ground. Each week these walks were made 5 min longer, thus helping the animal in gaining strength by an ample blood supply to the surrounding muscle mass and having an early recovery.

e) **A note on recovery time in each patient was recorded.**

f) **Overall functional recovery-** The functional recovery of the patients was evaluated according to Table 3.6.

Table 3.6 Classification of overall functional recovery on the basis of fracture healing

Very good	Normal fracture healing or good joint stability with normal limb usage
Good	Normal fracture healing or good joint stability but slight lameness persisting
Satisfactory	Fracture healing with slight malunion/ delayed union/ reduced joint mobility, leading to visible lameness
Unsatisfactory	Fracture failed to heal or joint unstable due to fixation failure or infection

Chapter-4 RESULTS AND DISCUSSION

The present study was undertaken to evaluate the efficacy of end threaded intramedullary pinning in management of various long bone fractures in canines. Initially, the technique of application of end threaded intramedullary pinning in long bone fractures was standardized in a few clinical cases presented in the Teaching Veterinary Clinical Complex of Dr. GC Negi College of Veterinary and Animal Sciences, Palampur, Himachal Pradesh. In standardization phase, end threaded pins of different profiles i.e. positive and negative, were used as the internal fixation technique and were evaluated on 6 dogs presented with long bone fractures. For comparative evaluation, post-operative radiographic images, weight bearing and other recovery parameters were recorded and analyzed from time to time. The technique with better results and less post-operative complications was then applied in clinical cases of dogs suffering from various long bone fractures and compared thoroughly. The results obtained are presented and discussed under following headings.

4.1 Technique Standardization Phase

4.1.1 Standardization of pinning technique

4.1.2 Post operative monitoring during technique standardization phase

i. Weight bearing and functional limb usage
ii. Callus formation and healing
iii. Pin migration and biomechanics
iv. Blood supply and healing
v. Method of implant application and removal

4.1.3 Comparative account on Negative (Group I) & Positive (Group II) profile pins

4.2 Clinical Application Phase

4.2.1 Incidences and type of fracture

4.2.2 Muscle girth measurement

4.2.3 End threaded positive profile pins used in clinical application phase

4.2.4 Technique of application

4.2.5 Post operative weight bearing

4.2.6 Post operative callus formation

4.2.7 Bone healing and recovery

4.2.8 Significant clinical presentations

4.2.9 Biomechanical and other advantages

4.1 Technique standardization phase

4.1.1 Standardization of pinning technique

End threaded intramedullary pins of two different profiles i.e. positive and negative were used in the treatment of long bone fractures. Negative profile pin was “trocar” pointed whereas positive profile pin was “screw” pointed and both were available in different diameters.

Six adult patients were utilized for standardization of technique of application of intramedullary pinning by categorizing them into two groups with three dogs in each. Muscle girth was measured with the help of a measuring tape at the point of fracture i.e. either proximal, middle or distal part of the affected bone at four different time intervals viz. pre-operatively, immediate post-operatively, 21 days post-operatively and 42 days post-operatively. In the same way, radiographic observations were obtained at four different intervals pre- and post-op, to analyze the degree of callus formation at the fracture site and degree of healing just to optimize the time of pin removal.

Group I:

In group I, end threaded negative profile pins were used in the treatment of femur fracture in three adult dogs (8, 3 and 1 years) weighing 26kg, 18kg and 20 kg respectively. The negative profile pins had fine threads with trocar point for its easy introduction.

The first case of this group was reported as complete comminuted proximal 3^{rd} epiphyseo-diaphyseal fracture of left femur (Plate-4.1); the second case as complete comminuted proximal epiphyseo-diaphyseal fracture of left femur (Plate-4.2) and the third case as complete oblique proximal diaphyseal fracture of right femur, as per radiographic examination. The pin used, had a pitch diameter of 5.2mm and major diameter of 5.0mm which makes it a negative profile. Pins were removed after complete attainment of weight bearing by the animals, which was 3 months in one case where as 4 months in second and 3 months in third case. Muscle girth of the affected limb was measured at regular intervals and the observations were listed in Table 4.1. The muscle girth changes decreased with time due to disuse atrophy as a result of delayed healing (Fig.4.1).

In all the cases slight pin migration was observed, which resulted in disruption of callus site causing delayed union in one patient and large callus formation in other two patients.

Group II:

In group II, end threaded intramedullary positive profile screw ended self tapping pins were used in the treatment of femur fracture in three adult dogs (18 months, 3 years and 10 years) weighing 16kg, 20.5kg and 30 kg respectively. The positive profile pins had coarse threads with screw point for its easy seating in the cancellous part of the fractured bone as they tap better in brittle material.

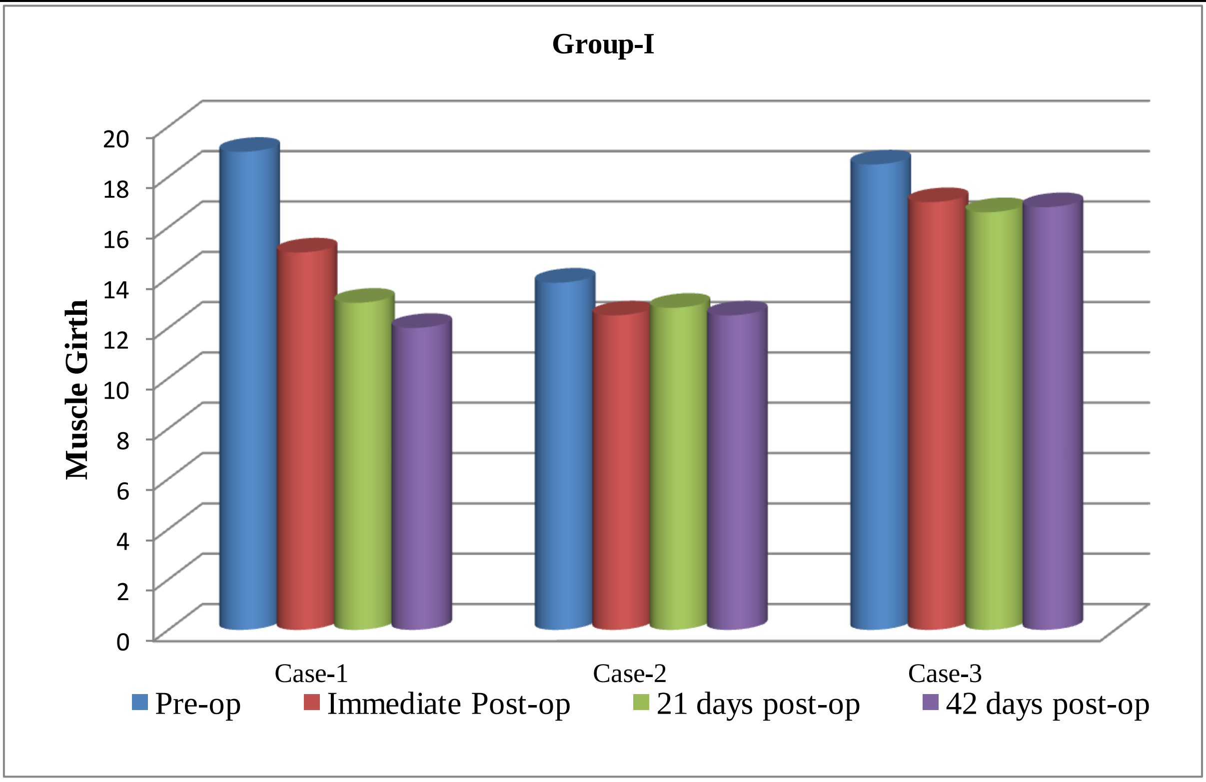
The first case of this group was reported as complete single spiral mid-diaphyseal fracture of right femur (Plate-4.3), the second case as complete single transverse mid-diaphyseal fracture of right femur (Plate-4.4) and the third case as complete comminuted distal diaphyseal fracture of left femur, as per radiographic examination. The pin used, had a pitch diameter of 4.5 mm and major diameter of 6.5 mm which makes it a positive profile. Pins were removed after complete attainment of weight bearing by the animals, i.e. 55 days in one case and 60 days in other two. Muscle-girth of the affected limb was measured at regular intervals and the observations were listed in Table-4.1. The muscle girth increased with time due to normal healing in group II (Fig.4.1)

Pin migration wasn't observed in any of the three patients. Radiographically, normal callus was evident with cortical bridging of fracture line indicative of normal healing.

Table 4.1 Comparative observations on muscle girth (Standardization phase)

Groups according to pin profile	**Case no.**	**Muscle girth (inches)**			
		Pre-op	**Immediate Post-op**	**21 days post-op**	**Post pin removal**
I (Negative Profile)	1	19	15	13	12
	2	13.8	12.5	12.8	12.5
	3	18.5	17	16.6	16.8
II (Positive Profile)	1	12.4	11	11.8	12.5
	2	12	10.5	11	13.2
	3	14	13	12	13

Fig.4.1: Bar diagram representing muscle girth changes in clinical patients studied under technique standardization phase as in Table 4.1



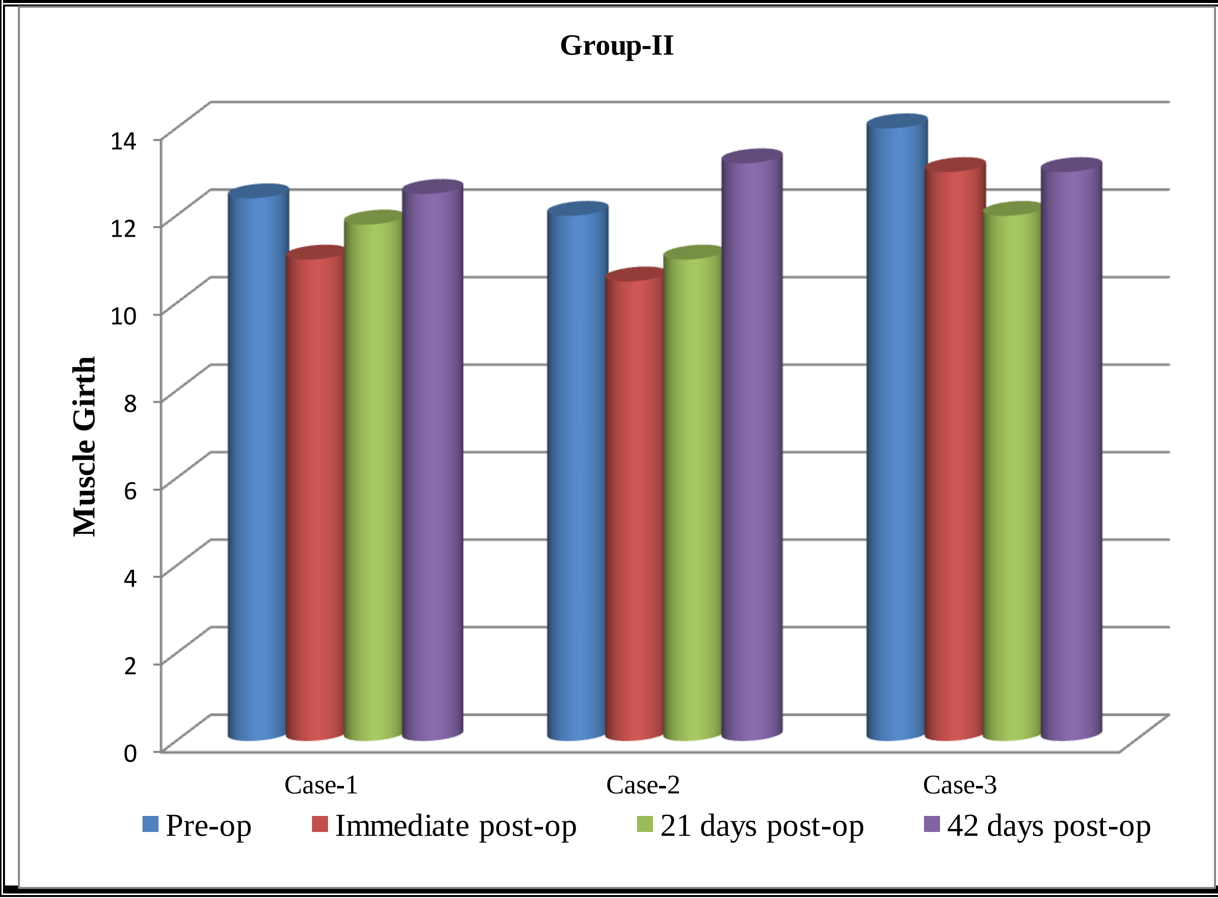


Plate-4.1: Serial Radiographic observations in Group-I (Negative profile pin) in one of the patients with complete proximal epiphyseo-diaphyseal comminuted fracture of left femur

A. Pre-op

B. Immediate Post-op (Pin implanted with threaded end in distal bone fragment)

C. 3 months Post-operatively

D. Post pin removal

Plate-4.2: Serial Radiographic observations in Group-I (Negative profile pin) in another patient presented with complete proximal epiphyseo-diaphyseal comminuted fracture of left femur

A. Pre-op

B. Immediate Post-op (Pin implanted with threaded end in proximal bone fragment)

C. 21 days Post-op

Plate-4.3: Serial Radiographic observations in Group-II (Positive profile pin) in one of the patients presented with complete mid-diaphyseal simple spiral fracture of right femur

A. Pre-op

B. Immediate Post-op

C. 21 days Post-op

D. Post pin removal

Plate-4.4: Serial Radiographic observations in Group-II (Positive profile pin) in another patient presented with complete mid-diaphyseal simple transverse fracture of right femur

A. Pre-op

B. Immediate Post-op

C. 21 days Post-op

D. 42 days Post-op

E. Post pin removal

4.1.2 Post-operative monitoring during Technique standardization phase

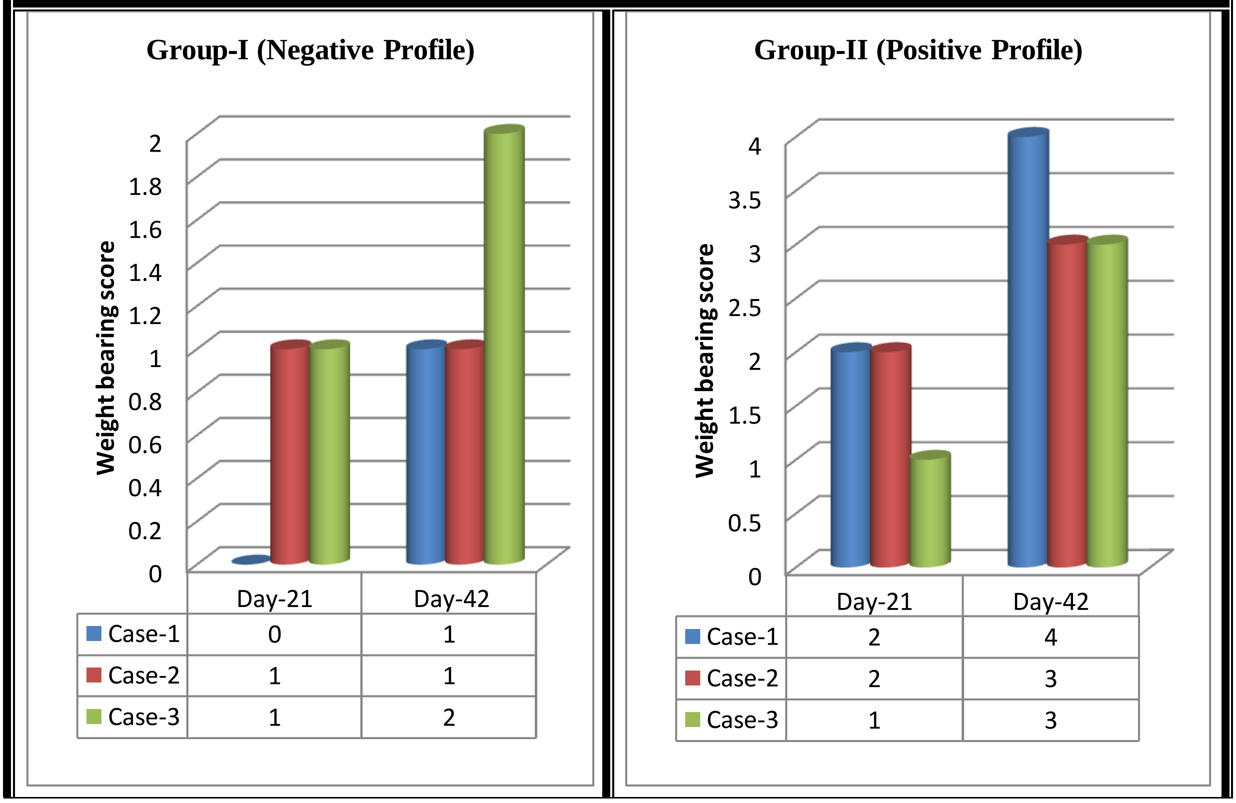
i. Weight bearing and functional limb usage

In group-I, two patients achieved a score of 1 i.e. non-use whereas one patient scored 2 i.e. slight limb use after 42 days of operation. This is due to slight pin migration in all the three cases.

In group-II, two patients achieved a score of 3 i.e. slight limping whereas one patient scored 4 i.e. normal limb use after 42 days of operation (Fig.4.2). Thus late weight bearing was observed in group-I implanted with negative profile pin where as normal weight bearing i.e. within 21-42 days was observed in cases implanted with positive profile pin as there was no pin migration in group-II. Similar findings on weight bearing were reported by Altunatmaz *et al.* (2012) i.e. the dogs appeared to bear weight on their limbs 5–15 days after the operation and functional recovery was seen to increase gradually and full weight-bearing without any signs of problems was seen to occur after day 20.

After 3 months of implant removal, functional limb usage was assessed using a scoring system. The animals of group-I scored 65, 70 and 45 whereas group-II scored 100 in all the cases.

Fig.4.2: Bar-diagram representing weight bearing score pattern by patients in Group I&II

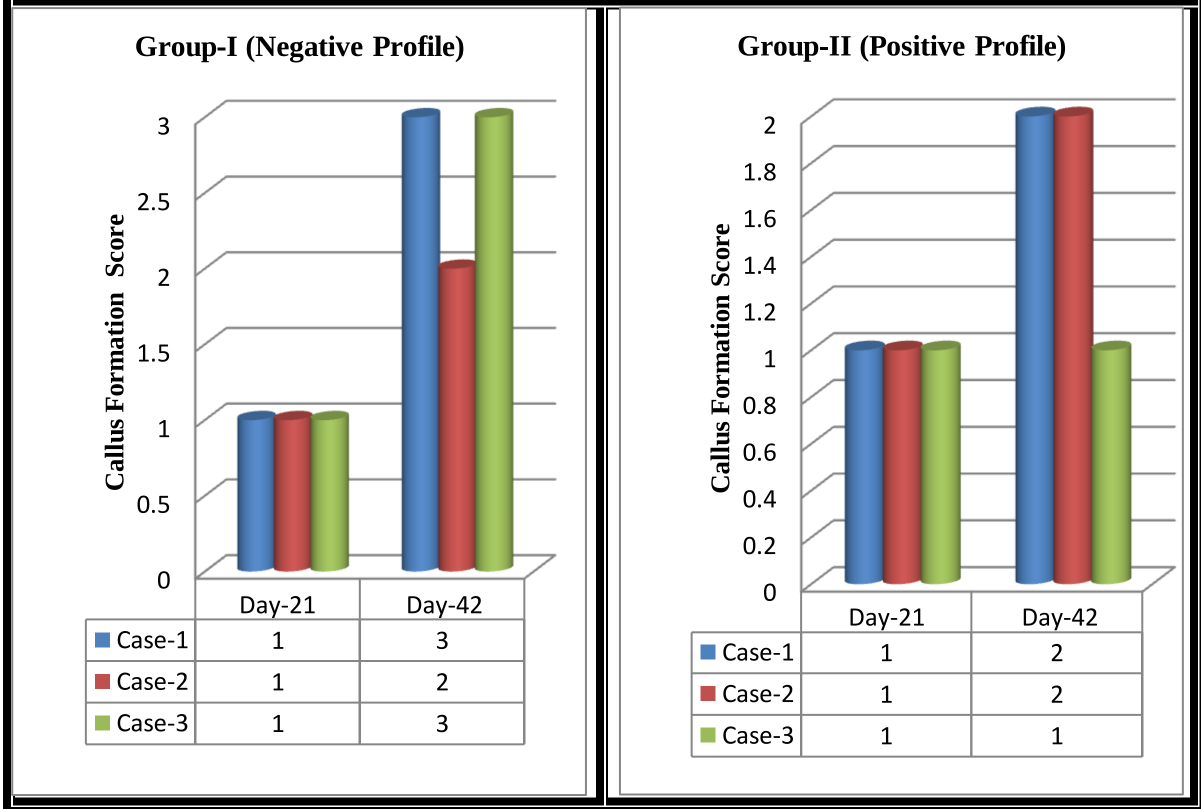


ii. Callus formation and healing

Delayed union (> 60 days) observed in group-I with large callus formation(score 3) in two patients (Plate-4.2) and moderate callus formation (score 2) in one patient whereas normal union (< 60 days) with gap healing in group-II with moderate callus formation with a score of 2 (Plate-4.3); except in one case reported with impacted transverse fracture in which healing was normal with very less periosteal callus formation with a score of 1 (Plate-4.4). These observations are presented graphically in Fig.4.3. Gap healing (Primary bone formation) occurs under rigid fixation in areas in which small gaps are present. In such healing, direct ossification takes place after in-growth of blood vessels and the original structure of bone is later restored by secondary haversian remodeling in the long axis of the bone (Rahn *et al*. 1971).

A large amount of external callus indicates the need for additional support beyond the normal contours of the bone. This represents a delay in osseous healing over what can be obtained by stable fixation (Nunamaker 1985). Other than in the young growing animal, the amount of callus is in inverse relation to the degree of stability at the fracture site (Piermattei *et al.* 2006). The more motion there is at a fracture site, the larger callus is needed to prevent this motion (Greenbaum and Kanat 1993; Einhorn 1998).

Fig.4.3: Graphical representation of callus formation scores in Group I & II



iii. Pin migration and biomechanics

Pin migration was observed in all the animals of group-I whereas pin migration was not observed at any stage in the animals of group-II. Rotational forces were not overcomed by the implant used in group-I. On the other hand the implant used in group-II overcomed rotational forces as the threads were embedded in distal cancellous bone firmly. The result of this study were in relevance with the findings of Ozsoy (2004) who conducted a study to examine the use of full threaded Steinmann pins for adequate rotational stability and prevention of pin migration when applied in normograde fashion in fractures of the femur, humerus and tibia of cat.

In group-I, while applying the implant in a femur fracture, it broke at the pin-thread interface especially when tightly thrusted for purchase in the distal fragment, whereas seating of the implant was seamless and smooth in group-II. The compression of the fractured segment at the fracture line was evident as the positive profile pin was screwed in the distal fragment ensuring near normal continuity of the bone length and contours. Partially threaded pins having a negative profile ending create a weak point in the pin-thread junction, so if these pins are to be used, the junction must not be near the fracture line (Olmstead *et al.* 1995; Denny and Butterworth 2000). Positive profile pins do not have this problem because the threads are raised above the core diameter of the pin. Thus, there is no stress riser (weak point) at the thread non-thread interface (Gilley and Gold 2006) and the implant appears very sturdy.

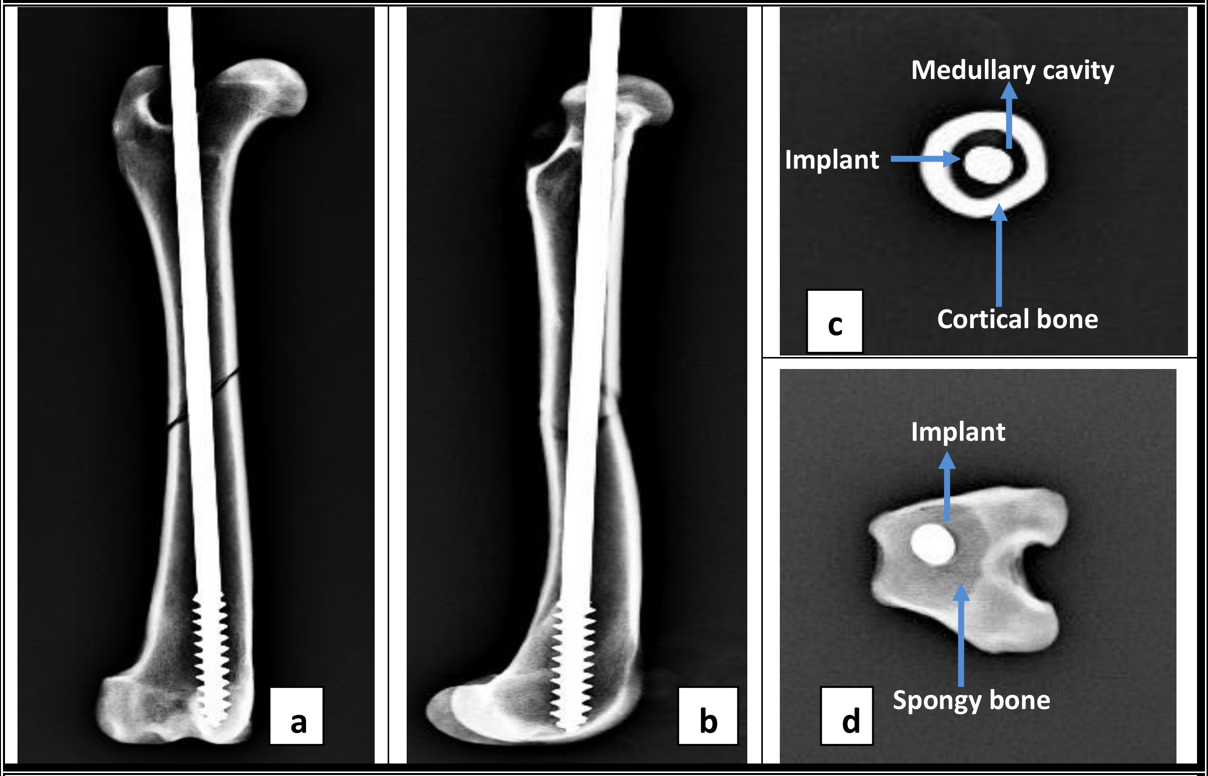
iv. Blood supply and healing time

Fracture fixation alters the blood flow at the fracture site because the blood supply to the fracture hematoma, the bone cortex and the soft tissue is affected by the operative procedure used (Smith *et al.* 1990; Claes *et al.* 1999).

In group-I, in order to provide better stability to the fractured fragments the pin was snuggly fitted into the medulla of long bone, covering maximum diameter thus obstructing medullary circulation to an extent causing an increase in healing time.

Whereas in group-II, only the threaded positive profile end of pin gets snuggly fitted into the spongy bone leaving the rest of the medullary cavity 30-40% unoccupied as shown in Plate-4.5; thus allowing the medullary circulation to regenerate aiding in early healing (Johnson *et al*. 2005).

Plate-4.5: Radiograph representing medullary occupancy by the implant in a cadaver bone



'a'-Craniocaudal projection; 'b'-Lateral projection; 'c'-Cross-sectional view of cortical bone along with implant(60% occupancy); 'd'-Cross-sectional view of cancellous bone with snuggly fitted implant

v. Method of implant application and removal

Technique of implant application was same in both the groups whereas removal of implant was always with anti-clockwise rotation in group-II whereas sometimes with anti-clockwise rotation in group-I because of firm grip attained by positive profile pin in the cancellous bone even at the time of pin removal. Similar findings were reported by Piermattei *et al.* (2006) i.e. on removing a threaded pin after fracture healing, it is sometimes necessary to "unscrew" the pin because bone has grown into the threads, not because the pin has been threaded into the bone.

4.1.3 Comparative account on Negative (Group I) and Positive (Group II) profile pins

Considering the above parameters, assessed during technique standardization phase, a suitable comparison was drawn between the two techniques of end threaded intramedullary pinning in long bone fractures in canines (Table 4.2). As observed in the pilot trials, the positive profile end threaded screw point pin didn't show migration in any of the stages of healing as compared to negative profile end threaded pin which showed migration, thus causing a normal callus formation, early weight bearing and healing without any muscle atrophy of fractured limb. The positive profile end threaded screw point pin showed moderate rotational resistance during its introduction into bone's medullary cavity, providing a better rotational stability in comparison to negative profile end threaded pin. These findings were further clinically assessed by implanting end threaded intramedullary positive profile screw ended pin in 19 patients presented with different long bone fractures, under clinical application phase to derive a plausible conclusion to the above study.

Table 4.2: Following comparison was made between the two techniques of end threaded intramedullary pinning on the basis of the results of technique standardization phase

S.no.	Properties	Technique of end threaded I9M pinning	
		Negative profile	Positive profile
1	**Weight bearing**	Late	Early
2	**Callus formation**	Large	Normal
3	**Pin migration**	Yes	No
4	**Rotational forces**	Not overcome	Overcome
5	**Blood supply**	Impaired	Least affected
6	**Healing time**	Late	Early
7	**Method of introduction**	Mild rotational resistance	Moderate rotational resistance
8	**Removal of implant**	Easy (sometimes with rotation)	Easy (always with rotation)
9	**Muscle girth**	Reduced	Normal

4.2 Clinical application phase

4.2.1 Incidence and type of fractures

In accordance with the criteria used in a study done by Mosneang and Igna (2012), frequency distribution for long-bone fractures based on a correlation between bone types, fracture localization, fracture line form, the degree of bone fragmentation, age, size, and weight, was evaluated. Results regarding frequency distribution depending on bone type, bone localization, fracture line and degree of bone fragmentation are revealed in Table 4.3.

From nineteen canine patients presented with long bone fracture in TVCC, Palampur; four involved humerus- 21.05 %, fourteen involved femur- 73.68 % and one involved tibia- 5.26%. Considering fracture localization, 14 diaphyseal fractures- 73.68%, 3 metaphyseal fractures- 15.79 % and 2 epiphyseal fractures- 10.52% were recorded (Table 4.3).

Table4.3: Classification of the clinical patients according to bone involved, fracture localization, fracture line and degree of bone fragmentation

Bone type	Fracture localization				Fracture line				Degree of bone fragmentation			
		Total no.	% from total no. of fractures	% from total no. of specific bone fractures		Total no.	% from total no. of fractures	% from total no. of specific bone fractures		Total no.	% from total no. of fractures	% from total no. of specific bone fractures
Humerus	D	3	15.79	75	T	2	13.34	50	S	3	15.79	75
	M	0	0	0	O	1	6.66	25	C	1	5.26	25
	E	1	5.26	25	S	0	0	0				
					I	0	0	0				
Femur	D	10	52.63	71.42	T	4	26.67	28.57	S	11	57.89	78.57
	M	3	15.79	21.43	O	5	33.34	35.71	C	3	15.79	21.43
	E	1	5.26	7.15	S	1	6.66	7.14				
					I	1	6.66	7.14				
Tibia	D	1	5.26	100	T	0	0	0	S	1	5.26	100
	M	0	0	0	O	1	6.66	100	C	0	0	0
	E	0	0	0	S	0	0	0				
					I	0	0	0				

Key: 'D'- diaphyseal, 'M'- metaphyseal, 'E'- epiphyseal (fracture localization); 'T'- transverse, 'O'- oblique, 'S'- spiral, 'I'- impacted (fracture line); 'S'- simple, 'C'- comminuted (degree of bone fragmentation)

A correlation between bone type and fracture localization reveals: 4 humerus fractures (3 diaphyseal – 75% and 1 epiphyseal – 25%), 14 femur fractures (10 diaphyseal – 71.42%, 3 metaphyseal – 21.43% and 1 epiphyseal – 7.15%), 1 tibia and fibula fracture (1 diaphyseal – 100%).

The femur is, by far, the bone that is fractured most often in the dog and cat, comprising almost half of all long bone fractures in some surveys. Because of the eccentric loading of the femur during weight bearing and spastic contraction of muscles during fracture, overriding and shortening of the bone occur (Piermattei *et al.* 2006).

It may be that these represent only those patients that survived the traumatic episode, so as to be treated surgically. It is likely that trauma, significant enough to fracture bones in the cranial half of the animal would more frequently cause lethal trauma to the head or chest. Similar trauma to the caudal half of the animal would be less likely to produce life-threatening injury. It may also be that animals see impending trauma coming (automobiles) and, in their effort to flee, they expose their hindquarters to the major force of the impact (Harasen 2003).

Taking in consideration a fracture classification as per fracture line, 6 transverse fractures – 40%, 7 oblique fractures – 46.67%, 1 spiral fractures – 6.67% and 1 impacted fractures – 6.67% were recorded.

Also, depending on the degree of bone fragmentation, 15 simple fractures – 78.95% and 4 comminuted fractures – 21.05% were recorded.

In Table 4.3, there were recorded high incidence rate, depending on bone involved and fracture line, of transverse fracture (50% humerus bone) and oblique fracture (35.71% femur and 100% involving tibia and fibula bones). By associating bone involved and degree of bone fragmentation it was shown that there were a very high percentage of simple fractures (75% humerus, 78.57% femur and 100% tibia and fibula).

A correlation between bone involved and patient's age revealed, 10 fractures with animals less than 6 months of age (1 humerus- 5.26% and 9 femur- 47.37%), 5 fractures with animals from 6 to 12 months of age (1 humerus- 5.26%, 4 femur- 21.05% and 1 tibia and fibula- 5.26%), 2 fractures with animals from 1 to 6 years of age (1 humerus- 5.26% and 1 femur- 5.26%), whereas no case reported in the clinical application phase from 6 to 12 years of age (Table 4.4).

Higher incidence was recorded, depending on bone type and patient age, of patients with femur fracture under 6 months of age i.e. 47.37% of total cases (Table 4.4).

Table 4.4: Classification of Clinical patients according to bone involved and patient age

Bone involved	**Patient age**			
	Category	Total no.	% from total no. of fractures	% from total no. of specific bone fractures
Humerus	Under 6months	1	5.26	25
	6-12 months	1	5.26	25
	1-6 years	1	5.26	25
	6-12 years	1	5.26	25
Femur	Under 6months	9	47.37	64.29
	6-12 months	4	21.05	28.57
	1-6 years	1	5.26	7.14
	6-12 years	0	0	0
Tibia	Under 6months	0	0	0
	6-12 months	1	5.26	100
	1-6 years	0	0	0
	6-12 years	0	0	0

Considering patient weight there were recorded 11 cases in group I i.e. 0-10 kg (2 humerus- 10.53%, 8 femur- 42.11% and 1 tibia and fibula- 5.26%), 6 cases in group II i.e. 10-20kg (1 humerus- 5.26% and 5 femur- 26.32%) and 2 cases in group III i.e. 20-30kg (1 humerus-5.26% and 1 femur-5.26%).

In Table 4.5, by associating bone involved and patient age, it was shown that high incidence was recorded for patients with femur fracture weighing 0 to 10 kg i.e. 42.11% of total number of fractures reported.

Table 4.5: Classification of Clinical patients according to bone involved & patient weight

Bone involved	**Patient weight (kg)**			
	Weight category	Total no.	% from total no. of fractures	% from total no. of specific bone fractures
Humerus	I	2	10.53	50
	II	1	5.26	25
	III	1	5.26	25
Femur	I	8	42.11	57.14
	II	5	26.32	35.71
	III	1	5.26	7.14
Tibia	I	1	5.26	100
	II	0	0	0
	III	0	0	0

Key: I-III (Weight categories in Kg: 0-10, 10-20, 20-30)

4.2.2 Muscle girth measurement

Most of the fracture cases brought to the clinics presented with different types of long bone fractures suffered from post traumatic inflammatory swelling as there is widespread vasodilatation and plasma exudation, leading to the acute edema along with inflammatory cells which migrate to the region of a fresh fracture (Cruess and Dumont 1985), muscle damage at the site of trauma or due to post traumatic pooling of blood at the site causing hematoma formation; thus resulting in increased muscle girth of the fractured limb.

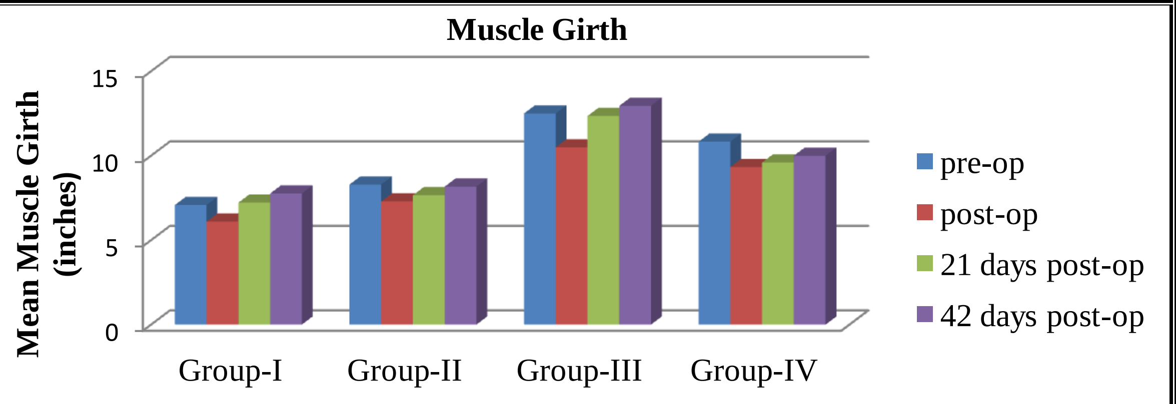
Categorizing all the 19 cases on the basis of body weight into four groups viz. Group-I (5kg and below), Group-II (5kg –below 10kg), Group-III (10kg- below 15kg) and Group-IV (15kg and above), a correlation between change in muscle girth at four different intervals i.e. pre-operatively, immediate post-operatively, 21 days post-op and 42 days post-op; was obtained (Table 4.6). It was shown that there was a sudden decrease in muscle girth immediately after operation followed by a gradual increase observed on 21st day post-op and 42^{nd} day post-op (Fig. 4.4). The initial decrease in muscle girth was due to the removal of haematoma formed at the site, due to reduction of fractured bone fragments back to their normal position and due to post operative anti-inflammatory drug administration. Whereas the gradual increase in muscle girth observed over a period of time was due to increased blood supply to the site of fracture, due to regeneration of healthy muscle tissue and callus formation at the fracture site. With the gradual use of affected limb by the animal, the group of muscles encapsulating the bone regains its normal strength and contour thus showing a progressive healing pattern.

Table 4.6: Table depicting Muscle girth measurement of the clinical patients at various time intervals

Groups according to body wt.	Case no.	Muscle girth (inches)			
		Pre-operatively	Immediate Post-operatively	21 days Post-op	42 days Post-op
I	2	8.2	7	9.5	10
	10	7.2	6.5	7.4	7.8
	11	7	6.2	6.8	7
	12	6	4.6	5.8	7
	15	7	6.2	6.6	7
	Mean	7.08	6.1	7.22	7.76
II	3	4.2	3.7	4	4.5
	4	7.6	6.8	7.1	7.3
	9	11	10	10.5	11
	13	8	7.2	7	7.8
	14	9.5	8.5	9	9.6
	18	8.5	7	7.5	8
	19	9.2	7.8	8.5	9
	Mean	8.29	7.29	7.66	8.17
III	1	12.5	11	12	12.8
	5	13	10.5	13.2	13.6
	7	12	9.5	12.2	12.8
	8	12.5	11	12	12.6
	Mean	12.5	10.5	12.35	12.95
IV	6	10	8	8.2	8.4
	16	8.5	7.8	8	8.4
	17	14	12.2	12.6	13.2
	Mean	10.83	9.33	9.6	10

Key: Group I: 5kg and below, Group II: 5kg - below 10kg, Group III: 10kg - below 15kg, Group IV: 15kg & above

Fig 4.4: Graphical representation of muscle girth measurements (Mean) of 4 groups



Key: Group I: 5kg and below, Group II: 5kg - below 10kg, Group III: 10kg - below 15kg, Group IV: 15kg & above

4.2.3 End threaded positive profile pins used in clinical application phase

End threaded positive profile, screw-pointed intramedullary pins, produced from stainless steel (316-L), were used; they were 3.5/4.0mm (n=7), 4.5/5mm (n=7) and 4.5/6.5mm (n=5) in diameter (Table 4.7) and 9 inches long. The pins were used alone or in conjunction with full cerclage wire as per the necessity in individual patient. The pins were cut at the nearest point to where they exited the bone to minimize irritation caused by the pin end.

Pin breakage, which can occur at the pin-thread junction in end threaded negative profile pins, was not encountered in any of the cases. Partially threaded pins have a negative profile ending that creates a weak point in the pin-thread junction, so if these pins are to be used, the junction must not be near the fracture line (Olmstead *et al.* 1995; Denny and Butterworth 2000).

Specification of iron based alloys (Kuhn 2000; Mears and Rothwell 1982)

- The combinations of their properties permit the manufacture of properly shaped and sized implants.
- They have suitable mechanical properties relative to allowable sizes for implantation, and compatibility *in vivo*, often for extended periods of time.

Table 4.7: Account of different size of End threaded positive profile pins implanted in the Clinical patients as per their body weight

Pin size	Cases	Age	Body weight (kg)
3.5/4.0mm	1	1 and ½ month	3.40
	2	2 months	3.70
	3	2 months	3.70
	4	3 months	4.70
	5	4 months	4.50
	6	4 months	4.30
	7	18 months	11.50
4.5/5.0mm	8	3 and ½ month	8.50
	9	4 months	9.75
	10	4 months	11.00
	11	6 months	7
	12	6 months	13
	13	6 months	13
	14	9 years	15
4.5/6.5mm	15	8 month	9.40
	16	11 month	21
	17	1 year	21
	18	4 months	7.5
	19	4 months	9.80

4.2.4 Technique of application (Piermattei *et al.* 2006)

All patients were subjected to clinical and radiological examinations preoperatively, those required mild sedation for pre-operative evaluation were administered Acepromazine @ 0.05 mg/kg B.Wt, I.M.; Butorphanol tartarate @ 0.2mg/kg B.Wt, I.M. and Atropine Sulphate @ 0.04 mg /kg B.Wt., S.C.

The patient scheduled for surgery were given a standard protocol comprising Inj. Butarphanol @ 0.2mg/kg B.Wt, I.V. and Inj. Diazepam @ 0.5mg/kg B.Wt, I.V. followed by Inj. Propofol (till effect I.V.) and maintenance by Isoflurane throughout the period of surgery .

The diameter and length of the implant were determined by pre-operative radiographs, size and weight of the dog and intra-operative assessment. An open reduction with a lateral approach was the technique of choice for diaphyseal, epiphyseal or metaphyseal femoral fracture repair; craniolateral approach was preferred for humeral fracture repair and medial approach was preferred for tibial fracture repair.

In case of femoral fracture (Plate-4.6);

- The skin incision was made along the cranio-lateral border of the shaft of the bone from the level of greater trochanter to the level of patella.
- The subcutaneous fat & superficial fascia were incised directly under the skin incision.
- The skin margins were undermined and retracted and the superficial layer of fascialata was incised along the cranial border of the biceps femoris muscle.
- This incision was extended to the entire length of the skin incision. Then the biceps femoris muscle was retracted caudally to reveal the shaft of femur.
- The vastus lateralis and intermedius muscles on the cranial surface of the shaft were retracted by freeing the loose fascia between the muscle and the bone.
- If a fissure was present on the fractured bone then, one or two cerclage wires were placed at first to reduce it at the proximal or distal fragment.
- The edges of the fractured ends of the bone were freshened by using a bone nibbler.
- Then the fracture was stabilized and held in position by a bone holding forceps.
- Using a Jacob's chuck, end threaded IM positive profile screw ended self tapping pin of appropriate size was inserted in a retrograde manner from the fracture site in the

proximal fragment of bone, keeping trocar end towards trochanter major till it comes out through the skin.

- The pin was further moved up by rotating in anti-clockwise direction till the last thread reaches the edge of fractured bone segment.
- After appropriate reduction and achieving optimal alignment of fracture fragments, the threaded end was driven into the distal cancellous bone, as described in Plate-4.9.
- The implant gets snugly fitted into the cancellous bone whereas it occupies 60-70% of the medullary canal, thus keeping the marrow and medullary cortical circulation least disturbed (Johnson *et al.* 2005).
- To enable removal of the pin following healing, a portion of approximately 5–10 mm was left outside the bone at the proximal end (Altunatmaz *et al.* 2012).

Plate-4.6: Pre-op and Post-op mediolateral radiographs of a clinical patient presented with femur fracture

Pre-op radiograph representing complete single transverse mid diaphyseal fracture of right femur

Post-op radiograph representing end threaded IM positive profile screw ended self tapping pinning in the femoral fracture

In humeral fracture (Plate-4.7);

- The skin incision was extended from the greater tubercle of the humerus proximally to the lateral epicondyle distally, following the craniolateral border of the humerus.
- Subcutaneous fat and fascia were incised on the same line and mobilized and retracted with the skin.

- Fat and brachial fascia were incised and dissected away to allow visualization of the cephalic vein. Brachial fascia was incised along the lateral border of the brachiocephalicus muscle and distally over the cephalic vein.
- The cephalic vein was ligated at the distal end of the field and again proximally, where it disappears under the edge of the brachiocephalicus muscle. The axillobrachial and omobrachial veins were similarly ligated & the isolated venous segment was removed.
- An incision was made in the craniomedial fascia of the brachialis muscle and in the insertion of the lateral head of the triceps brachii on the humerus.
- An incision was next made in the periosteal insertion of the superficial pectoral and brachiocephalicus muscles on the humeral shaft.
- The radial nerve overlying the brachialis muscle was identified and protected when making these incisions.
- Hohmann retractors were used to retract the brachialis and triceps muscles caudally and expose the musculospiral groove of the humerus.
- Biceps brachii, superficial pectoral, and brachiocephalicus muscles were elevated from the shaft by cranial retraction. Again, the radial nerve was protected during retraction.
- Rest of the technique was same as used for femoral fracture repair (Plate-4.9).

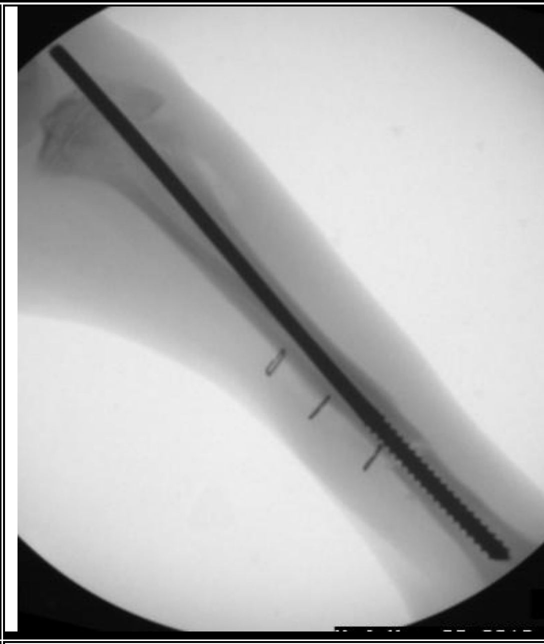
<table>
<tr><td colspan="2">Plate-4.7: Pre-op and Post-op mediolateral radiographs of clinical patient presented with humerus fracture</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Pre-op radiograph representing closed simple mid-diaphyseal oblique fracture of right humerus</td><td>Post-operative radiograph representing end threaded IM positive profile screw ended self tapping pinning in the humeral fracture</td></tr>
</table>

In tibial fracture (Plate-4.8);

- In normograde technique, the end threaded IM screw ended self tapping pin is inserted through the skin after a gliding (pilot) hole was created using a Steinmann pin of appropriate size.
- The pin with threaded end was introduced, along the medial border of the patellar ligament, entering the proximal tibia approximately one third to half the distance from the cranial surface of the tibial tubercle to the medial condyle of the tibia.
- After the pin enters the medullary cavity, it was just pushed and glided along the medial cortical surface, till the threaded end gets seated in the trabecular bone of distal metaphysis.
- Whereas in retrograde technique, a straight medial incision over the skin was used for end threaded intramedullary positive profile screw ended self tapping pinning.
- The bone was exposed by incising crural fascia over the medial shaft of the bone.
- The cranial tibial and medial digital flexor muscles were retracted by incising fascia along their borders to free them from the bone.
- Rest of the technique was same as used for femoral fracture repair (Plate-4.9).

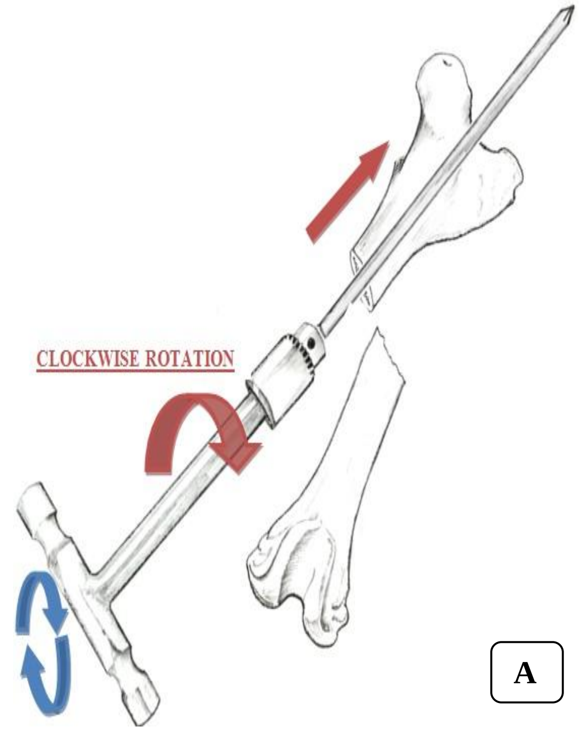
Plate-4.8: Pre-op and Post-op mediolateral radiographs of a clinical patient presented with tibial fracture

Pre-operative radiograph representing complete single distal diaphyseal oblique fracture of left tibia

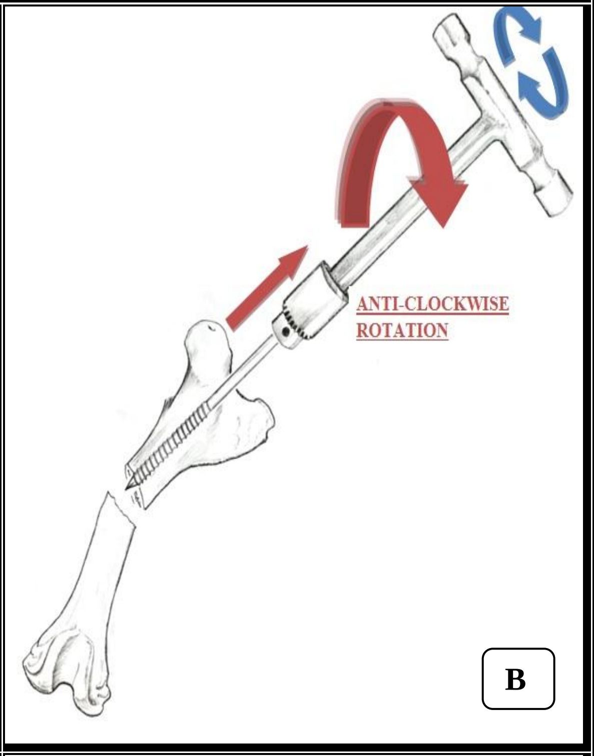


Post-operative radiograph representing end threaded IM positive profile screw ended self tapping pinning in the tibial fracture

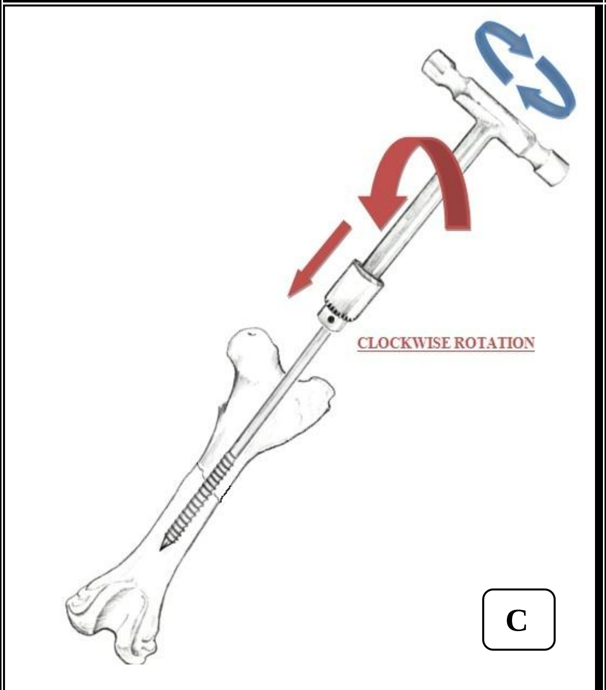
Plate-4.9: Technique of application of end threaded intramedullary positive profile screw ended self tapping pin (Dorso-plantar view)



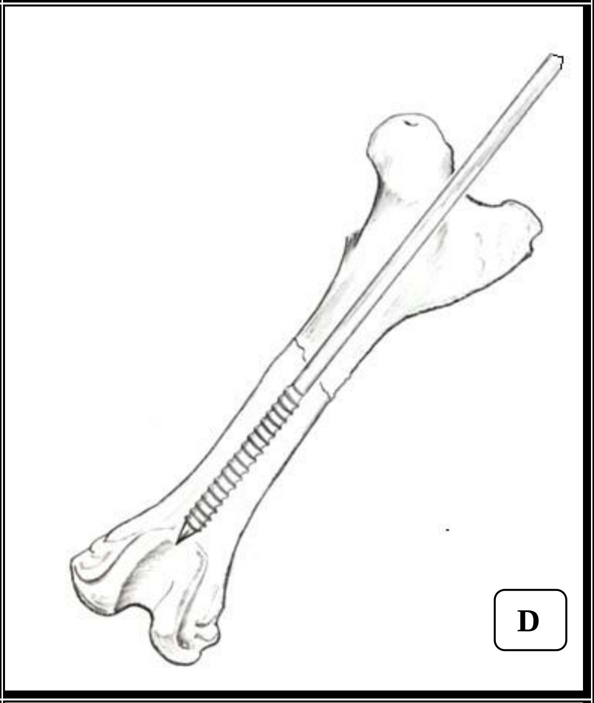
Introduction of pin from the fracture site in the proximal fragment of bone



Withdrawl of pin in upward direction till the last thread reach the fracture site



Reduction of fractured segments and introduction of threaded end into distal part of bone



Seating of the threaded end in distal cancellous bone followed by cutting of extra pin over the skin

Key: Curved arrow- Direction of rotation of Jacob's chuck;
Straight arrow- Direction of pin movement

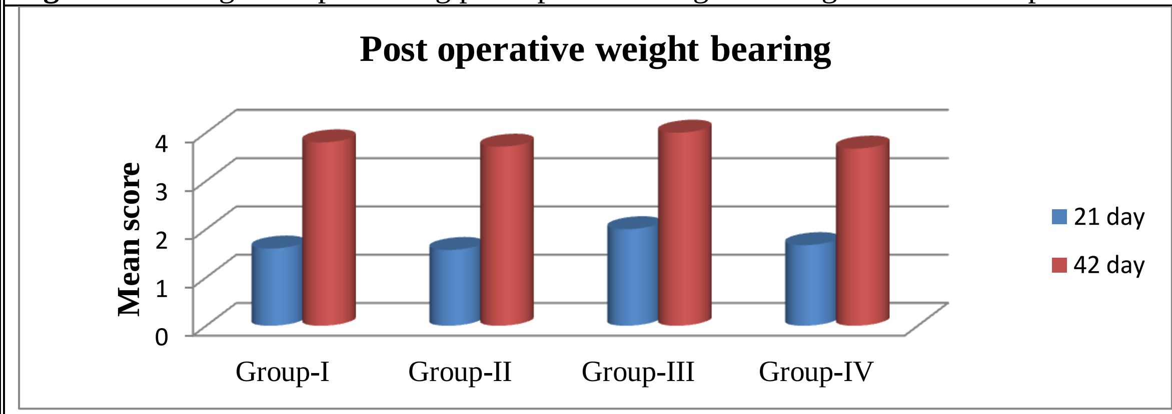
4.2.5 Post operative weight bearing

In nearly all the cases, partial weight bearing was noticed on 10th-14th post-operative day and nearly complete weight bearing on 21st to 42nd post-operative day with near normal limb function (Table 4.8). The above observations on post operative weight bearing in clinical patients were presented graphically in Figure-4.5. These findings were similar with those reported by Altunatmaz *et al.* (2012) on the use of fully threaded intramedullary pins in the treatment of various long bone fractures; the dogs appeared to bear weight on their limbs 5–15 days after the operation and functional recovery was seen to increase gradually, with full weight-bearing without any signs of complication after day 20.

Table 4.8: Table representing scores of post-operative weight bearing ability in all the clinical patients

Groups according to body weight	Case no.	Weight bearing	
		21st day post-op	42nd day post-op
I (5kg and below)	1	2	3
	2	1	4
	3	3	4
	4	1	4
	5	1	4
	MEAN	1.6	3.8
II (5kg - below 10kg)	6	2	4
	7	1	3
	8	2	4
	9	1	4
	10	1	4
	11	2	4
	12	2	3
	MEAN	1.57	3.71
III (10kg - below 15kg)	13	2	4
	14	1	4
	15	3	4
	16	2	4
	MEAN	2	4
IV(15kg and above)	17	2	3
	18	2	4
	19	1	4
	MEAN	1.67	3.67

Fig.4.5: Bar diagram representing post operative weight bearing in the clinical patients



4.2.6 Post-operative callus formation

As per the findings of Nunamaker (1985), the amount of periosteal callus reflects strictly the need for ancillary stabilization of the fracture fragments as healing progresses. A large amount of external callus indicates the need for additional support beyond the normal contours of the bone. This represents a delay in osseous healing over what can be obtained by stable fixation, but it is a normal repair process of warm-blooded animals and humans. Absence of all external callus results from accurate reduction and rigid fixation. Intercortical uniting callus occupies the space between the opposed ends of cortex at the fracture or osteotomy site. When the space is small, its blood supply comes entirely from the medulla and anastomoses with the extraosseous blood supply at the periosteal surface. Since the medullary arterial supply cannot extend beyond the contours of the bone itself, a large intercortical space contains chiefly callus of the periosteal type.

Following the above study, a radiographical follow-up carried out 21 and 42 days after surgery, revealed no pin migration in any of the cases and there was no bone shortening or fragment collapse**.** Whereas when single Steinmann pin was used as sole intramedullary implant, it was seen in animals where there is instability at the fracture site, the fracture collapsed over the pin, or where there is sufficient motion to cause loosening of the pin at its distal aspect. It was also found that if the Steinmann pin loosens, the fracture will usually distract or collapse and angulate. The single Steinmann pin may penetrate the skin through the site of initial insertion and create a tract for infection (Nunamaker 1985). When a bridge of periosteal callus was seen on 21^{st} -30^{th}day post-operatively, it was classified as healed. In all the cases healing was evident with a moderate degree of periosteal callus (Table 4.9). The pins were not removed in any of the cases till there was complete evidence of healing and proper weight bearing except in one, presented with impacted fracture, in which pin was removed after complete weight bearing was achieved by the animal though periosteal callus was not much evident. Series of radiographs representing callus formation were shown in Plate-4.10 and the graphical representation of post operative callus formation in the clinical patients was given in Figure-4.6.

Table 4.9: Table representing post-operative callus formation scores in clinical patients

Groups according to body weight	Case no.	Callus formation	
		21st day post-op	42nd day post-op
I (5kg and below)	1	2	2
	2	2	1
	3	2	3
	4	2	1
	5	2	1
	MEAN	2	1.6
II (5kg - below 10kg)	6	2	2
	7	1	2
	8	1	2
	9	2	1
	10	2	1
	11	2	1
	12	2	2
	MEAN	2	1.57
III (10kg - below 15kg)	13	1	2
	14	2	1
	15	1	1
	16	3	2
	MEAN	1.75	1.5
IV(15kg and above)	17	1	2
	18	3	2
	19	2	1
	MEAN	2	1.67

Fig.4.6: Bar diagram representing post operative callus formation in the clinical patients

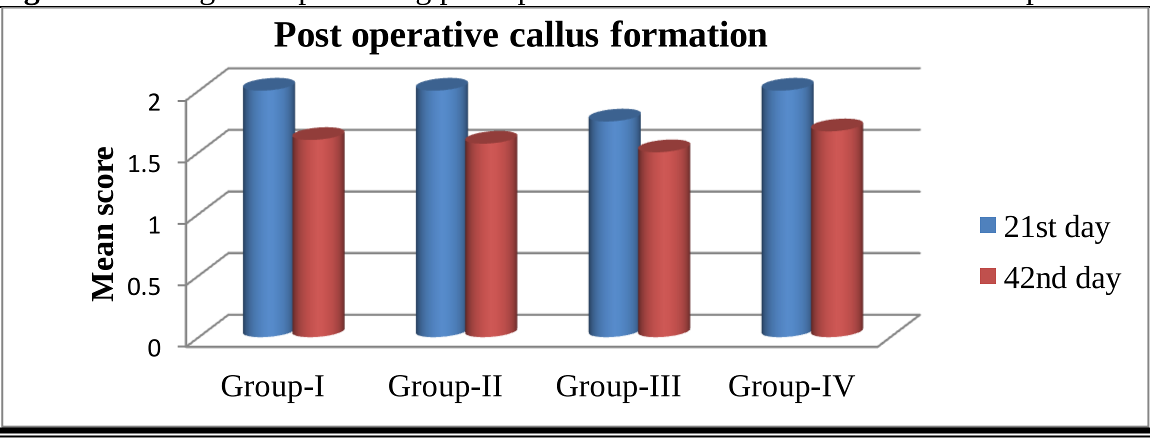
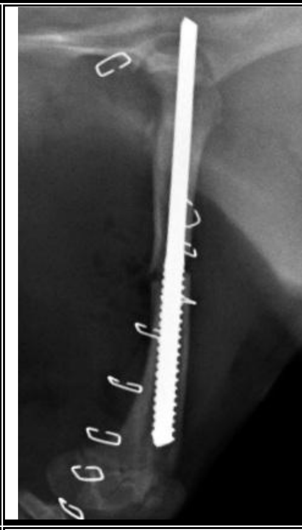
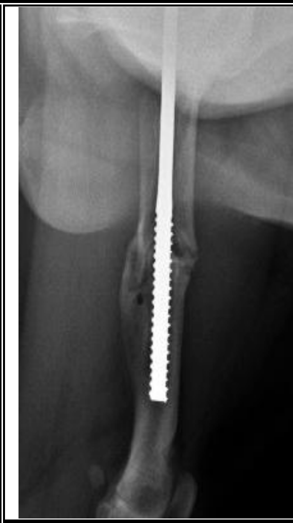


Plate-4.10: Series of radiographs showing callus formation in two of the clinical patients

Case 1: Closed complete oblique proximal diaphyseal fracture of left femur			
			
Pre-op	**Post-op**	**21 day Post-op**	**Post pin removal**
Case 2: Closed complete comminuted distal diaphyseal fracture of left femur			
			
Pre-op	**Post-op**	**21 day Post-op**	**Post pin removal**

4.2.7 Bone healing and recovery

In majority of the cases, the aetiology of fracture was automobile accident (n=12), followed by fall from a height (n=7). Fracture healing involved the restoration of normal strength of the bone to prevent fracture reoccurrence and to provide sufficient skeletal support.

Metaphyseal/epiphyseal (n=3) and distal or proximal 3rd diaphyseal (n=6) fractures healed early (within 21 days), as compared to mid-diaphyseal (n=4) fractures because cortical bone is much slower to heal than cancellous bone (Cook 1993). On an exception, two of the distal 3rd diaphyseal fractures healed bit late (40-50 days) as the animal's movements were not restricted by the owner. On the contrary four mid-diaphyseal fractures healed within 30 days, as they were young and properly managed postoperatively by the owner. The marrow around cancellous bone provides a ready source of osteoblasts and there is less bone to resorb during the remodeling phase. Osteoclasts also remodel the cuff of callus to reduce its size. With favorable conditions cortical bone usually requires about 8-12 weeks to heal whereas cancellous bone may be solidly united after just 4 weeks (Radin 1987).

In all the 19 cases direct bone healing occurred through contact healing, where osteonal remodeling occurred rapidly across a fracture in areas of apposed cortical bone, as with a fracture having interfragmentary compression. In most of the cases, where small gaps remained at the fracture site but the fixation was rigid, bone healing occurred through gap healing. In gap healing, spaces within the fracture fill with blood vessels and connective tissue and osteoblasts are rapidly deposited for bone production (Hulse and Hyman 2003).

Immediate post-operative radiographs revealed anatomical reduction, good cortical contact and stable implant in all the cases. The suture line healed normally without any complication and sutures were removed on 7^{th} -10^{th} day post-operatively. In nearly all the cases, partial weight bearing was noticed on 10-12^{th} post-operative day and nearly complete weight bearing on 21^{st} to 30^{th} post-operative day with near normal limb function. The 21^{st} to 30^{th} day post-operative radiographs showed stable implant and evidence of periosteal reaction at the fracture sites. There was no evidence of axial rotation or compression at either of the fracture lines in all the cases.

Post-operative grading (42^{nd} day post-operatively) of functional limb usage on the basis of weight bearing and gait of animal showed that out of 19 cases, 12 showed normal limb usage i.e. complete weight bearing with no sign of limping and 6 showed slight limping i.e. good weight bearing with slight limping, but they also showed complete limb function within next 21 days. One animal died due to unknown cause before 42^{nd} day observation.

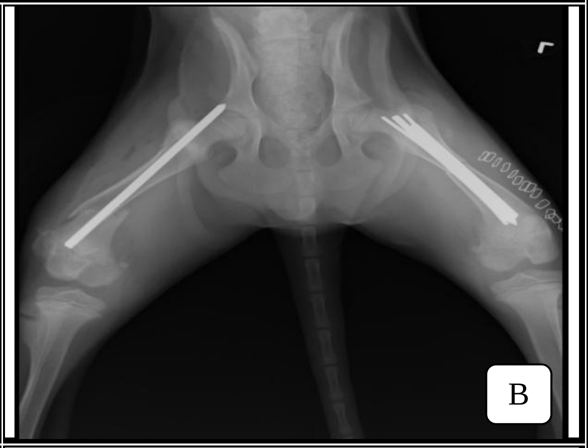
After 3 months of implant removal, functional recovery was assessed using a scoring system in all the cases. Out of 19 cases, 11 animals showed a score of 100, 4 animals scored 90 i.e. showing inconvenience while climbing stairs and while defecation as in squatting position, 3 scored 85 with difficulty in climbing stairs, jumping and squatting while defecation whereas 1 animal died due to certain odd circumstances. So in majority of the cases, fractured limb returned to normal function in a time span of 3-4 months.

4.2.8 Significant clinical presentations

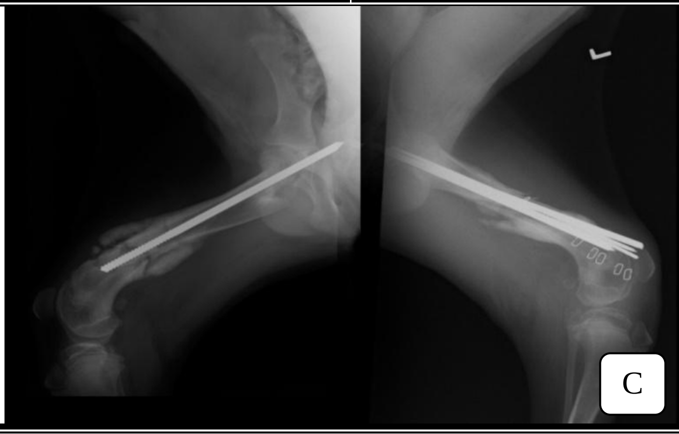
Case I: A 4 month old dog weighing 9.75 kg was presented in TVCC, COVAS, Palampur with a bilateral femoral fracture as a result of automobile accident. Preoperative radiographic evaluation revealed a simple complete distal metaphyseal oblique fracture of right femur and simple complete proximal metaphyseo-diaphyseal long oblique fracture of left femur (Plate-4.11). After stabilizing the patient, stack pinning was done in left femur whereas end threaded intramedullary positive profile screw ended self tapping pinning (4.5/5.0mm) was done in right femur. Two of the pins implanted in left femur were found migrated upwards; 21 days post operatively, whereas the end-threaded pin in right femur did not show migration. As a result right limb showed early healing with good weight bearing in comparison to left limb.

Plate-4.11: Radiographic projections of a case presented with bilateral femur fracture

Pre-op



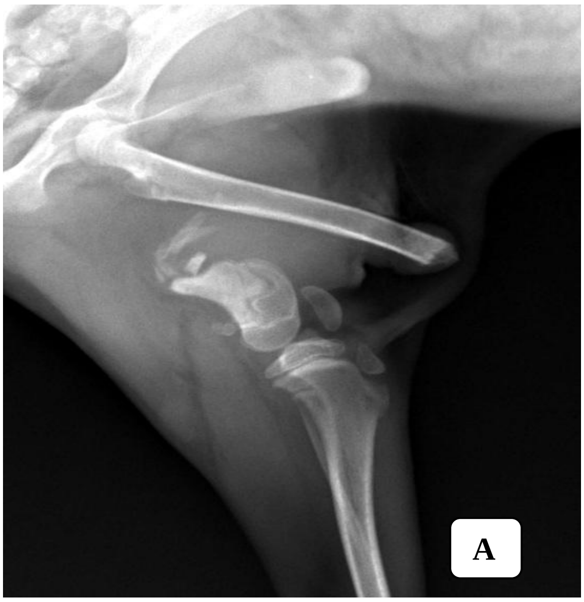
Immediate Post-op

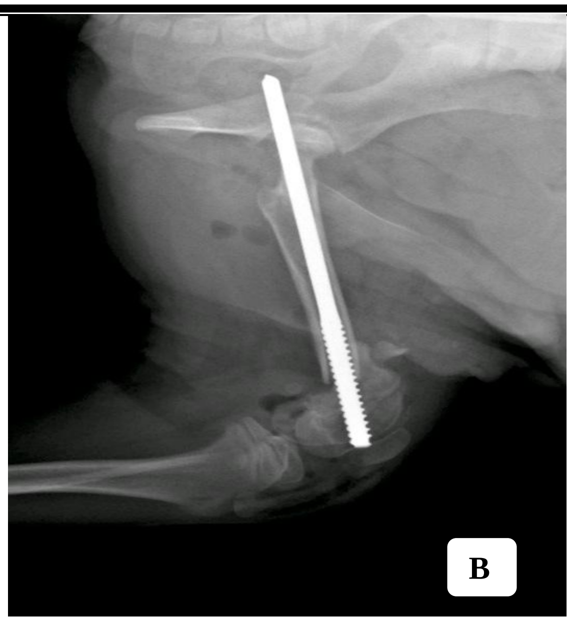


21 days Post-op

Case II: A 4 month old dog weighing 4.30 kg was presented in TVCC, COVAS, Palampur with an open femoral fracture and non weight bearing in left hind limb as a result of fall from a height. Preoperative radiographic evaluation revealed an open simple transverse distal epiphyseal (Supracondylar) fracture of left femur (Plate-4.12.A). After stabilizing the patient, normograde pinning was done in the fractured bone using an end threaded intramedullary positive profile screw ended self tapping pin (3.5/4.0mm) from the caudal most part of intercondylar fossa with threads embedded snuggly into distal cancellous bone (Plate-4.12.B). This was done by displacing the patella laterally over the bone and then introducing the implant with trocar end upward, through the intercondylar region of distal bone, into the medullary cavity. The pin was further advanced into the bone in upward direction using a Jacob's chuck, till the last thread enters the bone, thus providing a normal gliding surface for patella without any subtle interference. The implant was removed on 21st day after operation, without any migration and good weight, achieved by the animal with restored muscle mass, thus showing early signs of healing. The initial results have shown this method as a promising alternative in management of supracondylar fractures but it needs further investigation and larger database to prove its efficacy.

Plate-4.12: Mediolateral radiograph of femur representing management of supracondylar fracture using end threaded IM positive profile screw ended self tapping pin in one of the clinical patients





A. Pre-op: Open simple transverse distal epiphyseal fracture of left femur

B. Post-op: Supracondylar fracture reduced using end threaded IM positive profile screw ended self tapping pin in normograde manner

4.2.9Biomechanical and other advantages

In contrast to static osteosynthesis done with compression, it has been reported that some instability was always present with intramedullary pinning (Olmstead *et al.* 1995; Dean 1998; Hach 2000). A smooth single intramedullary pin cannot provide sufficient axial or rotational stability (Raiha *et al.* 1993; Hach 2000). Stack pin application has been reported to partially eliminate these disadvantages by increasing the strength of rotational stability and traction (Howard 1991; Dean 1998; Hach 2000). With the intramedullary end-threaded positive profile screw point pin, the possibility of trauma caused by the pin end was removed and axial strength is increased through the gripping of cancellous bone in the distal fragments.

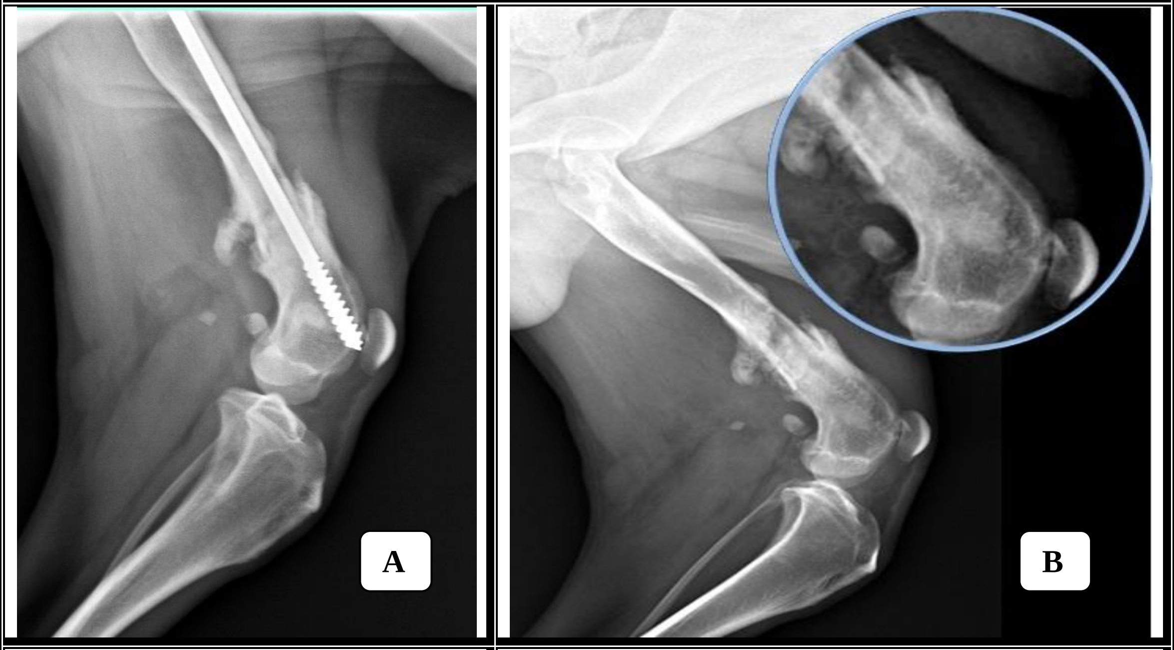
The biomechanical principle of intramedullary pinning in long tubular bone fractures is based upon the usage of a pin that precisely fits the medulla in order to hold the fragments together (Dean 1998; Denny and Butterworth 2000). The Kuntscher pin is advanced into the bone medulla by hammering. During this procedure, fragments in comminuted fractures may become displaced. Since the end-threaded intramedullary positive profile screw ended self tapping pin fits into the medulla like a screw it provides more effective rotational stability by gripping the spongy bone in the distal diaphysis at the same time. It can easily be advanced without moving the assembled fragments while sometimes even bringing together the fragments over the pin. With Kuntscher pins, the pin diameter was slightly larger than the medullary canal diameter in humans. This enables the pin to fit securely inside the bone (Deyoung and Probst 1993; Raiha *et al.* 1993; Denny and Butterworth 2000; Hach 2000). This, in turn, prevents fragments from rotating or sliding over the pin.

When an end-threaded intramedullary pin of suitable thickness was selected, both the instability problem seen with intramedullary pin was eliminated and rotational stability was achieved by the secure fit inside the medullary canal similar to a Kuntscher pin (Deyoung and Probst 1993; Raiha *et al.*1993; Denny and Butterworth 2000).

As the implant was placed in the medullary cavity, it resists bending in all directions (Nunamaker 1985). Its strength was related to its diameter, and its ability to restrict rotational force acting on the fracture fragment was related to the contact of its threaded end with the distal cancellous bone.

There was no evidence of axial rotation or compression or tension at either of the fracture lines in all the cases. It was anchored at the point of introduction, has contact with the isthmus of the medullary canal, and was impacted/ screwed into the distal cancellous bone. Thus providing three point fixation (Nunamaker 1985). Radiographic evidence of tight seating of implant in distal cancellous bone (Highlighted in circle) was evident by impression of self tapping threaded end in the distal fragment as shown in Plate-4.13.B.

Plate-4.13: Mediolateral radiograph of femur representing tight seating of implant



Before pin removal	After pin removal

As mentioned earlier, the radiographical follow up revealed no pin migration or pin breakage or pin bending in any of the cases because of implant’s good strength to resist all loads. The material properties of metal implant were not only determined by their composition, but also by the manufacturing process. Melting and casting of the alloy was followed by forging using compression, after which it was cold worked to elongate the grain structure into fibrous shapes parallel to the long axis of the implant and anticipated deforming loads *in vivo* (Malan 2012).This micro structure of the implant provides optimum strength to prevent breakage. Cold working also increases the stiffness of the implant and thereby reduces its ductility. A certain degree of ductility is, however, essential to prevent brittle fracture of an implant during *in vivo* cyclic loading and to allow contouring of the implant at surgery (Malan 2012). The use of heat can further refine an implant to increase its ductility and to obtain the desired properties for different implants. For example, 316L cerclage wire is more ductile than a 316L bone Plate, which in turn, is more ductile than a 316L Steinmann pin (Shaw and Daubert 1988).

In this study, there were not any radiological or clinical problems seen in the healing period of fractures belonging to skeletally immature patients. Fixation with an end-threaded intramedullary positive profile screw ended self tapping pin, even in cases of comminuted fractures, has the advantages of causing very little damage to surrounding tissues while easily achieving anatomical reduction over the pin and having a relatively short operation time. Ozsoy used threaded Steinmann pins to treat fractures of femur, humerus and tibia in cats (Ozsoy 2004). However, these pins were unsuitable for removal and, therefore, not removed. An end threaded intramedullary positive profile pin screw ended self tapping pin on the other hand can be removed when necessary as observed in the present study.

Iatrogenic damage to the sciatic nerve may occur following intramedullary pin application in femoral fractures as in stack pinning (Fortere *et al.* 2007). This may arise particularly during the bending of the intramedullary pin due to improper load sharing or due to movement of animal causing damage to the nerve itself. No damage to the nerve was encountered either during application or removal of end threaded intramedullary positive profile pin screw ended self tapping pin.

The end-threaded intramedullary positive profile screw ended self tapping pin allows the reconstruction procedure to be carried out easily, particularly in comminuted fractures, by being placed in the distal fragment and fracture fragments being positioned around the pin using full cerclage wiring. This feature of threaded pins has been considered to be an advantage in comparison to other intramedullary pins (Altunatmaz *et al.* 2012).

Post-recovery removal is easy and does not require a major surgical procedure. In the light of the findings achieved in our study we suggest that the end-threaded intramedullary positive profile screw ended self tapping pin, which was used successfully in the treatment of canine femoral, tibial and humeral fractures, will take its place among other intramedullary pins used in Veterinary orthopaedics. Thus, the end threaded intramedullary positive profile screw ended self tapping pin, which was also a cost-effective option, can be indicated in majority of long bone fractures.

Chapter-5 SUMMARY AND CONCLUSIONS

Trauma, the most common cause of fractures in small animals, is usually due to automobile injury or falling from a height. Treatment of fractures via intramedullary fixation is regularly used in Veterinary orthopaedics. The Steinmann pin appears to be the most often used material, either on its own or in combination, while the Rush pin, Kirschner wire, Kuntscher pin and interlocking pin have all been employed.

Many Veterinary practitioners in field do not have access to the specialized and costly equipment to undertake complex orthopaedic procedures, or lack the technical assistance required to perform such operations. However, many of them have access to, and are skilled in using the simpler, more affordable equipment necessary to place an intramedullary pin and cerclage wires. The fractures are managed with different techniques having their own pros and cons. A slight innovation and modification has been made with provision of positive profile threads and a screw point at one end of the existing Steinman pin and has been found to be one of the promising techniques in management of fractures in animals during our preliminary trials.

The compression and fixation device includes an elongated intramedullary stainless steel rod of sufficient length to project from one end of the bone past the fracture site and which is formed with a diameter of sufficient size to substantially occupy the medullary cavity of the bone.

The present study was carried out to assess the feasibility of using end threaded intramedullary pins which provides axial stability and resist bending, rotational & shear forces to an extent; but devoid of some complications like accurate proficiency as in plate application and its contouring with bone interface, as well as easy affordability. Initially, the technique of application of end threaded intramedullary pinning in long bone fractures was standardized in a few clinical cases. In this phase, end threaded pins of different profiles i.e. positive and negative, were used as the internal fixation technique and were evaluated on 6 dogs presented with long bone fractures. For comparative evaluation, post-operative radiographic images, weight bearing and other recovery parameters were recorded and analyzed from time to time. The technique with better results and less post-operative complications was then used in clinical cases of dogs suffering from various long bone fractures and compared thoroughly.

The six client-owned dogs presented with fracture of different long bones were randomly allocated into two groups. In group-I, three dogs with long bone fracture (8, 3 & 1 years weighing 26kg, 18kg & 20kg respectively) were implanted with end threaded intramedullary negative profile pin with a trocar end of 5.2/5.0 mm. Pins were removed after complete attainment of weight bearing by the animals which was 3 months, 4 months & 3 months respectively. Whereas in group-II, three dogs with long bone fractures (18 months, 3 years & 10 years weighing 16kg, 20.5kg & 30kg respectively) were implanted with end threaded intramedullary positive profile pin screw ended self tapping pin of 4.5/6.5 mm. Pins were removed after complete attainment of weight bearing by the animals which was 55, 60 & 60 days respectively.

The parameters evaluated, 21st and 42nd day postoperatively revealed slight pin migration in group-I, which resulted in disruption of callus site causing delayed union in one case and large callus formation in other two cases whereas no pin migration was observed in group-II. Other observations in group-I was reduced muscle girth and delayed healing time as compared to group-II.

On the basis of the results obtained from phase-I, 19 client-owned dogs (age; 1.5 month – 9 years and body weight; 3.40kg - 21kg), clinically presented with fracture of different long bones (Femur, Humerus and Tibia) were implanted with end threaded positive profile intramedullary pin with a screw end of size: 3.5/4.0mm, 4.5/5.0mm and 4.5/6.5mm.

Among 19 cases, there were recorded high values depending on bone involved and fracture line for transverse fracture (50% humerus bone) and oblique fractures (35.71% femur and 100% involving tibia and fibula bones). By associating bone involved and degree of bone fragmentation it was shown that a very high percentage was of simple fractures (75% humerus, 78.57% femur and 100% tibia and fibula). There were recorded high values depending on bone involved and patient age for patient with femur fracture under 6 months of age i.e. 47.37% of total cases and by associating bone involved and patient age, it was shown that high values were recorded for patients with femur fracture weighing 0 to 10 kg i.e. 42.11% of total number of fractures reported.

Immediate post-operative radiographs revealed anatomical reduction, good cortical contact and stable implant in all the patients. The suture line healed normally without any complication and sutures were removed on 7th -10th day post-operatively.

The parameters evaluated, 21^{st} and 42^{nd} day postoperatively showed initial decrease in muscle girth due to; removal of haematoma formed at the site, reduction of fractured bone fragments back to their normal position and postoperative anti-inflammatory drug administration. The gradual increase in muscle girth observed over a period of time was due to; increased blood supply to the site of fracture, regeneration of healthy muscle tissue and callus formation at the fractured site.

In nearly all the cases, partial weight bearing was noticed on 10^{th}-14^{th} post-operative day and nearly complete weight bearing on 21^{st} to 42^{nd} post-operative day with near normal limb function. The radiographical follow-up revealed no pin migration in any of the cases and there was no bone shortening or fragment collapse. When a bridge of periosteal callus was seen on 21^{st} -30^{th}day post-operatively, it was classified as healed; all cases healed with a moderate degree of periosteal callus. There was no evidence of axial rotation or compression at either of the fracture lines in all the cases.

Post-operative grading (42^{nd} day post-operatively) of functional limb usage on the basis of weight bearing and gait of animal showed that out of 19 cases, 12 showed normal limb usage i.e. complete weight bearing with no sign of limping and 6 showed slight limping i.e. good weight bearing with slight limping, but they also showed complete limb function within next 21 days. One animal died due to unknown cause before 42^{nd} day observation.

Based upon the above observations, following conclusions were drawn;

1. The end threaded intramedullary positive profile screw ended self-tapping pin used for fixation of long bone fractures in canines can resist pin migration, pin breakage and all loads acting on the bone i.e. rotation, compression, tension, bending and also shearing to an extent with no post-operative complications.

2. The end threaded intramedullary positive profile screw ended self tapping pin is economical and can be easily used in field conditions in managing long bone fractures in canines, as compared to other orthopaedic implants.

LITERATURE CITED

Alexander JW. 1982. Tibial fractures and their management. *Compendium on Continuing Education for the Practicing Veterinarian* 4: 78-87

Altunatmaz K, Ozsoy S, Mutlu Z, Devecioglu Y and Guzel O. 2012. Use of intramedullary fully-threaded pins in the fixation of feline and canine humeral, femoral and tibial fractures. *Veteterinary Comparitive Orthopaedics & Traumatology* 25(4):321-325

Aron DN, Foutz TL, Keller WG and Brown J. 1991. Experimental & clinical experience with an IM pin external skeletal fixator tie-in configuration. *Veterinary Comparative Orthopaedics and Traumatology* 4: 86-94

Audekercke RV and Martens M. 1984. Mechanical properties of cancellous bone. In: Hastings GW and Ducheyne P (ed) *Natural and Living Biomaterials.* CRC Press, Florida. p 7-18

Baadet JF, Hohnr B, Rudyr L and Olmsteaom L. 1983. Fractures of the humerus in dogs and cats- a retrospective study of 130 cases. *Veterinary Surgery* 12: 73-77

Blass CE and Piermattei DL. 1986. Static and dynamic cerclage wire analysis. *Veterinary Surgery* 15: 181-184

Boone EG, Johnson AL, Montovan P and Hohn RB. 1986. Fractures of the tibial diaphysis in dogs and cats. *Journal of the American Veterinary Medical Association* 188(1): 41-45

Boudrieau RJ. 2003. Fractures of the tibia and fibula. In: Slatter DH (3rd ed.) *Textbook of Small Animal Surgery.* Saunders, Philadelphia. p 2144-2157

Bouvy BM, Markel MD, Chelikani S, Egger EL, Piermattei D and Vanderby R. 1993. *Ex vivo* biomechanics of Kirschner-Ehmer external skeletal fixation applied to canine tibia. *Veterinary Surgery* 22: 194-207

Brinker WO, Hohn RB and Prieur WD. 1984. *Manual of internal fixation in small animals.* Springer-Verlag and Heidelberg. p 29-107

Brinker WO, Verstraete ME and Soutas-Little RW. 1985. Stiffness studies on various configurations and types of external fixators. *Journal of American Animal Hospital Association* 21: 280-288

Carter DR and Spengler DM. 1982. Biomechanics of Fracture. In Sumner-Smith G (ed) *Bone in Clinical Orthopedics.* WB Saunders, Philadelphia. p 586-595

Claes L, Heitemeyer U, Krischak G, Brau H and Hierholzer G. 1999. Fixation technique influences osteogenesis of comminuted fractures. *Clinical Orthopaedics and Related Resarch* 365: 221-229

Coetzee GL. 1999. Long bone fracture fixation with an intramedullary pin and C-clamp- on plate in dogs. *Veterinary Comparative Orthopaedics and Traumatology* 12: 26-32

Coetzee GL. 2002. Basic principles for the application of bone plates and screws in small animal patients. *CPD course for veterinary surgeons, Pretoria.* Roth Medical Components (Pty) Ltd, Pinelands, South Africa. p 1-23

Cook JE. 1993. Assessment of tibial fracture healing using dual energy X-ray absorptiometry. *M.Sc. thesis*, Durham University. http://etheses.dur.ac.uk/5679

Cruess RL and Dumont J. 1985. Healing of bone. In: Newton CD, Nunamaker DM (ed) *Textbook of Small Animal Orthopaedics.* JB Lippincott Company, Philadelphia

Dean WP. 1998. Stack pinning techniques. In: Bojrap J, *Current Techniques in Small Animal Surgery* (4th ed.). London:Waveryly Company. p 929-932

Denny HR and Butterworth SJ. 2000. Fracture Management. In: *A guide to canine and feline orthopaedic surgery* (4th ed.). Blackwell Science, Oxford, London. p 87-152

DeYoung DJ and Probst CW. 1985. In: Slatter DH (ed) *Textbook of Small Animal Surgery* (1st ed). WB Saunders, Philadelphia

DeYoung DJ and Probst CW. 1993. Methods of internal fracture fixation. In: Slatter DH (ed) *Textbook Of Small Animal Surgery* (2nd ed.). Philadelphia, W.B. Saunders. p 1610-1627

Dixon BC, Tomlinson JL and Wagner-Mann CC. 1994. Effects of three intramedullary pinning techniques on proximal pin location and articular damage in the canine tibia. *Veterinary Surgery* 23: 448-455

Durall I, Diaz-Bertrana MC, Puchol JL and Franch J. 2003. Radiographic findings related to interlocking nailing: windshield wiper effect, and locking screw failure. *Veterinary Comparative Orthopedics and Traumatology* 16: 217-222

Durall I, Falcon C, Diaz-Bertrana MC and Franch J. 2004. Effects of static fixation and dynamization after interlocking femoral nailing locked with an external fixator: an experimental study in dogs. *Veterinary Surgery* 33: 323-332

Eaton-Wells RD, Matis U, Robins GM and Whittick WG. 1990. The pelvis and the pelvic limb. In Whittick WG, *Canine Orthopaedics* (2nd ed.). Lea & Febiger, Philadelphia: 449-465

Einhorn TA. 1998. The cell and molecular biology of fracture healing. *Clinical Orthopaedics:* 7-21

Florin M, Arzdorf M, Linke B and Auer JA. 2005. Assessment of stiffness and strength of 4 different implants available for equine fracture treatment: A study on a 20° oblique long-bone fracture model using a bone substitute. *Veterinary Surgery* 34: 231-238

Flynn TJ. 1949. Intramedullary Pinning of a Fracture in a Dog. *Iowa State University Veterinarian* 11(2): 12

Fortere F, Tomek A and Rytz U. 2007. Iatrogenic sciatic nerve injury in eighteen dogs and nine cats. *Veterinary Surgery* 36:464-471

Gilley R and Gold R. 2006. Instrumentation: Orthopaedic pinning and wiring. University of Pennsylvania School of Veterinary Medicine. [http://cal.vet.upenn.edu/projects/orthopod/csfr/terms/pinnng and wiring.htm]

Gothman L. 1962. Local arterial changes associated with experimental fractures of the rabbit's tibia treated with encircling wires (cerclage) – a microangiographic study. *Acta Chirurgica Scandinavica* 123: 1-8

Greenbaum MA and Kanat IO. 1993. Current concepts in bone healing. Review of the literature. *Journal of American Podiatric Medical Association* 83: 123-129

Guille AE, Lewis DD, Anderson TP, Beaver DP, Carrera-Justiz SC, Thompson MS and Wheeler JL. 2004. Evaluation of surgical repair of humeral condylar fractures using self-compressing orthofix pins in 23 dogs. *Veterinary Surgery* 33(4): 314-322

Hach V. 2000. Initial experience with a newly developed medullary stabilisation nail (Trilam nail). *Veterinary and Comparative Orthopaedics and Traumatology* 13:109-114

Harari J. 2004. *Small Animal Surgery Secrets.* Hanley & Belfus Inc., Philadelphia. p 290

Harasen G. 2003. Common long bone fractures in small animal practice - Part 1. *Canadian Veterinary Journal* 44(4): 333–334

Hinko PJ and Rhinelander W. 1975. Effective use of cerclage in the treatment of long bone fractures in dogs. *Journal of American Veterinary Medical Association* 166: 520-524

Howard PE. 1991. Principles of intramedullary pin and wire fixation. *Seminars in Veterinary Medicine and Surgery (Small Animal)* 6:52-67

Hulse D and Hyman B. 2003. Fracture biology and biomechanics. In: Slatter DH (ed) *Textbook of Small Animal Surgery* (3rd ed.). Saunders, Philadelphia. p 1785-1792

Hulse D, Ferry K, Fawcet A, Gentry D, Hyman W, Geller S and Slater M. 2000. Effect of intramedullary pin size on reducing bone plate strain. *Veterinary and Comparative Orthopaedics and Traumatology* 13: 185-190

Hurov L and Seer G. 1968. Intramedullary Steinmann pinning of the radius in radial-ulnar fractures in the dog. *Candian Veterinary Journal* 9(4): 85-89

Johnson AL and Boone EG. 2003. Fractures of the tibia and fibula. In: Slatter DH (ed) *Textbook of Small Animal Surgery (2nd ed.).* WB Saunders Company, Philadelphia. p 1866-1876

Johnson AL, Houlton JF and Vannini R. 2005. *AO principles of fracture management in dog and cat.* AO Publishing, Thieme Punlishers Series.

Johnson K. 2009. Locking plates- the ultimate implant?. *Veterinary Comparative Orthopaedics and Traumatology* 22: 1-2

Kraus KH. 1993. Healing of bone fractures. In: Harari J (ed) *Surgical complications and wound healing in the small animal practice.* WB Saunders Company, Philadelphia. p 203-221

Kuhn H. 2000. Mechanical behaviour under tensile and compressive loads. In: Kuhn H, Medlin D (ed) *ASM Handbook®, Mechanical testing and evaluation.* ASM International, Materials Park, USA. p 99-108

Lanz OI, Lewis DD and Newell SM. 1999. Stabilisation of a physical fracture using an orthofix partially threaded Kirschner wire. *Veterinary and Comparative Orthopaedics and Traumatology* 12: 88-91

Lidbetter AD and Glyde MR. 2000. Supracondylar femoral fractures in adult animals. *Compendium on Continuing Education for the Practising Veterinarian* 22: 1041-1054

Lipowitz AJ, Newton CD, Caywood DD and Schwartz A. 1996. *Complications in Small Animal Surgery.* Williams & Wilkins, Baltimore. p 592-593

Little FM. 2001. Bending properties of stainless steel dynamic compression plates and limited contact dynamic compression plates. *Veterinary Comparative Orthopaedics and Traumatology* 14: 64-68

Malan F. 2012. An *in vitro* biomechanical comparison between intramedullary pinning and the use of plates in the dachshund tibia. *MSc.(Veterinary Science) thesis*, Department of Companion Animal Clinical Studies, Faculty of Veterinary Science, University of Pretoria. p 16-17.

McCartney WT, Garvan CB and Kiss K. 2009. Repair of thirty-six fractures in dogs using the Mennen clamp-on plate: preliminary results. *Veterinary Comparative Orthopaedics and Traumatology* 22: 406-411

Meade JB. 1989. The adaptation of bone to mechanical stress: Experimentation and current concepts. In: Cowin SC (ed) *Bone Mechanics.* CRC Press, Florida: 141-145

Mears DC and Rothwell GP. 1982. The mechanical behaviour of real materials. In: Mears DC (ed) *Materials and orthopaedic surgery (1st ed.).* Williams & Wilkins Company, Baltimore. p 75-89

Moşneang C and Igna C. 2012. Long-bone fracture frequency in companion animals. *Lucrari Stiintifice Medicina Veterinara* XlV(4): 5-10

Muir P. 1995. Area moment of inertia for comparison of implant cross-sectional geometry and bending stiffness. *Veterinary Comparative Orthopaedics and Traumatology* 8: 146-152

Ness MG. 2006. Implant failure. In: Coughlan AR, Miller A (ed) *BSAVA Manual of Small Animal Fracture Repair and Management.* Replika Press Pvt. Ltd, India. p 291-295

Ness MG. 2009. Repair of Y-T humeral fractures in the dog using paired “String of Pearls” locking plates. *Veterinary Comparative Orthopaedics and Traumatology* 22: 492-497

Nordin M and Frankel VH. 1980. Biomechanics of whole bones and bone tissue. In: Frankel VH, Nordin M (ed) *Basic Biomechanics of the Skeletal System*. Lea & Febiger, Philadelphia. p 132-137

Nunamaker DM. 1985. Fractures of the tibia and fibula. In: Newton CD, Nunamaker DM (ed) *Textbook of Small Animal Orthopaedics.* JB Lippincott Company, Philadelphia. p 439-444

Nunamaker DM. 1985. Methods of internal fixation. In: Newton CD, Nunamaker DM (ed) *Textbook of Small Animal Orthopaedics.* JB Lippincott Company, Philadelphia. p 261-286

Olmstead MI, Egger EL, Johnson AL and Wallace LJ. 1995. Principles of fracture repair. In: *Small Animal Orthopaedics*. Ed M.L. Olmstead, St.Louis, Mosby. p 111-146

Orfaly RM. 2011. Bone fixation using an intramedullary pin. United States Patent Application: 20110009865 .http://appft1.uspto.gov

Ozsoy S. 2004. Fixation of femur, humerus and tibia in cats using intramedullary threaded Steinmann pins. *Veterinary Records* 155: 152-153

Pardo AD. 1994. Relationship of tibial intramedullary pins to canine stifle joint structures: a comparison of normograde and retrograde insertion. *Journal of the American Animal Hospital Association* 30: 369-374

Parker RB and Bloomberg MS. 1984. Modified intramedullary pin technique for repair of distal femoral physeal fractures in the dog and cat. *Journal of American Veterinary and Medical Association* 184(10): 1259-1265

Perren SM. 1989. The biomechanics and biology of internal fixation using plates and nails. *Orthopaedics* 12: 21-26

Piekarski K. 1984. Fractography of bone. In: Hastings GW, Ducheyne P (ed) *Natural and Living Biomaterials.* CRC Press, Florida. p 36-40

Piermattei DL, Flo GL and DeCamp CE. 2006. In: *Brinker, Piermattei and Flo's Handbook of small animal orthopedics and fracture repair* (4th ed.). WB Saunders Company, Philadelphia. p 25-159, 512, 633-660

Pope ER. 2003. Fixation of tibial fractures. In: Bojrab MJ (ed) *Current techniques in small animal surgery*. (4th ed.) Williams & Wilkins, Baltimore. p 1050-1055

Radin EL. 1987. *Orthopaedics for the Medical Student.* JB Lippencott, Philadelphia. p 9-34

Rahn BA, Gallinaro P and Baltensperger A. 1971. Primary bone healing: An experimental study in the rabbit. *Journal of Bone and Joint Surgery* 53A(4): 783-786

Raiha JE, Axelson P and Rokkanen P. 1993. Intramedullary nailing of diaphyseal fracture with self-reinforced polylactide implants. *Small Animal Practise* 34: 337-344

Rani UR, Rajendran N and Vairavasamy K. 2012. Immobilisation and treatment of femoral diaphyseal oblique fractures in dogs using double intramedullary pinning and cerclage wiring - A study in twelve patients. *Intas Polivet* 13(2): 411-415

Rhinelander FW and Wilson JW. 1982. Blood supply to developing, mature, and healing bone. In: Sumner-Smith G (ed) *Sumner-Smith's Bone in clinical orthopaedics: a study in comparative osteology*. WB Saunders Company, Philadelphia. p 7-28

Rhinelander FW. 1974. Tibial blood supply in relation to fracture healing. *Clinical Orthopedics* 105: 34-39

Roe S. 2003. Internal fracture fixation. In: Slatter DH (ed) *Textbook of Small Animal Surgery* (3rd ed.). Saunders, Philadelphia. p 1798-1818

Roe S. 2006. Biomechanical basis of bone fracture and fracture repair. In: Coughlan AR, Miller A (ed) *BSAVA Manual of Small Animal Fracture Repair and Management.* British Small Animal Veterinary Association, Gloucester. p 14-24

Rooks RL and Tarvin GB. 1982. *In vitro* cerclage wire analysis. *Veterinary Surgery* 11: 39-43

Rudy RL. 1975. Principles of intramedullary pinning. *Veterinary Clinics of North America* 5(2): 209-228

Saikku-Backstrom A, Raiha JE, Valimaa T and Tulamo RM. 2005. Repair of radial fractures in toy breed dogs with self-reinforced biodegradable bone plates, metal screws, and light-weight external coaptation. *Veterinary Surgery* 34: 11-17

Schatzker J. 1991. Screws and plates and their application. In: Allgower M (ed) *Manual of internal fixation: techniques recommended by the AO-ASIF group* (3rd ed.). Springer-Verlag, Berlin. p 179-199

Schwarz PD. 1993. Fracture biomechanics of the appendicular skeleton: causes and assessment. In: Bojrab MJ (ed) *Disease mechanisms in small animal surgery* (2nd ed.) Lea & Febiger, Philadelphia. p 1009-1026

Seaman JA and Simpson AM. 2004. Tibial fractures. *Clinical Techniques in Small Animal Practice* 19(3): 151-167

Securos Catalog of Products. 2008. Securos (Pty) LtdCompany, 443 Main Street, Fiskdale, MA 01518: 98-99

Shaw JA and Daubert HB. 1988. Compression capability of cerclage fixation systems a biomechanical study. *Othopaedics* 11: 169-174

Sinibaldi KR. 1983. Fractures of the tibia. In: Bojrab MJ (ed) *Current techniques in small animal surgery* (2nd ed.). Lea & Febiger, Philadelphia. p 630- 636

Siraj M, Khan MA, Ali MM, Ijaz M and Imran M. 2011. Comparative efficacy of intramedullary pinning with full cerclage wires and screwing for the repair of mid shaft tibial fracture in dogs. *Pakistan journal of zoology* 43(5):1020

Sissener TR, Jones E and Langley-Hobbs SJ. 2005. Effects of three intramedullary pinning techniques on pin location and articular damage in the canine humerus. *Veterinary Comparitive Orthopaedics and Traumatology* 18(3):153-156

Smith SR, Bronk J T and Kelly P J. 1990. Effect of fracture fixation on cortical bone blood flow. *Journal of Orthopaedic Research* 8: 471–478

Sod GA, Hubert JD, Martin GS and Gill MS. 2005. An in-vitro biomechanical comparison of a limited-contact dynamic compression plate fixation with a dynamic compression plate fixation of osteotomized equine third metacarpal bones. *Veterinary Surgery* 34: 579-586

Stigen O. 1999. Supracondylar femoral fractures in 159 dogs and cats treated using a normograde intramedullary pinning technique. *Journal of Small Animal Practices* 40(11): 519-23

Ting D, Cabassu JB, Guillou RP, Sinnott MT, Meyer EG, Haut RC and Dejardin LM. 2009. *In vitro* evaluation of the effect of fracture configuration on the mechanical properties of standard and novel interlocking nail systems in bending. *Veterinary Surgery* 38: 881-887

Tomlinson JL and Payne JT. 1993. Effects of cerclage wire on bone. In: Bojrab MJ (ed) *Disease mechanisms in small animal surgery* (2nd ed.). Lea & Febiger, Philadelphia. p 1102-1104

Turner CH and Burr DB. 1993. Basic biomechanical measurements of bone: A Tutorial. *Bone* 14: 595-608

Vasseur PB, Paul HA and Crumley L. 1984. Evaluation of fixation devices for prevention of rotation in transverse fractures of the canine femoral shaft: an *in vitro* study. *American Journal of Veterinary Research* 45: 1504-1507

Wilson JW. 1987. Effect of cerclage wires on periosteal bone in growing dogs. *Veterinary Surgery* 16: 299-302

Wilson JW. 1991. Vascular supply to normal bone and healing fractures. *Seminars in Veterinary Medicine and Surgery* 6: 26-38

Zahn K and Matis U. 2004. The clamp rod internal fixator - application and results in 120 small animal fracture patients. *Veterinary Comparative Orthopaedics and Traumatology* 17: 110-120

Annexure

General Canine Orthopaedic Proforma

1) Case number :
2) Date :
3) Owner's name :
4) Phone no. :
5) Dog's name :
6) Address :
7) Breed :
8) Sex :
9) Age :
10) Wt(kg) :
11) Physical examination
    a) Heart rate/min :
    b) Respiration rate/min :
    c) Rectal temperature(°f) :
12) History:____
____
____
____
____

13) Parameters Evaluated
    a) Type of fracture-
    b) Type of fixation technique preferred-
    c) Immediate weight bearing after operation-
    d) Assessment of healing:

1. Clinical findings:

- Weight bearing-

Grades	0	1	2	3	4
Weight bearing	No weight bearing; carrying the limb while walking	slight weight bearing; touching the toe while walking	Moderate weight bearing; touching the sole while walking but with limping	Good weight bearing; with slight limping	Complete weight bearing; with no sign of limping

Score:
-Immediately after operation:
-21 days after operation**:**

- Muscle girth-

  Preoperative:
  Postoperative:

  2. Radiographic / Fluoroscopic findings-

- Callus formation:

	0	1	2	3
Amount of Callus formation	None(no visible callus)	Small(<10% increase in the bone diameter)	moderate(10-20% increase in the bone diameter)	Large(>20% increase in the bone diameter)

Score:

21 days after operation:

- Healing:

Type of healing	Time to fracture healing
Normal	Healing<60 days without complication/deformity
Delayed	Healing>60 days
Malunion	Union with angulation
Failure of healing	Due to fixation failure

e) Post-fixation physiotherapeutic technique used for early recovery

f) Time taken in recovery:

g) Overall functional recovery**:**

Very good	Normal fracture healing or good joint stability with normal limb usage
Good	Normal fracture healing or good joint stability but slight lameness persisting
Satisfactory	Fracture healing with slight malunion/ delayed union/ reduced joint mobility, leading to visible lameness
Unsatisfactory	Fracture failed to heal or joint unstable due to fixation failure or infection

Date:_________ Signature:___________

Brief Biodata of the Student

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Academic Qualifications:

Sr. No.	Degree/ examination passed	Year of passing	University/ board	Division	O.G.P.A/ Percentag e	Medium of instruction
1.	High school (10th)	2004	C.B.S.E. New-Delhi	Ist	82.40%	English
2.	Senior secondary (10+2)	2006	C.B.S.E. New-Delhi	Ist	81.20%	English
3.	B.V.Sc. & A.H.	2011	RAJUVAS, Bikaner	Ist	7.68/10.0 (76.8%)	English
4.	M.V.Sc. (Veterinary Surgery and Radiology)	2014	CSKHPKV, Palampur	Ist	8.10/10.0	English