ACRYLIC EXTERNAL SKELETAL FIXATOR FOR THE TREATMENT OF LONG BONE FRACTURE IN DOGS

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Thesis submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I, hereby declare that this thesis entitled **'Acrylic External Skeletal Fixator For The Treatment Of Long Bone Fracture In Dogs'** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **'Acrylic External Skeletal Fixator For The Treatment Of Long Bone Fracture In Dogs'** is a record of research work done independently by Julie B. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Introduction

1. INTRODUCTION

Fractures of the long bones (humerus, radius, ulna, femur, tibia and fibula) are very common in dogs and are usually the result of traumatic events such as automobile accidents and fall or jump from height (Aithal *et al.*, 1999). The basic surgery in veterinary orthopaedics has been repair of fractures. The immediate goal of fracture repair is to maintain anatomical reduction and fixation until the body's healing mechanism restore the structural continuity of the bone. The Association for the Study of Internal Fixation (ASIF) aims at restoring the full function to the injured limb as quickly as possible (Denny, 1991).

There are many methods and even more materials that can be used to assist in the repair of a fracture. External coaptation techniques can be used for immobilizing fractures, but fracture stability achieved with external coaptation is not so rigid and hence its application is limited to simple fractures that are stable. Also fractures proximal to elbow or stifle are not amenable to external coaptation techniques.

Using intramedullary pinning to stabilize fracture is a less costly and less time consuming technique and it is easier to implant also. But it provides only less stable fixation, slower return to function and involves more after care. Different authors have reported various complications involved in fixation by intramedullary pinning like rotational instability, fracture shortening, pin migration, joint penetration and osteomyelitis (Vaughan, 1975; Hunt *et al.,* 1980; Lesser, 1984; DeYoung and Probst, 1993).

Bone plating can be effectively used in transverse, short oblique, comminuted or segmental fractures. Bone plates are used to unite fractured ends together and to keep them in position using screws. Plates can serve as a compression, neutralization or buttress appliance. But it is a costly technique for fracture fixation in veterinary use. Removal of plates requires a major surgery also (Roe, 2003).

External Skeletal Fixation (ESF) is a means of stabilizing fractures or joints using percutaneous fixation pins that penetrate the bone cortices internally and are connected together externally to form an external frame. In 1947, Dr. E. A. Ehmer and the Kirschner Manufacturing Company introduced a device known as External Pin Splintage that gained acceptance for its value in fixing fracture in small animals. Later on, it was known as Kirschner- Ehmer fixation splint (Fox, 1986). It provides stable fixation of fractured bone segments with minimal damage to soft tissue and vascularity. It also provides joint mobility and thus prevents the chance of ankylosis and also aids in early return to function of the limb.

The components of external fixation are transfixation pins and an external frame formed of clamps and connecting bars (Harari *et al.,* 1998). The stainless steel external frame of the ESF has some disadvantages like high cost, heavy weight of the implant and also tendency to entangle with surrounding objects. In order to overcome these disadvantages different alternatives to the stainless steel connecting bar and clamps have been tried. The acrylic splints, made from dental grade non sterile polymethylmethacrylate, available from dental suppliers, seemed to be a good choice for replacing the stainless steel frame. Acrylic splints are lightweight, cost effective, and easy for application and are flexible so that it can be applied to treat different types of fractures (Piermattei and Flo, 1997).

On scanning the available literature, reports on the use of acrylic external skeletal fixators were found to be scanty from India. The present study was conducted with the objective of evaluating the efficacy of acrylic connecting bars in replacing stainless steel connecting bar of external skeletal fixators for the treatment of long bone fractures in dogs.

Review of Literature

2. REVIEW OF LITERATURE

2.1. INCIDENCE OF FRACTURE OF LONG BONES IN DOGS

2.1.1. Breed wise distribution

Balagopalan *et al.* (1995) reported highest incidence of fracture of long bones among Alsatian (27.9%) followed by Doberman pinscher (17.8%), non descript (17.3%) and Pomeranian (15.4%).

Survey of Aithal *et al.* (1999) revealed highest incidence of fractures among non descript dogs.

2.1.2. Age wise distribution

Singh *et al.* (1983) reported higher incidence of fractures in age group of 0 to 1 year followed by 1 to 3 years, 3 to 6 years and then in above five years group.

The incidence of fracture in dogs was more in the age group of 3 to 6 months (30.8%), followed by in 0 to 3 months (27.9%) in the survey report of Balagopalan *et al.* (1995).

Survey conducted by Aithal *et al.* (1999) revealed higher incidence of fracture in the age group of 1 to 3 years (35.52%) followed by in 6 to 12 months age group, 3 to 6 months, less than three months group and then in above three years age group.

2.1.3. Sex wise distribution

On reviewing fracture cases in canines, Singh *et al.* (1983) observed that the incidence of fracture was more among male animals than in females.

Results of a review of 208 fracture cases conducted by Balagopalan *et al.* (1995) revealed that male dogs (63.16%) were more affected than females (36.84%) dogs.

Aithal *et al.* (1999) reported a higher incidence of fracture in male dogs than in female dogs.

2.1.4. Bone wise distribution

The findings of Singh *et al.* (1983) in dogs showed higher incidence of femoral fracture followed by fracture of tibia, radius and ulna, and that of humerus.

According to Balagopalan *et al.* (1995), among fracture of long bones in dogs, fracture of femur was most common followed by tibia and fibula, then that of radius and ulna, and humerus.

Aithal *et al.* (1999) noticed that the incidence of fracture was highest in femur, followed by in tibia and fibula, radius and ulna, and then in humerus.

2.2. FRACTURE BIOLOGY AND BIOMECHANICS

Bones underwent both elastic (reversible) and plastic (irreversible) deformation before breakage. Fractures occurred when extrinsic or intrinsic forces were applied. The five basic forces acting on a bone were tension, compression, bending, shear and torsion. In an oblique fracture, shear and compressive forces predominated. In transverse fracture, rotational or torsion forces predominated (Hulse and Hyman,2003).

2.3. FRACTURE HEALING MECHANISM

According to Denny (1991) a considerable amount of bending will be tolerated, but torsion or rotation impeded healing because it caused tearing of fibroelastic network of the callus and this led to nonunion.

As noticed by Heim *et al.* (1992), axial compression in a simple transverse fracture by means of a stiff external fixator could result in primary fracture healing as in a plate fixation while complex fractures with external fixation could heal by means of callus formation as with a medullary nail. A fracture, which was rigidly stabilized, showed direct healing, characterized by minimal callus appearance, no fragment end resorption and direct bone formation. This type of healing could be seen after external fixation. Some degree of instability might result in increased callus formation and some tolerable fragment end resorption and was like indirect healing. This type of healing resulted in prompt and reliable bone union after external fixation. External fixation allowing the fragments excessive instability, whether primarily by application of too flexible a device or secondarily by significant resorption of bone at the contact surface with pins might delay or impede solid bone union. Soft tissue conditions after trauma and the start of weight bearing influenced the time of fracture healing.

Johnson and DeCamp (1999) have noticed that application of a weak fixator-bone construct caused excessive deflection of the fixator, resulting in movements at the fracture site and pin-bone interface. Excessive movement at the fracture site could result in delayed union or nonunion.

2.4. HISTORY OF EXTERNAL SKELETAL FIXATION

In 1947, Dr. E. A. Ehmer and the Kirschner Manufacturing Company introduced a device known as External Pin Splintage that gained acceptance for its value in fixing fracture in small animals. Later on it was known as Kirschner Ehmer fixation splint (Fox, 1986).

Anderson *et al.* (1997) reported in the review article that the concept of external skeletal fixators (ESF) was introduced first by Jean Francois Malgaine in 1849. Otto Stader first described a full pin transfixation splint in the veterinary literature. As a result of high complication rates during World War II, mainly pin loosening and pin tract infection, the Surgeon General banned the use of ESF. In 1950, the American Academy of Orthopaedic Surgeons recommended that ESF should not be employed unless the surgeon has seen or assisted with 200 cases. Improvement in instrumentation, ESF design and the technical skills of veterinary surgeons led to a resurgence in the use of ESF in the 1970's.

2.5. TYPES OF EXTERNAL SKELETAL FIXATORS

Nunamaker (1985) described the use of full pin fixation with connecting bar on both sides of the fracture and reported that it increased the strength of fixation fourfold than half pin fixations. Type III splintage/ triangulation splintage increased anterior/posterior bending rigidity.

Fox (1986) reported that the Kirschner apparatus was available in three sizes. In small animal surgery, medium sized device was commonly used. The small Kirschner apparatus was used in cats and dogs weighing less than 15 pounds. The large Kirschner apparatus was used infrequently, but could be effective for giant breeds.

The frame configurations of external fixators described by VanEe and Geasling (1992) was the one outlined by Hierholzer, an orthopaedic surgeon in human medicine. They were:

Type I: The fixation pin passing through only one skin surface and two cortices of the bone. The connecting rods and clamps were thus positioned on only one side of the bone.

Type II: The fixation pins passing through two skin surfaces and two cortices of the bone. Thus the connecting rods and clamps were positioned on opposite (both) sides of the bone (uniplanar).

Type III: This was a combination of the Type I and type II fixators, with the type I fixator positioned at 90 degrees to the type II fixator, giving the external frame a three dimensional shape.

As described by Harari *et al.* (1998), Type IA frames could be used to treat fractures above elbow or stifle joints, because bilateral configurations injured the body wall. Type IB and type II frames were used for fractures below elbow and stifle joints and for procedures involving bone lengthening or arthrodesis. Type III frame was used for highly comminuted fractures with bone loss involving the radius and tibia. The small Kirschner set could be used for dogs that weighed less than 26 lb (12kg), medium set for dogs of 26 to 99 lb (12 to 45 kg) and large set for heavier animals.

Krischak *et al.* (2002) observed complications like infections, nonunion and refractures only in two plane fixation. Callus formation, bone mineral content and bending stiffness were reduced and osteogenesis was seen decreased to approximately the half with two plane fixator compared to one plane device.

According to Marcellin (2003), external skeletal fixator frames could be linear, free form or circular. Linear frames may have a single connecting bar (unilateral), two connecting bar (unilateral, biplanar or bilateral) or three connecting bars (bilateral biplanar). With circular external skeletal fixation, the frame consisted of rings connected by threaded rods; termed as Illizarov method. Linear and circular frames could be combined to form hybrid frames.

2.6. COMPONENTS OF LINEAR EXTERNAL FIXATORS

2.6.1. Transfixation pins

On studying the thermal effects of external fixation pin insertion in human cadaveric cortical bone, Mathews *et al.* (1984) found that trocar and spade tipped pins produced very high temperature for long durations on drilling into the fracture fragments. Trocar tipped pins had four facets that were ground to a point.

Nunamaker (1985) noticed that, as the pin diameter increased (upto approximately 30% of bone diameter), the strength of fixation increased by fourth power function.

Ellis fixation pins were described by VanEe and Geasling (1992) as pins with a short, threaded portion to engage the transcortex and a smooth portion for the ciscortex. This reduced the risk of breakage and its threads increased the pull out resistance.

On comparing nonthreaded and threaded (positive profile and negative profile) pins used in external fixator, Anderson *et al.* (1993) found that the functional limb usage returned to normal only slowly in those animals where nonthreaded pins were used. The positive profile pins had lower pin pullout force and lower bone holding power than negative profile pins.

Johnson *et al.* (1996) opined that the type of pin (threaded or smooth) and number of pins did not have a significant effect on surgery time, time for development of bridging callus or time for fixator removal.

According to Anderson *et al.* (1997), external skeletal fixation pins were categorized as threaded and nonthreaded pins. Nonthreaded pins could be used as half pins or full pins. Unlike threaded pins, they did not have a tendency to wrap around soft tissue during application. Also they were inexpensive, readily available and resistant to breakage. But they were prone to premature pin loosening. Threaded pins were more commonly used because they improved the pin-bone interface stability immediately after surgery and maintained this stability longer. Threaded pins were again classified as positive profile (had threads rolled on the outside of the pin so that the outer thread diameter was greater than the pin's core diameter) or negative profile (had threads milled into the shaft of the pin so that the outer thread diameter was equal to or slightly wider than the pin's core diameter). Threaded pins were also sub classified as end threaded, centrally threaded or fully threaded. End threaded negative profile pins were available in two designs; one to allow the pin threads to inter-digitate with both the cortical surfaces and the other to allow the pin threads to engage only in the far cortex. The commonly used veterinary external skeletal fixation pins were smooth Steinmann pins, completely threaded Steinmann pins, partially threaded Steinmann pins and Ellis pins (end threaded negative profile pins). Increasing pin diameter increased the pin stiffness, decreased the strain at pin-bone interface and increased the pin-bone contact area. However, excessive pin diameter weakened the strength of the bone. So they recommended pin diameter range of 20% to 30% of the bone diameter at the site of implantation.

An *in vitro* comparison of hollow ground and trocar points on threaded positive profile external skeletal fixation pins was done by Marti and Roe (1999) in canine cadaveric bones. They found that trocar point produced higher temperatures for longer durations over larger areas of bone compared with Hoffmann's tip and half drill tips.

Various tips available on transfixation pins were described by McLaughlin and Roush (1999). Trocar and chisel point pins were the most common tips used in veterinary practice. It was also recommended that the diameter of the transfixation pins could be upto 20% of the bone diameter without markedly weakening the bone.

2.6.2. Clamps, connecting bars and wrench

Egger (1983) noticed that the weak component of the single connecting bar configuration was the connecting bar, particularly at the fracture gap.

Clamps were of two types; single and double. Single clamps joined transfixation pins to connecting bar. Double clamps connected connecting bars to connecting bars and allowed the frame of the fixator to be positioned in multiple planes. Connecting bars were special rods or Steinman's pins used to unite the fixation pins to provide a rigid frame outside the body (VanEe and Geasling, 1992).

The pin clamps had fixation pins of various sizes but required a specific connecting bar. Double clamps provided more versatility in attachment to two sidebars, but size, expense and frame stability limited their use. To tighten the pin clamps, an open ended bar or socket wrench was required (Harari *et al.* 1998).

2.7. ADVANTAGES AND DISADVANTAGES OF EXTERNAL SKELETAL FIXATORS

2.7.1. Advantages

It was noticed by Burny *et al.* (1980) that in case of simple fractures, half frame external fixation provided satisfactory stability because of the interfragmentary contact, which was always present. Early weight bearing ensured functional loading of bone and periosteal callus developed.

Straw (1984) reported KE splint to be useful in open or infected fractures, gun shot fractures, nonunions, delayed unions, highly comminuted fractures, as adjunct to fixation devices like pin, plate or cerclage, for immobilization of joints and for corrective osteotomy.

On evaluating effectiveness of Steinmann pin, Kuntscher nail, multiple Steinmann pins, combination of intramedullary Steinmann pin and half Kirschner splint and four pin full Kirschner splint, in transverse osteotomy fracture of canine femoral cadaveric bones, Vasseur *et al.* (1984) found that 4 pin full splints had marked superiority as an antirotation device when used for transverse shaft fractures.

External skeletal fixator was suggested by Fox (1986) as an economical, highly versatile, adjustable, lightweight fixation technique. The chief achievement was that the limb returned to a functional state earlier.

As noticed by Rochat and Payne (1993), external fixation was very useful for open tibial fractures in any size dogs, especially if degree of contamination and soft tissue damage precluded primary closure of the wound.

According to Harari *et al.* (1998), the advantages of external skeletal fixation included;

- Ability to treat open and closed fractures, simple and comminuted fractures, gun shot fractures, angular deformities, joint luxations, shortened bones and delayed unions.
- Compatibility with internal fixation devices such as intramedullary pins and cerclage.
- Ability to adjust fracture alignment and biomechanical properties of the fixator. Fracture stability could be maintained during healing and bone loading could be performed four to six weeks after repair during fractures remodelling by reducing the number of pins or sidebars.
- Accessibility for soft and osseous tissue wound management
- Reusability and economy of components such as pin clamps and sidebars.
- Absence of stabilization devices within contaminated wounds and no need for soft tissue coverage of implants.
- Preservation of neurovascular supplies to bone and soft tissues
- Technical ease of application and removal of external fixators.
- Mobilization of limb and patient with minimal interference of adjacent joints.

External fixator was reported by Rochat (2001) to be helpful to patients with highly comminuted and open fractures. Also they were minimally invasive, which allowed fracture haematomas and the associated vascular supply to remain intact. External fixation was the best method for repairing radial and tibial fractures when used as a sole method for fixation.

Ozsoy and Altunatmaz (2003) have reported that using closed or limited open approaches to treat fractures with external fixator ensured very short healing period, sufficient stability and early return to function in the extremity. The ease of application and low cost of external fixators was also mentioned. On using external fixator there was early return to function of the extremity, thereby avoiding possible complications like bone and muscle atrophy. They also observed that it was not a problem during fracture healing process that the bone fragments could not be aligned as well as with internal fixation.

2.7.2. Disadvantages

Whittick (1974) mentioned that half pin splintage provided rigid fixation only for three to five weeks and thus necessitated the use of external splint when the pins loosened.

According to Burny *et al.* (1980), in case of spiral or oblique fractures, the high shearing stress would not be avoided by simple half frame fixation. The solution recommended was delayed weight bearing (but active muscle function) and the addition of an internal screw to neutralize the shearing stress.

External fixators, when used for fracture repair in dogs, may get entangled to objects in the environment (Rochat and Payne, 1993).

The influence of external fixators on fracture motion during simulated walking was studied by Gardner *et al.* (1996). It was concluded that patients with unstable fractures supported by external fixators, might be expected to have similar patterns of healing to plaster casted patients with similar fractures.

Sequin *et al.* (1997) reported a case of transverse tibial fracture and bone sequestrum at the pin-bone interface following use of external fixator, where the pin diameter selected was one third of bone diameter.

According to Rochat (2001) external skeletal fixator was a poor choice for fixation of fractures of femur due to large muscle masses. Complications like premature pin loosening, pin tract infection, pin breakage, neurovascular injury, iatrogenic fracture, delayed union, poor limb function, muscle atrophy and loss of reduction were also observed.

It was reported by Harasen (2002) that a biological approach to fractures of the humerus or femur with external skeletal fixation required some modifications, since ESF alone was seldom applicable especially in large dogs.

Biological fracture repair principles were found to be problematic in the femur by Harasen (2003), because of the limitations in applying external skeletal fixator to the bone. Connecting bars and fixator pins could be placed only on the lateral aspect of the femur. Also the fixator pins had to go through the large muscle masses around the femoral diaphysis.

Hatt (2003) have described the possibility of patient manipulating the fixator when applied to a fractured limb.

2.8. ALTERNATIVES FOR STAINLESS STEEL EXTERNAL FRAME

According to Tomlinson and Constantinescu (1991), three types of acrylic could be used as alternative to the stainless steel connecting bar;

-A hoof repair material –Technovit (Jorgensen laboratories)

-Dental grade nonsterile methylmethacrylate which was inexpensive.

-Out dated or opened surgical grade methylmethacrylate, which could be obtained from local hospitals. In date surgical grade methylmethacrylate was costly.

Roe and Keo (1997) suggested epoxy putty as a suitable material for free form external fixators as they were easy to handle, inexpensive and had suitable setting times and mechanical properties.

A modified acrylic fixator was used by McCartney (1998) in which acrylic was used only at the junction between the pin and stainless steel bar and found that it gave results similar to those obtained with Kirschner external fixator.

Rochat (2001) reported the usage of dental acrylic, titanium and carbon fibre connecting rods as less costly and lightweight alternatives to stainless steel connecting bars.

Free form fixation was described by Johnson and Hulse (2002) as a form of external skeletal fixation in which the pins were interconnected with a polymer. Generally this was performed with polymethylmethacrylate columns as connecting bars. The availability of commercial kits for Acrylic –Pin External Fixation (APEF) was also reported.

2.9. ACRYLIC CONNECTING BARS

Polymethylmethacrylate is a polymer with chemical formula –$[CH_2C(CH_3)((CO)OCH_3)\text{-}]_n$. Polymethylmethacrylate was commonly used as bone cement or in special applications, as an implant housing material. It was the same material as Plexiglas or Lucite. It was supplied as a liquid and a powder. The liquid consisted of unpolymerised monomer (methylmethacrylate), a small amount of hydroquinone (to extend shelf life by preventing premature polymerisation of liquid) and a curing agent N, N-dimethyl-p-toluidine. The powder was composed of various sizes of small beads of polymethylmethacrylate and a copolymer such as ethyl methacrylate-styrene. The liquid was mixed with powder (20ml of liquid to 40g of powder was a common ratio selected for the strength and ease of polymerisation). The copolymer in powder helped the monomer liquid to wet the solid beads, allowing the whole mass of liquid and solid to polymerise completely and form a solid. A relatively small quantity of barium sulfate could also be added to the powder to allow the subsequent x-ray characterization. In addition, a small quantity of a polymerisation catalyst (benzoyl peroxide) was present in the bead as a residue of the bead polymerisation; which aided in polymerisation of the liquid on contact with the beads. The reaction gave off heat, capable of killing tissues in the immediate vicinity of the bone cement. Polymethylmethacrylate was created by a polymerisation reaction between liquid and powder monomers in which individual monomer constituents were linked together to form high molecular weight molecules (Greer and Pearson, 1993).

Solid methylmethacrylate was prepared by mixing a volatile liquid monomer solvent with methylmethacrylate powder. The initial liquid stage, which lasted for two to three minutes was followed by a doughy, mouldable phase (four to five minutes) that hardened into a very strong mass by seven to ten minutes after initial mixing. The recommended proportion of mixing of acrylic was three parts powder of dental acrylic to one part liquid for liquid stage application of acrylic (Piermattei and Flo, 1997).

2.9.1. Advantages of acrylic connecting bars

As noticed by Okrasinski *et al.* (1991) acrylic column was able to withstand significantly greater loads than the steel connecting rod in compression and shear loading. Acrylic was radiolucent; and hence did not impede the radiographic evaluation of underlying bone.

Multiple pins and methylmethacrylate ESF were used by Ross and Matthiesen (1993) for treatment of orthopaedic injuries in dogs and they found that acrylic connecting bars allowed the use of multiple pins in different planes without the limitation of pin diameter, spacing or spatial alignment that occurred with clamps.

On using acrylic injected into flexible mould as connecting bar of external skeletal fixator for repair of mandibular fractures, Stampley and Lawrence (1993) observed that, acrylic external skeletal fixator was light weight, easily moulded to curve around both mandibles and could be used with pins of multiple sizes placed in multiple planes.

Williams *et al.* (1997) reported that acrylic connecting bar provided the advantage of application ease, economical use and flexibility in placement of fixation pins. Also pins of varying diameter could be used in the column.

It was noticed by McLaughlin and Roush (1999) that acrylic connecting bars were lighter, less bulky and could be customized for any size and shape of the bone. The transfixation pins need not be perfectly aligned to be properly attached to an external acrylic connecting bar.

Chandy (2000) found that acrylic external fixator was a cheaper alternative to stainless steel external fixator as it did not require the expensive components as used in the latter. Acrylic fixator also provided proper external stabilization.

Advantages of acrylic connecting bar, as noticed by Shahar (2000), were low cost of the materials, simplicity of the technique and its adaptability to a wide variety of pin diameters when compared with the standard stainless steel system. It was suggested that, minimum diameter of the acrylic column should be 19.1mm (3/4 in) if it was used as a substitute for the connecting bar of the medium Kirschner apparatus.

Acrylic external fixator was used by Cook *et al.* (2001) for rostral mandibular fractures in dogs and found that polymethylmethacrylate connecting bar was advantageous in the clinical setting because of its low cost, ease of application and adaptability for use with curved bones.

2.9.2. Disadvantages of acrylic connecting bars

As reported by Tomlinson and Constantinescu (1991), acrylic underwent an exothermic reaction as it hardened which could burn the skin on contact.

VanEe and Geasling (1992) noticed that on using acrylic connecting bar, pin adjustment was not possible once polymerisation occurred.

As noticed by Ross and Matthiesen (1993) adjustments in fracture or luxation reduction following the operation were difficult with use of acrylic connecting bar when compared to conventional clamp and bar systems. If acrylic connecting bar was placed too close to the skin surface, skin irritation and infection at the skin-pin interface occurred. It was reported that acrylic could fracture if the methylmethacrylate used was not in sufficient quantity. They suggested its successful management by applying additional methylmethacrylate to bond the fractured cement together. Difficulty in removing individual fixation pins that were loose or infected was also encountered.

Martinez *et al.* (1997) reported that polymethylmethacrylate underwent an exothermic reaction during the polymerisation phase of acrylic hardening and could reach a temperature of 50 to 100^0 C. So they had the potential to maintain high temperature for time periods that were equal to or longer than those required to cause thermal injury of tissues.

According to Williams *et al.* (1997), the thermal injury caused by acrylic column was more over the radius and tibia because the column had to be positioned closer to the cortical bone.

The relative stiffness and stress of type I and type II external fixators using stainless steel and acrylic connecting bars were studied by Shahar (2000) and found that use of acrylic connecting bars in large external fixators for giant breeds was technically difficult. It was seen that large acrylic columns increased the risk of non homogenous acrylic formation, caused by air entrapment in the polymerisation process of the acrylic.

Rochat (2001) reported that when acrylic connecting bars were used in external skeletal fixation to repair long bone fractures, acrylic could fracture and pin adjustment was impossible once polymerisation occurs.

Bryant *et al.* (2003) reported that polymethylmethacrylate caused tissue necrosis because of highly exothermic reaction associated with hardening of the polymer.

2.10. PREOPERATIVE CONSIDERATIONS

2.10.1. Clinical evaluation of fracture case

Johnson and Hulse (2002) stated that thorough physical examination of the cases should be conducted before any surgical intervention to correct orthopaedic defects. Definitive repair should start only after life threatening injuries, if present, were attended.

2.10.2. Radiographic evaluation of fracture case

According to Roush and McLaughlin (1998) at least two divergent views of the entire affected bone, preferably at 90 degrees to one another, were needed to accurately assess the fracture configuration.

2.10.3. Preoperative preparation

According to Gorse (1998) "Hanging leg" position facilitated closed reductions. Suspending the affected limb from the ceiling helped to realign the fracture and allowed easy access to both sides of the limb.

As per Roush and McLaughlin (1998), fractures should be stabilized temporarily before surgical correction to increase patient comfort and minimize the local soft tissue swelling and further soft tissue injury.

2.10.4. Anaesthesia

While using circular skeletal fixators for the management of compound fractures in dogs, Dwivedi (2003) premedicated dogs with atropine sulphate followed by xylazine hydrochloride intramuscularly and diazepam intravenously. General anaesthesia was induced with ketamine hydrochloride intramuscularly and maintained with ketamine hydrochloride and xylazine hydrochloride as incremental doses intravenously.

2.11. SURGICAL APPROACH TO LONG BONES

Safe corridors were defined by Márti and Miller (1994a) as longitudinal regions through which pins could be safely inserted, as they contained neither musculotendinous units nor important neurovascular structures. They conducted anatomical dissection of fresh canine specimens and carried out cross sections to identify the location of safe corridors for external skeletal fixator pin insertion. No safe corridor for pin insertion existed in canine femoral region. So pin insertion was to be limited to the lateral aspect of femur. Their study showed that in the canine tibia, the entire medial aspect and part of the cranial aspect represented a safe corridor for external fixator pin insertion.

Marti and Miller (1994b) reported that no safe corridor existed for pin insertion in humerus. However, a safe area existed in the craniolateral aspect of the proximal humerus, which gradually tapered to a line distally. For immobilization of radius and ulna, fixator pins should be applied along the craniomedial to caudolateral plane in order to achieve maximum bone purchase and pin to bone contact.

Johnson *et al.* (1996) used closed reduction and type II external fixation for comminuted fractures of the radius and tibia in dogs. The landmark used for the most proximal radial pin was the head of the radius where it could be palpated on the lateral aspect of the limb. The most distal radial pin was inserted through an area immediately cranial to styloid process of the ulna on the lateral aspect of the limb. For the proximal and distal tibial pins, landmarks used were the medial surface of the proximal tibia and the medial or lateral epicondyle respectively.

The proper surface for the unilateral splint as suggested by Piermattei and Flo (1997), was medial on tibia, craniomedial or medial on radius, craniolateral on humerus and lateral on femur.

According to Gorse (1998), the ideal approach for external fixators application in tibial fracture was medial to lateral with frame on the medial aspect of tibia.

2.12. APPLICATION OF EXTERNAL SKELETAL FIXATORS

Gorse (1998) suggested open, limited open and closed surgical approach to radius and ulna or tibia for application of external skeletal fixator. The limited open and closed techniques preserved the vascular supply to the bone and soft tissue, minimized iatrogenic contamination of the fracture site and the fracture healed in a shorter time. Simple fractures that could be reconstructed were candidates for an open approach while comminuted fractures with no possibility of reconstruction were treated by a closed or limited open approach.

According to Harari *et al.* (1998), closed repair using external skeletal fixation permitted functional realignment of large bone fragments with minimal surgical invasiveness and shorter surgery times.

2.12.1. Principles and technique of application

The guidelines recommended by Bouvy *et al.* (1993) were to use bilateral splints whenever possible; maximize the number of pins in each fragment, apply four pins in each fragment; apply the largest KE splint the bone will allow, with pin diameters approximately 20% of the bone diameter; decrease bone-to-side bar distance to the smallest distance that still allowed drainage from the pin tract; widen pin spacing to span the entire length of each fragment; position the innermost pin as close to the fractured bone end that traumatized tissue allowed; position the clamps with bolts inside the side bar; and conform the lateral side bar to the skin.

The fundamentals of application of external skeletal fixator suggested by Piermattei and Flo (1997) were;

1. Use of aseptic technique
2. Proper bone surface location for insertion of pins
3. Use of the most suitable configuration of the splint
4. Use of auxiliary fixation when indicated
5. Reduction of fracture and maintenance in reduction during application of splint
6. Insertion of pins through soft tissue in a manner that does not distort the tissue
7. Proper pin drilling technique
8. Insertion of pins through both cortices of bone
9. Insertion of all related fixation pin clusters in the same plane
10. Insertion of pins in the proper location of bone fragment
11. Insertion of two or four pins in each major bone fragment
12. Choose optimal size fixation pins and connecting bar
13. Place the connecting rods at optimal distance between fixation clamps and skin
14. Bone graft significant cortical defects

2.12.2. Transfixation pins

Mathews *et al.* (1984) noticed that drilling speed did not have a great effect on temperature produced. But it was found that predrilling was highly effective in minimizing the thermal effects of drilling pins.

The percutaneous pins were inserted by Straw (1984), at an angle of 45 to 60 degree to the longitudinal axis of the bone since there was a possibility of the pin becoming loosened if the angle was too perpendicular to the long axis. The proximal and distal pins were placed relatively near the ends of the bone.

It was recommended by Nunamaker (1985) that the proximal and distal pins should be positioned as far away from the fracture site as possible and the middle pins should be placed near the fracture site, positioned as close to the fracture site as possible. It was also recommended that the percutaneous pins in each fragment should be placed at an angle of 35 to 40 degrees or greater in relation to each other to prevent the pins from pulling straight out of the bone.

Johnson *et al.* (1989), on using external skeletal fixators, found that in some cases, even if the fixation pins were inserted into or immediately adjacent to a fracture line, none of these pins caused an increased bone reaction and they did not appeared to affect fracture healing adversely.

According to VanEe and Geasling (1992), while applying an external fixator with the fracture site surgically opened, the skin had to be positioned in a manner it would be found when the wound was closed. Otherwise, the skin would be under tension where it contacted the fixation pins and necrosis would follow. Once a small skin incision was made, the fixation pin was introduced by hand through the soft tissues to the level of the bone. Pins should be inserted with a low speed (150 to 400 rpm) high torque power drill. A minimum of two fixation pins was required for each major segment of the bone to be stabilized, though it was preferable to use three or four pins per segment. The most proximal and distal pins within a segment should be positioned about 30 degrees from each other to increase pull out resistance.

The study conducted by Clary and Roe (1996) revealed that predrilling a pilot hole whose diameter approximated, but did not exceed the inner diameter of the positive profile pin improved initial pin stability compared with no predrilling, and also reduced microstructural damage that might lead to excessive bone resorption and premature pin loosening.

As noticed by Anderson *et al.* (1997), hand insertion of external skeletal fixator pins caused increased structural damage as a result of wobbling during pin insertion thereby predisposing to pin loosening. Hand insertion as well as high speed insertion increased the temperature of the bone around the pin causing bone necrosis. So low speed power insertion or insertion of pin into a pilot hole was recommended. Excessive pin advancement was to be avoided because retraction weakened the pin-bone interface.

Harari *et al.* (1998) recommended that, pins should be inserted at a 60 to 70 degree angle to the long axis of the bone, at least two centimetre away from the fracture site. At least two or three pins should be used for each large bone fragment.

The guidelines followed by McLaughlin and Roush (1999), to place the pins where, to make a small longitudinal stab incision on the skin over the insertion site and then to insert pins by low speed power insertion (about 150rpm) with a power drill, avoiding vessels, nerves and large muscles. To maximize fixator stiffness, the number of pins in each fragment had to be increased (three or four pins were ideal).

Rochat (2001) suggested application of atleast three, preferably four transfixation pins for each main fragment. The pins should be distributed from about one centimetre from the fracture site to one centimetre from the adjacent joints. The pins were inserted parallel to each other. After making a stab incision, the soft tissues should be bluntly separated and a drill sleeve should be inserted to protect the soft tissues. An appropriate drill bit should be inserted and both cortices should be drilled. Then a transfixation pin should be inserted by using a low speed (150rpm) drill until the pin tip emerged from the far cortex. Emergence could be determined by palpation and some spatial appreciation. While placing pins in wounds, the pin should be placed through the healthy skin whenever possible avoiding abraded or lacerated areas.

2.12.3. Stainless steel external frame

As distance of connecting bar from bone increased, the rigidity of fixation decreased by third power function (Nunamaker, 1985).

Harari *et al.* (1998) applied external fixator by placing the pins in the most proximal and distal positions initially, then attaching sidebars with open clamps (clamps with nothing in them, so they will grip a pin placed in them) for the central pins. Before tightening the proximal and distal clamps, the fracture was reduced manually or with reduction forceps. After tightening the proximal and distal pin clamps, the central pins were inserted into the large bone fragments alternating pin insertion above and below the fracture.

It was reported by Rochat (2001) that the most proximal and distal pins should be placed first, then connecting bar and the total number of clamps intended for use in the frame design should be applied to achieve appropriate reduction and alignment. The remaining pins should be applied sequentially through the clamps to the connecting bar.

2.12.4. Connecting acrylic connecting bar

The technique suggested by Okrasinski *et al.* (1991) was to drill all the pins through the bone first. Plastic tube was then fixed over the fixation pins. Methylmethacrylate was prepared and the liquid acrylic resin was poured into the plastic tube taking care to ensure complete filling of the tube.

After reduction of fracture, the most proximal and distal pins should be inserted first. Then the subsequent pins should be driven through the tubing before being driven into the bone. Acrylic was then to be mixed, loaded in a syringe and injected into the tubing (Tomlinson and Constantinescu, 1991).

While using multiple pin and methylmethacrylate ESF for the treatment of orthopaedic injuries in dogs and cats, Ross and Matthiessen (1993) mixed the methylmethacrylate to a doughy consistency, rolled into a cylinder and placed over the exposed pin ends to allow for a 1 to 2.5 cm space between the skin and the methylmethacrylate connecting bar. The cylinder of methylmethacrylate was to be 2 to 2.5 times the diameter of the bone being repaired.

According to Martinez (1997) the acrylic column should be positioned 10mm or greater from the skin in order to reduce the thermal effects of acrylic on the tissues.

Piermattei and Flo (1997) suggested a biphasic technique in order to overcome the difficulty in maintaining fracture reduction during attachment of acrylic column and the hardening of acrylic. In phase I, fracture was reduced and pins inserted. Stainless steel clamps and connecting bars were attached to the pins. It was found not necessary to attach all fixation pins to this temporary connecting bar. Then, radiographic confirmation of the reduction could be obtained, if desired. Then the acrylic column was used to join all pins. After acrylic got hardened, the temporary clamps and bar were discarded.

Williams *et al.* (1997) prepared polymethylmethacrylate by mixing the powder and liquid monomers in a two to one ratio for 90 seconds. Corrugated plastic column tubing was sealed at the bottom and positioned perpendicular to the fixation pins. The column tubing was filled by gravity flow. An applicator stick was then submerged in the column to facilitate removal of any potential air pockets, and then removed. The heat conduction of fixator pins with polymethylmethacrylate external fixation was studied and found that more heat was conducted along the external fixator pin as the size of the column was increased. Styrofoam thermal shield placed between the acrylic column and the skin decreased the thermal injury to skin from convection and radiation effects of the heat of polymerisation on the patient tissue. A minimum distance of one centimetre from the acrylic surface to the skin level should be maintained.

Dixon and Bone (1998) prepared the acrylic connecting bar by first reducing the fracture and temporarily stabilizing with clamps and connecting bar placed further away from the skin on a few of the pins. The approach incision was then closed. Methylmethacrylate was then mixed until it became doughy (three to four minutes) and then was moulded around the pins to form a connecting column that incorporated all the pins. Once the methacrylate had set (eight to ten minutes), the clamps and connecting bars were removed and the excessive fixation pin length was cut off.

A one stage and two stage technique was suggested by Johnson and Hulse (2002) for application of acrylic splints. Acrylic column moulding tube should be placed over the ends of the fixation pins two centimetre from the skin surface. In single stage technique, the fracture was reduced, acrylic was poured into the column and five to ten minutes was allowed for the acrylic to cure. In two stage technique, the tube was placed over the ends of the fixation pins but acrylic was not added. Instead, the fracture was reduced and a temporary stainless steel alignment frame was constructed and added to the fixation pins outside the column moulding tubes. Radiographs were taken to assess the fracture reduction. If satisfactory; acrylic was poured into the column and allowed to cure. In single stage technique, if postoperative radiographs showed fracture reduction to be unsatisfactory, a small section of the acrylic column was removed, appropriate adjustments were made and the acrylic column was patched by adding new acrylic to fill the gap.

Polymethylmethacrylate connecting bars were made by Marcellin (2003) by moulding polymer of doughy consistency around the pins or by pouring low viscosity polymer into plastic side tubing.

2.13. POSTOPERATIVE CARE

Early weight bearing was suggested by Burny *et al.* (1980) to ensure functional loading of bone and development of periosteal callus.

VanEe and Geasling (1992) recommended early ambulation following fracture fixation with external fixators, as weight bearing stimulated fracture healing and minimized fracture diseases. It was better not to clean the dried serum or scab normally formed around the fixation pin-skin interface.

Ross and Matthiesen (1993) reported that while using methylmethacrylate connecting bars, the individual fixation pins that were loose or infected could be removed from connecting bar by first cutting at methylmethacrylate-pin interface and then cutting a small section of exposed pin just above the skin surface. It should then be withdrawn until the cut end impinges on connecting bar. The procedure was to be repeated several times.

According to Harari *et al.* (1998), in case of pin tract infection, systemic administration of cephalothin at the rate of 10mg/lb orally thrice daily for 10 days was recommended.

Roush and McLaughlin (1998) recommended one time administration of a first generation cephalosporin at 20mg/kg intravenously and 20mg/kg intramuscularly to provide prophylactic antibiotic coverage for upto five hours of open reduction of fractures.

According to McLaughlin and Roush (1999), the patient's activity should be restricted after fixator application to prevent breakage of transfixation pins. They recommended on leash walking to avoid joint stiffness.

Carneiro *et al.* (2001) recommended maintenance of an appropriate wound dressing in the post surgical period since removal of the bandage accelerated the inflammatory process around pins and facilitated local infection. On culturing swabs from the pin perforations, they found that Staphylococcus infection predominated. Both 0.2% iodine alcohol and 0.9%sodium chloride solution were found to be equally efficient in the post surgical treatment of bone percutaneous transfixation in dogs.

According to Rochat (2001), the pin-skin interface was to be cleaned daily with dilute chlorhexidine acetate or hydrogen peroxide to allow drainage of exudates from the site until healthy granulation bed developed and scab formation no longer existed.

Johnson and Hulse (2002) recommended the usage of cefazolin 22mg/kg IV, IM or SC at six to eight hours interval as the prophylactic antibiotic for controlling orthopaedic infections.

2.14. EVALUATION OF THE STUDY

2.14.1. Clinical evaluation

Radiographic signs of osteomyelitis were observed by Johnson *et al.* (1989) in some cases of fractures treated with external skeletal fixation, but clinical signs like non weight bearing, swelling, pain and drainage at the fracture site where observed only in one out of twelve dogs.

According to VanEe and Geasling (1992) excessive drainage around a pin in the postoperative evaluation indicated premature pin loosening, excessive skin tension across the pin or large amounts of muscle mass trying to move across the pin during ambulation.

Sumner-Smith (1993) defined the degrees of lameness as;

0 : Sound
1 : Occasionally shifts weight
2 : Mild lameness at a slow trot, none while walking
3 : Mild lameness while walking
4 : Obvious lameness while walking, but places the foot when standing
5 : Degrees of severity
6 : Degrees of severity
7 : Degrees of severity
8 : Degrees of severity
9 : Places toe when standing, carries limb when trotting
10 : Unable to put the foot on the ground

According to Piermattei and Flo (1997), clinical union of fractured bones following external fixation was faster in young animals than in older animals.

Harari *et al.* (1998) described the implications of various clinical signs. Loose pins were characterised by bone lysis and patient discomfort. In pin tract sepsis, there would be persistent purulent drainage, soft tissue inflammation and patient discomfort. Acute onset of lameness in postoperative healing period indicated osteolysis around pins and pin migration. In excessive pin tract drainage and reduced limb activity, myotendinous damage was to be suspected.

Ozsoy and Altunatmaz (2003) treated 30 cases with external fixators and found that all except one made slight ground contact with the leg 3 to 10 days after external fixation and functioned close to normal within 20 days with full weight bearing on the fractured leg. This helped to avoid complications such as muscle atrophy.

2.14.2. Radiographic evaluation

Kantrowitz *et al.* (1988) noticed that ring sequestra appeared radiographically as a zone of radiolucence surrounding the pin and adjacent periosteal new bone formation.

Radiographic evidence observed by Johnson *et al.* (1989) on using external skeletal fixator for reduction of radial and tibial fractures were presence of periosteal and endosteal callus formation and in some cases, primary cortical union during healing process. All the bones had periosteal reaction to the transfixation pins. Radiographic signs of osteomyelitis observed were soft tissue swelling, aggressive periosteal reaction, cortical lysis and an increase in medullary density.

Mean time to bone union or bridging of comminuted fractures with callus on using external fixation was found to be 11.4 weeks by Johnson *et al.* (1996). Type of bone healing observed radiographically was of endosteal and uniting callus formation. Periosteal callus formation was minimal.

It was noticed by Roush and McLaughlin (1998) that early signs of fracture healing included periosteal reaction near the fracture, callus formation at fracture site, minor resorption and remodelling of fracture ends or primary bridging of a rigid stable fracture with woven bone.

According to Langley-Hobbs (2003), immediate postoperative radiographs should be assessed for the four A's- Apposition, Alignment, Angulation and Apparatus. Follow up radiographs should be assessed for six A's- Apposition, Alignment, Angulation, Apparatus, Activity and Architecture.

According to Toal and Mitchell (2002), formation of periosteal callus could be due to stripping of periosteum at fracture site during injury or during surgery.

Ozsoy and Altunatmaz (2003) observed that the fractures healed with the formation of a large callus, both periosteal and endosteal, on closed and limited approaches to the fracture treatment with external fixator.

2.14.3. Haematological evaluation

According to Whittick (1974), the assessment of VPRC, haemoglobin count and total WBC count were to be considered in presurgical care in order to provide attention to any lesions which may affect the outcome of the fracture in a patient.

2.14.4. Blood biochemistry

Singh *et al.* (1976) reported a non significant variation in the level of calcium and inorganic phosphorus during the postoperative healing period of experimental ulnar defects. There was a significant increase in the serum concentration of alkaline phosphatase at seven and fourteen days postoperatively followed by a fall to normal values during healing periods.

The finding of Kumar *et al.* (1992) was that there was a significant decline in plasma calcium and inorganic phosphorus during the healing period of 21 days in fracture cases.

Chandy (2000) analysed the serum calcium, phosphorus and alkaline phosphatase level postoperatively after using acrylic external skeletal fixator as an adjunct to intramedullary pinning and observed no variation in the serum calcium and phosphorus level. But serum alkaline phosphatase level showed a significant and steady increase through out the healing period.

2.15. POST OPERATIVE COMPLICATIONS AND THEIR MANAGEMENT

It was noticed by Mathews *et al.* (1984) that thermal necrosis of bone occurred due to heat generated during pin insertion. This resulted in pin loosening and infection.

Egger *et al.* (1986) opined that the pin tract drainage could result from loose pins or tension of the soft tissues against pins.

Complications observed by Fox (1986) on using external skeletal fixators to treat fractures in dogs were pin tract sepsis, premature pin loosening, breakage or fracture of appliance and focal osteomyelitis.

Johnson *et al.* (1989) found that pin loosening and pin track drainage were a normal progression with bilateral and unilateral fixation frames applied to fractures and that they did not adversely affect the fracture healing. It was also hypothesized that loosening of pins later in the healing period advocated an increase in forces across the fracture and thereby increased the stiffness of fracture. Other complications observed were osteomyelitis, nonunion, delayed union, angular deformities and osteolysis.

According to Heim *et al.* (1992), fracture that does not heal within four to six months was considered to be a delayed union and absence of union after eight months of fracture treatment was considered to be nonunion or pseudoarthrosis.

Ross and Matthiesen (1993) reported breakage of methylmethacrylate column while fractures where treated with external fixators using acrylic connecting bar. Other complications noticed were pin loosening, pin tract drainage, infection, fixation failure, osteomyelitis, angular limb deformities, malunion, delayed union and nonunion.

Osteolysis around pin track was more frequently encountered around pins placed proximal to the fracture line by Johnson *et al.* (1996). But despite osteolysis, dogs were able to use limb while fixator was in place.

As noticed by Piermattei and Flo (1997), pin loosening was the major postoperative complication following external fixator application. They opined that loosening of pins was caused by soft tissue interference or with instability of the fracture and recommended removal of pins when it loosened.

The most common complications of external fixators noticed by Harari *et al.* (1998) were pin tract sepsis, premature pin loosening and soft tissue puncture. Osteolysis around pin tracts indicated micromovement of the pins within the bone (loose pins) causing bone resorption

The postoperative complications observed by Gausepohl *et al.* (2000) on using external fixation technique in distal radius fractures in humans where redisplacement and late collapse, pin track infection, fractures at the pin sites and reflex sympathetic dystrophy.

Clasper *et al.* (2001) suggested that fluid accumulation around the pin-bone interface significantly contributed to spread of bacteria from superficial pin track to the medulla of the bone.

In the study using external skeletal fixation to repair long bone fractures, complications observed by Rochat (2001) were premature pin loosening, pin tract infection, pin breakage, neurovascular injury, iatrogenic fracture, delayed union, poor limb function, muscle atrophy and loss of reduction.

Complications observed by Ozsoy and Altunatmaz (2003) with external fixator application were pin loosening, pin-base infection, valgus deformation, nonunion and ankylosis.

2.16. REMOVAL OF IMPLANTS

On using external skeletal fixation for radial and tibial fractures, Johnson *et al.* (1989) observed a median time of tenth week for fixator removal in 26 dogs with fractures. However, additional support after removal of skeletal fixation included a POP cast in four dogs, metasplint in four dogs and soft padded bandage in two dogs.

According to Okrasinski *et al.* (1991), acrylic external skeletal fixator could be removed by cutting the acrylic with an oscillating cast saw into pieces and the piece still attached to the pins could be used as a handle for removal of the pins.

VanEe and Geasling (1992) reported that sedation rather than general anaesthesia could be used when removing the fixator device.

Acrylic fixator was removed by Ross and Matthiesen (1993) by cutting the pins using pin cutters and removing them using a hand chuck or pliers.

On using closed reduction and type II external fixation for comminuted fractures of radius and ulna in dogs by Johnson *et al.* (1996), the mean time between surgery and removal of external fixator was 14.7 weeks.

As suggested by Harari *et al.* (1998), pins could be removed when there was evidence of fracture healing, by pulling with Jacobs chuck if nonthreaded, or unscrewed if threaded.

Materials and Methods

3. MATERIALS AND METHODS

3.1. SELECTION OF CASES

The study was conducted in twelve clinical cases of complete fracture of long bone in dogs presented to the Surgery Units of Veterinary Hospitals, Mannuthy and Kokkalai, College of Veterinary and Animal Sciences, Mannuthy, during the period from December 2003 to May 2005. Those dogs presented with lameness were subjected to clinical examination and fracture of long bone was confirmed by radiography. The cases were selected irrespective of age, sex or breed.

3.2. BROAD OUTLINE OF WORK

The dogs selected for study, were subjected to detailed clinical and radiological investigation followed by haematological and serum biochemical evaluation. After confirming fitness of the animal for surgical correction of fracture, the patients were subjected to treatment with external skeletal fixation with acrylic connecting bar. Periodic clinical, radiological, haematological and serum biochemical evaluations were conducted preoperatively and at second, fourth and sixth postoperative weeks and again at two weeks interval until clinical healing of fracture and removal of the implant.

3.3. HISTORY TAKING

The signalment, anamnesis and symptoms noticed by the owner in each case were recorded.

3.4. PREOPERATIVE CONSIDERATIONS

Thorough physical examination of all the dogs was conducted. The cases presented due to trauma were first examined routinely and any life threatening injuries present were attended. Wounds present were dressed and bandaged. If needed, surgery was postponed until the animal's general condition improved. The patients were fasted for 12 hours preoperatively.

3.4.1. Patient evaluation

3.4.1.1. Clinical observations

General clinical condition, dehydration, nature of wound present at the fracture site, presence of pain, nature of peripheral lymph nodes and functional limb usage were recorded. Degree of lameness was graded as follows: (Sumner-Smith, 1993).

0 : Sound
1 : Occasionally shifts weight
2 : Mild lameness at a slow trot, none while walking
3 : Mild lameness while walking
4 : Obvious lameness while walking, but places the foot when standing
5 : Degrees of severity
6 : Degrees of severity
7 : Degrees of severity
8 : Degrees of severity
9 : Places toe when standing, carries limb when trotting
10 : Unable to put the foot on the ground

3.4.1.2. Physiological parameters

Rectal temperature (^{0}C), pulse rate (per minute), respiratory rate (per minute), capillary refill time (CRT) in seconds and colour of mucous membrane of all the dogs were recorded.

3.4.1.3. Radiographic evaluation

Plain lateral and craniocaudal radiographs of the affected portion of the limb were taken and the bone involved, fracture configuration and displacement were analysed and recorded.

3.4.2. Selection of immobilization materials

3.4.2.1. External fixators configurations adopted

The types of external fixator configurations adopted were unilateral uniplanar (type IA) with acrylic connecting bar, bilateral uniplanar (type II) with acrylic connecting bar on one side and stainless steel connecting bar on the other side and bilateral uniplanar (type II) with acrylic connecting bar on both sides (Fig. 1). The configuration suitable for each case was selected based on the body weight and temperament of the animal, the bone involved and the location and type of fracture.

*3.4.2.2. **Fixation pins***

In cases where half pin splintage was found suitable, Schanz screws (end threaded trocar pointed negative profile pins) were used as fixation pins. For bilateral splintage, nonthreaded trocar pointed pins were used (Plate 1). The required size of the pin was decided by observing the lateral radiographs of the fractured bone.

*3.4.2.3. **Stainless steel clamps, connecting bars and wrench***

When their usage was found necessary, stainless steel single clamps suitable for the fixation pins selected, were used. Steinmann pins of suitable size, which fitted the holes of the clamp, were selected as connecting bars. Wrench of suitable size was used to tighten the clamps (Plate 1).

*3.4.2.4. **Acrylic column moulding tube***

Commercially available corrugated plastic tubes (Flexipipe used as insulation for electrical wires available from electrical accessories shop) of inner diameter one centimetre were used as mould for the acrylic (Plate 2). Appropriate length of the tube was cut and one of the ends of the tube was closed by melting and sealing.

*3.4.2.5. **Polymethylmethacrylate***

DPI RR Cold Cure[1], dental grade acrylic repair material used for dentures, was used for preparing the acrylic connecting bar (Plate 2). It was available as liquid and powder monomers in separate containers (Piermattei and Flo, 1997).

*3.4.2.6. **Accessories for mixing the acrylic monomers and for filling the moulding tube***

Plastic 10ml measuring vials were used to measure out the required amount of the acrylic monomers for mixing. The acrylic monomers were mixed in a stainless steel bowl into a semisolid consistency and filled in the mould using a syringe or by pouring through a funnel.

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[1] DPI-RR Cold Cure, Dental Products of India, Mumbai, India.

3.4.3. Preoperative preparation

The affected limb was prepared aseptically for surgery. The injured area was shaved including the joints above and below and scrubbed the area with povidone iodine scrub solution[1] and washed. The area was mopped dry. In case of over riding fractures, traction was applied to the limb by suspending the limb for about 30 minutes before surgery (Plate 3). The animal was restrained on lateral recumbency with the surgical site upward. The distal extremity of the limb was covered with a sterile bandage and the surgical site was painted with Tr. Iodine and draped (Plate 4). The animal was maintained on intravenous infusion with Ringer's lactate solution through out the surgery.

3.4.4. Anaesthesia

The surgery was done under general anaesthesia. The dogs were premedicated with atropine sulphate[2] at the dose rate of 0.045mg/kg body weight administered intramuscularly. After 15 minutes, xylazine hydrochloride[3] was given intramuscularly at the dose rate of 1 mg/kg body weight. Anaesthesia was induced with ketamine hydrochloride[4] intramuscularly at the dose rate of 5mg/kg body weight. Following induction of anaesthesia, endotracheal intubation was performed and the anaesthesia was maintained with intravenous administration of xylazine-ketamine mixture (equal volumes) and diazepam[5] at the rate of 0.25mg/kg body weight.

3.5. SURGICAL PROCEDURE

The immobilization of the fractured bone could be accomplished either by a closed approach or open approach.

3.5.1. Closed approach

In case of stable fractures, the external skeletal fixator was applied by closed approach to the bone. The fracture was reduced to normal alignment and apposition by external manipulation. After putting a small nick incision at the proposed site for drilling pins, the fixation pins were drilled percutaneously through the safe corridor of

[1] Microshield*PVP- Povidone Iodine surgical handwash, 500ml, Johnson and Johnson Ltd., 30, Forjett street, Mumbai
[2] Atropine sulphate injection IP. (0.6mg/ml), Mount Mettur Pharmaceuticals Ltd., India
[3] Xylaxin, Indian Immunologicals Ltd., (20 mg/ml), Guntur dist., Andhra Pradesh, 2ml vial
[4] Ketmin 50, (50mg/ml), Themis Medicare Ltd., Mumbai, 2ml ampoule
[5] Calmpose injection, Ranbaxy laboratories Ltd.,(5mg/ml), Mumbai. 2ml ampoule

the respective bone. (Marti and Miller, 1994a; Marti and Miller, 1994b; Gorse, 1998). In closed approach to the bone, the fixation pins were introduced by hand through the soft tissues to the level of the bone and then drilled.

3.5.2. Open approach

For unstable fractures, which could not be reduced by external manipulation, open approach to the fracture segments was adopted. The surgical incision was made along the safe corridor, directly over the fracture site, large enough to allow manipulation of the fragments (Plate 5). The fractured ends were reduced to normal alignment and apposition by applying traction and toggling, as needed.

Two methods were used to retain the fracture fragments in reduced position until application of external fixator.

3.5.2.1. Retaining the reduced fracture using bone reduction forceps

The reduced fracture fragments were retained in normal alignment and apposition temporarily using bone reduction forceps and the pins were drilled through the bone through the surgical site. Then the stainless steel framework was applied. Once the rigid fixation was achieved with stainless steel external fixators, the bone reduction forceps were removed. The surgical site was closed by apposing the separated muscle bellies with chromicised catgut of size 1/0 or 2/0. After applying subcuticular suture, the skin edges were closed by cross mattress sutures.

3.5.2.2. Retaining the reduced fracture using other adjuncts to external skeletal fixator

Cerclage wire was used to retain the fractured fragments in normal alignment and apposition (Plate 6). Then the surgical site was closed (Plate 7). The further fixation of the external skeletal fixator was done just like a closed approach.

3.5.3. Principles followed in application of external fixator

3.5.3.1. Transfixation pins

The pins were drilled through the safe corridors of the respective bone (Plate 8). For femur, the half pins were inserted through craniolateral aspect. Pins were drilled from craniomedial to caudolateral aspect in radius as well as in tibia (Marti and Miller, 1994a; Marti and Miller, 1994b; Gorse, 1998). A minimum of two fixation pins was drilled through each segment of the bone. But in cases where the distal fragment was too short, only one pin was drilled through the distal fragment. The pins were drilled almost at right angle to the long axis of the bone and parallel to each other. Care was taken to ensure that all pins entering bone penetrated both cortices completely. When half pins were used, the tip of the pins penetrating the opposite cortex could be judged by feeling the tip at the opposite cortex. Also the resistance offered by the tissue to the drilling gave an idea about the èxtent of penetration. Low speed, high torque power drill (150 to 400rpm) was used to drill the pins. To reduce thermal necrosis of bone during open reduction, the drilling site was irrigated with normal saline during drilling.

3.5.3.2. Stainless steel clamps and connecting bar

Clamps and connecting bars were positioned close to the skin leaving only a small space of one centimetre between them. The stainless steel frame could be fixed to the bone in different methods depending upon the stability of the fracture.

The most proximal and distal pins were placed first. Then the clamps, corresponding in number to the number of pins to be used in the framework, were connected to the connecting bar. This frame was then applied to the bone by connecting the clamps at either end of the connecting bar to the pins at either end of the bone already drilled. These clamps were tightened taking care that the fractured fragments were in correct alignment and apposition. The remaining pins were applied sequentially guided through the clamps in the connecting bar and drilled through the bone (Fig. 2). All the clamps were then tightened with the wrench (Harari *et al.*, 1998). But in highly unstable fractures, the propér apposition of the fractured fragments got distorted on drilling the pins guided through the clamps.

So another technique was also tried. The middle two pins, one on each fragment, close to the fracture end, were drilled first and then connecting bar with the clamps was connected to it (Plate 9a). The pins farther from the fracture site were then drilled, guided through the clamps in the connecting bar (Plate 9b).

Another method followed for the application of stainless steel frame to the bone was the first phase of the biphasic technique for application of acrylic fixator suggested by Piermattei and Flo (1997). First, all the pins were drilled in an almost straight line through the bone and then the stainless steel frame was applied by connecting the framework to it. While tightening the clamps, proper alignment and apposition of the fractured fragments was ensured. In this method it was not necessary to include all the pins in the stainless steel framework.

3.5.3.3. Application of acrylic external skeletal fixator

In stable fractures, and where the fracture was well stabilized with adjuncts to external fixator prior to drilling pins, stainless steel connecting bars were avoided and the acrylic connecting bar was directly applied. If stainless steel connecting bars were used initially, then the tube was fixed above it, close to the connecting bar.

The corrugated moulding tube was fixed longitudinally parallel to the long axis of the bone by piercing the tube along its width through the free ends of the pins leaving a small space of one centimetre between the skin and the tube (Plate 10). The limb was held upright and the space between the tube and the skin was packed with moist cotton.

The acrylic monomers where mixed in the ratio of 2:1 by volume. For a one centimetre diameter tube of approximately 15cm length, 30ml by volume of powder and 15ml by volume of liquid were mixed. In the semisolid consistency, the mixture was filled into the tube with a syringe or by pouring through a funnel (Plate 11). A setting time of 10 to 15 minutes was allowed. The transfixation pins were cooled during the exothermic phase of acrylic hardening by pouring normal saline.

Once the acrylic hardened, the stainless steel connecting bar was removed by loosening the clamps and dismantling the components of the clamp.

In animals of less than 15kg body weight, type IA fixators with acrylic connecting bar or type II fixators with acrylic connecting bars on both sides (Plate 12) were used. In case of heavy animals of more than 15kg body weight, type II fixators (bilateral configuration) with acrylic connecting bar on one side and stainless steel connecting bar on the other side were used.

3.6. POSTOPERATIVE CARE

The excess length of the pins projecting above the acrylic column were cut and removed. The tips were covered with cotton and concealed with adhesive plaster. The suture line and the pin entry points were covered with sterile gauze pads and a bandage was applied with thick cotton padding.

Antibiotic was administered for five days postoperatively with Ceftriaxone sodium[1] at a rate of 20mg/kg body weight as intravenous injection on the day of surgery and as Cephalexin[2] tablets orally on the subsequent days. Antibiotic therapy was prolonged, whenever needed.

Owners were advised to restrict the movement of the animal for two weeks after surgery and then to allow on leash walking.

Postoperative evaluation was carried out on the third and tenth postoperative days, whenever possible, and then at two weeks interval, upto six weeks or until healing was complete.

3.6.1. Postoperative wound dressing

The suture lines as well as the pin entry points were cleaned. Povidone iodine was infused through the pin tracts when there was discharge from the tracts. Normal saline was sprayed with force with a syringe to clean the skin-acrylic bar interface. Framycetin ointment[3] was applied around the pin entry points on the skin and the suture line and was bandaged with sterile cotton and gauze. Sutures were removed on the tenth postoperative day.

3.7. REMOVAL OF THE IMPLANTS

The implants were removed when there was sufficient callus formation and when the animal could bear weight on the affected leg. Removal of the implant was done also in cases where there was severe pin loosening and lose of rigid fixation.

Sedation was induced with xylazine hydrochloride at the rate of 1mg/kg body weight after premedication with atropine sulphate at the rate of 0.045mg/kg body

[1] SAFEVET 500mg injection, Dosch pharmaceuticals private Ltd., Mumbai.
[2] SPORIDEX AF 375 mg tablets, Ranbaxy laboratories Ltd., A.P.
[3] Soframycin skin cream, 20g tube, Aventis Pharma Ltd., Pune.

weight for implant removal. The unilateral acrylic connecting bars and transfixation pins were removed by cutting the acrylic column in between pins and using each piece attached to the pins as handle to unscrew them out of the bone (Okrasinski *et al.*, 1991). Bilateral connecting bars were removed by cutting the pins in order to separate the connecting bar and then the pins were pulled out using hand chuck (Ross and Matthiesen, 1993).

3.8. EVALUATION OF THE STUDY

The efficacy of the acrylic fixator on the operated cases was evaluated by clinical, radiological, hematological and serum biochemical studies done at two weeks interval from the day of surgery. Complications, if any, observed were recorded.

3.8.1. Patient evaluation

3.8.1.1. General clinical condition

3.8.1.1.1. Peripheral lymph nodes

The size of the peripheral lymph node of the affected limb was assessed and recorded as normal, slightly enlarged or enlarged.

3.8.1.1.2. Pain

The level of pain was assessed on the basis of the response of the animal when the fracture site and pin entry points were gently pressed with fingers and graded as absent, mild, moderate or severe.

3.8.1.1.3. Proprioceptive reflex

Proprioceptive reflex of the affected limb was checked and graded as present or absent. The deficit was assessed by examining the patient on carriage of limb while walking.

3.8.1.1.4. Functional limb usage

Functional limb usage was assessed and graded as 0 to 10 as suggested by Sumner-Smith (1993).

3.8.1.2. Physiological parameters

Rectal temperature (^{0}C), pulse rate (per minute), respiratory rate (per minute), capillary refill time (seconds) and colour of mucus membrane were recorded preoperatively and on 2^{nd}, 4^{th} and 6^{th} postoperative weeks in all the animals.

3.8.1.3. Haematological evaluation

Blood samples were collected preoperatively and on the 2^{nd}, 4^{th} and 6^{th} postoperative weeks for the evaluation of haematological parameters viz. haemoglobin concentration, volume of packed red cell (VPRC), erythrocyte sedimentation rate (ESR), total leucocyte count (TLC) and differential count (DLC) (Schalm *et al.*, 2000).

3.8.1.4. Serum biochemical evaluation

Blood samples were collected preoperatively and on the 2^{nd}, 4^{th} and 6^{th} postoperative weeks for serum biochemistry.

Photometric determination of alkaline phosphatase was done by kinetic method using serum alkaline phosphatase analysis kit. Serum calcium and phosphorus were estimated by photometric method (Endres and Rude, 2001).

3.8.2. Implant evaluation

3.8.2.1. Apparatus stability

The stability of the fixator to maintain the necessary mechanical configuration during treatment was judged by gross observation and detailed physical examination. The external frame was checked for loosening of the transfixation pins and for breakage of acrylic bar. Loosening of pins was judged by gently moving the pins laterally.

3.8.2.2. Patient acceptance

The acceptance of the external fixator by the patients was studied based on tissue reactions and graded as satisfactory or unsatisfactory.

3.8.2.3. Mutilation

Incidence of mutilation of the external frame by the animal was assessed based on the history collected from the owner and from clinical observation.

3.8.2.4. Pin tract drainage

The pin entry and exit points were inspected for any discharge form the pin tracts.

3.8.3. Radiographic evaluation

Plain lateral radiographs of the fractured bones were obtained immediately after surgery and at 2^{nd}, 4^{th} and 6^{th} week postoperatively. The four A's ie., Alignment of fragments, Apposition of fragments, Angulation between fragments and Apparatus were assessed in the immediate postoperative radiograph. The six A's ie., Alignment of fragments, Apposition of fragments, Angulation between fragments, Apparatus and Activity and Architecture at fracture site were assessed from the postoperative radiographs obtained at 2^{nd}, 4^{th} and 6^{th} week postoperatively (Langley-Hobbs, 2003).

3.8.3.1. Apposition

Accuracy of fracture reduction was assessed from percentage of bone ends in contact in the immediate postoperative radiograph. Maintenance of fracture reduction was ascertained in the radiographs taken at two weeks interval.

3.8.3.2. Alignment and angulation

Whether the bone is straight in alignment or not postoperatively was assessed from the immediate postoperative radiograph ie., craniocaudal or mediolateral bend, if present, was noticed. Also any degree of rotation between the bone fragments was analysed.

3.8.3.3. Apparatus

From the immediate postoperative radiograph, the correct implant usage in terms of length, positioning and size of the pins was analysed. Any sort of implant failure like pin loosening or bending, breakage of acrylic bar or changes in position of fracture fragments were assessed from the radiographs taken at two weeks interval.

3.8.3.4. Activity

Evidences of bone healing were noticed in the radiographs taken at two weeks interval. Fracture gap and callus formation were noticed. Increase in radiodensity at fracture site, either endosteal or periosteal, indicated the callus formation.

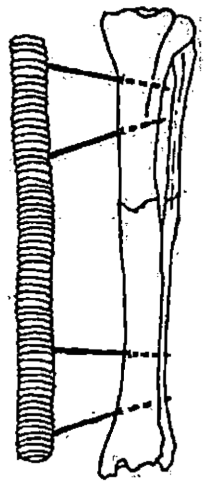
3.8.3.5. Architecture

Periosteal reactions or osteolysis present along the length of the bone were analysed. Periosteal reaction was observed on the basis of radiographic appearance and was graded as mild, moderate or severe. Decrease in the radiographic density was considered as the sign of osteolysis. The entry and exit points of pins as well as the pin tracts where examined for osteolysis and were graded as present or absent.

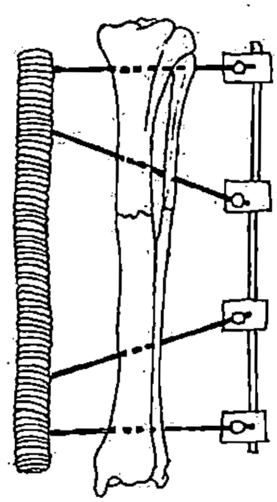
3.8.4. Statistical analysis of data

The data were analysed using paired t test (Snedecor and Cochran, 1985).

Fig 1. Diagramatic representation of external fixator configurations used in the study



A. Unilateral fixator (Type IA) with acrylic bar



B. Bilateral uniplanar fixator (type II) with acrylic bar on one side and stainless steel bar on the other side

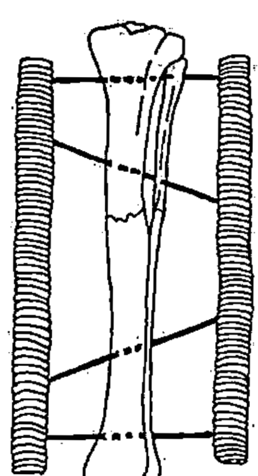
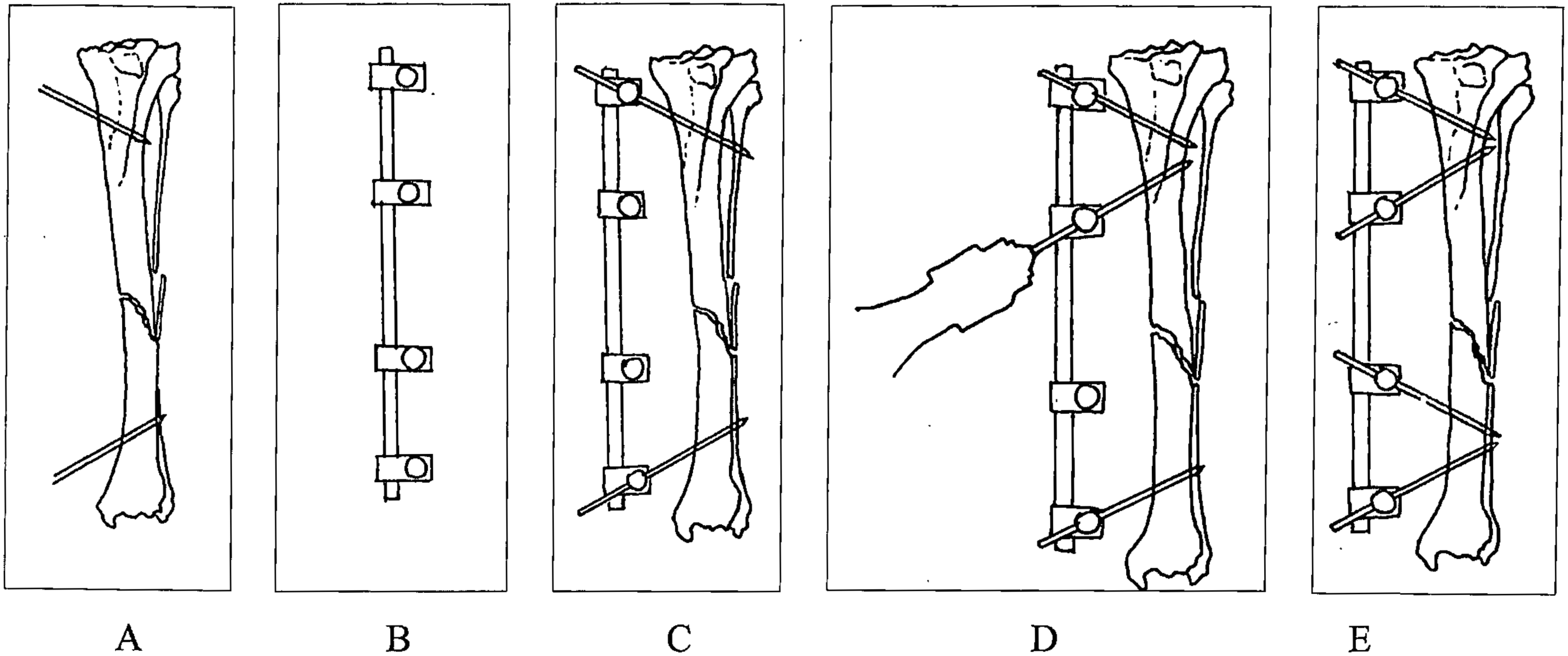


Fig. 2. Diagramatic representation of steps in application of stainless steel external **fixator**

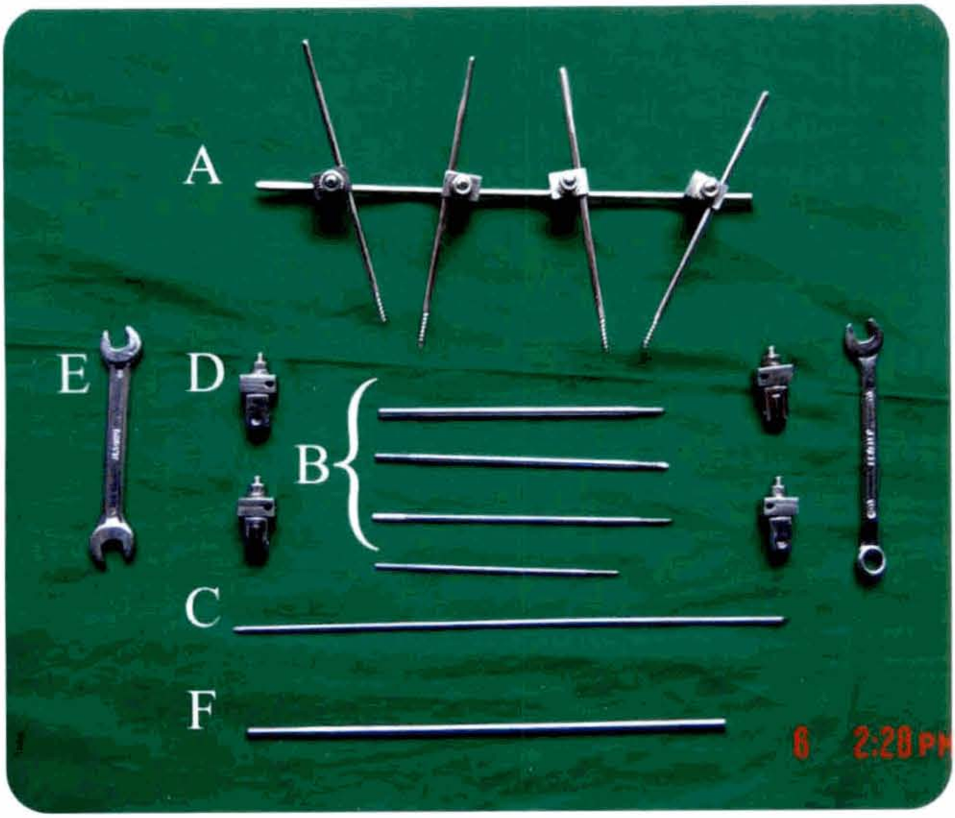


A. The most proximal and distal pins were placed first

B. and C. Connecting bar and the total number of clamps intended for use in the frame design were applied to achieve appropriate reduction and alignment

D. and E. The remaining pins were applied sequentially through the clamps in the connecting bar

Plate 1. Components of external fixator



A. External fixator assembly

B. Schanz screws

C. Smooth pin

D. Single clamps

E. Wrench

F. Connecting bar

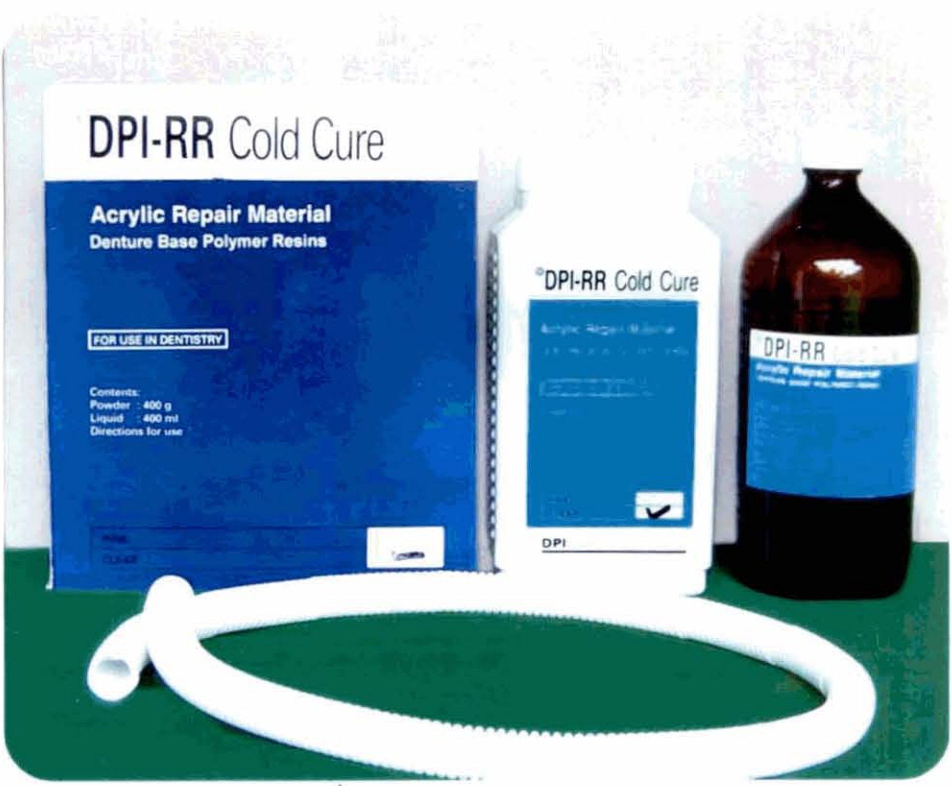


Plate 3. Fractured limb under traction (Case No. 11)

Plate 4. Surgical site- prepared aseptically (Case No. 6)

Plate 6. Fragments immobilized with hemicerclage wiring (Case No. 6)

Plate 7. Surgical site closed with cross mattress skin sutures (Case No. 6)

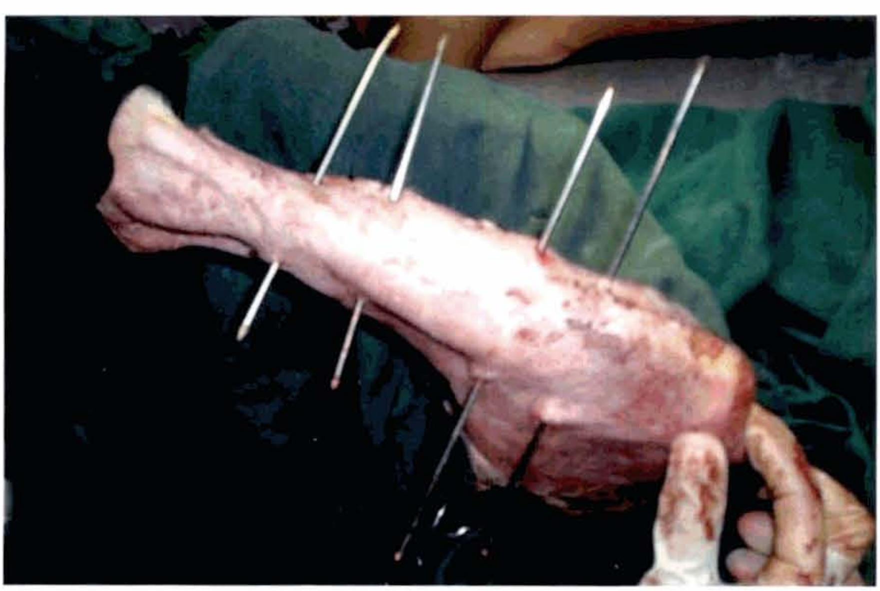
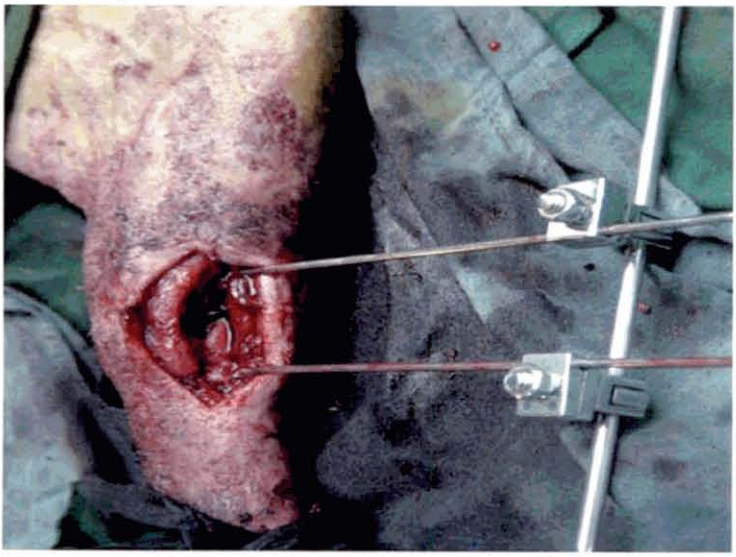
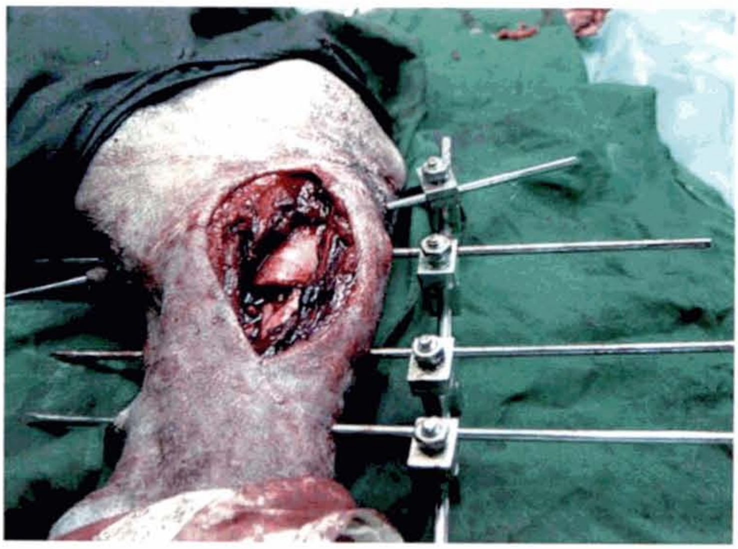


Plate 9. Application of acrylic frame aided by stainless stee
frame (Case No. 9)



a Middle two pins drilled close to fractured ends and stainless steel external frame connected



b. Remaining pins drilled through the clamps in the external frame

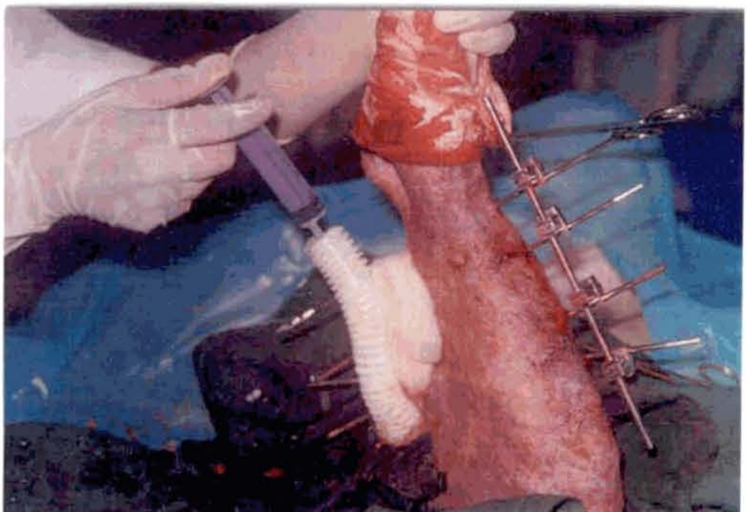


Plate 10. Acrylic moulding tube fixed to free ends of the pins (Case No. 6)

Plate 11. Acrylic being filled into the moulding tube (Case No. 6)

Results

4. RESULT

The study was carried out in the Department of Veterinary Surgery and Radiology, during the period of December 2003 to May 2005.

4.1. SELECTION OF CASES

Twelve clinical cases of complete fracture of long bones in dogs of either sex presented to the Surgery Units of Veterinary College Hospitals, Mannuthy and Kokkalai, were selected for the study.

4.2. ANAMNESIS

The signalment, exciting cause of fracture and limb affected while presented to the hospital were recorded (Table 1).

Number of animals selected for the study belonging to each breed were non descript (2), Spitz (2), Lhasa apso (2), Labrador (1), German Shepherd Dog (2), Doberman (2) and Great Dane (1). The age group of the animals ranged from three-and-a-half months to eight years with the majority between three months to two years of age. The animals weighed between five to thirty kilogram body weights. Of the animals, eight were males (66.67%) and the rest four were females (33.33%).

The exciting causes for the fracture were automobile accidents, fall from a height, injury while jumping, trauma caused by external violence and injury due to strangulation with a rope.

The duration of fracture in the cases, when presented, ranged from one day to three weeks.

The limbs involved in the fracture were the right forelimb in three animals, left forelimb in one animal, right hindlimb in three animals and left hindlimb in four animals. Both the hindlimbs were affected in one animal, of which, the left hindlimb was chosen for the study. The fracture of femur on right hindlimb was immobilized with intramedullary pin.

4.3. TYPES OF FRACTURES ON RADIOGRAPHIC EVALUATION

The types of fractures under study were represented in table 2. Among the cases selected, six cases were of tibial fracture (50%), four cases of radius and ulna fracture (33%) and two cases of femoral fracture (17%). Seven of the fractures were transverse (58.34%), three oblique (25%), one spiral (8.33%) and one comminuted fracture (8.33%). Of the radial fractures, two were of malunion.

4.4. SELECTION OF MATERIALS

4.4.1. Transfixation pins

Selection of transfixation pin was done from lateral radiograph of the bone such that it occupied 30% of the diameter of the bone. The pins selected were suitable in all the cases.

4.4.2. Acrylic column moulding tube

Corrugated flexipipe could be effectively used as the mould for the acrylic. The one centimetre diameter tube was found effective as mould for acrylic in animals with body weight less than 15kg.

4.4.3. Accessories for mixing the acrylic monomers for filling the tube

The accessories used were satisfactory for mixing the monomers and filling the tube. Occasionally, there was blockage of the syringe by hardening of acrylic, which did not pose a major problem.

4.4.4. External fixator configuration adopted

The external fixator configuration adopted in each case was recorded in table 3. Type IA configuration with acrylic connecting bar was used in Case Nos. 2, 3, 4 and 7. In Case Nos. 5, 6, 9, 11 and 12, a bilateral acrylic fixator was used. Case Nos. 5 and 9 with tibial fracture (20kg and 19kg body weight respectively), being heavier animals, the bilateral acrylic fixator, even though aided in fracture healing, provided only less stability. A bilateral fixator with acrylic connecting bar replacing the stainless steel connecting bar only on one side was used in Case No. 1 and 8 with radial fracture (16kg and 25kg body weight respectively), and in Case No.10 (30 kg body weight) with tibial fracture. It gave adequate stability in Case Nos. 1 and 8, but not in Case No. 10.

4.5. EVALUATION OF THE TECHNIQUE

4.5.1. Anaesthetic protocol

The anaesthetic protocol followed for the surgery was satisfactory for the surgical intervention. The dogs were premedicated with atropine sulphate at the dose rate of 0.045mg/kg body weight intramuscularly. After 15 minutes, xylazine hydrochloride was given intramuscularly at the dose rate of 1 mg/kg body weight. Anaesthesia was induced with ketamine hydrochloride at the dose rate of 5mg/kg body weight. The anaesthesia was maintained with intravenous administration of xylazine-ketamine mixture (equal volumes) and diazepam at the rate of 0.25mg/kg body weight. Maintenance of anaesthesia could be done well with the protocol followed.

4.5.2. Reduction and retention of fracture fragments

The fracture was stable in Case No. 3 and so no surgical manipulation was found necessary for reducing the fracture. Case No. 11 had a comminuted fracture and so open reduction of all the fracture segments seemed to be impossible. So closed reduction was attempted in Case Nos. 3 and 11 and the technique was quite satisfactory in reducing the fracture. But fracture gap was wide in Case No. 11. In all the other cases, open reduction of the fracture was done.

For retention of the reduced fracture segments, on open reduction, bone reduction forceps were used in all cases except Case Nos. 4, 6 and 9. Since Case Nos. 4, 6 and 9 were highly unstable, cerclage wiring had to be done to retain the reduced fragments before application of external fixator. But angulation between fragments was noticed in Case No. 9, in the immediate postoperative radiograph.

4.5.3. Insertion of pins

The safe corridors chosen for pin insertion were found not to cause any serious injuries to any nerves, blood vessels, muscles or tendons. The technique followed for the insertion of the pins was suitable. In all the cases, except Case No. 8, a maximum of only two pins were drilled through each segment. In Case No. 8, three pins were drilled through the proximal fragment. Even though only one pin was drilled through the distal segments in Case Nos. 1 and 11, it did not affect fracture stability significantly.

The pins were drilled almost parallel to each other and not at an angle. This did not pose a problem in type II fixators. However, pin loosening resulted in Case Nos. 2, 3 and 4 where unilateral fixators were used. Pouring saline on the pins while drilling was effective in preventing thermal injury. Digital palpation to confirm the pin exit through the transcortex was effective in preventing improper penetration of the transcortex.

4.5.4. Application of stainless steel external frame

In Case Nos. 2, 6 and 11, the stainless steel frame was not used. Instead the pins were drilled and the acrylic connecting bar was directly applied to the free ends of the pins. Postoperative radiograph revealed proper alignment and apposition of fracture fragments in Case Nos. 6 but mild angulation between segments resulted in Case No. 2. In Case No. 11, since fracture was reduced by closed approach, fracture gap was wide.

For connecting the stainless steel connecting bar, the method suggested by Harari *et al.* (1998), ie., drilling the proximal most and distal most pins first followed by connecting the connecting bar with clamps and then drilling the remaining pins guided through the clamps in the connecting bar, was used in Case Nos. 4 and 5. But, it was found difficult to maintain the proper apposition and alignment of the fragments while drilling the middle pins in this manner. So the middle two pins, one on each fragment, closer to the fracture end, were drilled first and then the connecting bar with the clamps were connected to it in Case Nos. 8, 9, 10 and 12. The pins farther from the fracture site were then drilled, guided through the clamps in the connecting bar. The apparatus usage proved to be satisfactory in the postoperative radiograph in all these cases, except, Case No. 9 in which there was mild angulation.

In Case Nos. 1, 3 and 7, the fracture was reduced and all the pins were drilled first. Then the stainless steel connecting bar was attached to the pins, and clamps were tightened ensuring proper alignment and apposition between fragments. The fracture reduction was satisfactory in these cases.

After application of the acrylic connecting bar, the stainless steel frame was removed. However, the stainless steel frame was retained on one side of the bilateral fixator in Case Nos. 1, 8 and 10 since they were heavier animals.

4.5.5. Application of acrylic connecting bar

The method of preparation of acrylic connecting bar was simple and inexpensive. Sealing one end of the tube and packing the tube-skin interface with moist cotton prevented leakage of acrylic while pouring into the tube. Mixing the acrylic monomers in 2:1 ratio by volume resulted in adequate consistency of the acrylic for filling the tube. The acrylic hardened in 10 to 15 minutes. The acrylic bar was kept as close as, at one centimetre distance from the skin and this did not pose any remarkable difficulties postoperatively except for some difficulty in cleaning the bar-skin interface.

4.5.6 Postoperative care

The method adopted for cleaning and dressing of the pin entry points on the skin was found effective in keeping the sites clean and dry. The skin-acrylic bar interface could be cleaned satisfactorily by flushing normal saline into the region with a syringe. The use of cephalosporins was found to be satisfactory to prevent postoperative infection.

4.5.7 Removal of implant

The external fixators were removed by the sixth weeks in almost all cases, except Case Nos. 5 and 8, based on functional limb usage, clinical union of fracture and radiographic evaluation of the fracture site. In Case No. 3, the implant could be removed by fourth week. Implant was removed only by eighth week in Case Nos. 5 and 8. The method adopted for removal of the implant was easy and without any complications.

4.6. PATIENT EVALUATION

All the animals were evaluated until implant removal at two weeks interval and then upto 60 days, and any noticeable observations were recorded.

4.6.1. General clinical condition

All the animals were active and alert preoperatively except Case Nos. 4 and 5. Case No. 4 met with an accident and had fracture of femur on both hindlimbs. It showed difficulty in urination and was dull and so the surgical correction was attempted one week later only, after the animal had regained good health condition. Case No. 5

was not bearing weight on both hind limbs but had fracture of left tibia only. It showed lumbar pain also. Therefore, it was treated medically with steroids and analgesics for a week, before it could bear weight on three limbs and then surgical correction of fracture was attempted.

The animals under study were clinically normal through out the observation period and did not show any signs of systemic disturbances.

4.6.2. Functional limb usage

The functional limb usage of the animals under study was represented in Table 4. All dogs, except Case Nos. 5, 9 and 10, were seen to make slight ground contact with the leg by the third postoperative day and had near to normal gait by the fourth week of observation with full weight bearing on the fractured leg. All the animals showed a progressive improvement in functional limb usage. Case Nos. 3 and 11 had an absolutely sound limb usage by the tenth postoperative day and Case No. 6 had sound limb usage by second postoperative week (Plate 13). Case No. 7 had sound limb usage by first week itself but there was implant failure due to breakage of acrylic connecting bar by the second week and hence resulted in lameness. Case No. 8 started bearing weight partially on the affected limb on the first postoperative day itself (Plate 14b). Case Nos. 5, 9 and 10 were not bearing weight on the limb while standing even at sixth week of observation, but were touching toe on the ground occasionally while trotting. However, they showed progressive improvement in limb usage after implant removal.

4.6.3. Peripheral lymph nodes

Peripheral lymph nodes were normal in size preoperatively in all the cases. There was slight increase in size during the second postoperative week, which subsided by the fourth week and remained normal in size later on.

4.6.4. Pain at the fracture site

Preoperatively all the animals evinced severe pain at the fracture site on palpation. There was mild pain through out the period of observation in Case No. 10. Case Nos. 1, 3, 6, 8, 11 and 12 evinced no pain from second week of observation onwards. Case Nos. 5 and 9 had mild pain until fourth week of observation but evinced no pain by the sixth week. Case No. 7 had severe pain at fracture site by second week, when there was implant failure.

4.6.5. Proprioceptive reflex

All the animals except Case No. 12 lacked proprioceptive reflex preoperatively. Through out the observation period, the reflex was normal in all other cases except Case No. 5. However, reflex was sluggish even by the second postoperative week in Case Nos. 1 and 4 but improved to normal by the fourth week. In Case No. 5, the reflex was absent in second postoperative week, which improved by fourth week so that the animal could touch the tip of digit while walking. The reflex became normal five days after the removal of the implant by the eighth week.

4.6.6. Physiological parameters

The physiological parameters were within normal range preoperatively and through out the observation period (Table 5).

4.6.6.1. Respiratory rate

The respiratory rate (per min) was 31.33 $\pm$ 1.68 on the day of presentation and was within the normal range. The respiratory rate recorded was 30.17 $\pm$ 1.49, 31.90 $\pm$ 2.36 and 30.5 $\pm$ 1.86 on second week, fourth week and sixth week respectively. The variations were within the normal range.

4.6.6.2. Pulse rate

The pulse rate (per min) was 96.17 $\pm$ 6.81 on the day of presentation and was within the normal range. The pulse rate recorded was 96.33 $\pm$ 6.90, 97 $\pm$ 5.53 and 99.75 $\pm$ 5.75 on second, fourth and sixth postoperative week respectively. The variations observed were within the normal range.

4.6.6.1. Rectal temperature

The rectal temperature (^{0} C) was 38.79 $\pm$ 0.3 on the day of presentation and was within the normal range. The temperature recorded was 39.01$\pm$ 0.18, 38.82 $\pm$ 0.23 and 38.93$\pm$ 0.15 on second, fourth and sixth postoperative week respectively and the values were within the normal range.

4.6.6.4. Capillary refill time

Capillary refill time was less than one second to one second in all the cases preoperatively and through out the observation period.

4.6.6.5. Colour of mucous membrane

The conjunctival mucous membrane was pale pink in all the animals on the day of presentation and through out the observation period

4.7. IMPLANT EVALUATION

The implants were evaluated during the postoperative periods and the results were represented in table 6.

4.7.1. Apparatus stability

The acrylic connecting bar remained intact through out the observation period in all the cases except Case Nos. 7 and 9. However, mild damage to the acrylic bar occurred in Case No. 3 also. Pin loosening occurred in Case Nos. 2, 3 and 4 (Plate 16).

Case No. 7 with femur fracture, when presented on the second week, there was breakage of the acrylic between the second and third pin, between the two bone fragments, and the fracture reduction was completely lost. In Case No. 9 where bilateral acrylic fixator was used, severe mutilation by the animal resulted in damage of the acrylic bar between the first and second pin by second week (Plate 18).

In Case No. 3, where a type I fixator was used, by the fourth week, the acrylic connecting bar got damaged at the proximal end due to mutilation by the animal and there was loosening of the proximal most pin. The shaft of the proximal most pin within the acrylic bar was partially exposed. Since fracture healing was satisfactory by fourth week itself, the implant could be removed and the damaged acrylic bar did not cause any remarkable adverse effect.

When type I fixator was used in Case Nos. 2, 3 and 4, the pins got loosened by the fourth week. In Case No. 3, the fracture healed almost completely by fourth week itself. In Case Nos. 2 and 4 also, there was clinical union by fourth week and sixth week respectively and the animal's gait was normal. So implants could be removed by sixth week. Nevertheless, additional support with coaptation bandage was given for the next two weeks.

4.7.2. Patient acceptance

There was no tissue reaction to the apparatus and patient acceptance was satisfactory through out the observation period in all the cases.

4.7.3. Mutilation

There was mild mutilation on the implant by Case Nos. 1, 3, 6, 9 and 10. Case No. 1 showed tendency to lick the limb during the first two weeks and it resulted in cellulitis on the medial aspect of the limb. By fourth week, the tendency to lick the implant reduced. In Case No. 3, mild mutilation was present through out the observation period and the animal chewed the connecting bar, until removal of the implant. Mutilation was exhibited by the Case No.6, also until two weeks and then the tendency subsided. There was mutilation on the implant by the Case Nos. 9 and 10 through out the observation period.

4.7.4. Pin tract drainage

Mild pin tract drainage was noticed in Case Nos. 1,3,4, 6, 8 and 9, which subsided without any complications. There was purulent pin tract drainage in Case No. 5. The mild serous discharge from the proximal most pin tract on craniomedial aspect during the second week of observation, in Case No. 1 subsided by the fourth week. In Case No. 4, there was mild pin tract drainage from the proximal most pin through out the observation period, but it was negligible. Purulent pin tract drainage was noticed from the proximal two pin tracts, on craniomedial aspect by second week, in Case No. 5 and was given antibiotic treatment orally. The discharge became mild serous on observation after three days which persisted through out the observation period. There was mild pin tract drainage from the proximal most pin tract, on craniomedial aspect, in Case No. 6 by the second week. However, no discharge was noticed later on. Mild pin tract drainage was noticed from the third pin tract on craniomedial aspect in Case No. 8 by the second and fourth week. Case No. 9 had mild pin tract drainage until fourth week of observation period from the first and second pin tracts on craniomedial aspect.

4.8. RADIOGRAPHIC EVALUATION

The four A's ie., Alignment, Apposition, Angulation and Apparatus were evaluated in the immediate postoperative radiograph and the six A's ie., Alignment, Apposition, Angulation, Apparatus, Activity (fracture gap and callus formation) and Architecture (periosteal reaction and osteolysis) were evaluated in the follow up radiographs (Table 7).

Case No. 1

Preoperative radiograph: Simple complete transverse fracture of ulna and oblique over riding fracture of distal one third of radius with malunion (Plate 15a).

Immediate postoperative radiograph: There was good apposition and alignment between the segments. Implant usage was satisfactory (Plate 15b).

II week: There was no callus formation. Fracture gap was evident. Mild periosteal reaction was present (Plate 15c).

IV week: Thin periosteal and endosteal callus formation was visible bridging the fracture gap in radius and ulna. Mild periosteal reaction was noticed (Plate 15d).

VI week: There was thick callus completely filling the fracture gap. Mild periosteal reaction could be noticed (Plate 15e).

Case No. 2

Preoperative radiograph: Simple complete transverse fracture of mid shaft of tibia.

Immediate postoperative radiograph: There was a mild angulation craniocaudally between the segments. The apparatus was properly placed and of correct length and size.

II week: Fracture gap was visible with no callus formation.

IV week: Fracture gap was visible. However, thin endosteal callus was visible.

VI week: There was no visible fracture gap. More endosteal callus formation could be noticed.

Case No. 3

Preoperative radiograph: Simple complete transverse fracture of distal one third of radius and ulna.

Immediate postoperative radiograph: A mild deviation from the straight alignment could be noticed. Implant usage was satisfactory.

II week: A fracture gap was present in the radius but no fracture gap in ulna. Only endosteal callus was noticed in radius, but not completely filling the gap. Mild degree of periosteal reaction was noticed through out the length of the bone; more around the pin tracts. Some degree of osteolysis could be noticed around the most proximal two pin tracts.

IV week: No appreciable malalignment could be noticed. There was severe periosteal reaction and mild degree of osteolysis around the two most proximal pin tracts. Fracture gap was only faintly visible.

The implant was removed by the fourth week.

VI week: The malalignment between fragments got nullified with callus formation. Fracture gap was almost radioopaque. Moderate periosteal reaction was observed.

Case No.4

Preoperative radiograph: Comminuted fracture of midshaft of left femur with a butterfly fragment.

Immediate postoperative radiograph: There was good alignment and apposition between the fractured segments. Implant usage was perfect. Cerclage wiring was done to keep the middle butterfly fragment intact.

II week: There was good apposition between the fragments. Thin endosteal callus could be appreciated.

IV week: An increase in the fracture gap due to loosening of the cerclage wire and slight distraction of butterfly fragment proximally. Thin endosteal callus was visible.

VI week: More loosening of the cerclage wire was noticed which resulted in slight displacement of the middle butterfly fragment from the shaft. All pins got loosened form the distal cortex such that the tips of the pins were in the medullary cavity. Thin endosteal callus was visible at the fracture gap. Osteolysis was evident around the pin tracts (Plate 16).

Case No. 5

Preoperative radiograph: Simple complete transverse fracture of midshaft of tibia and fibula.

Immediate postoperative radiograph: Alignment between fragments was not proper. A craniocaudal malalignment by about one centimetre was noticed between the segments. The apparatus was properly placed and of correct length and size.

II week: A fracture gap was present and the fracture fragment margins were indistinct. Moderate periosteal reaction was present through out the length of the bone between pins. Thin endosteal callus was visible.

IV week: Malalignment was not obvious. Fracture gap got reduced with thin periosteal and endosteal callus formation. There was severe periosteal reaction.

VI week: Proper apposition between segments was attained. There was periosteal and endosteal callus formation but the fracture line was still wide and visible. Severe periosteal reaction could be noticed (Plate 17).

VIII week: Fracture line was very faint and the gap was found filled with periosteal and endosteal callus. Severe periosteal reaction was noticed.

Case No. 6

Preoperative radiograph: Simple complete over riding spiral fracture of midshaft of tibia and fibula.

Immediate postoperative radiograph: There was mild mediolateral malalignment between fragments. Apparatus was properly placed and of correct length and size.

II week: Fracture gap was present. Thick periosteal callus was visible. There was moderate periosteal and endosteal reaction at middle two third of the bone.

IV week: The malalignment got corrected with periosteal and endosteal callus formed at the fracture gap. There was moderate periosteal and endosteal reaction.

VI week: Bridging of fracture gap with callus could be appreciated. There was a reduction in the severity of periosteal reaction. Fracture gap was not visible. Implants remained intact.

Case No. 7

Preoperative radiograph: Simple complete over riding transverse fracture of midshaft of femur.

Immediate postoperative radiograph: Alignment and apposition between segments were good. Apparatus was properly placed and of correct dimensions.

II week: Breakage of acrylic connecting bar resulted in loss of reduction between segments and the segments were found over riding.

The fracture was further reduced and retained with intramedullary pin.

Case No. 8

Preoperative radiograph: Simple complete over riding transverse fracture of distal one third of radius and ulna.

Immediate postoperative radiograph: Alignment, apposition, angulation and apparatus were good.

II week: Fracture gap was present. There was no callus formation.

IV week: Irregularity noticed at fractured ends indicating initial stage of fracture healing. Mild periosteal reaction was visible around pin tract.

VI week: Fracture gap was filled with thin periosteal and endosteal callus. There was mild osteolysis around the proximal most pin tract.

VIII week: Implant was intact. Fracture gap was only faintly visible and was filled with thick endosteal and thin periosteal callus. Mild periosteal reaction was noticed. Osteolysis was present around the proximal most pin tract.

Case No.9

Preoperative radiograph: Simple complete oblique fracture of midshaft of tibia and fibula.

Immediate postoperative radiograph: There was marked craniocaudal angulation between the fracture fragments.

II week: Fracture fragment margins were indistinct. Mild periosteal reaction was present.

IV week: Thin endosteal callus formation could be noticed at the fracture site. Mild periosteal reaction was present along the shaft of tibia.

VI week: Angulation between fragments was still present. Fracture line was not visible except for a small linear radiolucency. Thick endosteal callus could be noticed. There was mild periosteal reaction. Osteolysis was present around proximal pin tract.

Case No. 10

Preoperative radiograph: Simple complete oblique fracture of midshaft of tibia.

Immediate postoperative radiograph: Alignment, apposition and angulation between fragments were good. Implant usage was satisfactory.

II week: Irregularity of fracture ends noticed. Severe periosteal reaction could be observed.

IV week: Fracture gap filled partially with thin endosteal callus. Severe periosteal reaction noticed.

VI week: Fracture gap was filled with thick periosteal and endosteal callus. There was severe periosteal reaction.

Case No. 11

Preoperative radiograph: Simple complete comminuted fracture of midshaft of tibia.

Immediate postoperative radiograph: Fragments not in proper apposition or alignment. A fracture gap of 4mm was present at the fracture site.

II week: Fracture gap partially filled with thin endosteal and periosteal callus. Mild periosteal reaction noticed.

IV week: Fracture gap progressively being filled with callus but the gap still present. There was mild periosteal reaction.

VI week: Thick endosteal callus and thin periosteal callus was present bridging the fracture fragments. There was mild periosteal reaction.

Case No. 12

Preoperative radiograph: Simple complete transverse fracture of distal one third of radius and ulna with malunion.

Immediate postoperative radiograph: Alignment, apposition and angulation between fragments were proper. Apparatus was of proper length and size and was properly placed. Fracture gap was narrow.

II week: Periosteal and endosteal callus formation was evident in radius and ulna. Mild periosteal reaction noticed.

IV week: Thin endosteal and periosteal callus was noticed filling the fracture gap completely. There was mild periosteal reaction at the second pin tract.

VI week: Endosteal and periosteal callus completely bridging the two fracture fragments. Mild periosteal reaction and osteolysis was noticed around the proximal two pin tracts.

4.9. HAEMATOLOGICAL EVALUATION

The haematological parameters recorded were represented in table 8.

The haemoglobin concentration (g/dl) was 12.73 ± 0.62 preoperatively. It was 12.09 ± 0.77, 12.73 ± 0.61 and 13.82 ± 0.52 by second, fourth and sixth postoperative weeks respectively. There was a significant increase ($P<0.05$) in the haemogolobin concentration by the fourth week of observation.

The VPRC (%) was 33.64 ± 1.70 preoperatively. It was 32.73 ± 1.34, 37.27 ± 1.81 and 37.64 ± 1.34 by the second, fourth and sixth postoperative weeks respectively. There was a significant increase ($P<0.01$) in the VPRC by the fourth week of observation, which remained so during the sixth week also.

The ESR (mm/hr) was 6.91 ± 2.44 preoperatively. It was 5.18 ± 1.36, 3.45 ± 1.21 and 3.82 ± 1.65 by second, fourth and sixth postoperative weeks respectively. Variations during the postoperative observation periods were marginal and within normal range.

The WBC counts (10^3 /cu.mm) was 11.05±0.97 preoperatively. It was 9.53±0.70, 9.99±0.95 and 7.98±0.26 by second, fourth and sixth postoperative weeks respectively. Variations during the postoperative observation periods were marginal and within normal range.

The mean neutrophil count (%) was 69.08±2.53 preoperatively. It was 66.22±2.08, 67.75±1.16 and 67.33±1.08 by second, fourth and sixth postoperative weeks respectively. Variations during the postoperative observation periods were marginal and within normal range.

The mean lymphocyte count (%) was 28.92±2.40 preoperatively. It was 31.17±1.26, 30.00±1.04 and 31.25±1.26 by second, fourth and sixth postoperative weeks respectively. Variations during the postoperative observation periods were marginal and within normal range.

The mean monocyte count (%) was 1.83±0.99 preoperatively. It was 1.50±0.50, 0.92±0.47 and 1.25±0.52 by second, fourth and sixth postoperative weeks respectively. Variations during the postoperative observation periods were marginal and within normal range.

Eosinophils were observed only in Case No. 4 during the preoperative period (one percent), Case No. 12 in second week observation (one percent), in Case No. 1 and 2 in the fourth week observation (three percent each) and in Case No. 3 and 4 in the sixth week observation (one percent). The observation was within the normal range.

4.10. SERUM BIOCHEMICAL EVALUATION

The serum biochemical parameters recorded were represented in table 8.

The serum calcium concentration (mg/dl) was 11.35±0.38 during the preoperative evaluation. It was 10.45±0.66, 9.12±0.63 and 10.06±0.53 during the second, fourth and sixth postoperative weeks respectively. There was a significant decrease ($P<0.5$) in the serum concentration of calcium by the fourth week of observation, which remained so during the sixth week also.

The serum phosphorus concentration (mg/dl) was 4.01± 0.83 during the preoperative evaluation. It was 2.90±0.40, 1.86±0.40 and 2.17± 0.40 during the second, fourth and sixth postoperative weeks respectively. There was a significant decrease (P<0.5) in the serum phosphorus level during the fourth and sixth week of observation.

The serum alkaline phosphatase concentration (IU/l) was 146.46$\pm$ 10.4 during the preoperative evaluation. It was 163.65$\pm$7.6, 79.83$\pm$ 7.13 and 81.86$\pm$18.12 during the second, fourth and sixth postoperative weeks respectively. There was a significant increase (P<0.5) in the serum alkaline phosphatase level during the second week of observation and significant decrease (P<0.5) in the enzyme concentration by the fourth week of observation, which remained so during the sixth week of observation also.

4.11. MANAGEMENT OF COMPLICATIONS

The various complications observed during the study period were angular deformity, pin loosening, pin tract drainage and breakage of acrylic connecting bar.

4.11.1. Angular deformity

Angulation between the fracture segments was observed in immediate postoperative radiographs in Case Nos. 2 and 9. However, since there was no gross deformity clinically, no corrective measures were taken.

4.11.2. Pin loosening

Pin loosening was noticed during the observation period in Case Nos. 2, 3 and 4 where unilateral fixators were used. In Case No. 3, pin loosening was observed by fourth week. Nevertheless, by that time there was appreciable fracture healing clinically and radiographically and hence the loosening did not affect the fracture stability much. So itself no measures were found necessary to counteract the pin loosening.

Pin loosening was observed in Case Nos. 2 and 4 by the fourth and sixth week respectively. There was sound functional limb usage and good clinical union in both the cases and so the external fixators were removed. But radiographic union was not complete in Case No. 4. Hence, the limb was immobilized with bandage for next two weeks. The owner was advised to give rest to the animal during this period.

4.10.3. Pin tract drainage

Pin tract drainage was noticed in Case Nos. 1, 4, 5, 6, 8 and 9. The pin tract entries were cleaned with moist cotton and povidone iodine was infused through the pin tracts where there was serous discharge from the tracts. This was found to be effective in controlling pin tract drainage in Case Nos. 1, 6, and 8. But in Case Nos. 4, 5 and 9, the drainage persisted until implant removal.

4.10.4. Breakage of acrylic bar

There was damage to acrylic bar in Case Nos. 3, 7 and 9. In Case No. 3 where a unilateral type I fixator was used, the moulded acrylic got damaged by the fourth week, at the proximal end due to mutilation by the animal. Since there was appreciable fracture healing clinically and radiographically the implant was removed.

Case No. 7, when presented on the second week, there was breakage of the acrylic between the second and third pin, between the two bone fragments, and the fracture reduction was completely lost. In order to correct it, traction was applied by suspending the limb under general anaesthesia and then the broken acrylic segments were connected together by mixing acrylic in a doughy consistency and moulding over the correctly placed broken acrylic segments. But radiograph following this procedure revealed persistence of over riding of fragments. Hence surgical correction was again resorted to and fragments were reduced and retained with intramedullary pin.

Severe mutilation by the animal resulted in damage to the acrylic bar between the first and second pin, by second week, in Case No. 9, where bilateral acrylic fixator was used. But since the breakage was not between the fracture fragments, the fracture reduction was not lost. So another acrylic bar was fixed at the pin tips distal to the one already present.

Table 1. Anamnesis of animals under study

CASE NO.	BREED	AGE	SEX	BODY WEIGHT(KG)	EXCITING CAUSE OF FRACTURE	LIMB AFFECTED	DURATION OF ILLNESS
1	Non-descript	3½ months	Male	16	While jumping	Left forelimb	3 weeks
2	Spitz	3 yrs	Male	10	External violence	Right hindlimb	2 days
3	Non-descript	8 months	Male	11	Automobile accident	Right forelimb	1 day
4	Lhasa apso	7 years	Male	5.5	Automobile accident	Left hindlimb	4 days
5	Labrador	1 ½ yrs	Male	20	Fall from height	Left hind limb	1 week
6	German Shepherd	3 months	Female	10	Strangulated with a rope	Left hind limb	5 days
7	Lhasa apso	7 months	Female	6	External violence	Right hindlimb	1 day
8	German Shepherd	8 yrs	Male	25	Automobile accident	Right forelimb	4 days
9	Doberman	1 ¼ yrs	Female	19	Fall from height	Left hind limb	5 days
10	Great Dane	5 months	Male	30	Strangulated with a rope	Left hind limb	1 day
11	Spitz	2 yrs	Male	7	Automobile accident	Right hindlimb	6 days
12	Doberman	3 months	Female	8	Fall from height	Right forelimb	3 weeks

Table 2. Radiographic appearance of fractures under study

CASE NO.	BONE INVOLVED	LOCATION	TYPE OF FRACTURE
1	Radius and ulna	Distal one third	Simple complete oblique over riding fracture of radius with mal-union
2	Tibia and fibula	Midshaft	Simple complete transverse fracture
3	Radius and ulna	Distal one third	Simple complete transverse fracture
4	Femur	Midshaft	Comminuted fracture with a butterfly fragment
5	Tibia and fibula	Midshaft	Simple complete transverse fracture
6	Tibia and fibula	Midshaft	Simple complete over riding spiral fracture
7	Femur	Midshaft	Simple complete over riding transverse fracture
8	Radius and ulna	Distal one third	Simple complete over riding transverse fracture
9	Tibia and fibula	Midshaft	Simple complete oblique fracture
10	Tibia and fibula	Midshaft	Simple complete oblique fracture
11	Tibia and fibula	Midshaft	Simple complete comminuted fracture
12	Radius and ulna	Distal one third	Simple complete transverse fracture with malunion

Table 3. External fixator configurations adopted in cases under study

CASE NO.	BODY WEIGHT (KG)	BONE INVOLVED	FIXATOR CONFIGURATION	CONNECTING BAR
1	16	Radius and ulna	Type II	Acrylic bar at caudolateral aspect and stainless steel bar at craniomedial aspect
2	10	Tibia and fibula	Type I	Acrylic bar
3	12	Radius and ulna	Type I	Acrylic bar
4	5.5	Femur	Type I	Acrylic bar
5	20	Tibia and fibula	Type II	Bilateral acrylic bar
6	10	Tibia and fibula	Type II	Bilateral acrylic bar
7	6	Femur	Type I	Acrylic bar
8	25	Radius and ulna	Type II	Acrylic bar at caudolateral aspect and stainless steel bar at craniomedial aspect
9	19	Tibia and fibula	Type II	Bilateral acrylic bar
10	30	Tibia and fibula	Type II	Acrylic bar at caudolateral aspect and stainless steel bar at craniomedial aspect
11	7	Tibia and fibula	Type II	Bilateral acrylic bar
12	8	Radius and ulna	Type II	Bilateral acrylic bar

Table 4. Evaluation of functional limb usage in animals under study

CASE NO.	PREOPERATIVE PERIOD	POSTOPERATIVE PERIOD			
		II WEEK	IV WEEK	VI WEEK	TIME OF CLOSE TO NORMAL GAIT
1	9	7	3	1	IV week
2	10	7	2	1	IV week
3	10	0	0	0	Tenth day
4	10	8	6	2	VI week
5	10	9	9	6	After implant removal
6	10	0	0	0	Tenth day
7	10	10	------*	------*	------*
8	10	2	0	0	I day
9	10	9	9	9	After implant removal
10	10	9	9	9	After implant removal
11	10	2	1	0	Tenth day
12	9	2	1	1	II week

0 : Sound
1 : Occasionally shifts weight
2 : Mild lameness at a slow trot, none while walking
3 : Mild lameness while walking
4 : Obvious lameness while walking, but places the foot when standing
5 : Degrees of severity
6 : Degrees of severity
7 : Degrees of severity
8 : Degrees of severity
9 : Places toe when standing, carries limb when trotting
10 : Unable to put the foot on the ground

* Not available

Table 5. Physiological parameters (mean$\pm$ SE) of the cases under study

n=11

PARAMETERS	DAY OF OBSERVATION			
	0^{TH} DAY	II WEEK	IV WEEK	VI WEEK
Respiratory rate (per minute)	31.33 $\pm$ 1.68	30.17 $\pm$ 1.49	31.90 $\pm$ 2.36	30.5 $\pm$ 1.86
Pulse rate (per minute)	96.17 $\pm$ 6.81	96.33 $\pm$ 6.90	97.00 $\pm$ 5.53	99.75 $\pm$ 5.75
Rectal temperature (^{0}C)	38.79 $\pm$ 0.30	39.01$\pm$ 0.18	38.82 $\pm$ 0.23	38.93$\pm$ 0.15

Table 6. Implant evaluation on cases under study

CASE NO.	OBSERVATION PERIOD	APPARATUS STABILITY	PATIENT ACCEPTANCE	MUTILATION	PIN TRACT DRAINAGE
1.	II week	Intact	S	+	+
	IV week	Intact	S	-	-
	VI week	Intact	S	-	-
2	II week	Intact	S	-	-
	IV week	Pin loosening	S	-	-
	VI week	Pin loosening	S	-	-
3	II week	Intact	S	+	+
	IV week	Damage to acrylic bar, Pin loosening	S	+	-
4	II week	Intact	S	-	+
	IV week	Pin loosening	S	-	+
	VI week	Pin loosening	S	-	+
5	II week	Intact	S	-	++
	IV week	Intact	S	-	+
	VI week	Intact	S	-	+
	VIII week	Intact	S	-	+
6	II week	Intact	S	+	+
	IV week	Intact	S	-	-
	VI week	Intact	S	-	-
7	II week	Breakage of acrylic bar	S	-	-
8	II week	Intact	S	-	+
	IV week	Intact	S	-	+
	VI week	Intact	S	-	-
	VIII week	Intact	S	-	-
9	II week	Breakage of acrylic bar	S	+	+
	IV week	Intact	S	+	+
	VI week	Intact	S	+	-
10	II week	Intact	S	+	-
	IV week	Intact	S	+	-
	VI week	Intact	S	+	-
11	II week	Intact	S	-	-
	IV week	Intact	S	-	-
	VI week	Intact	S	-	-
12	II week	Intact	S	-	-
	IV week	Intact	S	-	-
	VI week	Intact	S	-	-

S- Satisfactory
\+ present
++ purulent discharge
\- absent

Table 7. Radiographic evaluation of fractures under study during observation period

CASE NO.	ALIGNMENT				APPOSITION				ANGULATION				ACTIVITY (CALLUS)								ARCHITECTURE							
													PERIOSTEAL				ENDOSTEAL				PERIOSTEAL REACTION				OSTEOLYSIS			
	PO	II	IV	VI	PO	II	IV	VI	PO	II	IV	VI	PO	II	IV	VI	PO	II	IV	VI	PO	II	IV	VI	PO	II	IV	VI
1	+	+	+	+	+	+	+	+	-	-	-	-	-	-	+	+	-	-	+	+	-	+	+	+	-	-	-	-
2	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
3	-	-	+	*	+	+	+	*	-	-	-	*	-	+	+	*	-	+	+	*	-	+	+	*	-	+	+	+
4	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	+
5	-	-	+	+	+	+	+	+	-	-	-	-	-	-	+	+	-	+	+	+	-	+	+	+	-	-	-	-
6	-	-	+	+	-	-	+	+	-	-	-	-	-	+	+	+	-	-	+	+	-	+	+	+	-	-	-	-
7	+	-	*	*	+	-	*	*	-	-	*	*	-	-	*	*	-	-	*	*	-	-	*	*	-	-	*	*
8	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	+	-	-	-	+	-	-	+	-	-	-	-	+
9	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-	-	+	+	-	+	+	+	-	-	-	+
10	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	+	-	-	+	+	-	+	+	+	-	-	-	-
11	-	-	+	+	-	-	+	+	-	-	-	-	-	+	+	+	-	+	+	+	-	+	+	+	-	-	-	-
12	+	+	+	+	+	+	+	+	-	-	-	-	-	+	+	+	-	+	+	+	-	+	+	+	-	-	-	+

PO – Immediate postoperative
II - Second week
IV - Fourth week
VI - Sixth week
\- -Absent
\+ - Present
* - Not available

Table 8. Haematological and serum biochemical evaluation (mean± SE) of dogs under study

n=11

PARAMETERS		DAY OF OBSERVATION			
		0^{TH} DAY	II WEEK	IV WEEK	VI WEEK
Haemoglobin concentration (g/dl)		12.73 ± 0.62	12.09 ± 0.77	12.73± 0.61*	13.82 ±0.52
VPRC (%)		33.64±1.70	32.73±1.34	37.27±1.81**	37.64±1.34
ESR (mm/hr)		6.91±2.44	5.18±1.36	3.45±1.21	3.82±1.65
Total leucocyte count (per 10^3/cu.mm)		11.05±0.97	9.53±0.70	9.99±0.95	7.98±0.26
Differential count	N%	69.08±2.53	66.22±2.08	67.75±1.16	67.33±1.08
	L%	28.92±2.40	31.17±1.26	30.00±1.04	31.25±1.26
	M%	1.83±0.99	1.50±0.50	0.92±0.47	1.25±0.52
Serum calcium (mg/dl)		11.35±0.38	10.45± 0.66	9.12±0.63*	10.06±0.53
Serum phosphorus (mg/dl)		4.01± 0.83	2.90±0.40	1.86±0.40*	2.17± 0.40*
Serum ALP (IU/l)		146.46± 10.40	163.65±7.60*	79.83± 7.13*	81.86±18.12

* P<0.05   ** P<0.01

Plate 13. Functional limb usage evaluation (Case No. 6)

a. Limb carriage- before operation

b. Weight bearing at second week

(Plate 13 continued)

c. Weight bearing at fourth week

d. Weight bearing at sixth week

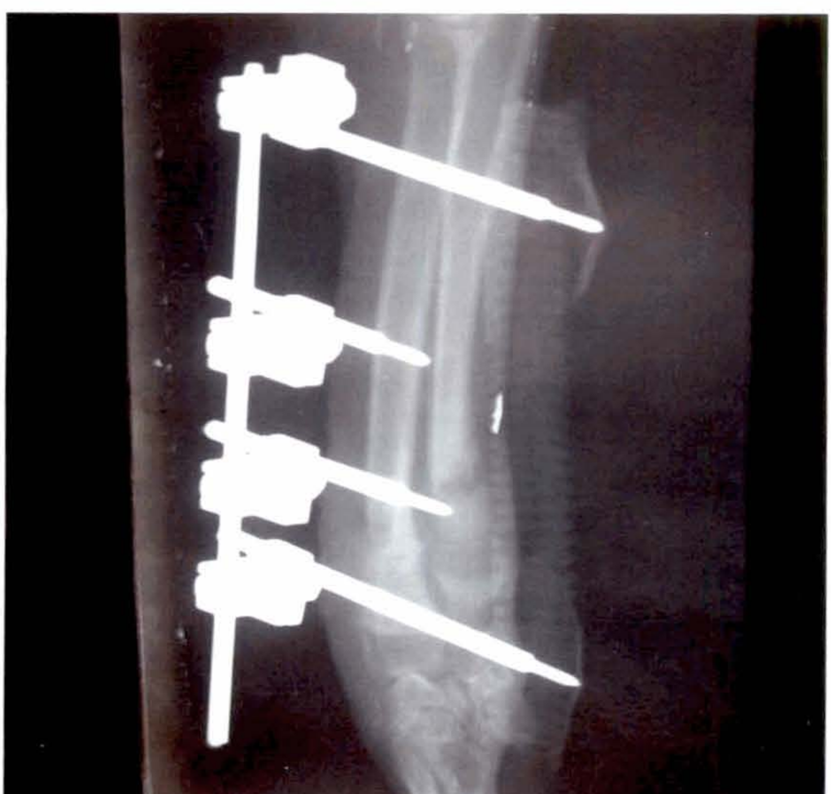
Plate 14. Functional limb usage evaluation (Case No. 8)

a. Limb carriage- before operation

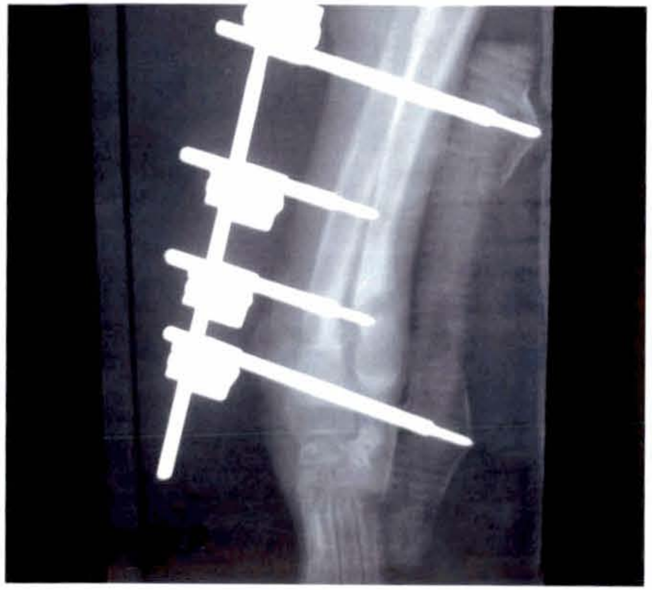
b. Weight bearing at first postoperative day

Plate 15. Skiagram showing distal radial fracture with malunion (Case No. 1)

a. Preoperative observation - Fracture of distal one thir
of radius with malunion



(Plate 15 continued)



c

d

e

c. Second week observation- Mild periosteal reaction present

d. Fourth week observation- Thin callus bridging fracture segments, mild periosteal reaction present

e. Sixth week observation- Thick callus filling fracture gap, mild periosteal reaction

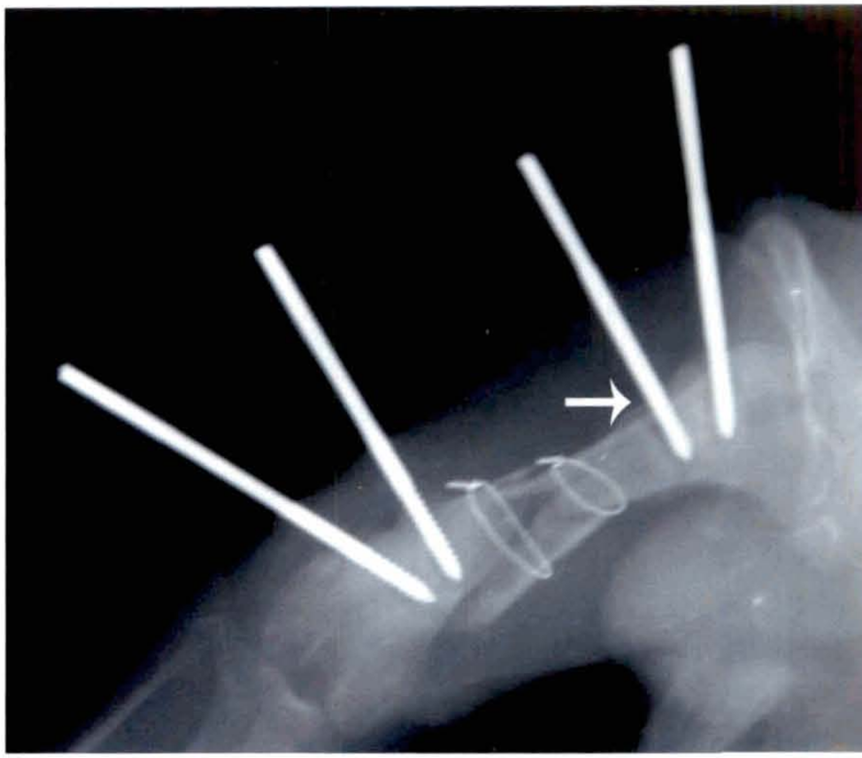


Plate 16. Skiagram showing pin loosening, osteolysis (→
cerclage loosening by sixth week (Case No. 4)

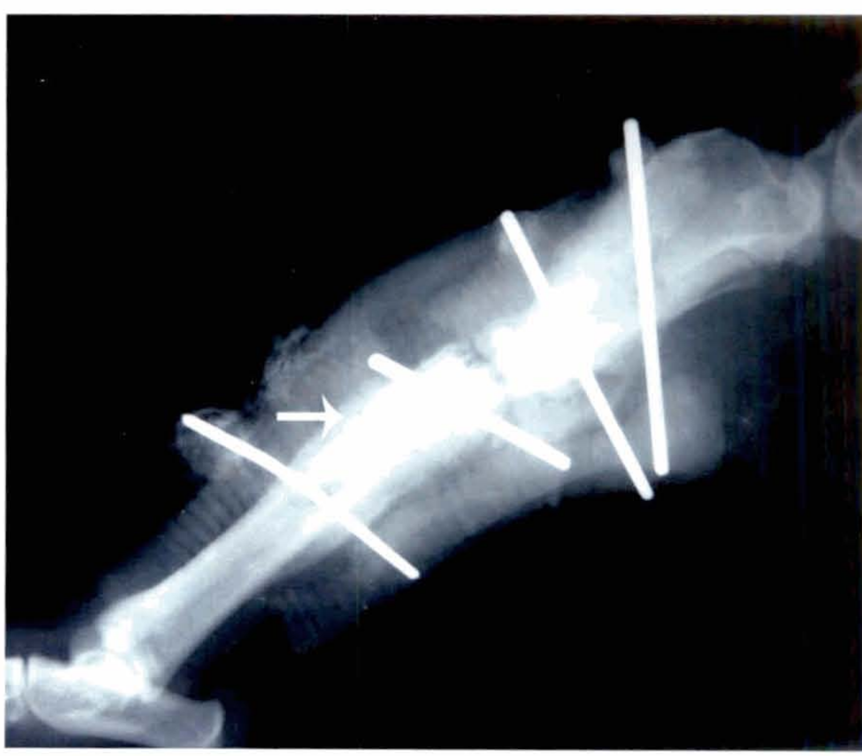


Plate 17. Skiagram showing severe periosteal reaction
by sixth week (Case No. 5)

Plate 18a. Photograph showing damaged acrylic bar by second week (Case No. 9)

Plate 18b. Photograph showing a second acrylic bar connected to free ends of the pins to neutralize the damage (Case No. 9)

Discussion

5. DISCUSSION

Fracture of long bones is a common orthopaedic condition encountered in dogs. The present study was conducted with the objective of evaluating the efficacy of replacing stainless steel connecting bar of external skeletal fixators with acrylic connecting bars for the treatment of long bone fractures.

5.1. SELECTION OF CASES

The study was conducted in twelve clinical cases of complete fracture of long bone in dogs presented to the Surgery Units of Veterinary Hospitals, Mannuthy and Kokkalai, College of Veterinary and Animal Sciences, Mannuthy, during the period from December 2003 to May 2005. The patients selected for the study were subjected to treatment with acrylic external skeletal fixator. Periodic clinical, radiological, haematological and serum biochemical evaluations were conducted to assess the fracture healing at second, fourth and sixth postoperative weeks and again at two weeks interval until clinical healing of the fracture and removal of the implant.

5.2. ANAMNESIS

The breeds of animals affected and selected for the study were non descript, Spitz, Lhasa apso, Labrador, German Shepherd Dog, Doberman and Great Dane. Balagopalan *et al.* (1995) reported highest incidence of fracture of long bones among Alsatian followed by in Doberman pinscher, non descript and then in Spitz. The age group of the animals ranged from three-and-a-half months to eight years with the majority between three months to two years. Survey conducted by Aithal *et al.* (1999) also revealed highest incidence of fracture in the age group of 1 to 3 years. The animals weighed between five to thirty kilogram body weights. Of the animals, eight were males and the rest four were females. Singh *et al.* (1983), Balagopalan *et al.* (1995) and Aithal *et al.* (1999) have also reported higher incidence of fractures in males than in females.

5.3. TYPES OF FRACTURES

Among the cases selected, six cases were of tibial fracture (50%), four cases of radius and ulna fracture (33%) and two cases of femoral fracture (17%). Seven of the fractures were transverse (58.34%), three oblique (25%), one spiral (8.33%) and one comminuted fracture (8.33%). Aithal *et al.* (1999) noticed that the incidence of fracture was highest in femur, followed by in tibia and fibula, radius and ulna and then in humerus.

5.4. SELECTION OF MATERIALS

5.4.1. Transfixation pins

Schanz screws were used in half pin splintage. According to Anderson *et al.* (1997), negative profile pins had a greater tendency to break at the thread-nonthread interface. But pin breakage did not occur in any of the four cases (Case Nos. 2, 3, 4 and 7) in which Schanz screws were used in the type I fixator. In all the type II fixators smooth pins (K wires) were used and its usage was found to be satisfactory. Also smooth pins costed only less than half that of threaded pins of the same size.

5.4.2. Acrylic column moulding tube

Flexipipe of one centimetre diameter was used as mould for acrylic. It was found effective in animals with body weight less than 15kg. In heavier animals, Case No. 5 (20kg body weight) and Case No. 9 (19kg body weight), even though the one centimetre diameter acrylic fixator aided in fracture healing, the stability achieved was not adequate. A bilateral fixator with acrylic connecting bar replacing the stainless steel connecting bar only on one side was used in Case Nos. 1, 8 and 10 (16 kg, 25 kg and 30 kg body weight respectively). Harari *et al.* (1998) reviewed that small Kirschner set could be used for dogs that weighed less than 26 lb (12kg), medium set for dogs of 26 to 99 lb (12 to 45 kg) and large set for heavier animals. Shahar (2000) suggested that minimum diameter of the acrylic column should be 19.1mm (3/4 in), if it is used as a substitute for the connecting bar of the medium Kirschner apparatus. In the present study also, acrylic column of only one centimetre diameter was found to be adequate for substituting stainless steel connecting bar of small device i.e., for animals less than 15 kg body weight.

5.4.3. Acrylic connecting bar as alternative to stainless steel connecting bar

The method of preparing acrylic connecting bar was simple and inexpensive. One packet of acrylic monomer (400g powder and 400 ml liquid), which costed only Rs. 546/-, was sufficient for use in all the twelve cases. At the same time, one single clamp costed minimum of Rs. 150/- and a connecting bar costed Rs. 50/- (varies with manufacturer). So for a stainless steel external fixator of type II configuration with four pins, the external frame alone would cost at least Rs. 1700/-. Even if the clamps and connecting bars could be reused, the net cost for application of an acrylic fixator was far less than that for a stainless steel external fixator. This was supported by Williams *et al.* (1997), Chandy (2000) and Shahar (2000) also.

5.5. EVALUATION OF THE TECHNIQUE

5.5.1. Anaesthetic protocol

The anaesthetic protocol followed for the surgery with atropine as preanaesthetic and induction and maintenance with xylazine, ketamine and diazepam was satisfactory for the surgical intervention. Dwivedi (2003) premedicated dogs with atropine sulphate followed by xylazine hydrochloride intramuscularly and diazepam intravenously followed by Ketamine intramuscularly for application of circular fixator in dogs and found it to be effective.

5.5.2. Reduction and retention of fracture fragments

Closed method of reduction and retention was done in Case Nos. 3 and 11. Functional limb usage returned to normal faster in these animals compared to the others. Gorse (1998), Johnson and DeCamp (1999) and Ozsoy and Altunatmaz (2003), reported that closed method for application of external fixator preserved vascular supply to the bone and soft tissue, minimized iatrogenic contamination of the fracture site and reduced the fracture healing time. "Hanging leg" position, as suggested by Gorse (1998), was found to facilitate closed reductions.

5.5.3. Insertion of pins

The use of only two pins through each fragment did not affect fracture stability significantly. VanEe and Geasling (1992) and McLaughlin and Roush (1999) commented that increasing the number of pins in each fragment (three or four pins were ideal) maximized fixator stiffness. So by increasing the number of pins, the reduced fixator stability in heavier animals could have been overcome to some extend. But Johnson *et al.* (1996) opined that the type of pin (threaded or smooth) and number of pins did not have a significant effect on surgery time, time to development of bridging callus or time to fixator removal.

The pins were drilled almost parallel to each other and not at an angle. According to Bradley and Rouse (1980), Straw (1984) and Nunamaker (1985), the pins should be passed obliquely through the skin and through both cortices. If pins are placed parallel, premature pin loosening might occur. However, pins were placed parallel to each other by Rochat (2001) and did not report any pin loosening. In the present study, there was pin loosening in cases where unilateral fixators were used (Case Nos. 2, 3 and 4) but no pin loosening occurred in bilateral fixators. Drilling pins parallel to each other was preferred in order to prevent formation of larger holes on the sides of the tube while sliding the tube down through the sharp edges of the pins. Such large holes, if produced on the sides of the tube, would result in more leakage of acrylic through the holes while filling the tube.

Case No. 11 had a long oblique fracture of the tibia and external fixator was applied by closed method. So the middle pins were drilled through the fracture line connecting the two segments. Rochat (2001) recommended that the pins should be distributed from about one centimetre from the fracture site to one centimetre from the adjacent joints. But drilling pin through the fracture line did not affect the fracture healing in Case No. 11. This was supported by Johnson *et al.* (1989) who found that even if the fixation pins were inserted into or immediately adjacent to a fracture line, fracture healing was not adversely affected.

5.5.4. Application of stainless steel connecting bar

In Case Nos. 2 and 9, angulation of the bone fragments resulted. This angulation might have been due to improper technique of application of stainless steel connecting bar and clamps. When the stainless steel connecting bar and clamps were connected as recommended by Harari *et al.* (1998) and Rochat (2001), there was difficulty in maintaining the fracture reduction while the subsequent pins were drilled.

Improper tightening of the clamps attached to the two pins at each end, which formed the base of the external frame, was found to be one reason for the loss of reduction during subsequent pin drilling. Even after proper tightening, there was mild change in the reduced fracture position while inserting the subsequent pins. The fragments could be better kept in alignment and apposition by drilling the pins closer to fracture site first and connecting the bar with clamps on them (Plate 9a and 9b). The technique suggested by Piermattei and Flo (1997) was also effective in applying stainless steel connecting bar and clamp without affecting the alignment and apposition of the fracture fragments.

5.5.5. Application of acrylic connecting bar

The use of acrylic required some experience to become familiar with the hardening process. Acrylic that was too stiff failed to fill the mould adequately and that which was too fluidly easily leaked through the pin entry points in the mould.

The technique followed for the application of the acrylic bar was satisfactory. In the present study only a distance of one centimetre was left between acrylic column and skin. This was done to reduce the chance of the fixator getting entangled on surrounding objects. Also finding of Nunamaker (1985), VanEe and Geasling (1992) and Bouvy *et al.* (1993) was that reducing the distance between the external frame and limb increased stability of the fixator. Ross and Matthiesen (1993) recommended maintenance of a distance of I to 2.5 centimetre between the acrylic bar and skin. However, retaining the bar at one centimetre from skin did not pose any remarkable difficulties postoperatively but cleaning the bar-skin interface was difficult. It could be handled by flushing the region with normal saline with a syringe.

5.5.6. Postoperative care

Povidone iodine was used for infusing the pin tracts and it was found effective in controlling pin tract drainage. In the present study, the pin entry points were cleaned and scabs removed at two weeks interval and there was infection only in Case No. 5. VanEe and Geasling (1992) suggested that it was better not to remove the scab formed at the pin exit and entry points so as to avoid entry of infection. But, daily cleaning of pin-skin interface was recommended by Rochat (2001).

On leash walking, as suggested by McLaughlin and Roush (1999) helped to prevent joint stiffness. Also early ambulation following fracture fixation with external fixator was recommended by VanEe and Geasling (1992) as weight bearing stimulated fracture healing and minimized fracture diseases.

5.5.7. Removal of the implant

The acrylic fixator could be removed on an average at sixth postoperative week in most of the cases. A wide variation in the time for implant removal has been described by many authors. The mean time for fixation removal noticed by Johnson *et al.* (1989) was at tenth week and by Johnson *et al.* (1996) was at 14.7 weeks. Removal of the acrylic connecting bar was found to be quite easier in this study also. Sedation, as suggested by VanEe and Geasling (1992) was found to be sufficient enough for external fixator removal.

5.6. PATIENT EVALUATION

Preoperative evaluation of all the parameters ie., clinical, physiological, haematological and serum biochemical, was useful for comparing and evaluating the postoperative observations.

5.6.1. General clinical condition

5.6.2. Functional limb usage

Functional limb usage was regained very early in all the cases except Case Nos. 5, 9 and 10. According to Rochat (2001), stable fixation was required to prevent delayed union and to avoid poor limb function. So early return to sound functional limb usage indicated the stability of the fixator. Case Nos. 5, 9 and 10 were heavier animals weighing 20kg, 19kg and 30kg respectively. All of them had fracture of tibia. In Case Nos. 5 and 9, a bilateral acrylic fixator was used. But the apparatus proved to be of insufficient stability. A bilateral fixator with acrylic bar on one side and stainless steel bar on the other side was used in Case No. 10. Even then, the apparatus remained unstable and the animal could bear weight properly on the limb only after a longer period of fracture healing. This suggested that acrylic fixator of one centimetre diameter provides only insufficient stability to tibial fracture in heavier animals ie., with more than 15 kg body weight. Shahar (2000) suggested that minimum diameter of the acrylic column should be 19.1mm (3/4 in) if it is used as a substitute for the connecting bar of the medium Kirschner apparatus. ie., for animals of 12 to 45 kg body weight.

Case Nos. 1 and 8 were also heavier animals weighing 16 kg and 25 kg respectively with fracture of radius and ulna. They responded to bilateral fixator with acrylic bar on one side and stainless steel bar on the other side with early return of sound functional limb usage. So it can be assumed that radial fracture needs less stability and so the acrylic bar was sufficient for immobilization of radial fractures even in heavy animals.

None of the animals under study had joint stiffness. Harari *et al.* (1998) have also mentioned about minimal interference of adjacent joints while using external fixators for immobilization of fractures.

5.6.3. Peripheral lymph nodes

The mild increase in size of peripheral lymph nodes during second postoperative week could be due to the inflammatory process of wound healing. The same finding was observed by Chandy (2000).

5.6.4. Pain at the fracture site

Absence of pain in most of the dogs by the second week of observation indicated that the fixation method was stable in them. Mild pain at the fracture site noticed in Case Nos. 5, 9 and 10 during the observation period indicated the degree of instability. Case No.7, which had implant failure by breakage of acrylic, had severe pain at the fracture site on second week of observation. Chandy (2000) also observed that most of the animals had pain at fracture site only during the first postoperative week.

5.6.5. Propioceptive reflex

Proprioceptive reflex deficit indicated nerve damage; radial nerve in forelimb or peroneal nerve in hindlimb. Any injury to the nerve during trauma, surgery or pin insertion would cause proprioceptive reflex deficit. The sluggish reflex in Case Nos. 1 and 4 in second week of observation could be due to postoperative inflammatory reaction and oedema compressing the nerve. However, it improved to normal by fourth week of observation. The reflex deficit in Case No. 5 could be due to injury during trauma since it had the deficit before surgery also.

5.6.6. Physiological parameters

None of the physiological parameters showed any significant variation from the normal range. The observation on the physiological parameters revealed that the incidence of fracture and the immobilization procedures employed did not produce any untoward systemic effects.

5.7. IMPLANT EVALUATION

5.7.1. Apparatus stability

Stability of the apparatus is essential for early fracture healing. In this study, apparatus instability was observed in Case Nos. 2, 3, 4, 7 and 9. Type I fixators, in Case Nos. 2, 3 and 4, even with threaded pins, were more prone to pin loosening and the pins got loosened by the fourth week. This was also supported by Whittick (1974) who mentioned that half pin splintage provided rigid fixation only for three to five weeks and thus necessitated the use of external coaptation when the pins loosened. None of the cases with type II fixator had pin loosening problem. However, Johnson *et al.* (1989) hypothesized that loosening of pins later in the healing period increased the forces across the fracture, thereby increasing the stiffness of fracture. In Case Nos. 5 and 8, the implant had to be retained for more than six weeks. Even then none of the cases had loose pins. Bouvy *et al.* (1993) had also recommended usage of bilateral splints when ever possible.

Breakage of acrylic connecting bar occurred in Case Nos. 7 and 9. In Case No. 7 (Lhasa apso weighing 6kg), the femur fracture was reduced and retained with type I acrylic ESF alone and no adjuncts were used. Femur is a bone with very strong muscle attachments. Egger (1983) noticed that the weak component of the single connecting bar configuration was the connecting bar, particularly at the fracture gap. In this case, the one centimetre diameter acrylic bar could not withstand the high muscle pull on the femur fragments and so it broke at the site of maximum strain, i.e., at the level of fracture site (between second and third pins). In Case No. 4 (Lhasa apso weighing 5.5kg) also femur fracture was immobilized with same type of ESF, but cerclaging was also done and the apparatus remained stable, except for negligible pin loosening, until fracture healing. The dog had apparently sound limb usage by sixth week. Also, being a case of bilateral fracture, (left femur was subjected to the study and right femur was immobilized with intramedullary pin) the animal could not stand on itself until ten days and later on started partial weight bearing and put two or three steps by fourth week. By this time, the fracture might have attained partial stability with soft callus and so the strain on the implant was less. So the apparatus was able to provide sufficient immobilization for the healing. Thus acrylic external skeletal fixator was a poor choice for fixation of fractures of femur due to strong muscle pull. This was supported by Rochat (2001). Harasen (2002) have also suggested that in femur, external skeletal fixator should be used with an intramedullary pin to facilitate alignment and augment stability. Usage of double connecting bar configuration, usage of acrylic column of increased diameter or using adjuncts to external fixator would have provided more stability. However, more research is needed in this aspect.

5.7.2. Patient acceptance

There was no tissue reaction to the apparatus and patient acceptance was satisfactory through out the observation period in all the cases.

5.7.3. Mutilation

Animal may mutilate the implant if there is severe pain, itching or irritation. In the present study, mutilation exhibited by Case Nos. 1 and 6 could be due to pain of surgery, which subsided within few weeks. The continuous mutilation of the implant by Case No. 3, 9 and 10 could be due to the stretched skin during pin insertion. Harari *et al.* (1998) stated that patient discomfort occurred with loose pins. According to VanEe and Geasling (1992), when applying an external fixator with the fracture site surgically opened, the skin was to be positioned in the manner it would be found when the wound was closed. Otherwise, the skin would be under tension where it contacts the fixation pins and necrosis would follow. This can be a reason for mutilation by the animal. However, the innate nature of some animals to mutilate on bandages, casts or other foreign materials on their body also should be considered. Hatt (2003) have described the possibility of patient manipulating the fixator when applied to a fractured limb.

5.7.4. Pin tract drainage

Mild pin tract drainage was observed in Case Nos. 1, 4, 6, 8 and 9. But appreciable pin tract drainage was not noticed in any of the cases under study except Case No. 5. However, drainage of serosanginous fluid from the pin tracts during the immediate postoperative period was normal which later becomes thick leading to scab formation at the pin entry and exit points as observed by VanEe and Geasling (1992). Pin tract sepsis recorded in Case No. 5 may be a common finding in external fixation as observed by Harari *et al.* (1998). However it did not result in osteomyelitis. All the cases had pin tract drainage from the proximal pin tracts only, that too on the craniomedial aspect. Egger *et al.* (1986) opined that pin tract drainage could result from loose pins or tension of the soft tissues against pins. Since radius and tibia have more muscle mass proximally, the tension of the soft tissue against pins might have resulted in pin tract drainage. According to VanEe and Geasling (1992) excessive drainage around a pin can occur due to large amounts of muscle mass trying to move across the pin during ambulation.

5.8. RADIOGRAPHIC EVALUATION

5.8.1. Fracture reduction and apparatus stability

There was good apposition between fracture fragments in most of the cases and it was maintained well throughout the observation period in all these cases with progressive bridging of fragments with callus. Malalignment between segments was noticed in Case Nos. 3, 5, 6 and 11. But in none of the cases, it was marked or affected the fracture healing. Instead, the malalignment became less obvious when the callus filled the fracture gap and finally the straightness of the bone was restored to close to normal in all the cases. Oszoy and Altunatmaz (2003) also observed that while using external fixators, the bone fragments need not be aligned as well as with internal fixation. Mild angulation was noticed between the segments in immediate postoperative radiograph in Case Nos. 2 and 9. But the angulation appeared insignificant clinically. Case No. 2 started bearing weight on the limb well by fourth week itself with no noticeable abnormality in gait. However, due to less stable apparatus, the functional limb usage of Case No. 9 returned to normal gradually only, after removal of the implant. Johnson *et al.* (1989) also noticed that even when angular deformities were visually evident, no effect could be noticed on the function of the limb. The apparatus remained stable through out the observation period in all cases except for breakage of acrylic and loss of fracture reduction in Case No. 7.

5.8.2. Fracture healing

The fracture gap in all the cases was found progressively being filled with callus. However, rate of callus formation varied with age of the animal. In young animals, the gap got obliterated earlier while it took more time in older animals. This was supported by Piermattei and Flo (1997). Case Nos. 4 and 8 being older animals (seven years and eight years of age respectively) took longer time for callus formation while Case Nos. 3 and 6 being younger animals (eight months and six months of age respectively) had their fracture healed earlier. The apparatus instability in Case No. 5 resulted in longer fracture healing time and so slower callus formation.

Some of the fractures under study healed with only endosteal callus (Case Nos. 2, 3, 4 and 9) while that in others healed with periosteal and endosteal callus formation. Periosteal reaction was mild in Case Nos. 1, 8, 9, 11 and 12, moderate in Case Nos. 3 and 6 and severe in Case Nos. 5 and 10. No periosteal reaction was noticed in Case Nos. 2 and 4. Johnson *et al.* (1989) have reported periosteal reaction following external fixator application. This could be due to sensitization of the periosteum to the presence of pin or microdamage to periosteum during pin insertion or thermal sensitization of the periosteum through transfixation pins from acrylic bar during the exothermic phase. Johnson and Hulse (2002) opined that excessive periosteal callus was indicative of the fact that the fixation was not perfectly stable. But the stabilization and fracture fixation in the present study was satisfactory, with early return of functional limb usage, in majority of the cases. Even then the fracture healed with periosteal callus also. Johnson *et al.* (1989) and Oszoy and Altunatmaz (2003) also have observed that fractures healed with periosteal and endosteal callus when immobilized with external fixator. Johnson *et al.* (1996) observed only minimal periosteal callus and more of endosteal callus in fractures healed under external fixator immobilization. Early weight bearing was suggested by Burny *et al.* (1980) to ensure functional loading of bone and development of periosteal callus. However, formation of periosteal callus can also be due to stripping of periosteum at fracture site during injury or during surgery (Toal and Mitchell, 2002).

In Case No. 5, the rate of fracture healing was very slow and there was severe periosteal reaction also. The fracture line was not obliterated radiographically even at sixth week. Heim *et al.* (1992) reported that external fixation allowing the fragments excessive instability, whether primarily by application of too flexible a device or secondarily by significant resorption of the bone at the contact surface with the pins, delayed or impeded solid bone union. Johnson and DeCamp (1999) have also noticed that application of a weak fixator-bone construct caused excessive deflection of the fixator, resulting in movements at the fracture site and pin-bone interface. Excessive movement at the fracture site could result in delayed union or nonunion. This instability might have been the reason for poor limb functioning also in this case.

Case Nos. 9 and 10, even though heavy animals and had poor limb function, did not show a significant delay in fracture healing radiographically. Case No. 5 had a transverse fracture of tibia while Case Nos. 9 and 10 had oblique fracture of tibia. In transverse fracture, rotational or torsion forces predominated and in an oblique fracture, shear and compressive forces predominated (Hulse and Hyman, 2003). According to Denny (1991) a considerable amount of bending will be tolerated, but torsion or rotation impeded healing because it caused tearing of fibroelastic network of the callus and this could lead to nonunion. This could be the reason for delayed union in Case No. 5 while there was no significant delay in fracture healing in Case Nos. 9 and 10.

5.8.3. Osteolysis

Osteolysis around pin tracts indicates thermal necrosis of the bone cortex (Mathews *et al.* 1984) or micromovement of the pins within the bone (loose pins) causing bone resorption (Harari *et al.* 1998). In the present study, osteolysis was observed in Case Nos. 3 and 4 from second week onwards and in Case Nos. 8, 9 and 12 by the sixth week. Except in Case No. 4, osteolysis was noticed around the proximal most pin tract only. The same finding was observed by Johnson *et al.* (1989). Since osteolysis was observed only in the proximal pin tract, thermal necrosis cannot be attributed to it. So it can be due to micromovement of the pins within the bone as suggested by Harari *et al.* (1998). There was pin loosening also in Case Nos. 3 and 4, which again confirmed it. However, osteolysis did not result in any serious consequences in any of the cases.

5.9. HAEMATOLOGICAL EVALUATION

Most of the haematological parameters showed no significant variation during the observation periods. However, a significant decrease in the mean VPRC was noticed by the fourth week, which remained so during the sixth week observation also. Also there was a significant decrease in the mean haemoglobin concentration by the sixth week of observation. The marginal variation observed in haemogram may be due to the cellular reaction to trauma during the healing process.

5.10. SERUM BIOCHEMISTRY

The significant increase in the alkaline phosphatase level by the second week of observation and the significant decrease by the fourth week of observation could be due to the progress in fracture healing process. Singh *et al.* (1976) noticed a significant increase in serum alkaline phosphatase level at 7 and 14 days postoperatively followed by a fall to normal value.

There was a significant decrease in the serum concentration of calcium by the fourth week of observation, which remained so during the sixth week observation also. A significant decrease in the serum phosphorus level was noticed during the fourth and sixth week of observation. Kumar *et al.* (1992) have also observed a significant decline in plasma calcium and inorganic phosphorus levels during the healing period of 21 days in fracture cases.

5.11. COMPLICATIONS

Complications observed in the present study were angular deformity, pin tract drainage, pin loosening and breakage of acrylic bar. Different authors have noticed different complications following application of external fixators like pin loosening (Mathews *et al.*, 1984; Piermattei and Flo, 1997; Rochat, 2001; Ozsoy and Altunatmaz, 2003), pin tract drainage (Johnson *et al.*, 1989), iatrogenic fractures (Gausepohl *et al.*, 2000; Rochat, 2001) and pin tract infection (Mathews *et al.*, 1984;

Gausepohl *et al.*, 2000; Rochat, 2001; Ozsoy and Altunatmaz, 2003). Ross and Matthiesen (1993) have reported breakage of acrylic bar while using acrylic fixators. The other complications noticed by Rochat (2001) were neurovascular injury, delayed union and pin breakage.

The angular deformity that occurred in Case Nos. 2 and 9 might have been due to improper technique of application of stainless steel connecting bar and clamps. Improper tightening of the clamps after application of the external frame could be one reason for the deformity. Johnson *et al.* (1996) also have reported angular deformities as complication of external fixator application.

Infusing povidone iodine through the pin tracts when there was serous discharge from the tract was found to be effective in controlling pin tract drainage in most animals. Carneiro *et al.* (2001) found both 0.2% iodine alcohol and 0.9%sodium chloride solution to be equally efficient in the postsurgical treatment of bone percutaneous transfixation in dogs. Clasper *et al.* (2001) suggested that fluid accumulation around the pin-bone interface significantly contributed to spread of bacteria from superficial pin track to the medulla of the bone.

Pin loosening in Case Nos. 2, 3 and 4 did not cause much adverse effects. Case No. 3, being a young animal, the fracture healed almost completely by fourth week itself. In Case Nos. 2 and 4 also, there was clinical union by fourth week and sixth week respectively and the animal's gait was normal and so implants could be removed. But additional support with coaptation bandage was given for the next few weeks.

The correction tried by external manipulation in Case No. 7 was a failure. On surgical reduction of the fracture by intramedullary pinning, the fracture site revealed soft callus, which might have prevented correction of the fracture by external manipulation. This difficulty in adjustments in fracture reduction once acrylic has hardened was noticed by Ross and Matthiesen (1993) and Rochat (2001). Thus acrylic external fixator was a poor choice of fixation for fractures of femur due to strong muscle masses.

The breakage of the acrylic bar in Case No. 9 was due to mutilation by the animal. However, it did not affect apparatus stability and could be successfully managed by applying additional methylmethacrylate to bond the fractured cement together as suggested by Ross and Matthiesen (1993).

The effect of acrylic to cause thermal necrosis had been reported by many authors like Ross and Mattiesen (1993), Martinez (1997), Williams *et al.* (1997) and Shahar (2000). Thermal necrosis of bone as a complication during pin drilling was also reported by many authors like VanEe and Geasling (1992), Anderson *et al.* (1997), Harari *et al.* (1998), McLaughlin and Roush (1999) and Rochat (2001). Pin loosening and pin tract drainage were suggested by Mathews *et al.* (1984) and Williams *et al.* (1997) as secondary to thermal necrosis of bone and soft tissue. However, pin loosening and pin tract drainage was considered as a normal progression with bilaterally and unilaterally applied external fixators by Johnson *et al.* (1989). In the present study no significant pin loosening or pin tract drainage occurred in any case except for the pin tract sepsis in Case No. 5. So the technique adopted for the insertion of the pin as well as for the application of the acrylic bar in this study seems to be satisfactory for preventing thermal necrosis.

Summary

6. SUMMARY

The efficacy of replacing stainless steel connecting bar in external skeletal fixator (ESF) with acrylic connecting bar was evaluated by using acrylic connecting bar in twelve clinical cases of complete fracture of long bones in dogs presented to the Surgery Units of Veterinary Hospitals of Mannuthy and Kokkalai, College of Veterinary and Animal Sciences, Mannuthy, during the period from December 2003 to May 2005.

All the animals were subjected to detailed clinical, radiological, haematological and serum biochemical evaluations before application of acrylic fixator and also postoperatively at two weeks interval upto sixth week or until the removal of the implant.

The net cost required for application of acrylic fixator was far less than that for stainless steel external fixator.

Closed approach for reduction and retention of fracture could be employed satisfactorily in stable fractures and there was early return of functional limb usage and faster fracture healing.

Use of only two pins in a fragment, use of smooth pins, drilling all pins at almost parallel to each other, drilling pins through fracture line and fixing the acrylic bar close to the skin leaving only one centimetre between skin and the bar did not cause any adverse effects, but gave satisfactory results.

Early return of sound functional limb usage following fixation with acrylic ESF was remarkable. All the animals, except three, could make slight ground contact with the fractured leg by the third postoperative day and had apparently normal gait by the fourth week of observation with full weight bearing on the affected limb. Case Nos. 5 and 9 (weighing 20 kg and 19 kg respectively), with fracture of tibia immobilized with bilateral acrylic fixator and Case No. 10 (weighing 30 kg) with fracture of tibia immobilized with bilateral fixator; one with acrylic and other with stainless steel connecting bar, had poor limb usage which returned to normal only after fixator removal. At the same time, Case Nos. 1 and 8 (weighing 16 kg and 25 kg respectively) with radial fracture, immobilized with bilateral fixator, one with acrylic and other with stainless steel connecting bar had early return of sound functional limb usage.

Rectal temperature, pulse rate and respiratory rate showed variation within the normal range during the period of observation in all the animals.

Loosening of the proximal most pin occurred in Case Nos. 2, 3 and 4, by fourth week of observation, where type I acrylic fixator was used, but none of them affected the fracture healing significantly.

Damage to acrylic bar occurred in Case Nos. 7 and 9. In Case No.7, with femoral fracture, it was due to the strong muscle pull on the femur fragments, which, the one centimetre diameter acrylic bar failed to tolerate and resulted in implant failure. In Case No.9, breakage was due to severe mutilation by the animal and the breakage was between the two pins in the proximal fragment, there was no implant failure and it could be managed by connecting another acrylic column farther to the one already present.

Mutilation of any kind on the implant was exhibited by four animals, but severe mutilation was shown by only one of them.

Mild pin tract drainage occurred in four animals and pin tract sepsis resulted in one animal.

Sufficient alignment and apposition between the fracture fragments could be achieved following application of acrylic fixator. Some degree of malalignment occurred in Case Nos. 3, 5, 6 and 11, but the way the malalignment got nullified with progressive callus formation resulting in restoration of normal straight line alignment of the bone was noticeable. However, significant angulation between the bone fragments occurred in Case Nos. 2 and 9.

The fracture gap in all the cases was found progressively getting filled up with callus. Rate of callus formation varied with age of the animal, type of fracture and stability of the apparatus. Sufficient callus was formed by fourth week of observation, in Case Nos. 3 and 6 which belonged to age group of less than one year, while it took more than six weeks for callus to form in Case Nos. 4 and 8 which belonged to age group of more than six years of age.

In 50% of the cases, the fracture healed with endosteal callus only while it healed with endosteal and periosteal callus in the rest of the animals. Periosteal reaction of varying degree occurred in most of the cases but did not affect fracture healing or functional limb usage. Osteolysis was noticed around proximal pin tract in four animals, which could be due to loosening of pins. However, no significant alteration in fracture healing was observed.

Acrylic column of one centimetre diameter was found sufficient for use as connecting bar of ESF for immobilization of fractures of radius and ulna and tibia and fibula in animals weighing less than 15 kg body weight. Further research is required to ascertain whether an acrylic bar of one centimetre diameter can be used for femoral fractures. In heavier animals, a bilateral configuration of ESF with acrylic bar on one side and stainless steel connecting bar on the other side provided satisfactory stabilization for radius and ulna. But even though such an apparatus aided in fracture healing without any implant failure in tibial fractures of heavier animals, the stability was less so that return of sound functional limb usage was slower in them.

No noticeable thermal necrosis of bone or soft tissue was produced by the heat generated during exothermic phase of acrylic hardening.

From the study, the following conclusions could be arrived at.

- Acrylic external fixator was an economical, technically feasible, clinically successful and reliable alternative for stainless steel external fixators for the immobilization of fractures of radius and ulna and tibia and fibula in animals of less than 15 kg body weight and it provided early return of functional limb usage.
- In heavier animals, usage of acrylic bar on one side of the type II fixator could reduce the cost of the fixators. It provided good stability in the case of radial fractures.
- Pin loosening and implant failure by breakage of acrylic column occurred while acrylic fixator was used for immobilization of femoral fractures.
- While using acrylic fixators, mild degrees of malalignment that occurred during fracture reduction got nullified to a great extend during callus formation.

- In majority of the fracture cases immobilized with acrylic fixator, healing occurred by the formation of endosteal callus alone. However, healing with endosteal and periosteal callus formation may also occur.
- The patient acceptance of the acrylic fixator was satisfactory and none of the animals exhibited appreciable mutilation of the implant.
- Complications that occurred with the use of acrylic fixator for immobilization of fractures were angulation between fracture fragments, pin loosening, implant failure due to breakage of acrylic bar and pin tract drainage.

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ACRYLIC EXTERNAL SKELETAL FIXATOR FOR THE TREATMENT OF LONG BONE FRACTURE IN DOGS

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ABSTRACT

The efficacy of replacing stainless steel connecting bar in external skeletal fixator (ESF) with acrylic connecting bar was evaluated by using acrylic connecting bar in twelve clinical cases of complete fracture of long bones in dogs presented to the Surgery Units of Veterinary Hospitals of Mannuthy and Kokkalai, College of Veterinary and Animal Sciences, Mannuthy, during the period of December 2003 to May 2005. All the animals were subjected to detailed clinical, radiological, haematological and serum biochemical evaluations before application of acrylic fixator and also postoperatively at two weeks interval upto sixth week or until the removal of the implant.

Type IA or type II acrylic fixators were applied by closed or open approach under general anaesthesia depending on the type of fracture. Transfixation pins were drilled and the acrylic connecting bar was connected directly or following the application of a temporary stainless steel connecting bar, which was removed later. Fixator with acrylic connecting bar on one side and stainless steel connecting bar on the other side was used in three animals.

Acrylic external fixator proved to be an economical, technically feasible, clinically successful and reliable alternative for stainless steel external fixators for the immobilization of fractures of radius and ulna and tibia and fibula in animals of less than 15 kg body weight. In heavier animals, usage of acrylic bar on one side of the type II fixator gave adequate stability in case of radial fractures but not for tibial fractures.

Early return of sound functional limb usage following fixation with acrylic ESF was remarkable. All the animals, except three, could make slight ground contact with the fractured leg by the third post operative day and had apparently normal gait by the fourth week of observation with full weight bearing on the limb.

Loosening of the proximal most pin occurred in Case Nos. 2, 3 and 4, by fourth week of observation, where type I acrylic fixator was used, but none of them affected the fracture healing significantly. Breakage of acrylic bar occurred in Case Nos. 7 and 9. In Case No. 7, the acrylic bar failed to tolerate the strong muscle pull on the fractured femoral fragments and in Case No. 9 severe mutilation by the animal resulted

in breakage of the bar. Four animals exhibited mutilation on the implant, but only one on them showed severe mutilation. Mild pin tract drainage occurred in four animals and pin tract sepsis resulted in one animal. The heat generated during exothermic phase of acrylic hardening produced no apparent thermal necrosis of bone or soft tissue.

Mild to moderate degrees of malalignment occurred following application of acrylic fixator in Case Nos. 3, 5, 6 and 11, which got nullified with progressive callus formation and resulted in restoration of normal straight line alignment of the bone. Marked angulation of the bone fragments occurred in Case Nos. 2 and 9. The fracture gap in all the cases was found to be progressively getting filled up with callus. Rate of callus formation varied with age of the animal, type of fracture and stability of the apparatus. In 50% of the cases, the fracture healed with endosteal callus only, while it healed with endosteal and periosteal callus in rest of the animals. Periosteal reaction of varying degree occurred in most of the cases but did not affect fracture healing or functional limb usage. Osteolysis was noticed around proximal pin tract in four animals, which could be due to loosening of pins. However, no significant alteration in fracture healing was produced.

Acrylic column of one centimetre diameter was found sufficient for use as connecting bar of ESF for immobilization of fractures of radius and ulna and tibia and fibula in animals of less than 15 kg body weight.