

**COMPARATIVE EVALUATION OF PIN-IN-FIBERGLASS CAST, KIRSCHNER-EHMER  
EXTERNAL FIXATIVE AND FIBERGLASS CAST IN THE MANAGEMENT OF RADIUS  
AND ULNA FRACTURES IN NIGERIAN INDIGENOUS DOGS**

**BY**

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**SEPTEMBER, 2016**

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**BY**

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**DEPARTMENT OF VETERINARY SURGERY AND RADIOLOGY,  
AHMADU BELLO UNIVERSITY, ZARIA  
NIGERIA**

**SEPTEMBER, 2016**

## DECLARATION

I declare that the work in this dissertation entitled “**Comparative Evaluation of Pin-In-Fiberglass Cast, Fiberglass Cast and Kirschner-Ehmer External Fixative in the Management of Radius and Ulna Fractures in Nigerian Indigenous Dogs**” has been performed by me in the Department of Veterinary Surgery and Radiology, Ahmadu Bello University, Zaria, under the supervision of Prof. A. Z. Hassan and Dr C. A. Awasum. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

ABDULAZIZ ABDULLAHI BADA

Name of Student

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Signature

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Date

## CERTIFICATION

This dissertation entitled “**COMPARATIVE EVALUATION OF PIN-IN-FIBERGLASS CAST, FIBERGLASS CAST AND KIRSCHNER-EHMER EXTERNAL FIXATIVE IN THE MANAGEMENT OF RADIUS AND ULNA FRACTURES IN NIGERIAN INDIGENOUS DOGS**” by Abdulaziz Abdullahi BADA, meets the regulations governing the award of the degree of Masters of Science of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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## ABSTRACT

Six adult (Three males and three females) dogs were used to evaluate the effectiveness of pin-in-fiberglass cast, Kirschner-Ehmer external fixative and fiberglass cast in the management of surgically created radius and ulna fractures in dogs. These dogs were assigned to three groups (A, B, and C) with each group made up of two dogs. The dogs were all treated under general anaesthesia for midshaft radius and ulna fractures as follows: Group A, pin-in-fiberglass casts; Group B, Kirschner-Ehmer external fixatives; and Group C, Fiberglass casts. The dogs were administered Diclofenac Sodium (4 mg/kg) pre- and post-operative. Minimal increase in vital parameters value post-operative were insignificant ( $P>0.05$ ) when compared with pre-operative values for all the groups. Radiographic evaluation revealed minimal soft tissue swelling and periosteal tissue reaction in all the groups. Adequate callus formation was observed at the 6<sup>th</sup> week for group A and B, and 10<sup>th</sup> week for C post-operative respectively. Group B attained the fastest fracture healing time (7 weeks) followed by Group A (8 weeks) and Group C (12 weeks). Dogs of group A and B bore weight on the operated limb and could walk on day 1 post-operative, while these were observed on day 10 for dogs of group C. Functional and cosmetic appearances were graded as excellent for group A and B, and fair for group C. The overall duration of repair was less for the pin-in-fiberglass cast technique (5.5 hours) than the Kirschner-Ehmer external fixation (22 hours) and the fiberglass cast techniques (8.5 hours). The operative and post-operative management cost analysis of pin-in-fiberglass casting, Kirschner-Ehmer external fixation and fiberglass casting were N11,550, N54,350, N7,750 respectively. However, the potential economic implication to a dog breeder for pin-in-fiberglass casting, Kirschner-

Ehmer external fixation and fiberglass casting techniques were, N191,550N214,350, and N307,750 respectively. Pin-in-fiberglass casting was most economical. Complications associated with wound healing and haematological indices were within acceptable normal limits. Thus, it was concluded that pin-in-fiberglass cast is easily applicable and produce desired result in the managementof radius and ulna fractures in dogs.

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## CHAPTER ONE

### INTRODUCTION

#### 1.1 Preamble

Traumatic injuries to musculoskeletal system are common problems in companion animal practice which most often arises from automobile accidents, cruelty, gunshot, and others (Brinker, 1985; Greg, 2003; AbdulRahman *et al.*, 2006). These injuries, mostly fractures are disruptions or discontinuities of the surface of mesothelial organs generally or skeletal structure specifically (Hassan and Hassan, 2003). Fractures may be classified according to etiologic factors, nature (open or closed), pattern and the degree of stability (Permattei *et al.*, 2006). According to Hassan and Hassan (2003), when stress level on a bone exceed its loading capacity, disruption occurs. Bones form an essential part of the locomotors system, acting as lever arms during motion and resisting the forces of gravity. In addition to these mechanical functions, bones serve an important chemical function, providing a reservoir for mineral homeostasis. Bone also protect and support adjacent tissues (slatter, 1985). The radius and ulna are paired bones that connect the elbow to the carpus or wrist joint. The radius is the major weight-bearing bone of the two (Permattei, 2006). Adeyanju *et al.* (1988) reported that when fractures of the lower front limb occur, both bones are usually fractured together. It is however not uncommon to have a fractured radius and an intact ulna following trauma to a front limb (Permattei, 2006).

Fracture repair in small animals is divided into 3 categories; close reduction with external support, internal fixation alone and internal fixation with secondary external support (Hassan and Hassan, 2003). The use of closed method of immobilization of fracture has a long history in veterinary orthopedics (Charles and David, 1985). Greg (2012) reported that no form of orthopedic therapy has been used and misused more and over a longer period than external coaptation. Casts, splints, slings, and support bandages trace their origins to the earliest medical practitioners (Greg, 2012). In a publication by Charles and David (1985), the ancient Egyptians and the writings of Hippocrates described the use of splints for fracture immobilization in humans. Over the centuries, everything from flour and egg white to animal fat and starch were added to bandages to stiffen them and improve stability at the fracture site (Charles and David, 1985). As has so often been the case, especially in the field of orthopedics, the use of external coaptation gained popularity as a result of treating battle casualties during wartime and in the mid-19th century, plaster of Paris (POP) bandages were developed during the Crimean War (Greg, 2012).

Although Parkhill (Parkhill, 1897), may have been the first person to use external fixation with percutaneous pins in humans, the use of such pins with some sort of external frame for controlling the motion of fractures was found practical in veterinary medicine only after Stader's introduction of his splint (Lewis *et al.*, 1993) and Ehmer's modification of Roger Anderson's device (Anderson, 1934). External skeletal fixation (ESF) is a versatile method of fracture repair that can provide both primary and ancillary support (Palmer *et al.*, 1992; Hassan and Hassan, 2003). ESF consists of multiple percutaneous transcortical pins placed proximal and distal to the fracture, osteotomy, or joint, which are incorporated in a

surrounding external frame (Hassan and Hassan, 2003). Comminuted, infected, and nonunion fractures are amenable to repair by ESF (Bouvy *et al.*, 1993; Hassan and Hassan, 2003). These systems may be applied following closed or open reduction (Aron, 1991). In addition to producing minimal disruption at the fracture site, external fixators can control all the forces acting on the site and are easily removed once the fracture has healed (Sherman, 2004). The stability conferred by a transfixation pin is determined by 2 factors; strength of the construct and its stability at the bone–pin interface (Permattei *et al.*, 2006). The extremely high cost and the high technical skills needed in applying these devices in animal patient has been the major drawback limiting their usage in veterinary practice (Hassan and Hassan, 2003).

Although plaster of Paris remains in use due to its low cost and moldability, its poor radiolucency, susceptibility to moisture and relative density has seen it give way to a range of synthetic casting materials led by the thermomoldables and fiberglass resins materials (Permattei *et al.*, 2006). These casting materials have been shown to be economical, strong, resistant to moisture, and harden rapidly; however, they are less easy to work with and mold faster than plaster of Paris (Weinstein and Ralphs, 2004). The use of cast is usually limited to easily reduced fractures of the radius and ulna and tibia in which the joint above and below the fracture line are immobilized (Permattei *et al.*, 2006). This is because the limited soft tissue covering of these bones makes reduction by closed manipulation possible (Slatter, 1985).

Problem associated with casting is immobilization of joints above and below the fracture site which may result in joint stiffness. But according to Hassan and Hassan (2003), it is often advantageous to do so to maintain stability at the fracture site, thus initiating fracture healing. If immobilization of the joint above or below the fracture site will cause limitation of joint movement following fracture healing, other forms of fracture treatment should be considered (Matthew and Kenneth, 2008).

Meticulous attention to the indications for cast use is the key to success with this technique. These indications include; a closed fracture below the elbow or stifle and above the metacarpal/metatarsal phalangeal joints where it is possible to immobilise the joint above and the joint below the fracture (Greg, 2012). Fractures appropriate for cast immobilisation are those in which closed reduction can be accomplished and maintained with at least 50% of the fracture end surface area in apposition (Simpson *et al.*, 2001).

In a study conducted by Onyilofe (2009) on the prevalence of fracture cases presented to the Small Animal Clinic of Ahmadu Bello University Veterinary Teaching Hospital, Zaria (1970 to 2008), it was found that fractures in dogs accounted for about 54.2% of all fracture cases present to the clinic out of which about 9.5% were fractures of the radius and ulna bones, which in a separate report by AbdulRahman *et al.* (2006) had the highest incidence during the breeding season. These fractures were most often associated with automobile accident (Kadima *et al.*, 2008), cruelty from those individuals who consider their behavior as a nuisance (AbdulRahman *et al.*, 2006) and occasionally falling or jumping off the arms of the owner (Greg, 2003). Management and prognosis of these fractures depends greatly

on the size of the dog involved (Greg, 2003a). Medium to large breeds of less than a year old, carry an excellent prognosis with external coaptation in stable fractures (Muir, 1997)

## **1.2 Statement of Research Problem**

In contemporary times, animals have been exposed to various forms of dangers e.g road traffic accident, gunshot and cruelty (Brinker, 1985), and most often musculoskeletal injuries results (AbdulRahman *et al.*, 2006). Several methods have been employed for the repair of long bone fractures. These include closed reduction, open reduction and internal fixation (Denny, 1993), with minimal success in some (Meeson *et al.*, 2011).

Previously, many external fixation splints were applied and result in a high incidence of pin tract infection and nonunion (Anderson *et al.*, 1997). Consequently external fixation was discouraged as a form of fracture management until a rebirth of interest occurred in the 1970s (Karlstrom and Olerud, 1975). The recent popularity of these external fixation devices has caused a sudden increase in the numbers and types of systems available through most orthopedic supply houses (Ann and Dianne, 2005). Incomplete or complete transverse, diaphyseal fracture of long bones such as the radius, ulna, and fibula without marked displacement can be manage by closed reduction via external fixation and immobilisation (Adeyanju *et al.*, 1988) but the major drawbacks to most of these new devices are their extremely high cost couple with the lack of availability of the complete kits, and they require quite some technical skill for their application (Hassan and Hassan, 2003; Permattei

*et al.*, 2006; Meeson *et al.*, 2011). External fixative are also known to be bulky and heavy hence posing a burden to the animal (Shahar, 2000; Hassan and Hassan, 2003).

### **1.3 Justification of the Study**

Over the past 2 decades, there has been a global paradigm shift from more invasive to less invasive approach for long-bone fracture reduction and many treatment modalities have been proposed for these fractures such as those of the radius and ulna bones (Matthew and Kenneth,2008). The ideal objective of fracture treatment is to provide a completely rehabilitated patient as quickly as possible (Greg, 2012). There is increasing number of automobile accidents maybe because there is no enforced leash law in Nigeria (Emmanuel, 2010). Thus there is need to investigate materials and methods that would aid in the management of fracture sustained from accidents or otherwise.

The standard orthopedic implants for example external fixatives are often difficult to come by and if gotten are usually relatively expensive (Emmanuel, 2010). External fixatives available are mostly for humans and are often cost prohibitive for use by veterinarians (Stiffler, 2004). External coaptation alone have resulted in more complication and delayed healing (Hassan and Hassan, 2003), so that more modern external fixatives are needed (Carmichael, 1991). At this point, it is important to note that the inherent complications associated with external coaptation, unavailability of veterinary variants of these external fixatives coupled with high prohibitive cost compounded with sentimental pet owners, it

would be good to explore a relatively cheaper, technically less tedious, less cumbersome and less invasive small animal orthopedic appliances, for the survival of the small animal practice in Nigeria. This study is therefore intended to evaluate some conventional materials, techniques and approaches in fracture repair in our environment.

#### **1.4 Aim of the Study**

To comparatively evaluate the effectiveness of pin-in-fiberglass, Kirschner-Ehmer external fixative and fiberglass casts in the management of radius and ulna fractures in Nigerian Indigenous dogs

#### **1.5 Objectives:**

1. Assess the level of soft tissue swelling, periosteal tissue reaction, callus formation, weight bearing, union, functional and cosmetic result, and duration of repair of fractures repaired with pin-in-fiberglass cast, Kirschner-Ehmer external fixative and fiberglass casts.
2. Evaluate the cost-to-benefit ratio of the three reduction techniques.
3. Evaluate for evidence of complications post fracture reduction.
4. Evaluate for haematological changes that may accompany the three reduction processes and,
5. Recommend appropriately.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Fracture

##### 2.1.1 Definition

Fracture is dissolution of bony continuity with or without displacement of the fragments (Denny, 1993). It is often accompanied by soft tissue damage of varying degrees: torn vessels, bruised muscles, lacerated periosteum, and contused nerves. Sometimes there are injured internal organs and lacerated skin (Charles and David, 1985). The trauma to soft tissue must always be taken into consideration and is often vitally more important than the fracture itself (Charles and David, 1985).

##### 2.1.2 Causes of fracture

###### 2.1.2.1 *Extrinsic causes*

Direct violence: Trauma is the most common cause of fractures in small animals and is usually due to automobile accidents, cruelty, gunshot, falling from a height and others (Brinker, 1985; Greg, 2003; AbdulRahman *et al.*, 2006). Since direct trauma is rarely delivered in a calibrated amount to a specific place, the resultant fracture is rarely predictable. The amount and direction of force will vary from accident to accident (Charles and David, 1985). Most fractures resulting from violent direct trauma are either comminuted or multiple (Charles and David, 1985; Slatter, 198; Permattei *et al.*, 2006).

Indirect violence: Fractures due to indirect trauma are more predictable than those caused by direct trauma. Generally a force is transmitted to a bone in a specific fashion and at a "weak link" within the bone, causing a fracture to occur(Charles and David, 1985). Bone exhibits specific failure or fracture patterns associated with different modes of loading (Gilley and Gold, 2006a). Such loading includes;

Bending forces:Bending fractures occur when force is applied to a specific focal point on a bone to the extent that the traumatic force overcomes the elastic limit of the bone diaphysis (Gilley and Gold, 2006a). The initial effect of a bending force is a cortical break opposite the site of the trauma (Gilley and Gold, 2006a). The periosteum will remain intact on the side of the force while tearing over the fracture on the opposite side (Gilley and Gold, 2006a). With additional force, the entire bone snaps, with attendant tearing of vascular and soft tissue structures within or on the diaphysis (Permattei *et al*, 2006). Bending fractures are generally oblique or transverse, or they may have a butterfly fragment (Charles and David, 1985).

Torsional forces: Torsional fractures occur when a twisting force is applied to the long axis of a bone (Gilley and Gold, 2006a). Usually this is a result of one end of a bone being placed in a fixed position while the other end of the bone is forced to rotate (Permattei *et al.*, 2006). The resulting fracture will be a very long spiral with sharp points and often sharp edges. It is possible for the sharp points or edges to compromise soft tissues or to cut through the skin

and result in an open fracture (Slatter, 1985). Torsional forces generally result in short or long spiral fractures (Charles and David, 1985; Slatter, 1985).

**Compression forces:** Compressive forces along the long axis of a bone may force the smaller diaphyseal or metaphyseal portion of a bone to impact into the larger epiphysis: bony substance is thereby crushed (Slatter, 1985). Similarly, a compressive force directed along the axis of the spine may result in collapse of a vertebral body (Charles and David, 1985). For compressive force to result in fracture, one end of a bone must be in a fixed position while the other end is forced toward the fixed end (Gilley and Gold, 2006a). Compressive forces result in impacted fractures or compression fractures (Charles and David, 1985; Slatter, 1985).

**Shearing forces:** A shearing fracture is caused by a force transmitted along the axis of a bone, which is then transferred to a portion of the same bone that lies peripheral to the axis or across a joint to other bones that are not protected by the axis of the bone. The force shears off that bony portion unable to continue transmission of the force along the axis (Charles and David, 1985). The fracture line in a shear fracture will be parallel to the direction of the applied force. Shearing forces result in the fracture of bony prominences not placed along the direct axis of a diaphysis (Charles and David, 1985; Slatter, 1985).

### *2.1.2.2 Intrinsic causes*

Fractures due to muscular action: Fractures caused by violent contraction of a muscle are called avulsion fractures (Gilley and Gold, 2006a). They may occur because of violent isometric contraction but are associated more commonly with trauma that results in forceful muscular shortening (Gilley and Gold, 2006a). These fractures frequently occur in immature animals while the physal plate remains open (Charles and David, 1985). Such muscular forces are more likely to separate a cartilaginous union than the eventual bony union of mature animals. Avulsion fractures affecting bony prominences that serve as the major origin or insertion of a muscle are seen routinely (Charles and David, 1985). The processes commonly avulsed include the acromion, scapular tuberosity, greater humeral tubercle, olecranon, ischial tuberosity, greater trochanter, tibial tuberosity, and the calcaneus of the fibular tarsal bone (Charles and David, 1985; Slatter, 1985).

Pathologic fractures: Pathologic fractures occur because of underlying bony or systemic disease that causes one, many, or all bones of an animal's skeletal system to be abnormal and thus more susceptible to fracture (Charles and David, 1985; Gilley and Gold, 2006a). Pathologic fractures may occur from any type of trauma: bending force, torsional force, compressive force, or shearing force (Gilley and Gold, 2006a). Often the only force necessary to cause fracture is the animal's weight; thus, spontaneous fracture occurs without overt trauma (Charles and David, 1985; Slatter, 1985). Pathologic fracture may occur through any of the following types of bony pathology: neoplasia, bone cysts, nutritional hyperparathyroidism, localized bone infection (osteomyelitis), osteoporotic bone caused by

disuse following prolonged external fixation or removal of a rigid internal device (Charles and David, 1985)).

### **2.1.3 Classification of fractures by type**

Fractures are classified into many types based on the severity of the fracture, whether it communicates through the skin, the shape of the fracture line, or the anatomical location of the fracture within an individual bone (Seyed, 2006).

#### *2.1.3.1 Incomplete fractures*

An incomplete fracture implies that a bone has not completely lost continuity; some portion of the bone remains intact (figure 2.1). There are several types of incomplete fractures (Seyed, 2006).

**Greenstick fracture:** As the name implies, a greenstick fracture resembles the break that results when a supple green branch of a tree is bent and breaks incompletely (Seyed, 2006). Usually the side opposite the bending force fractures completely, while the side under the force remains intact. Since a portion of the bone cortex remains intact, this fracture cannot override and result in limb shortening; however, the limb may deform along its axis at the point of the bending force (Charles and David, 1985)

**Fissure fracture:** Cracks or fissure lines will occur when direct trauma is applied to any long or flat bone. Generally the fissures are formed in one cortex of the bone and are covered by

an intact periosteum (Charles and David, 1985). Bones may have single or multiple fissure lines of any configuration: transverse, oblique, spiral, longitudinal, or radiating from a central point (Seyed, 2006). Since fissure fractures occur only in a single cortex and represent an incomplete fracture, the fractured bone should maintain its normal shape (Charles and David, 1985)

**Depression Fracture:** Depression fractures represent areas in which multiple fissure fracture lines intersect(Seyed, 2006). With sufficient force, the entire area will depress from the direction of force(Seyed, 2006). This usually occurs in the calvarium, the maxilla, or the frontal bone areas of the head (Charles and David, 1985).

#### 2.1.3.2 Complete fractures

Complete fractures are indicated by the complete loss of bony continuity, allowing overriding and deformation (Seyed, 2006; Charles and David, 1985). Complete fractures are far more common than incomplete fractures. They may be classified further by the shape of the fracture line. The following system according to Charles and David (1985), describes complete fractures.

**Transverse fracture:** Transverse fracture implies a fracture line that is transverse to the long axis of the bone (Figure 2.1)(Seyed, 2006). Transverse fractures may be relatively smooth or may be rough or have deep teeth on the fractured surfaces(Charles and David, 1985). Most are caused by bending forces. Roughness simplifies anatomical alignment and increases the

likelihood of rotational stability once reduced. Once these fracture fragments have been reduced, fragment override should not occur (Seyed, 2006; Charles and David, 1985)

**Oblique fracture:** Oblique fracture implies a fracture line that is oblique to the long axis of the bone (Charles and David, 1985). The two cortices of each fragment are in the same plane without spiraling (Figure 2.1) (Slatter, 1985). The edges of an oblique fracture may be rough but are usually smooth (Slatter, 1985). These fractures generally result from bending, with superimposed axial compression(Seyed, 2006). As a result of the obliquity of the fracture line, this fracture tends to override or rotate unless traction is maintained throughout the period of healing (Seyed, 2006; Charles and David, 1985).

**Spiral fracture:** Spiral fracture indicates a fracture line that spirals along the long axis of the bone; it is caused by torsional twisting or rotational forces (Seyed, 2006; Charles and David, 1985). Spiral fractures tend to have extremely sharp points and edges, which frequently accompany soft tissue trauma or an open fracture (Figure 2.1)(Gilley and Gold, 2006a). Reduction of spiral fractures is difficult without constant traction or internal fixation, since these fractures tend to override and rotate into deformity (Seyed, 2006; Charles and David, 1985).

**Comminuted fracture:** Comminuted fracture implies at least three fracture fragments, the fracture lines of which interconnect (Figure 2.1). The individual fracture lines that form the comminuted fracture may be transverse, oblique, or spiral(Gilley and Gold, 2006a). Comminuted fractures are generally caused by high-energy trauma, as typified by

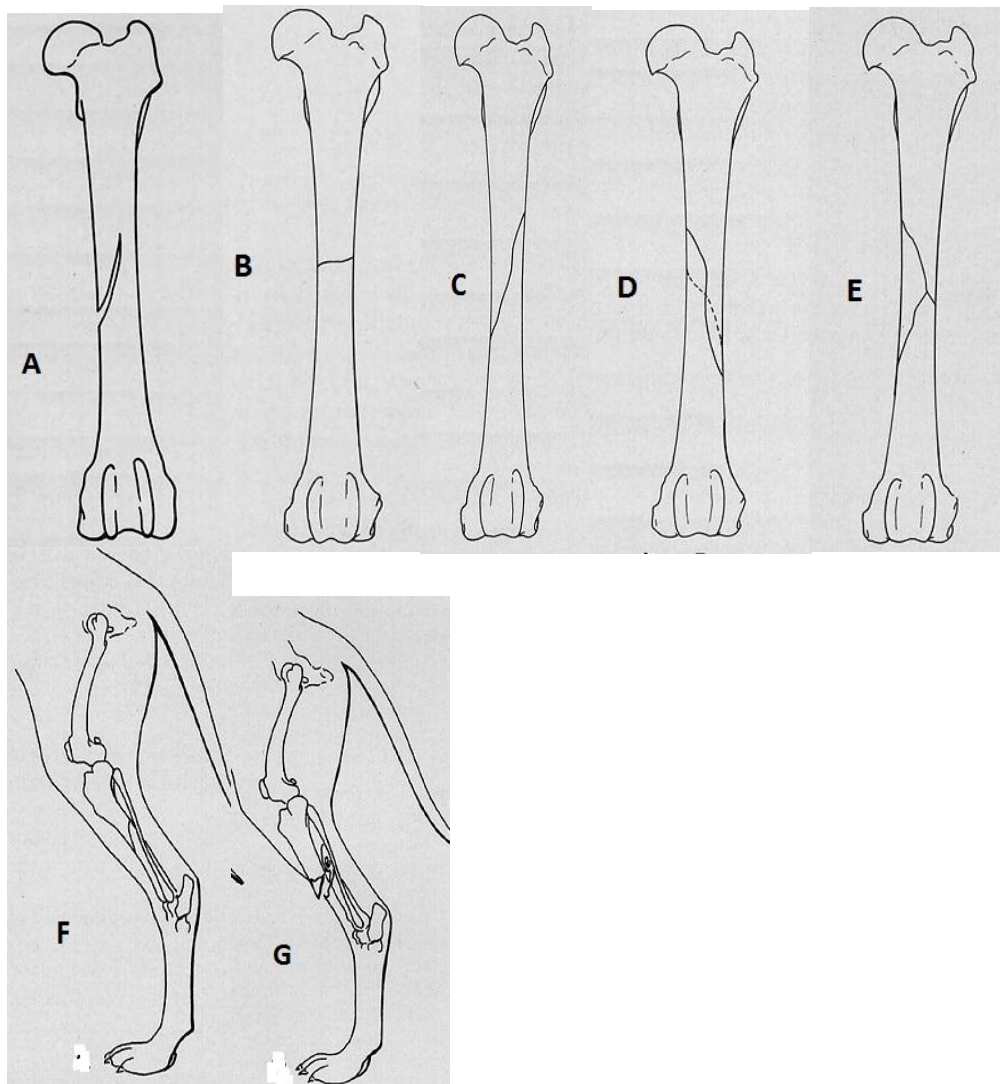
automobile accidents, and are a common type of animal fractures (Charles and David, 1985). Comminuted fractures are difficult to reduce and fix because they have no inherent stability. Constant external traction and alignment or internal fixation is required (Seyed, 2006; Charles and David, 1985).

#### *2.1.3.3 Closed fracture*

A closed fracture implies a fracture that remains encased within the skin and musculature that surround it (Figure 2.1) Charles and David, 1985). No wound or mucosal membrane overlies the fracture. The fracture does not communicate with the outside environment (Permattei *et al.*, 2006). Most fractures in animals are closed. A synonym found in older literature is "simple fracture" (Seyed, 2006; Charles and David, 1985).

#### *2.1.3.4 Open fracture*

Unlike a closed fracture, the open fracture communicates with the outside environment (Figure 2.1). This may occur through a large wound in the soft tissue and skin or through a tiny puncture wound (Seyed, 2006). Regardless of wound size, any fracture that has communicated with the outside is considered an open fracture. Of greatest significance is the potential for contamination of the fracture itself (Permattei *et al.*, 2006). A synonym found in older literature is "compound fracture." (Seyed, 2006).



**Figure 2.1: Types of fractures; A: Incomplete fracture line; B: Transverse fracture line; C: Oblique fracture line; D: Spiral fracture line; E: Comminuted fracture line; F Closed fracture; G: Open fracture. (Source: Charles and David, 1985)**

#### **2.1.4 Classification of fractures by location**

Fractures may be classified by their anatomical location in relation to a specific bone.

Identifying a fracture by location does not indicate whether the fracture is open or closed, nor does it indicate the type of fracture: transverse, oblique, spiral, or the like (Seyed, 2006).

The systems of classification by type and classification by location are compatible and should be used together (Charles and David, 1985).

##### *2.1.4.1 Diaphyseal fracture*

For purposes of description, fractures are termed midshaft if they occur near the axial center of the diaphysis (Permattei *et al.*, 2006). All other fractures of the diaphysis are referred to by breaking the diaphysis into equal thirds (Seyed, 2006). Therefore, fractures can be proximal third, middle third, or distal third of the diaphysis. A proper description would be closed, transverse fracture of the proximal third diaphysis of the femur (Permattei *et al.*, 2006). This classification should suggest a fracture within the skin, as well as the shape, anatomical location, and the bone fractured (Charles and David, 1985).

##### *2.1.4.2 Metaphyseal fracture*

Any fracture within the anatomical metaphysis of a long bone is referred to as a metaphyseal fracture (Permattei *et al.*, 2006). For a clearer description, the terms proximal or distal should be added, such as a closed, oblique fracture of the distal femoral metaphysis (Permattei *et al.*, 2006). Since most metaphyseal fractures are through cancellous bone, they generally heal rapidly (Charles and David, 1985).

#### *2.1.4.3 Epiphyseal plate fracture*

Fracture of the epiphyseal plate occurs in immature animals during the time that the epiphyseal plate remains open and cartilaginous (Charles and David, 1985). Fracture occurs through the zone of hypertrophied cartilage cells (Charles and David, 1985; Permattei *et al.*, 2006). Referral to such fractures should specify the proximal or distal epiphyseal plate (Charles and David, 1985). In mature animals, such fractures are called physal fractures or fracture of the physis (Seyed, 2006). Fractures of the epiphyseal plate are classified further to accurately describe their shape and severity of the fracture (Seyed, 2006). The method of Salter- Harris is the standard classification for all species (Seyed, 2006).

#### **2.1.5 Clinical signs of fracture**

In most instances, the clinical signs associated with fracture make diagnosis uncomplicated; early signs include; lameness, pain, local swelling abnormal, crepitus, abnormal mobility of involved bone, fever, anemia, shock, neurological deficit and in neglected open fracture, gangrene ( O'Connor, 2005). Although all these signs do not always occur in all fractures, combination of these signs are always present (O'Connor, 2005).

#### **2.1.6 Diagnosis of fracture**

In most instances, the clinical signs associated with fracture make diagnosis uncomplicated. Although the owner of an animal often would have observed the fractured bone, locating a fracture can at times be difficult. In these instances, the practitioner needs a systematic, logical approach to diagnose the fracture (Charles and David, 1985).

### *2.1.6.1 Dysfunction*

Dysfunction is most commonly exemplified by lameness. In the orthopaedic examination, the focal site of the lameness must be found and the diagnosis pursued (Charles and David, 1985). Impairment or loss of function is a constant sign of complete fracture and is the result of pain or loss of mechanical support (O'Connor, 2005). Only in cases of incomplete or impacted fracture that the animal may bear some weight on the affected bone (Charles and David, 1985).

### *2.1.6.2 Pain*

Pain over the site of fracture is common. In incomplete fractures this may be the only clinical indication (Hassan and Hassan, 2003). Direct tenderness can be misleading, since it may be due to a contusion or other soft tissue damage caused by a blow (O'Connor, 2005). Indirect tenderness is a more accurate sign of fracture. It is produced by pressure in the long axis of the bone exerted at its two extremities. If there is a break in the continuity of the shaft, such pressure will cause pain at the fracture site that is quite distinct from the pain of injured soft tissue parts (Charles and David, 1985).

### *2.1.6.3 Abnormal posture or limb positioning*

Abnormalities of positioning, when of acute onset and associated with trauma, usually reflect a fracture (Hassan and Hassan, 2003). Deformity, a deviation from the normal anatomical structure, may be caused by displacement of the bony framework as in a fracture or dislocation, but it may also be caused by changes in configuration due to a neoplasm (O'Connor, 2005). The displacement of bone fragments that produces deformity in a fracture may be angular, longitudinal, or rotational (Charles and David, 1985).

#### *2.1.6.4 Crepitus*

Crepitus is a sign of fracture that is considered pathognomonic (Hassan and Hassan, 2003). Bony crepitus is the gritting sensation transmitted to the palpating fingers by the contact of the broken bone ends on each other (Hassan and Hassan, 2003). There are other forms of crepitus (pseudocrepitus) such as occurs in some cases of arthritis, partial luxations of the patella, or luxations of the coxofemoral joint (Permattei *et al.*, 2006). The absence of crepitus however does not necessarily indicate the absence of a fracture (Charles and David, 1985).

#### *2.1.6.5 Radiographic signs*

Fracture, either diagnosed or suspected, should be documented by radiography (Denny, 1993; Hassan and Hassan, 2003). At least two views including the joints above and below the fracture are needed (Easton, 2006). Fracture of joints or special anatomical locations may require additional radiographs or special positioning (Hassan and Hassan, 2003). Radiographs should be read on a well-illuminated flat surface. If questions about anatomical structures exist, the opposite limb or side of the body may be radiographed for comparison (Easton, 2006). The specific radiographic signs of fracture include: a break in the continuity of a bone, a line of radiolucency when the fragments are distracted, or a line of radiopacity when the fragments are compressed or superimposed (Charles and David, 1985).

## 2.2 Radius and Ulna Bones

### 2.2.1 Anatomy

The radius and ulna are paired bones that connect the elbow to the carpus (Sardinas and Montavon, 1997). The radius is the main weight-supporting bone while the ulna bone supports very little weight (Permattei *et al.*, 2006). The anatomy of the radius and ulna has been well described by several authors (Miller *et al.*, 1964; Sisson and Grossman, 1975; Anderson and Anderson, 1994; Boyd *et al.*, 2001). The radius is formed proximally by the oval and concave radial head, which articulates with the humeral capitellum (Anderson and Anderson, 1994). The metaphyseal area tapers slightly to become the flattened radial diaphysis (Figure 2.2). The diaphysis is of uniform shape, flattened cranio-caudally, and curves slightly as it moves from a lateral position at the elbow to a medial position at the carpus (Anderson and Anderson, 1994). Distally the metaphysis enlarges and enters the epiphysis (Permattei *et al.*, 2006). The distal epiphysis has a concave articular surface that sits upon the radial carpal bone (Permattei *et al.*, 2006). A medial pointed prominence, the styloid process serves as proximal attachment of the medial collateral ligament (Anderson and Anderson, 1994).

The proximal ulna is formed by a large bony process, the olecranon, which serves as the insertion of the triceps muscles (Anderson and Anderson, 1994). The articular surface, termed the trochlear notch or semilunar notch, articulates with the humeral trochlea of the medial condyle (Boyd *et al.*, 2001). The proximal trochlear notch is formed by the anconeal

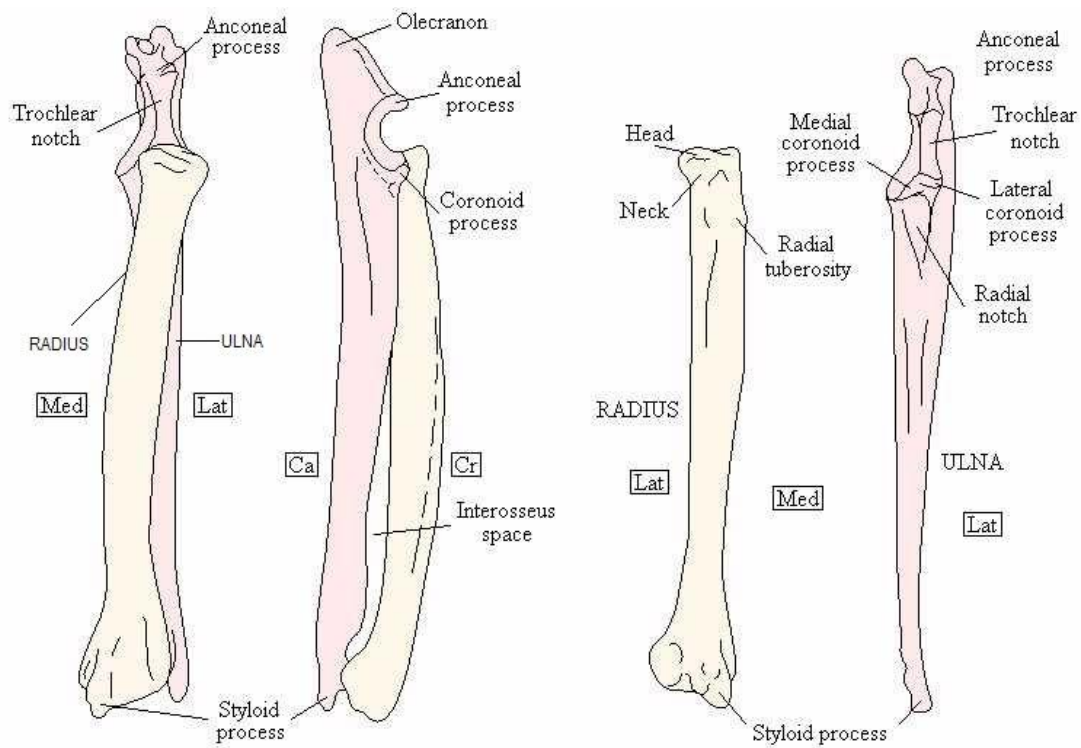
process, while the distal trochlear notch ends in the coronoid process (Boyd *et al.*, 2001). The ulna tapers below the articular surface and curves cranially, and the diaphysis continues to taper along its length, which begins medially at the elbow and ends laterally at the carpus (Permattei *et al.*, 2006). The distal process, the styloid process, is the proximal attachment of the lateral collateral ligament of the carpus (Boyd *et al.*, 2001).

The medullary canal of the radius is usually uniform in size and much wider medio-laterally than cranio-caudally (Permattei *et al.*, 2006). The ulnar medullary cavity is wide proximally and tapered along its entire length. In some small dogs it may be very small or nonexistent (Permattei *et al.*, 2006).

### **2.2.2 Blood supply to the radius and ulna**

The blood supply to the radius and ulna bones has been described (Miller *et al.*, 1964; Sisson and Grossman, 1975; Anderson and Anderson, 1994; Sardinas and Montavon, 1997; Boyd *et al.*, 2001). The major arteries enter the radius through the nutrient foramen on its caudal surface in the proximal one-third of the diaphysis (Sardinas and Montavon, 1997; Boyd *et al.*, 2001). A separate nutrient artery enters the ulna on its cranial surface in the proximal one-third of the diaphysis. Both nutrient arteries are branches of the palmar interosseous artery (Boyd *et al.*, 2001). The immature dog may have diaphyseal blood supply from vessels in the Pronator quadratus muscle originating between the radius and ulna on their medial surfaces. Small breed of dogs have a poor blood supply to the lower fourth of the radius bone, therefore it is more susceptible to being fractured; also healing of

the fracture can take longer than other bones in the body (Permattei *et al.*, 2006). Large breed of dogs have a much better blood supply to this region, therefore a very substantial force needs to be applied to the bone before a fracture develops (Permattei *et al.*, 2006).



**Figure 2.2: Bone anatomy of the radius and ulna bones (Source: University of Bristol, 2000)**

### **2.2.3 Fractures of the radius and ulna bones**

Fractures of the radius and ulna is one of the commonest fractures in dogs which comprises about 17% of the fractures seen in small animal practice (Greg, 2003), with highest incidence during the breeding season (AbdulRahman *et al.*, 2006). Adeyanju *et al.*, (1988) reported that when fractures of the lower front limb occur, both bones are usually broken together, however, it is not uncommon to have a fractured radius and an intact ulna following trauma to a front limb. Shaft fractures of the radius and ulna occur at all levels; however, fractures of the distal one-third of the radius and ulna are the most common (DeAngeliset *al.*, 1973). Fractures may be complete or incomplete and may include one or both bones (Kadima *et al.*, 2008). The level of the fracture site may be the same in both bones or may be widely separated (Greg, 2003). Fractures of the distal one-third of the radius and ulna are associated with a higher incidence of delayed union or nonunion, which has been related to the precarious blood supply of this area in small breed dogs (Sumner-Smith, 1970). Most animals that have radial and ulnar fractures will present non-weight-bearing on the affected limb, but occasionally animals with greenstick fractures or nondisplaced epiphyseal injuries may present weight-bearing. Most forelimb fractures, however, are displaced and unstable at the time of presentation (AbdulRahman *et al.*, 2006). The small muscle mass surrounding the radius and ulna on the forelimb, especially in the distal forelimb, allows open fractures to occur commonly (Permattei *et al.*, 2006). Biplane radiographic techniques are used to establish the extent of the fracture and for assessing treatment and prognosis (Permattei *et al.*, 2006). The age of the patient is significant in choosing fixation techniques as well as in determining prognosis. Likewise, the size of the

animal seems to be very important in the prognosis. The smaller the dog, the more difficult it may be to achieve healing, probably as a result of diminished surface contact. Thus the combination of age and size makes the determination of treatment modality for a radial and ulnar fracture dependent upon the individual animal (Jeff, 2004). Treatment regimens may vary markedly yet produce equally good results (Permattei *et al.*, 2006)

## **2.2.4 Management of fractures of the radius and ulna**

### *2.2.4.1 Closed reduction and external coaptation*

External coaptation has been shown to be a very effective means of stabilizing a fracture when used properly (Jeff, 2004). As a general rule, external coaptation is an acceptable mode of fracture repair for young animals that are not older than 1 year of age (Oakley, 1999). Closed reduction has been achieved with the integument largely intact and is suitable when bone fragments are palpable and can be aligned by external manipulation (Hassan and Hassan, 2003). This technique is used whenever fractures of the radius and ulna can be reduced to the point at which the displacement is not more than one half the width of the diaphysis of the broken bones (Hassan and Hassan, 2003). Axial and rotational alignment is usually corrected, and the fracture fragments should be inherently stable after reduction so overriding does not occur (Permattei *et al.*, 2006). If these criteria are met, radius and ulna fractures can be safely treated with external coaptation (Charles and David, 1985; Permattei *et al.*, 2006). Adequate reduction with less soft tissue trauma is often accomplished if gentle traction is applied first (Permattei *et al.*, 2006). Fractures of the radius and ulna, for instance, are often treated by suspension of the limb using the hanging limb traction technique which

provide a gentle traction for 10 to 20 minutes prior to closed reduction (Permattei *et al.*, 2006). The reduction itself is usually accomplished by placing the elbow joint in flexed position and then re-establishing the axis of the bone with proper rotation. Flexion of the elbow releases some tension on the extensors of the forearm, making reduction easier. External coaptation has several advantages when compare to other forms of repair (Permattei *et al.*, 2006). First, there is minimal distruption at fracture site. Secondly, no implant is introduced into the fracture site and this reduces the chance of infection in the future (Jeff, 2004). External coaptation involves the use of splints, plaster of Paris, fiberglass cast etc. (Jeff, 2004; Permattei *et al.*, 2006).

**Splints:** These are rigid applications for the immobilization of long bones such as those of radius and ulna (Hassan and Hassan, 2003). They include the Thomas, wood and metal splints. Splints are applied after alignment of the fracture, bandages or tapes are then applied to secure the splints (Hassan and Hassan, 2003). The joint above and below the fracture are always immobilized along the fracture (Permattei *et al.*, 2006). Because of nature splints, transverse fractures are best suited for this type of repair (Hassan and Hassan, 2003; Permattei *et al.*, 2006). Temporary splints and bandages should be considered with open fractures of radius and ulna occurs. This allows the materials to be removed dailywhile the wounds are appropriately treated (Beardsley and Schrader, 1995). This assists in reducing the risk of infection, and provides ample time for the swelling and tissue damage to decrease before definitive repair in considered (Beardsley and Schrader, 1995)

**Plaster of Paris (POP):** This is historically the most enduring method which has been used since time immemorial but became more popular in the mid-19th century (Greg, 2012).For

reasons of economy and acceptable performance, plaster casts find widespread application in veterinary orthopaedics; hence, has been the most frequently used external coaptation device for radius and ulna fractures (Charles and David, 1985). POP bandage consist of rolls of muslin stiffen with either dextrose or starch impregnated with hemihydrate of Calcium Sulphate (MacDonald *et al.*, 1980). When immersed in water the Calcium sulphate takes up its water of hydration, liberating heat (Arun, 2015). In long bone fractures such as those of radius and ulna, the general principle is that the cast should immobilize the joint above and the joint below the fracture line (Hassan and Hassan, 2003). It has the advantage of being easily handled, with the ability to conform completely to any surface. Its strength capabilities are more than adequate for small-animal application (Charles and David, 1985; Hassan and Hassan, 2003). A minimum of 50 % contact area between the fragments is required for healing to progress. Because of the nature of the plaster cast, transverse fractures of the radius and ulna are amenable with this type of technique (Jeff, 2004).

Fiberglass Cast: Although plaster of Paris still remains in use in the management of radius and ulna fractures, due to its low cost and moldability, poor radiolucency, susceptibility to moisture and relative density has seen it give way to a range of synthetic casting materials led by the fiberglass resins materials (Permattei *et al.*, 2006). Fiberglass cast is a fiber reinforced polymer made of a plastic matrix reinforced by fine fibers of glass (Nawy, 2001). Fiberglass casts just like the Plaster of Paris are also suited for transverse fracture of the radius and ulna bones. This is because the primary force involved is a bending force which is easily neutralized by the cast. In contrast, shearing, compressive, and distractive forces are not neutralized by the application of only cast. This makes the use of cast as the primary

technique for the repair of oblique or comminuted fracture difficult (Leighton,1991).All of these splinting materials have special advantages along with certain disadvantages. Their greater cost in comparison with plaster has not brought them into wide acceptance in small-animal veterinary practice in the management of these fractures (Permattei *et al.*, 2006; Meeson *et al.*, 2011)

#### *2.2.4.2 Open reduction and internal fixation*

Internal fixation provides mechanical stability to a fractured bone allowing early weight bearing, early use of the limb, and rapid bone healing (Hassan and Hassan 2003). Open reduction and internal fixation of closed fractures is usually performed when the fracture is inherently unstable, as with comminuted fractures or long oblique fractures, or when closed reduction is not possible or a simple open reduction is unstable (Jeff, 2004; Permattei *et al.*, 2006). Although internal fixation provide excellent mechanical support, it is usually disruptive to the biologic environment (Kevin, 2004). There are various methods of internal fixation in the management of radius and ulna fractures.

Plate and screw: Application of bone screw and plate for radial fracture is an adaptable and very stable method of fixation allowing for immediate weight bearing, but requires a standard surgical approach (Milovancev and Ralph, 2004). The disadvantage of the surgical approach in bone plating is that it results in some disruption of local blood supply (Permattei *et al.*, 2006). Bone plate is applied to either the medial or cranial surface of the radius, and no attempt is made to stabilize the ulna (Permattei *et al.*, 2006). If the radius heals and the ulna is in contact, the ulna will heal (Charles and David, 1985; Permattei *et al.*, 2006).

Exception to this are fractures of the proximal radius, as the medial aspect of this bone is not suitable for plating (Sardinas and Montavon, 1997). Plate and screws are available in a variety of lengths, sizes, thread types and metals to enhance greater functionality (Kevin, 2004). Screws are placed by predrilling a hole, measuring the length of the screw needed, pretapping grooves for the screw threads and then inserting the screw under low torque (Kevin, 2004). Multiple types of plates may be used. A dynamic compression plate is usually recommended for transverse fractures while long oblique or spiral fractures are amenable to lag screw with subsequent neutralization plate application (Milovancev and Ralph, 2004). Severely comminuted fractures can be addressed with a buttress plate. For extremely distal fractures such as those of Salter Harris, a T plate is useful in dogs (Milovancev and Ralph, 2004).

Intramedullary (IM) nailing: Intramedullary pinning is not feasible nor is it recommended in the repair of radius fractures (Milovancev and Ralph, 2004). Pin placement generally necessitates invading either the elbow or carpal joints, which can result in severe future degenerative changes of the affected joints (Hassan and Hassan, 2003). In addition, the narrow medullary cavity of the radius does not lend itself to IM pinning because of the anterior curvature of the radius which make it very difficult for a straight pin to pass (Permattei *et al.*, 2006). In contrast, IM pinning of the ulna is a feasible and practical option for providing ancillary support of a radial repair. Usually, the pin is driven non-axially from the proximal surface of the olecranon distally as far as possible without penetrating the cortex (DeYoung and Probst, 1993).

External Fixation: External fixators are a good option to consider for open fractures (Milovancev and Ralph, 2004). Their use gives room for invasion of the fracture site and allows for easy implant removal after healing is complete (Permattei *et al.*, 2006). Closed reduction, although preferred, can be challenging (Anderson *et al.*, 2002). Manual distraction of transfixation pins, hanging limb traction, and use of a fracture distractor are all methods that can be used to aid in closed reduction (Harariet *al.*, 1996; Egger, 1998; Permattei *et al.*, 2006). If an open approach is necessary, a minimal approach is used in an attempt to preserve blood supply and avoid causing further tissue trauma (Milovancev and Ralph, 2004). Bilateral transfixation pins are preferred by most surgeons, but the anterior curvature of the radius often disallow their use hence unilateral pins may be preferred (Eager, 1998). Type I frames are applied to the medial or craniomedial aspect of the radius so as to avoid penetration of major muscle masses (Anderson *et al.*, 1997). Type II frames are inherently stronger construct, but requires penetration of muscle masses that may result in increased implant loosening and morbidity (Anderson *et al.*, 1997; Eager, 1998).

## **2.3 Fracture Healing**

### **2.3.1 Preamble**

During the last two decades, our understanding of fracture healing has rapidly evolved. It is known that bone is one of few tissues that can heal without forming a fibrous scar (Permattei *et al.*, 2006). As such, the process of fracture healing recapitulates bone development and can be considered a form of tissue regeneration (Marsel and Einhom, 2010). Once a fracture

occurs, the basic healing process is auto-activated naturally to repair the site (Hassan and Hassan, 2003). Healing involves the differentiation of several tissues (cartilage, bone, granulation, etc.), with different patterns that are directly influenced by the mechanical environment, which is in turn governed by the load applied and the stability of the fracture site. Despite the regenerative capacity of skeletal tissue however, this biological process sometimes fails and fractures may heal in unfavourable anatomical positions, such as delay in healing or even develop pseudo-arthritis or non-unions (Marsel and Einhorn, 2010). When a fracture occurs, the blood vessels of the periosteum rupture, resulting in haematoma and bone necrosis, and the tissue is invaded by polymorphonuclear leucocytes, macrophages and mononuclear cells (Al-Aql et al., 2008). The haematoma is organized by ingrowth of vessels, and fibroblasts produce fibrous tissue (Al-Aql et al., 2008). In this reparative phase, chondrocytes are active and woven bone is laid down by endochondral ossification with the formation of a provisional fibrocartilaginous callus (Einhorn, 2005). Osteoblasts are gradually differentiated and a bridging mineralized callus is formed internally and externally over the fracture. This is called bony union (Einhorn, 2005). Over the ensuing weeks, osseous ingrowth of the callus closes the fracture and the remodeling phase begins (Kitaori et al., 2009). Remodeling goes on for years with increasing deposition of organized mature lamellar bone (Carano and Filvaroff, 2003). If the fracture is repositioned, the normal microscopic architecture of the bone can be recreated (Carano and Filvaroff, 2003).

### **2.3.2 Indirect fracture healing**

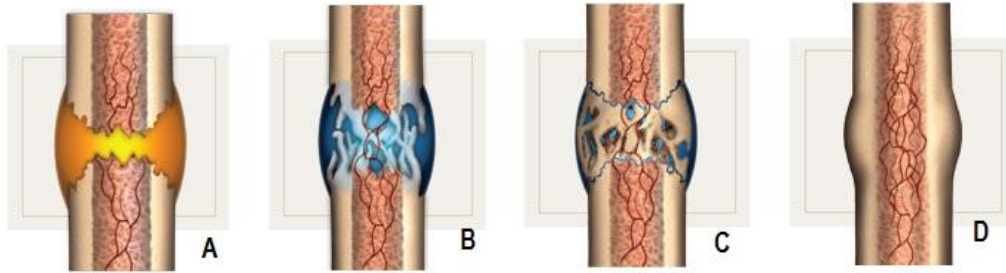
Indirect (secondary) fracture healing is the most common form of fracture healing, and consists of both endochondral and intramembranous bone healing (Gerstenfeld *et al.*, 2006). It does not require anatomical reduction or rigidly stable conditions (Green and Lubahn, 2005). On the contrary, it is enhanced by micro-motion and weight-bearing. However, too much motion and/or load is known to result in delayed healing or even non-union (Green and Lubahn, 2005). Indirect bone healing typically occurs in non-operative fracture treatment and in certain operative treatments in which some motion occurs at the fracture site such as intramedullary nailing, external fixation, or internal fixation of complicated comminuted fractures (Perren, 2002).

#### *2.3.2.1 Stages of indirect (secondary) healing*

The acute inflammatory response: Immediately following the trauma, a haematoma is generated and consists of cells from both peripheral and intramedullary blood, as well as bone marrow cells (Hassan and Hassan, 2003; Sfeir *et al.*, 2005) (Figure 2.3). The injury initiates an inflammatory response which is necessary for the healing to progress. The response causes the haematoma to coagulate in between and around the fracture ends, and within the medulla forming a template for callus formation (Gerstenfeld, *et al.*, 2003).

The acute inflammatory response peaks within the first 24 h and is complete after 7 days, although proinflammatory molecules also play an important role later in the regeneration (Cho *et al.*, 2002). The initial proinflammatory response involves secretion of tumour

necrosis factor- $\alpha$  (TNF- $\alpha$ ), interleukin-1 (IL-1), IL-6, IL-11 and IL-18 (Gerstenfeld, *et al.*, 2003). These factors recruit inflammatory cells and promote angiogenesis (Sfeir *et al.*, 2005).



**Figure 2.3: Stages of secondary bone healing. A: Heamatoma forms at fracture site; B:Cartilaginous and a periosteal bony callus; C: Hard boney callus; D: Bone remodeling(Source: Astha Hospital, 2015).**

Recruitment of mesenchymal stem cells (MSCs): In order for bone to regenerate, specific mesenchymal stem cells (MSCs) have to be recruited, proliferate and differentiate into osteogenic cells. Exactly where these cells come from is not fully understood (Marsell and Einhorn, 2011). Although most data indicate that these MSCs are derived from surrounding soft tissues and bone marrow, recent data demonstrate that a systemic recruitment of circulating MSCs to the injured site might be of great importance for an optimal healing response (Kitaori, *et al.*, 2009).

Generation of a cartilaginous and a periosteal bony callus: Although indirect fracture healing consists of both intramembranous and endochondral ossification, the formation of a cartilaginous callus which later undergoes mineralisation, resorption and then replaced with bone is the key feature of this process (Gerstenfeld, *et al.*, 2003) (Figure 2.3). Following the formation of the primary haematoma, a fibrin-rich granulation tissue forms. (Rahn, 2002). Within this tissue, endochondral formation occurs in between the fracture ends, and external to periosteal sites (Dimitriou *et al.*, 2005). These regions are also mechanically less stable and the cartilaginous tissue forms a soft callus which gives the fracture a stable structure (Dimitriou *et al.*, 2005). At the same time, an intramembranous ossification response occurs subperiostally directly adjacent to the distal and proximal ends of the fracture, generating a hard callus. It is the final bridging of this central hard callus that ultimately provides the fracture with a semi-rigid structure which allows weight bearing (Gerstenfeld *et al.*, 2006).

Revascularisation and neoangiogenesis at the fracture site: Fracture healing requires a blood supply and revascularisation is essential for successful bone repair (Keramariset *al.*, 2008). In endochondral fracture healing, this not only involves angiogenic pathways, but also chondrocyte apoptosis and cartilaginous degradation as the removal of cells and extracellular matrices are necessary to allow blood vessel in-growth at the repair site (Al-Aqlet *al.*, 2008).

Mineralisation and resorption of the cartilaginous callus: In order for bone regeneration to progress, the primary soft cartilaginous callus needs to be resorbed and replaced by a hard bony callus(Dimitriou *et al.*, 2005) (Figure 2.3). This step of fracture healing, to some extent, recapitulates embryological bone development with a combination of cellular proliferation and differentiation, increasing cellular volume and increasing matrix deposition (Breuret *al.*, 1991). The connection between bone regeneration and bone development has been further strengthened by a recent understanding of the role of the Wnt-family of molecules, which is of great importance in embryology and has also been shown to have an important role in bone healing (Einhorn, 2005). The Wnt-family is thought to regulate the differentiation of pluripotent MSCs into the osteoblastic lineage and, at later stages of development, to positively regulate osteoblastic bone formation (Chen and Alman, 2009).

As fracture callus chondrocytes proliferate, they become hypertrophic and the extracellular matrix becomes calcified (Dimitriou *et al.*, 2005). The peak of the hard callus formation is usually defined by histomorphometry of mineralised tissue, but also by the measurement of extracellular matrix markers such as type I procollagen, osteocalcin, alkaline phosphatase

and osteonectin (Einhorn, 1998). As the hard callus formation progresses and the calcified cartilage is replaced with woven bone, the callus becomes more solid and mechanically rigid (Gerstenfeld *et al.*, 2006).

**Bone remodeling:** Although the hard callus is a rigid structure providing biomechanical stability, it does not fully restore the biomechanical properties of normal bone (Gerstenfeld, 2003). In order to achieve this, the fracture healing cascade initiates a second resorptive phase, this time to remodel the hard callus into a lamellar bone structure with a central medullary cavity (Gerstenfeld, 2003) (Figure 2.3). This phase is biochemically orchestrated by IL-1 and TNF- $\alpha$ , which show high expression levels during this stage (Al-Aqlet *al.*, 2008; Mountziaris and Mikos, 2008). The remodelling process is carried out by a balance of hard callus resorption by osteoclasts, and lamellar bone deposition by osteoblasts (Al-Aqlet *al.*, 2008). The remodelling may take years to be completed to achieve a fully regenerated bone structure (Wendeberg, 1961).

### **2.3.3 Direct fracture healing**

Direct healing does not commonly occur in the natural process of fracture healing. This, since it requires a correct anatomical reduction of the fracture ends, without any gap formation, and a stable fixation (Marsel and Einhorn, 2010). However, this type of healing is often the primary goal to achieve after open reduction and internal fixation surgery (Marsel and Einhorn, 2010). When these requirements are achieved, direct bone healing can occur by direct remodelling of lamellar bone, the Haversian canals and blood vessels. Because

most fractures are managed in a way that results in some degree of motion, primary healing per se is rare (Marsel and Einhorn, 2010). Depending on the species, it usually takes from a few months to a few years, before complete healing is achieved (Rahn, 2002). Primary healing of fractures can either occur through contact healing or gap healing (Rahn, 2002).

#### *2.3.3.1 Contact healing*

If the gap between bone ends is less than 0.01 mm and interfragmentary strain is less than 2%, the fracture unite by so-called contact healing(Shapiro, 1988). Under these conditions, cutting cones are formed at the ends of the osteons closest to the fracture site (Hulse and Hyman, 1993). The tips of the cutting cones consist of osteoclasts which cross the fracture line, generating longitudinal cavities at a rate of 50–100  $\mu\text{m}/\text{day}$  (Hulse and Hyman, 1993). These cavities are later filled by bone produced by osteoblasts residing at the rear of the cutting cone (Rahn, 2002). These result in the simultaneous generation of a bony union and the restoration of Haversian systems formed in an axial direction (Kaderly, 1991; Rahn, 2002).The re-established Haversian systems allow for penetration of blood vessels carrying osteoblastic precursors (Einhorn, 1998). The bridging osteons later mature by direct remodelling into lamellar bone resulting in fracture healing without the formation of periosteal callus (Rahn, 2002)

#### *2.3.3.2 Gap healing*

Gap healing differs from contact healing in that bony union and Haversian remodelling do not occur simultaneously (Kaderly, 1991). It occurs if stable conditions and an anatomical reduction are achieved, although the gap must be less than 800  $\mu\text{m}$  to 0.01 mm (Kaderly,

1991). In this process, the fracture site is primarily filled by lamellar bone oriented perpendicular to the long axis, requiring a secondary osteonal reconstruction unlike the process of contact healing (Schenk and Hunziker, 1994). The primary bone structure is then gradually replaced by longitudinal revascularised osteons carrying osteoprogenitor cells which differentiate into osteoblasts and produce lamellar bone on each surface of the gap (Shapiro, 1988). This lamellar bone, however, is laid down perpendicular to the long axis and is mechanically weak (Shapiro, 1988). This initial process takes approximately 3 and 8 weeks, after which a secondary remodelling resembling the contact healing cascade with cutting cones takes place (Schenk and Hunziker, 1994). Although, not as extensive as endochondral remodelling, this phase is necessary in order to fully restore the anatomical and biomechanical properties of the bone (Shapiro, 1988).

## **2.4 External Skeletal Fixatives**

### **2.4.1 History of external fixatives**

Even though external fixation is considered to be a rather "new" trend in orthopedics and traumatology (Paul, 2003), there are few things in surgery which are actually new, and this also applies to external fixation (David, 2001). In fact it has been something used by physicians and surgeons for thousands of years (Paul, 2003). In the mid 1800's, external fixation would see some substantial growth and evolution, pioneered by physicians and surgeons whose principles are still in use today (Paul, 2003). Through the 1900's, the indications and usage would continue to expand, not to mention the modernization of the

external fixation apparatus (David, 2001). Many surgeons in this era are notable for their work with external fixation, especially GraviIIIizarov, considered to be the father of external fixation (Paul, 2003)

External fixation has an extensive history that can be traced back to the days of Hipocrates (Charles and David, 1985). In those days, external fixation consisted of wooden rods acting as a wooden rods tied around a forelimb acting as a splint(David, 2001). Despite the advances of technology and metallurgy, modern principles of external fixations are still based largely upon its earlier predecessors (Paul, 2003). According to David (2001), the first use of "pins" is credited to Jean-Francois Malgaigne who, in 1840, created a simple metal pin in a leather strap for the percutaneous pin treatment of tibial fractures which in addition he also made an external fixator for patella fractures he called a "griffe", or "claw." (David, 2001) Later that decade, Rigaud took this concept to the next level by embedding the spikes into the bone itself for a fractured olecranon(David, 2001).

According to Paul (2003), in 1902, Albine Lambotte, a Belgian surgeon, was the first to develop an external fixation device which allowed the placement of transfixation pins in any needed direction and were connected to the connecting rod by adjustable clamps. In addition Lambotte was also credited with developing the first self-tapping threaded pin (Paul, 2003).

As part of history, one must acknowledge the works of GraviI A. Ilizarov, whose frame design bears his name (Permattei *et al.*, 2006). During the World War II, he treated war veterans using his system from parts of bus factory (Rozbruch and Ilizarov, 2006). Much

like spokes on a wheel, the design had several Kirschner wires passing through the bone while been secured to the ring (Paul, 2003).

The use of external fixators to treat human injuries was first reported in 1897 (Parkhill, 1897). A fixator specifically for veterinary use was designed in the late 1940s by Ehmer, based on human design (Bini and Syam, 2014). External fixation developed a bad reputation as its use in human declined following high incidence of complications associated with the treatment of fractures during World War II (Bini and Syam, 2014). As external fixation technique matured, however, it went through many changes as the various complications were addressed (Paul, 2003).

#### **2.4.2 Component of external skeletal fixatives**

An amazing variety of fixators are available throughout the world, most developed for human use (Permattei *et al.*, 2006). Because of their size and cost, most are not practical for veterinary use, although some are adaptable, especially those designed for hands and forearm use (Permattei *et al.*, 2006). Most external fixators used in veterinary medicine today are based on the Kirschner-Ehmer adaptation of Roger Anderson splint (Sherman, 2004). According to Bini and Syam (2014), the main components of an external fixator are:

- Fixator pins
- Connecting bars
- Clamps

#### 2.4.2.1 Fixator pins

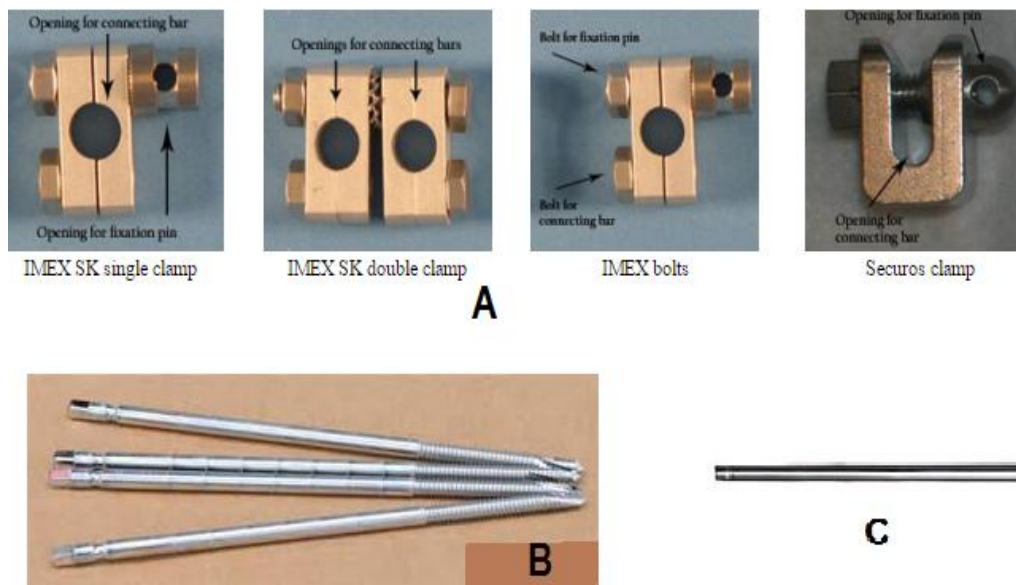
Most fixator frames are fastened to the bone by stainless steel fixation pins that must penetrate both first and second cortices (Sherman, 2004; Permattei *et al.*, 2006) (Figure:2.4). Fixation pins come in several different varieties and lengths (Bini and Syam, 2014). Increasing the number of pins in a fracture fragment increases the overall rigidity of the device (Sherman, 2004). If the fixator pin penetrates only one skin surface and two bone cortices, it is called a *half pin*, and it is the only pin used in type I frame (Permattei *et al.*, 2006). Those pins that penetrate two skin surfaces and two bone cortices are called *full pins* and are the bases of type II frame (Crauss *et al.*, 2003). These pins may be smooth, partially threaded, or fully threaded in design; the latter are not widely used because of their lack of stiffness (Bini and Syam, 2014). Smooth pins are good for use in young patients with simple, stable fractures, with very small bones (Permattei *et al.*, 2006). They are inexpensive, but can prematurely loosen. Partially threaded are either end-threaded or center-threaded pins. Thread can be cut from the stock of the pin (negative-thread-profile pins) or can be built up (raised thread, enhanced thread, or positive-thread-profile pins) (Permattei *et al.*, 2006). Typically, a mixture of threaded and smooth pins are used in most frames (Permattei *et al.*, 2006; Bini and Syam, 2014). Kirschner-Ehmer clamp allow the use of pin diameters up to  $\frac{5}{64}$  inch (2.0 mm) in small clamps to  $\frac{1}{8}$  inch (3.2 mm) in medium clamps, and to  $\frac{3}{16}$  inch (4.8 mm) in large clamps (Permattei *et al.*, 2006). The fixation pin size chosen depend on the size of the animal and bone involved, and as a general rule, the diameter of the pin should not exceed one-third the width of the bone into which it is being placed, otherwise stress-related fracture may occur (Bini and Syam, 2014).

#### 2.4.2.2 *Connecting Bars*

The connecting bar, or *rod*, functions to connect the fixation pins clusters attached to the bone fragments (Bini and Syam, 2014) (Figure:2.4). The resulting bone-frame construct provides enough stability to allow the bone to heal while maintaining functional use of limb. The bars are typically solid stainless steel rods with diameter between  $\frac{1}{8}$  to  $\frac{1}{4}$  inch (3.2 and 6.5mm) (Permattei *et al.*, 2006). Several authors have reported the use of carbon fiber, titanium, and aluminium, acrylic materials to allow for increased connecting bar diameter and stiffness without significantly increasing weight (Bini and Syam, 2014; Permattei *et al.*, 2006; Browner *et al.*, 2009).

#### 2.4.2.3 *Clamps*

Clamps function to secure the fixation pins to the connecting bars (Bini and Syam, 2014). Traditionally, external fixator clamps are designed as part of the Kirschner-Ehmer system and have been marketed and available as single or double clamps (Figure 2.4). Single clamp grip the fixation pin and connecting bar and are rotatable in two axis: that of the fixation pin and that of the bolt (Permattei *et al.*, 2006). Single clamps are the only clamps required for one-plane frames. Where two connecting bars need to be connected to each other, double clamps are used, in which two clamps rotate around the bolt axis (Bini and Syam, 2014). The design of the double clamp allows construction of multiple frames (Permattei *et al.*, 2006).



**Figure 2.4: Components of external skeletal fixative. A: Clamps; B: Fixator pins; C: Connecting bar (Source: Gilley and Gold, 2006).**

### 2.4.3 Classification of frame configurations

For many years the various types of frame were described and named in a variety of ways. Gradually, however, some uniformity of nomenclature has been emerging which is necessary for easy communication (Permattei *et al.*, 2006). According to Permattei *et al.*, (2006), the most common nomenclature was described by Roe (1992). This was based on how many sides of the bone there were connecting to the bars and whether the fixation pins occupy up to or more than 90° of the bone circumference (Gilley and Gold, 2006).

#### *2.4.3.1 Type I/Unilateral*

The unilateral frame (figure 2.5), is one that employs one bar connecting two or more pin-gripping clamps, which are attached to half-pins (Sherman, 2004). It is the simplest configuration (Bini and Syam, 2014). This category includes Parkhill's original bone clamp, Lambotte's external fixator, and the apparatuses devised by Stader, Hoffmann, and Wagner (Browner *et al.*, 2009). Although type I splints can be used in either one or two planes, perhaps the most widely used frame is the type I/unilateral half-pin splint (Sherman, 2004). Such a splint can be further described using the alphanumeric descriptor “IA” or the adjectival form “one plane” (Gilley and Gold, 2006). Further description requires the use of the adjectives “double” or “single” to specify the type of clamps or number of connecting bars (Roe, 1992).

#### *2.4.3.2 Type II/Bilateral one plane*

A bilateral frame (Figure 2.5) is one that employs a rigid bar on both sides of the limb, connected to full pins that transfix the bone (Roe, 1992). Roger Anderson's external skeletal

fixator was of bilateral design(Browner *et al.*, 2009). Because they utilize full pins, these frames are applicable only to the lower limbs, distal to the elbow or stifle (Sherman, 2004). Various combinations of full and half pins are used in these frames and are subclassify as; IIA/Full Pins, IIB/ Full and Half Pins (Permattei *et al.*, 2006).

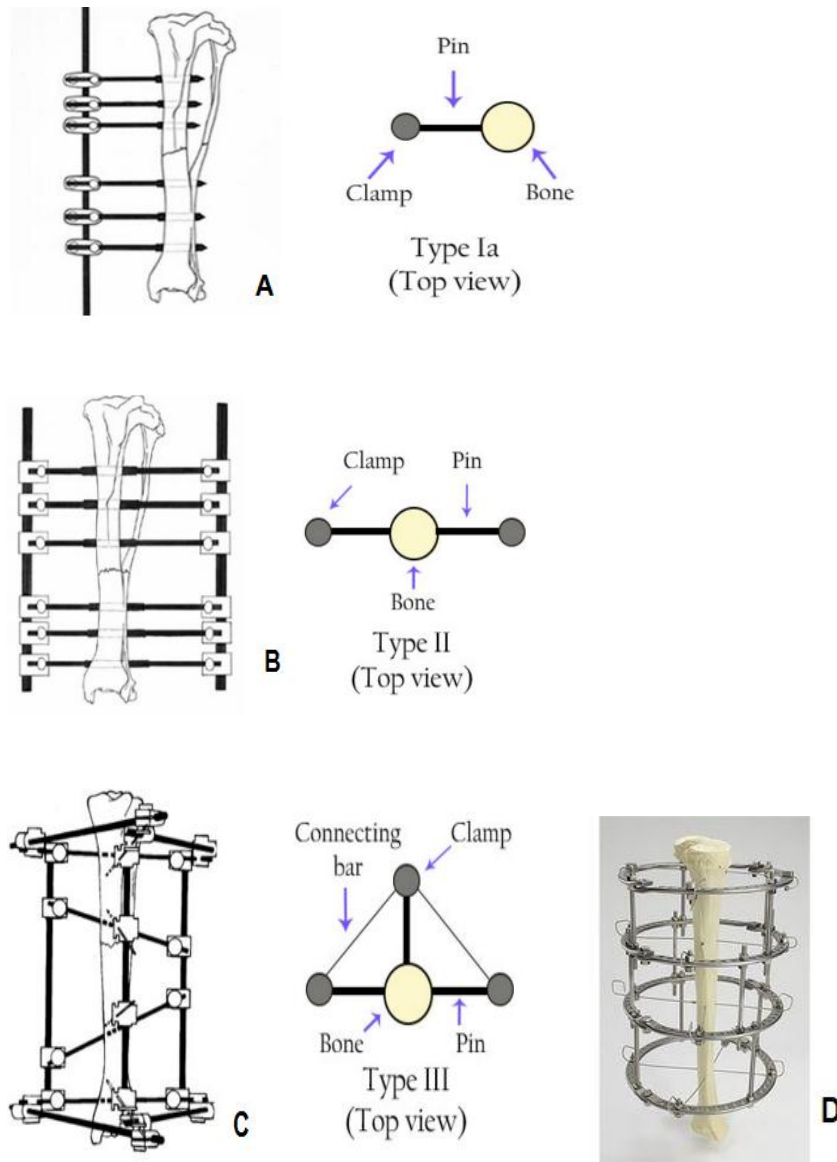
#### *2.4.3.3 Type III/Bilateral two planes*

A bi- or multiplanar frame(Figure 2.5), utilizes combination of half-pin and full-pin splintage(Browner *et al.*, 2009). Type I and II systems are placed at 90 degree to each other and the frames are interconnected (Sherman, 2004).This frame is used only in situation of extreme instability(Permattei *et al.*, 2006).

#### *2.4.3.4 Ring*

Unlike other frames that depend on stiff fixation pins for stability at the bone-pin interface, the ring fixator(Figure:2.5), pioneered by Ilizarov utilizes small diameter, flexible Kirschner wires as fixator pins connected to transverse bars that completely encircle the limb (Permattei *et al.*, 2006). Pins transfix the limb and connect to the rings in various locations (Bini and Syam, 2014). By use of threaded connecting rods, the ring can be adjusted to align the bone fragments and to provide either compression or tension on the fragments (Bini and Syam, 2014). Although ring fixators were originally employed for fracture fixation such as in corrective osteotomy for angular deformity or limb lengthening, they seems to have very little veterinary application in fracture repair because they are costly and complex than conventional fixators (Permattei *et al.*, 2006).





**Figure 2.5: Classification of external skeletal fixativesg. A: Type I/Unilateral-Uniplanar configuration; B: Type II/Bilateral-uniplanar configuration; C: Type III/Bilateral-biplanar configuration; D: Ring confuguration (Source: Gilley and Gold, 2006).**

#### 2.4.4 Fixator preparation and fixation

Decreasing postoperative morbidity associated with external skeletal fixation begins during and immediately after surgery (Permattei *et al.*, 2006). Proper application is essential to preventing complications and includes using safe corridors that avoid placing fixation elements through large muscle groups or neurovascular structures, predrilling pilot holes for pin placement, using threaded fixation pins, and ensuring that the construct applied provides adequate stability (Lewis and Bloomberg, 1994). The technique for the application of external fixator has been described by many authors (Aron and Dewey, 1992, Permattei *et al.*, 2006, Rovestiet *al.*, 2007).

#### *2.4.4.1 Fracture alignment*

Fracture alignment using manual force or by gravity traction has been described by (Permattei *et al.*, 2006). Position the animal on its back and place a gauze tape around the paw of the affected limb, then attach this to an infusion stand (Permattei *et al.*, 2006). The length of the attaching material is adjusted to raise the animal slightly off the table so that a portion of the body weight is being supported and thus producing traction on the limb. Traction for 10 to 30 minutes adequately fatigues the muscles and aid in reduction (Permattei *et al.*, 2006)

#### *2.4.4.2 Fixator application*

The technique for the application of external fixator has been described by many authors (Aron and Dewey, 1992; Permattei *et al.*, 2006; Rovestiet *al.*, 2007). Make a release incision through the skin and continue it via blunt dissection through the underlying soft tissues

when placing fixation elements (Rovestiet *et al.*, 2007). The release incisions should be a minimum of 1 cm and of sufficient length that the fixation element does not create tension in the adjacent tissues as the limb is put through a full range of motion (Aron and Dewey, 1992, Permattei *et al.*, 2006).

Thoroughly tighten all clamps, bolts, and nuts associated with the frame (Aron and Dewey, 1992; Permattei *et al.*, 2006). After surgery, clean the fixator and limb of any blood or debris, and dry the fixator and limb segment. Cut fixation pins about 2 to 3 cm from the fixation bolt authors (Aron and Dewey, 1992; Permattei *et al.*, 2006;Rovestiet *et al.*, 2007)

#### **2.4.5 Post-operative care**

External skeletal fixation is a highly versatile and effective treatment modality, but it requires diligent care during the convalescent period (Christina *et al.*, 2011). While construct design and application can vary substantially, the principle of external fixators either linear, circular, and hybrid consist of an extracorporeal frame and fixation elements either pins or small-diameter wires that stabilize the engaged bone segments (Aron and Dewey, 1992). The protruding fixation elements and external frame present unique considerations with regard to appropriate postoperative management (Christina *et al.*, 2011).

##### *2.4.5.1 Initial postoperative care*

Immediately after surgery, a compressive bandage, similar to a modified Robert-Jones bandage is applied on the operated limb to protect the incisions and minimize swelling (Charles and David, 1985; Permattei *et al.*, 2006). First, apply topical antibiotic

(*e.g.* bacitracin, neomycin, and polymyxin B) ointment at the fixation element-skin interfaces to decrease microbial contamination and migration from the skin surface to the fixation element tract (Rovestiet *et al.*, 2007). Any open wounds and all incisions are covered with a sterile non adherent dressing(Christina *et al.*, 2011). Cut slits in the dressing to facilitate placement around individual fixation elements (Anderson *et al.*, 2002). Then, cotton or padding is rolled on the leg from the toes to the frame (Christina *et al.*, 2011). The padding is then compressed with an elastic conforming bandage (Christina *et al.*, 2011). It is important that the padding and wrapping start at the toes and then proceed proximally to cover the frame. Wrapping only the stabilized limb segment with this type of dressing will cause severe edema and congestion of the limb distal to the frame. In most cases this bandage will be removed after 2 to 5 days (Permattei *et al.*, 2006). Once the compressive bandage is removed, it is replaced with a gauze and elastic bandage which encloses the connecting bar and clamps and the protruding ends of the fixation pins of the fixator(Permattei *et al.*, 2006). This cover protects the animal and the owner from the sharp ends of the fixation pins and decrease the chance of catching the apparatus on fixed objects (Permattei *et al.*, 2006). Protection of the apparatus with a cover should be maintained until the device is removed (Crauss *et al.*, 2003).The use of a broad-spectrum antibiotic is indicated for contaminated open or infected fractures until a culture and sensitivity can direct more specific therapy(Crauss *et al.*, 2003). Because of the soft tissue trauma attending even most closed fracture, Permattei *et al.*, (2006),advocated the use a broad-spectrum antibiotic for 4-7 days after surgery, until the body defenses are mobilized

#### 2.4.5.2 Fixation element-skin interface care

The apparatus is inspected daily and usually a small amount of dry crust develops at the skin-pin interface (Anderson *et al.*, 2002). The pin/skin interface is cleaned around with disinfectant to remove exudate 1-2 times daily for 7-10 days. When the skin and soft tissue heals and dries over the pin tracts, cleaning is no longer required (Permattei *et al.*, 2006). According to Christina *et al.*, (2011), although there is a lack of consensus regarding the appropriate disinfectant in the management of the fixation element-skin interfaces in dogs and cats, 0.05% dilute chlorhexidine solutions is advocated by many surgeons (Harariet *al.*, 1996; Anderson *et al.*, 2002). Other cleansing agents for fixation element-skin interface recommended by other authors includes; povidone iodine and hydrogen peroxide (Permattei *et al.*, 2006; Radaschet *al.*, 2008).

#### **2.4.6 Complication of external skeletal fixation (ESF)**

The application of an external skeletal fixator, especially one that involves the slow repositioning of bone fragments, is different from most other surgical procedures because the “operation” does not end when the patient leaves the operating room (Christina *et al.*, 2011). Instead, the procedure stretches out over many weeks, with many clinic visits needed to follow the progress of the bone fragments (Paley, 1990). During this period complications may be notices such as pin tracts drainage, fixation pin loosening, nerve and vessel injury (Bini and Syam, 2014).

##### *2.4.6.1 Pin tracks drainage*

The most common cause of morbidity after external skeletal fixation is drainage from the fixation pin tracks (Permattei *et al.*, 2006). This problem is associated with excessive skin and deeper soft tissue movement causing pressure against the pins, or with loose pins (Permattei *et al.*, 2006). Constant motion of soft tissue around the pin or motion of pins relative to soft tissue prolongs the debridement phase of wound healing and result in continual exudation of the pin track (Aron and Dewey, 1992). Other causes include: (1) the development of an abscess (closed space) around the pin; (2) the presence of necrotic tissue in the pinhole, which can become the focus of sepsis (Paley, 1990). Nevertheless, the contamination presents no special problem as long as the pinhole drains freely to the outside (Permattei *et al.*, 2006), the skin around the site is healthy and the pins remain stable (Bini and Syam, 2014).

#### *2.4.6.2 Fixation pin loosening*

Fixation pin loosening is a common problem with external fixators (McLaughlin and Roush, 1999). Clinical and analytical studies have demonstrated that the pin-bone interface is potentially a weak link in the stability of an external fixation system (Sherman, 2004). Loose pins can substantially decrease the stability of an externally fixed fracture and lead to soft tissue problems (McLaughlin and Roush, 1999). Commonly cited reasons for pin loosening include pin design and pin placement, pin tract infection, necrosis due to surgical trauma during pin placement, and necrosis due to unfavorable bone stress and contact pressure at the pin-bone interface (Sherman, 2004). Suggested solutions to the pin loosening problem include: changes in surgical technique, use of a hydroxyapatite coating, changes in pin

properties and thread design, and changes in frame rigidity (McLaughlin and Roush, 1999, Sherman, 2004).

#### *2.4.6.3 Nerve and vessel injury*

When vascular injuries do occur, they sometimes present in a peculiar way. A pin directed at a vessel usually pushes it to the side without transecting it. As time passes, the pin resting against the vessel, erodes its wall (Bini and Syam, 2014). As a result, the patient may suddenly experience bleeding from the implant hole quite some time after fixator application (Bini and Syam, 2014). Alternatively, the pin may create a hole in the side of a vessel, which does not become apparent until the pin is removed (Bini and Syam, 2014). Excessive bleeding through the pinhole may occur (Carnmicheal, 1991). Reports describing serious distal vascular compromise following pin insertion are also rare, perhaps because collateral circulation is usually adequate to sustain the limb (Carnmicheal, 1991). In those few cases in which a limb has become ischemic after pin or wire insertion, severe trauma usually has preceded fixator application, suggesting loss of collaterals (Carnmicheal, 1991).

Acute transection of a major nerve is unlikely with external skeletal fixation (Permattei *et al.*, 2006). Nerves may however, be nicked during the course of pin insertion or, more commonly, stretched during limb lengthening or bone transplant (Bini and Syam, 2014). In spite of the relative infrequency of reports of serious neurovascular injury, great care is nevertheless required during pin insertion so that major neurovascular structures are not stretched or damaged (Carnmicheal, 1991).

#### **2.4.7 Bone healing with external skeletal fixation (ESF)**

In biological fracture fixation or bridging osteosynthesis, some degree of interfragmentary motion or loading is accepted if the fracture can be stabilized in a manner that minimally disrupts soft tissues and bone vascular supply (Harari *et al.*, 1996). Reliance is placed on early bridging callus to stabilize the fracture and allow continued healing (Permattei *et al.*, 2006). Placement of external skeletal fixation with closed reduction is ideally suited to such a strategy (Permattei *et al.*, 2006).

Healing in fractures treated using external fixation occurs mainly via endosteal callus formation rather than a periosteal one (Harari *et al.*, 1996). Some cases however, heal primarily (Harari, 1992). Researchers (Harari *et al.*, 1996; Egger, 1998) reported that healing takes place in 8–12 weeks with this application in the treatment of fracture of radius and ulna. As well as healing, delayed healing and non-union cases have also been reported (Aron *et al.*, 1986; Carnmicheal, 1991; Harari, 1992). In fractures to which they applied external fixation, Johnson *et al.* (1989) observed that, bone healing or duration of union occurred at the same time or earlier compared to those treated with internal fixation.

## 2.5 Fiberglass

### 2.5.1 Preamble

Fiberglass is a synthetic casting material also called glass-reinforced plastic (GRP) (Mayer, 1993), or glass-fiber reinforced plastic, (GFRP) (Nawy, 2001). It is a fiber reinforced polymer made of a plastic matrix reinforced by fine fibers of glass (Nawy, 2001). Fiberglass is a lightweight, extremely strong, and robust material, the material is typically far less brittle (Weinstein and Ralphs, 2004). Its bulk strength and weight properties are also very favorable when compared to metals, and it can be formed using molding processes (Nawy, 2001).

There are many types of synthetic casting materials and of different colours on the market today; Delta-Lite Conformable<sup>®</sup>, Scotchcast Plus<sup>®</sup>, Vet Cast II<sup>®</sup>, Zim-Flex<sup>®</sup> (Wilson, and Vanderby, 1995; Monument *et al.*, 2009). All are composed of the basic components of a fabric matrix impregnated with a thermal setting resin that will set-up at room temperature (Dwain and Mel, 1991; Wilson and Vanderby, 1995). The Johnson and Johnson's Delta-Lite Conformable<sup>®</sup> Casting Tape for example has been used successfully to obtain circumferential impressions (Wilson, and Vanderby, 1995). It is made of a knitted elasticized fiberglass substrate which has been impregnated with a polyurethane resin. Its elasticity provides excellent conformation to the body (Johnson and Johnson, 2015). Applied like any other standard elastic wraps, Delta-Lite Conformable<sup>®</sup> can be rolled onto the body without

excessive gaping or bulging. Its malleable consistency permits it to be handled with ease and allows for a smooth inside finish (Johnson and Johnson, 2015).

### **2.5.2 Principle of fiberglass cast application**

The majority of the time, casts applied in the emergency department are of the traditional plaster of Paris type (Arun, 2015). This is partly due to the cheaper cost and to a belief that the synthetic casts give less leeway for posttraumatic swelling and are, therefore, more likely to produce a compartment syndrome (Tomlinson, 1991). A major influence on the decision on casting material is the greater difficulty in applying these synthetic materials, as they set too quickly (Nawy, 2001).

Initially a stockinette sleeve may be applied which extends proximally and distally beyond the limits of extent of the cast (Hassan and Hassan, 2003). Over this, cast padding is wrapped especially covering bony prominences (Arun, 2015). The quantity of padding below the cast should be well thought out. However, In a randomised, prospective, crossover, clinical trial study in human patients conducted by Monument *et al.*, (2009), in which they determined the quantity of cotton under padding needed for a comfortable, functional, below-elbow fibreglass cast, discovered that no significant trend for either two or four layers of cotton under padding was shown. Care must be taken when applying a fiberglass cast (Arun, 2015). The technician or surgeon must wear gloves as many of the synthetic casting materials can create an exfoliative dermatitis when exposed to bare skin (Arun, 2015). When immersing the fiberglass casting tape in water, a dip water temperature

>24 °C should be avoided so as to avoid thermal injury regardless of the thickness of the cast (Halanski *et al.*, 2007). As it is applied, it should be stretched, allowed to relax, and then laid on the limb. The bandage should not be applied with tension (Johnson and Johnson, 2015). Desired number of bandages is applied depending on limb position, circumference and extent of the cast. After some time, the cast material will begin to harden with exothermic reaction (Arun, 2015).

### **2.5.3 Fiberglass setting time**

The setting time of Delta-Lite Conformable<sup>®</sup> will vary from four to six minutes, as compared to the Plaster of Paris' 20 to 30 minutes (Johnson and Johnson, 2015). Fiberglass sets quickly, therefore experience is required to time the application well. It is hygroscopic and setting time decreases with humidity and warmth (Arun, 2015).

### **2.5.4 Removal of fiberglass cast**

Once it is time for the cast to come off, an oscillating cast saw is used to remove the cast (Jonathan, 2014). The saw has a sharp, small-toothed blade that rapidly vibrates back and forth; it does not spin around like a circular saw (Shuler and Grisafi, 2008). Cast saws are very safe but should only be used by personnel who have been trained in their proper use (Shore *et al.*, 2014)

### **2.5.5 Complications arising from fiberglass cast removal**

Cast saws are safe, but there are possible complications of their use that can occur;

**Burns:** Skin burns are the most common complication that occur when removing fiberglass cast (Shuler and Grisafi, 2008). Because of the vibration of the cast saw blade against the very hard cast material, very high temperature can be generated (up to 55 °C) due to the frictional force. When the blade is heated up and makes close contact with the skin, serious burn can occur. Shuler and Grisafi (2008) have shown that skin temperature beneath the cast can rise significantly higher when cutting through fiberglass cast material but concluded that four layers of padding beneath a fiberglass cast offer more protection against cast saw burns.

**Cuts:** Small skin lacerations are uncommon, but can occur when cutting through a fiberglass cast material (Shore *et al.*, 2014). If ample padding is under the cast material, a skin cut is unlikely (Shuler and Grisafi, 2008). A recent study found the most common reasons patients had complications from the use of cast saw were worn out blades, insufficient cast padding, uncooperative patient or improper training and experience (Shore *et al.*, 2014)

### **2.5.6 Advantages of fiberglass cast**

Several authors (Dwain and Mel, 1991; Shuler and Grisafi, 2008; Jonathan, 2014; Johnson and Johnson, 2015) have elucidated on the advantages of using a synthetic casting material in obtaining circumferential impressions over plaster of Paris cast:

- i. Ease of use: fiberglass cast handles very nicely, much in the same manner as a standard elastic bandage. The resin is not excessively sticky, and the roll keeps its integrity throughout the application.
- ii. Thermal effects are significantly reduced
- iii. The synthetic impressions are 63 percent lighter in weight than plaster of Paris impressions.
- iv. The amount of synthetic material needed to obtain a good impression varies with the size of individual being cast. In general, at least two to three thicknesses of material are desired, but one thickness in isolated areas is acceptable.
- v. Fiberglass cast does not splatter and drip like plaster of Paris. The water runoff is free of resin and poses no hazard or difficulties. This reduces the effort involved in clean-up.

### **2.5.7 Disadvantage of fiberglass cast**

Although fiberglass has been extensively used as a substrate material in orthopedic casting, with different reactive polymers, all of these casting materials suffer certain disadvantages (Wilson, and Vanderby, 1995). The major disadvantage is the conformability of the fiberglass casting tape to body of the patient (Dwain and Mel, 1991). Generally, Fiberglass cast is stiffer in handling than casting tape made of other fibers like plaster of Paris (Wilson, and Vanderby, 1995). Over time, cast technicians and surgeon have had some difficulties in conforming these synthetic materials to the limb of the patient. Although the recently introduced fiberglass casting tapes such as the Johnson & Johnson's Delta-Lite

Conformable<sup>®</sup> have a greater conformability (Johnson and Johnson 2015), but still not as conformable as plaster of Paris (Dwain and Mel, 1991).

## **CHAPTER THREE**

### **MATERIALS AND METHODS**

#### **3.1 Materials**

##### **3.1.1 Location of the experimental study**

The study was carried out in the Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria, Kaduna State, Nigeria (between Longitude 7° and 8° East, and Latitude 11° and 12° North) (Wikipedia, 2015). The surgical and sample processing procedures were carried out in the Teaching theater and Research Laboratory of the Veterinary Surgery and Radiology Department and Veterinary Teaching Hospital. Radiologic evaluations were conducted in the Diagnostic Imaging unit of the Veterinary Teaching Hospital, Ahmadu Bello University, Zaria.

##### **3.1.2 Source of animals**

Six (3 males and 3 females) apparently healthy 10-month-old Nigerian indigenous dogs of various weights (9-11 Kg) were acquired from Samaru, Zaria for this study. They were humanely transported in a vehicle to the Faculty of Veterinary Medicine where they were housed in the kennels of the Department of Veterinary Surgery and Radiology and Veterinary Teaching Hospital, Ahmadu Bello University, Zaria.

### **3.1.3 Ethical approval**

Ethical approval was sought from Ethical Committee on Animal Use and Care of Ahmadu Bello University, Zaria.

### **3.1.4 Materials (Fixed and consumables)**

The materials used in this study (Table 3.1) were obtained from the Departments of Veterinary Surgery and Radiology and Veterinary Teaching Hospital of ABU, Zaria. The consumables included; suture materials, antibiotics, pre-medications, anaesthetic agents, wound dressing materials (Table 3.1), food, and feeding and watering items (Table 3.2).

**Table 3.1: Consumable and surgical materials used in the study**

<b>Description of item</b>	<b>Quantity</b>
<b>Consumables</b>	
1. Detergent powder and table soap	5 Kg
2. Chlorhexidine gluconate B.P (liters, 0.3% w/v Purit®)	4 litres
3. Sodium Hypochlorite (0.5% w/v- Jik®)	20 litres
4. Dog chains and collar	10 pieces
5. Razor blades	1 packet
6. Sterile disposable syringes (10 mls)	1 packet
7. Sterile disposable syringes (5 mls)	1 packet
8. Sterile disposable syringes (2 mls)	1 packet
9. Pair of surgical gloves (size 7.5 and 8)	2 packets
10. Elizabethan collars (Improvised)	4 pieces
11. Gauze	2 rolls
12. Gauze bandage	7 rolls
13. Cotton wool	1 bundle
14. Adhesive plaster (large size; 10cm x 5cm)	1 packet
15. 10 % Povidone iodine solution	1 litre
16. Intravenous cannula (20 Gauge)	50 pieces
17. Surgical cap and mask	100 pieces
18. Fiberglass cast	10 pieces

19. Orthopedic Cast padding 5 pieces

**Anaesthetics, pre-medications and other related items**

20. Thiopental sodium injection (1g vial) 10 vials

21. Ketamine Hydrochloride injection (10 mls) 10 bottles

22. Atropine sulphate injection (1ml ampoules) 2 packets

23. Chlorpromazine hydrochloride injection (2mls ampoules) 20 ampoules

24. Endotracheal tubes (Size 8.5 and 9.5) 4 pieces

**Surgical materials**

25. Standard general surgical pack 1 pack

26. Standard orthopedic pack 2 packs

27. Surgical gowns 2 sets

28. Surgical drapes 2 sets

29. Surgical blades 10 pieces

30. Low-speed power drill machine 1 piece

31. Kirschner-Ehmer External fixator 2 sets

32. Pin cutter 1 piece

**Suture materials**

33. Nylon with needle size 2 1 packet

### **Antibiotics and analgesics**

34. Procaine Penicillin injection (4,000,000 IU)	20 bottles
35. Streptomycin Sulphate injection (5 gram)	20 bottles
36. Diclofenac sodium injection	3 packets

### **Other drugs and items**

37. Vitamin B complex injection (10 mls)	10 bottles
38. Amitraz solution (Amitik®)	10 litres
39. Praziquantel (600mg) tablets	20 tablets
40. Pyrantel permeate (125mg) tablets	30 tablets
41. Ivermectin injection (1% w/v 100ml)	50 mls

### **Laboratory materials**

42. Mobile x-ray unit (Recorder and medical systems RMS (P) Ltd)	1 unit
43. X-ray films 15×12(Agfa®)	100 pieces
44. Developer powder 22.5L	1 packet
45. Fixer powder 22.5Lt	1 packet
46. Radiographic hangers 15×12	10 pieces
47. X-ray film dryer WT502(Heizstufe®)	1 piece
48. Radiographic viewer 17×14cm	1 piece

49. Glass slides (packet)	200 pieces
50. Microhaematocrit capillary tubes	200 pieces

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**Table 3.2: List of food, feeding and drinking items and other related objects used in the study**

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<b>Description of item</b>	<b>Quantity</b>
1. Restaurant food (Rice, beans , fish and bones)	18 plates/day
2. Kennel attendants (cleaner)	1 person
3. Feeding and drinking bowls for the dogs	20 sets
4. Water bucket	2 pieces
5. Water reservoir (200 litres capacity)	1 piece
6. Sweeping brooms	4 bundles

---

## **3.2 Methodology**

### **3.2.1 Housing and feeding of dogs**

The 6 dogs to be used for the study were housed in the kennels of the Veterinary Surgery and Radiology Department and Veterinary Teaching Hospital, Ahmadu Bello University, Zaria. They were fed with meals obtained from a restaurant restaurant (Rice, beans, fish and bones) in A.B.U campus, twice daily and clean tap water provided *ad libitum*.

### **3.2.2 Experimental animal screening**

The experimental dogs were acclimatised for 8 weeks prior to the commencement of the study. During the conditioning period, the dogs were examined clinically by physical and laboratory examinations. The animals were screened for ecto- and endo-parasites and tick samples were sent to Entomology Laboratory for parasite identification. Two milliliters of blood were collected through cephalic venipuncture using a 23 G 1<sup>1</sup>/<sub>2</sub> inch needle (Menoject<sup>®</sup>, Shandong Zibo Shanchuan Medical Instrument Co. Ltd, China) which was placed in a sample bottle containing ethylene diamine tetra acetic acid (EDTA), divided into two, properly labeled and sent to Protozoology (for haemoparasites screening) and Clinical Pathology Laboratories for haemogram. The haematologic parameters evaluated were; the pack cell volume (PCV) by microhaematocrit method, haemoglobin (Hb) concentration according to the method described by Alan (2002), the total plasma protein (TP) was determined using hand held refractometer as described by Morag (2002). Post-operative haemogram evaluations were also undertaken periodically (1, 4, 8, 12 weeks). Faecal

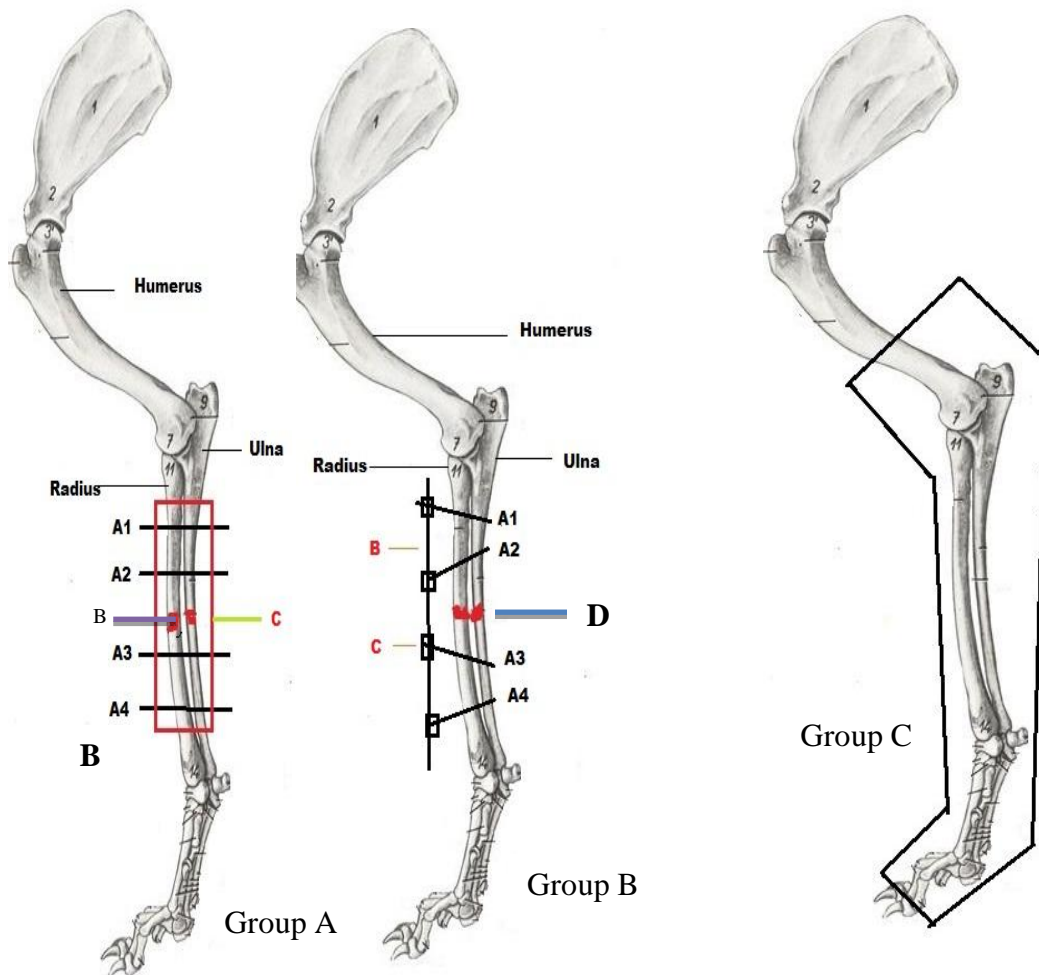
samples were collected per rectum three times prior to operation which was sent to Helminthology Laboratories for enteroparasites screening. Positive cases were treated accordingly.

### **3.2.4 Animal Grouping**

The dogs for surgically created fractures of the radius and ulna used for this study were divided into 3 groups based on the technique that was employed in the repair of the fractures as shown in Table 3.1, and Fig. 3.1-3.

**Table 3.3: Animal distribution, fracture site and reduction techniques for all the animals that underwent the study**

<b>Group</b>	<b>No. of dogs</b>	<b>Sub groups</b>	<b>Management</b>
A	2	A1	Transverse mid-shaft radius and ulna fractures repaired by Pin-in-fiberglass casting (P.IC)
		A2	Transverse mid-shaft radius and ulna fractures repaired by Pin-in-fiberglass casting (P.I.C)
B	2	B1	Transverse distal one-third radius and ulna fractures repaired by Kirschner-Ehmer external fixation (K-ESF)
		B2	Transverse mid-shaft radius and ulna fractures repaired by Kirschner-Ehmer external fixation (K-ESF)
C	2	C1	Transverse mid-shaft radius and ulna fractures repaired by fiberglass casting (F.G.C)
		C2	Transverse mid-shaft radius and ulna fractures repaired by fiberglass casting (F.G.C)



**Figure 3.1: Schematic diagram of the configuration of reduction techniques for the dogs that underwent the study. Group A; A1-A4: Two pairs of Percutaneous pins inserted into the radius and ulna B: Fracture site C: Fiberglass cast incorporating the pins, Group B; A1-A4: Two pairs of Percutaneous pins inserted into the radius and ulna B: Connecting bar C: Clamp D: Fracture site, Group C; Fiberglass cast incorporating the elbow and carpal joints. Source: Sisson and Grossman (1975)**

### **3.2.5 Pre-operative preparation**

In preparation for surgery, the right fore limb of the dogs were carefully and liberally shaved from mid-humerus to the mid metacarpus for group A and Group B. The shaved sites were washed and scrubbed clean with soap and water

### **3.2.6 Anesthesia**

All procedures were carried out under general anesthesia. The cephalic vein was cannulated; Atropine Sulphate (0.02mg/kg) (Amopin<sup>®</sup>, YanzhouXierkangtaiPharma Ltd, China) and Chlorpromazine Hydrochloride (4mg/Kg) (Pauco Chlorpromazine HCL Injection<sup>®</sup>, Pauco Pharmaceutical Ltd, Nigeria) were administered through the established intravenous line. Anesthesia was induced using Thiopental Sodium (15mg/Kg). The dog was then intubated with appropriate sized endotracheal tube post induction to maintain patent airway. Ketamine Hydrochloride (22 mg/Kg) (Pauco Ketamine Injection<sup>®</sup>, Kwaliti Pharmaceutical Ltd, India) was employed for maintenance of anesthesia which was administered intravenously.

### **3.2.7 Operative procedure**

#### *3.2.7.1 Fracture creation*

All the fractures on the radius and ulna in the dogs were created as described by (Marturano *et al.*, 2008) using the modified Marturano fracture device (Plate I). The area extending from the radio-ulnar carpal(wrist) joint to the humero-radio-ulnar (elbow) joint of the right fore limb was well padded using a sterile surgical drape. The limb was held to the device by two

assistants. An external blow using the striker of the device was then applied to the radius and ulna bones without violating the skin to create a closed, complete diaphyseal fractures of the radius and ulna which were verified radiographically (Plate II). Once the fracture was created, the dog was moved to the operation table where it was properly restrained on dorsal recumbency.

#### *3.2.7.2 Fracture reduction*

The fracture manipulation, reduction and percutaneous pins insertion were carried out as described by Ann and Dianne (2005). The dogs were positioned on dorsal recumbency to permit access to both sides of the forelimb and to facilitate reduction through the technique of hanging limb traction. This was done by suspending the fractured limb from a drip stand with tension using a stirrup to facilitate fracture reduction. The surgical table was then lowered to allow the animal's weight to distract the joint of the limb and assist in positioning the fractured fragments (Plate III).

The surgical site was fine-swabbed with 0.05% chlorhexidine gluconate (Purit<sup>®</sup> SaroLifecare Ltd, Ibadan, Nigeria) and 10% povidone iodine solution (Povidone Iodine Topical Solution<sup>®</sup> SirmaxoChemical Ltd Maharashtra, India) before being draped. The foot and foot pads were covered with sterile gauze to reduce contamination of the surgical field by microorganisms on the foot and securely taped to the foot with adhesive tape (Plate IV)

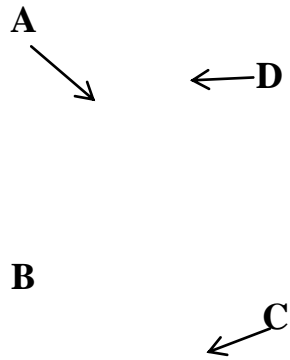


←A

←B

}C

**Plate I: Modified Marturano fracture device. A: Shaft, B: Striker, C: Limb positioning system**



**Plate II: Fracture creation. A: Modified Marturano fracture device. B: Experimental dog, C: padded limb of experimental dog placed on limb positioning system, D: Striker**



**Plate III: Hanging limb traction technique; the dog was placed on dorsal recumbency with the fractured limb suspended from a drip stand and the weight of the animal was allowed to distract the fractured fragments**



**Plate IV: The foot and foot pad covered with sterile gauze to reduce contamination of the surgical field (Thick arrow); 18 Gauge needle was inserted percutaneously into the fractured site to prevent inadvertent placement of transfixation pins into fractured site (Thin arrow)**

## **GROUP A**

### *3.2.7.3 Transfixation*

The transfixation was carried out as described by Permattei *et al.* (2006). An 18 gauge needle was inserted percutaneously into the fracture site (Plate IV) to avoid inadvertent placement of transfixation pins into the fracture line. Another 18 gauge needle was placed through the skin to the radius; two points proximally and two points distally to the fracture line on the cranial aspect of the limb to select sites for placement of transfixation pins. Stab incisions were made at each needle site through the skin for insertion of 4.0 mm threaded Steinman pins (Front threaded pin, Shanz Screw 3.5 x 200 mm, stainless steel, Asco, India) (Plate V). The stab incisions were made into the Extensor carpi radialis muscle belly. Using a power drill, the Steinman pin was drilled at a low speed (less than 150 rotations/minute) into the most distal stab incision on the proximal fracture fragment of the radius in a caudal direction until the pin has passed through both cortices of the radius and continued to pass through both cortices of the ulna bone taking into consideration the cephalic vein, collateral ulnar artery and vein, ulnar nerve, and the radial nerve not to hit them. Once the pin had passed through both cortices of the ulna the drilling was continued until the pin was just about to exit the skin of the opposite side (Plate VI). A stab incision was then made to allow the pin to penetrate the skin and emerge on the other side (opposite side). After the first pin was placed, the other three pins were inserted in similar fashion proximal to the first pin through the remaining three skin stab incisions (Plate VII). After insertion of all the pins, the projecting part of each pin was cut at about 3 cm from the skin surface using pin cutter (Plate VIII). Skin incisions were then sutured where necessary using size 2/0 Nylon suture

with care not to create excess tension of the skin at pin entry sites. Povidone-iodine ointment was applied around each pin site and covered with a layer of sterile gauze (Permattei *et al.*, 2006).

#### 3.2.7.4 *Pin-in-casting*

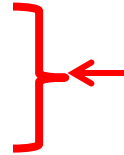
Appropriate fracture reduction was maintained by hanging limb traction. The cast material served as an external frame to maintain pin position and fracture reduction. Orthopedic Cast padding was applied in double thickness over and fenestrating the protruding transfixation pins extending from the level of the carpus to the elbow. The padding overlapped as it was applied to the limb from the carpus downward to the elbow and then overlapped as it returned to the carpus (Plate: IX). The fiberglass cast material (Perfect Cast<sup>®</sup> Hospital and Home Care UK) was wetted by immersion in water at room temperature for 5 seconds and the water wrung off. The cast material was then rolled on the limb with the fiberglass cast fenestrated at the point of the protruding pins unto the cast padding extending from proximal radius to distal radius. This continued until the whole length of the projecting transfixation pins have been incorporated and covered by the cast (Plate X). After the cast had set, normal flexion and extension of the elbow and carpus were verified. Immediately after surgery, a compression bandage, similar to a modified Robert-Jones bandage was applied on the operated limb to minimise postoperative swelling.



**Plate V:Stab incisions made at each needle site through the skin for insertion of Steinman pins  
(Arrow)**



**Plate VI: First Steinman pin drilled into the most distal stab incision in the proximal fracture fragment (Arrow)**



**Plate VII All the four Steinman pins drilled into the skin stab incisions, through the Radius and ulna bones (Arrow)**



**Plate VIII: The projecting part of each pin being cut using a pin cutter to 3 cm from skin surface (Arrow)**



**Plate IX: Orthopedic Cast padding material fenestrated at the point of the protruding pins applied unto the limb extending from the level of the carpus to the elbow (Arrow)**

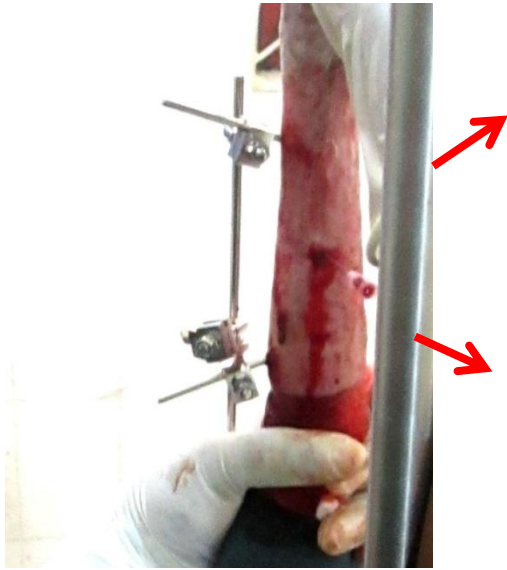


**Plate X: Fiberglass cast material fenestrated by the protruding transfixation pins applied unto the cast padding extending from proximal radius to distal radius.(Arrow)**

## **GROUP B**

### *3.2.7.5 Application of Kirschner-Ehmer external fixator*

The application of the standard Kirschner-Ehmer Type I/unilateral external fixative was carried out as described by Permattei *et al.* (2006). The placement of threaded transfixation pins (Front Threaded Pin, Shanz Screw 3.5 x 200 mm, stainless steel, Asco, India) was done similarly to those of Group I. but was inserted at an angle of 30 degrees between the outermost pins placed in each fracture segment. The most proximal and distal transfixation pins were placed first in the two segments at appropriate angles. A single connecting bar (Connecting Rod 4.0 mm x 300 mm, Asco, India) was then loosely attached to the pins using the clamps (Small Single Pin Clamp 4.0 x 3.5 mm) with the anticipated number of “open” clamps in the middle. The fractures were then reduced and the two end clamps tightened (Plate: XI). The remaining two fixation pins were then driven through the open clamps (Plate XII). All the fixation pins were slightly squeezed together and all the clamps tightened. Excess fixation pins and connecting bar length were removed using a pin cutter (Plate XIII). Immediately after surgery, a compression bandage, similar to a modified Robert-Jones bandage was applied on the operated limb to protect the incisions and fixative and to minimise postoperative swelling (Plate XIV).



**Plate XI: The most proximal and distal Steinman pins inserted obliquely first and connected to a cross bar by clamps (Arrows)**



**Plate XII: The middle pins inserted through the remaining two open clamps (Arrows) and connected to the bar with clamps**



**Plate XIII: The application of Kirschner-Ehmer external fixative completed; The fixation pins is squeezed together gently and all the clamps tightened using a wrench, excess fixation pins and connecting bar length removed using a pin cutter, the pin-skin interface was padded with povidone iodine soaked gauze**



**Plate XIV: A modified Robert-Jones bandage was applied on the operated limb overriding the ESF to protect the fixative and to minimize postoperative swelling**

## **GROUP C**

### *3.2.7.6 Fiberglass Casting*

With the fracture held in reduction via the hanging limb traction technique as described earlier, the application of the fiberglass cast was carried out as described by Hassan and Hassan (2003). Strips of adhesive tape was placed on the cranial and caudal surface of the limb and allowed to protrude several inches distal to the end. Cast padding of cotton wool was applied in double thickness. The padding overlapped as it was applied to the limb from the foot downward to the mid humerus and then overlapped as it was returned to the foot. The olecranon was doubly padded with the cast padding. This was then followed by the application of gauze padding in a similar fashion as done for the cotton wool padding. The fiberglass cast material (Perfect Cast<sup>®</sup> Hospital and Home Care UK) was then wetted by immersion in water at room temperature for 5 seconds and the water was wrung off. The cast material was rolled onto the limb overriding the cast padding from the foot to mid-humerus and returned distally to the foot.

### **3.2.8 Post -operative care**

Following recovery from anesthesia, improvised Elizabethan collars were applied on the dogs. An analgesic, Diclofenac sodium injection (4mg/Kg) (Diclowin<sup>®</sup>, Chupet Pharm. Ltd, China) was given for 3-5 days. Procaine penicillin injection (20,000IU/kg) (Gossipain<sup>®</sup> Shanxi Federal Pharmaceutical Ltd., China) and Streptomycin (20mg/Kg) (Paulio<sup>®</sup> Shandong Reyoung Pharmaceutical Ltd., China) were given for 5-7 days. Skin

sutures were removed between day 7 and 10 for Group B dogs. Compression bandage was removed at day 7 for Group A and B, and replaced with gauze bandage only for Group B, which enclosed the connecting bar and clamps, and the protruding ends of the fixation pins of the fixator up till when the fixative was removed. Exercise restriction was ensured for all groups

### **3.2.9 Post-operative clinical and radiographic examination**

Physiological parameters of rectal temperature, respiratory rate, and pulse rate were monitored daily throughout the duration of recovery. Clinical assessment was undertaken for all the groups by subjecting the animals to ambulation test weekly, starting from the time of post anesthetic recovery. The time of first weight bearing on the affected limb was noted. Lameness was assessed weekly and was graded as present or absent.

Post-operative radiograph was also taken immediately after the surgery (day 0) using Medio-Lateral and Cranio-Caudal projections (Hassan and Hassan, 2003; Easton, 2006) which were repeated at 2 weeks interval until union (Hassan and Hassan, 2003; Easton, 2006). The radiographs were evaluated to estimate angulation, maintenance of fracture reduction and rate of bone healing. Bone healing was evaluated, and radiographic results graded as described by Gianet *al.* (2009), thus;

- Excellent: fracture healed and angular deformity in any plane was  $< 5^\circ$ ,
- Good: fracture healed and  $5^\circ$  to  $10^\circ$  angular deformity in any plane was present,

- Fair: fracture healed and 10° to 30° angular deformity in any plane was present,
- Poor: fracture not healed or healed with angular deformity in any plane was > 30°.

Early complications were noted. Complications were considered minor if they were managed without additional procedures under general anesthesia, and complications were considered major if they required additional procedures or substantial modification under general anesthesia (Gianet *al.*, 2009).

The cast, pins and external fixatives were removed when the fractures were adjudged to have healed. The functional and cosmetic results were evaluated and clinically graded as described by Fox *et al.* (1995).

- Excellent: functionally normal and similar in appearance to the contralateral normal limb.
- Good: slight lameness only after extensive exercise, or minor difference from the contra lateral normal limb.
- Fair: slight to moderate lameness but consistent weight bearing, or noticeable difference from the contra lateral normal limb.
- Poor: non-weight bearing lameness, or marked, disfigured alteration from the contralateral normal limb.

### **3.2.10 Data recording and analysis**

Physiological parameters and hematological values were summarised in graphic and tabular presentation. Data obtained were expressed as mean  $\pm$  standard error of the mean (Mean  $\pm$  SEM) and analyzed by one way analysis of variance (ANOVA) using Graph Pad version 4.0 for windows (Graph Pad Software, san Diego, California, USA) to compare the level of significance between the test groups. Values of  $p < 0.05$  were considered as significant. Radiographic interpretation was used to objectively evaluate the healing profile.

## CHAPTER FOUR

### RESULTS

#### 4.1 Pre-operative findings

##### 4.1.1 Physical examination

Physical examination revealed that all the dogs had ticks (*Rhipicephalus sanguinus*). The dogs were treated using Ivermectin injection (Kepromec®, Kepromec B. V. Holland) at the dose rate of 0.4 mg/ kg. The acaricide used to control the ticks was effective.

##### 4.1.2 Clinical and laboratory evaluation

Generally, the pre-operative vital parameters and haemogram values obtained following the treatment of dogs during acclimatization and conditioning period of the dogs were used as baseline data as shown in appendices 1a-1c and 2a. Laboratory blood examination did not reveal any haemoparasite. Fecal samples analysis showed *Ancylostomacanthum* eggs for all the dogs and were treated using Ivermectin injection ((Kepromec®, Kepromec B. V. Holland) at the dose rate of 0.4 mg/ kg subcutaneously.

## **4.2 Surgical Procedure**

### **4.2.1 Outcome of surgically created fractures**

Fractures were successfully created on the right forelimb (radius and ulna) of the dogs in all groups. Fractures were closed, transverse with minimal spikes and chips. All fractures were midshaft except group B1 which was at distal one-third (Plate XVa, XVb and XVc)

### **4.2.2 Success of fracture reduction**

Fracture reduction was achieved in all the groups. They were stable, well aligned and limbs were adequately immobilized (Plate XVIa, XVIb and XVIc).

### **4.2.3 Evaluation of fracture healing**

#### *4.2.3.1 Radiographic evaluation of fracture healing*

In all the groups, at second week post reduction, there was no observed remarkable difference on the radiograph of the radius and ulna fractures (Plate XVIIa, Plate XVIIb, Plate XVIIc). However minimal soft tissue and periosteal reaction were evident in all the groups. At week 4, the pin-in-fiberglass cast showed a decline in fracture lines with minimal periosteal reaction (Plate XVIIIa). In the Kirschner-Ehmer external fixative group also, there was evidence of minimal periosteal reaction with a reduction in size of fracture line (Plate XVIIIb). However, in the fiberglass walking cast group (Group C), fracture lines were still clear with presence of very mild periosteal reaction (Plate XVIIIc). At week 6 post-

operatives, X-ray features in pin-in-fiberglass cast group (Group A) showed that fracture lines had disappeared, but callus formation continued (Plate XIXa). The Kirschner-Ehmer external fixative group (Group B) showed a disappearance of fracture lines, but callus formation continued (Plate XIXb). In the fiberglass group fracture lines was still apparent with increased periosteal reaction. At week 7 post-operative, the Kirschner-Ehmer external fixative group showed a complete disappearance of fracture lines and decline in external callus size. Fractured bones started to reform their shapes (Plate XXb). In the pin-in-fiberglass group at week 8 post-operative, there was complete disappearance of fracture lines and decline in external callus size. Fractured bones started to reform their shapes (Plate XXa). In the fiberglass walking cast group, the fracture lines were still clear (Plate XXc). By week 12 post-operative, the fracture lines in the fiberglass walking cast group disappeared. Plate XXIa, XXIb, and XXIc shows radiographs after the removal of fracture reduction devices at week 9, 8, and 12 for pin-in-fiberglass, Kirschner-Ehmer fixative, and fiberglass walking cast groups respectively.



**Plate XVa: Lateral view radiograph of the radius and ulna fractures managed with pin-in fiberglass cast (group A) pre-reduction with apparent fracture gaps (arrow).**



**Plate XVb: Lateral view radiograph of the radius and ulna fractures managed with Kirschner-Ehmer external fixative (group B) pre-reduction with apparent fracture gaps (arrow).**



**Plate XVc: Lateral view radiograph of the radius and ulna fractures managed with fiberglass cast (group C) pre-reduction with apparent fracture gaps (arrow).**



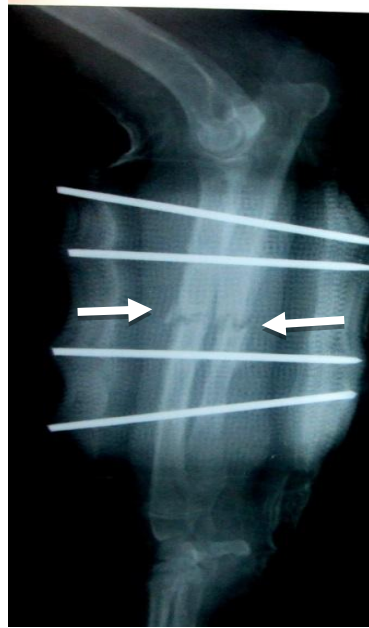
**Plate XVIa:** Postoperative lateral view radiograph of radius and ulna fractures managed with pin-in-fiberglass cast (Group A, day 0) with apparent fracture gaps (arrow).



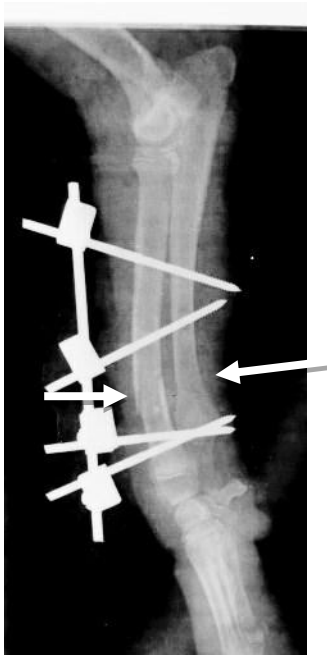
**Plate XVIb:** Postoperative lateral view radiograph of the radius and ulna fractures managed with Kirschner-Ehmer external fixative (Group B, day 0) with apparent fracture gaps (arrow).



**Plate XVIc:** Postoperative cranial-caudal view radiograph of the radius and ulna fractures managed with fiberglass cast (Group C, day 0) with apparent fracture gaps (arrow).



**Plate XVIIa:** Postoperative lateral view radiograph of the radius and ulna fractures managed with pin-in fiberglass cast (Group A, 2 weeks). Fracture lines still clear with presence of mild periosteal reaction (arrow).



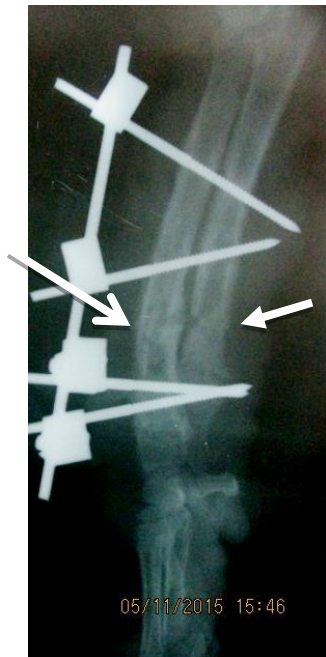
**Plate XVIIb:** Postoperative lateral view radiograph of the radius and ulna fractures managed with Kirschner-Ehmer external fixative (Group B, 2 weeks). Fracture lines clear with presence of mild periosteal reaction (arrow).



**Plate XVIIc:** Postoperative lateral view radiograph of the radius and ulna fractures managed with fiberglass cast (Group C, 2 weeks) with apparent fracture gaps (arrow) with no periosteal reaction.



**Plate XVIIIa:** Postoperative lateral view radiograph of the radius and ulna fractures managed with pin-in fiberglass cast (Group A, 4 weeks). Fracture lines declined with increased callus formation (arrow).



**Plate XVIIIb:** Postoperative lateral view radiograph of the radius and ulna fractures managed with Kirschner-Ehmer external fixative (Group B, 4 weeks). Fracture lines declined and callus formation continued (arrow).



**Plate XVIIIc:** Postoperative lateral view radiograph of the radius and ulna fractures managed with fiberglass cast (Group C, 4 weeks) fracture lines were still clear with presence of mild periosteal reaction (arrow).



**Plate XIXa: Postoperative lateral view radiograph of the radius and ulna fractures managed with pin-in fiberglass cast (Group A, 6 weeks). Fracture lines disappeared but callus formation continued.**



**Plate XIXb: Postoperative lateral view radiograph of the radius and ulna fractures managed with Kirschner-Ehmer external fixative (Group B, 6 weeks). Fracture lines disappeared with increased external callus formation (arrow).**



**Plate XIXc: Lateral view radiograph of the radius and ulna fractures managed with fiberglass cast (Group C, 6 weeks). Fracture lines apparent with mild callus reaction (arrow).**



**Plate XXa: Postoperative lateral view radiograph of the radius and ulna fractures managed with pin-in fiberglass cast (Group A, 8 weeks). Complete disappearance of fracture lines, decline in external callus size. Bones started to reform their shapes.**



**Plate XXb: Postoperative lateral view radiograph of the radius and ulna fractures managed with Kirschner-Ehmer external fixative (Group B, 7 weeks). Complete disappearance of fracture line, and decline in external callus (arrow) Bones started to reform their shape.**



**Plate XXc: Lateral view radiograph of the radius and ulna fracture managed with fiberglass cast (Group C, 8 weeks). Increase external callus size (arrow).**



**Plate XXIa:** Postoperative lateral view radiograph of the radius and ulna fractures managed with pin-in-fiberglass cast (Group A, 9 weeks). Fixative removed. Note the restoration of trabecular pattern, and restoration of medullary continuity (arrow).



**Plate XXIb:** Postoperative lateral view radiograph of the radius and ulna fractures managed with Kirschner-Ehmer external fixative (Group B, 8 weeks). Fixative removed. Note the restoration of trabecular pattern, and restoration of medullary continuity (arrow).



**Plate XXIc:** Postoperative lateral view radiograph of the radius and ulna fractures managed with fiberglass cast (Group C, 12 weeks). Cast removed. Note the restoration of medullary continuity.

#### **4.2.3.2** *Clinical evaluation of fracture healing*

The post-operative mean value of the vital parameters in all the groups showed a slight deviation from the pre-operative mean values as shown in appendix 1a, Appendix 1b and Appendix 1c. There was an immediate rise in mean rectal temperature which was observed to reach a peak of  $39.5 \pm 0$  on day 2 for the pin-in-fiberglass group (Appendix 1a),  $39.2 \pm 0.05$  on day 4 for Kirschner-Ehmer external fixative group (Appendix 1b) and  $40 \pm 0$  °C on day 2 for fiberglass walking cast group (Appendix 1c). Post-operative fluctuation in the mean pulse rate and respiratory rate values in the three groups coincided with the changes observed in the mean rectal temperature for all the groups.

Immediately after the surgical procedure, all the dogs in all the groups abducted their limbs. However, the mean time of first ground contact with the fractured limb post-surgery was noted subsequently for all the animals. The mean time for first weight bearing on the operated leg by the dogs was  $1 \pm 0$ ,  $1 \pm 0$ ,  $10 \pm 0$  days for pin-in-fiberglass, Kirschner-Ehmer external fixative, and fiberglass cast group respectively.

One week post-operative, the animals in the pin-in-fiberglass cast group were able to bear weight on the fractured limb with a display of slight lameness. At week 5 post-operative, the dogs in this group were able to bear full weight and were able to run with the operated limb, however with slight lameness. In Kirschner-Ehmer external fixative group, the dogs were also able to bear weight on the fractured limbs with a display of slight lameness after a week post-operative. At week 4 post-operative, the animals in this group were able to run with the fractured limb accompanied with slight lameness except for dog B2 which showed moderate

limping. In the fiberglass walking cast group, the animals were unable to bear substantial weight on the affected limb even up to 6 week post-operative. It was good to note that in all the groups, limping continued even up till the time of removal of devices. The fixatives were removed at the 7<sup>th</sup>, 8<sup>th</sup>, and 12<sup>th</sup> post-operative week for the Kirschner-Ehmer external fixative, pin-in- fiberglass cast, and fiberglass cast group respectively.

#### **4.2.4 Functional and cosmetic results**

The pin-in- fiberglass cast and Kirschner-Ehmer external fixative groups were graded excellent while fiberglass cast group was graded as fair.

#### **4.2.5 Time and Cost-benefit analysis**

The operative and post-operative care time for the three techniques in the management of radius and ulna fractures were determined as shown in table 4.1. The study showed that the operative time required for performing pin-in-fiberglass casting, Kirschner-Ehmer external fixation and fiberglass casting techniques were 1.75, 2.5, and 0.75 hours respectively. While it required 3.75, 19.5, and 7.75 hours on the overall to perform post-operative care for pin-in-fiberglass casting, Kirschner-Ehmer external fixation and fiberglass casting techniques respectively from the time of post-operative recovery to patient discharge after fracture union.

The cost implication of carrying out management of closed, stable, fracture of radius and ulna using the three techniques is as shown in Table 4.2. The cost of carrying out radius and ulna fracture reduction in a dog based on this study were N11,550, N54,350 and N7,750 (1.5: 7: 1) for pin-in- fiberglass casting, Kirschner-Ehmer external fixation and fiberglass casting respectively.

The cost-benefit analysis of managing fractures of the radius and ulna bones in a performing dog like a breeding stud is as shown in table 4.3. The loss that would be incurred by the breeder (owner of the stud) during the morbidity period (dog-hour lost) was N191,550, N214,350, and N307,750 (1: 1.1: 1.6) for pin-in-fiberglass casting, Kirschner- Ehmer external fixation and fiberglass casting techniques respectively.

**Table 4.1: Operative and post-operative time analysis for pin-in-fiberglass casting (Group A), Kirschner- Ehmer external fixation (Group B) and fiberglass casting techniques (Group C)**

	Group A	Group B	Group C
Operative time (OT)	1.75 hours	2.5 hours	0.75 hours
Average Post-operative care time/days (APD)	0.25 hour	0.5 hour	0.25 hour
Number of Post-operative care days (NPD)	15 days	39 days	31 days
Total post-operative care time (TPT)= (APD+NPD)	3.75 hours	19.5 hours	7.75 hours
<b>Total management time TMT= (OT + TPT)</b>	<b>5.5 hours</b>	<b>22 hours</b>	<b>8.5 hours</b>
<b>Ratio</b>	<b>1</b>	<b>4.4</b>	<b>1.6</b>

**Table 4.2: Cost analysis of managing fractures of the radius and ulna with pin-in-fiberglass cast, (Group A), Kirschner- Ehmer external fixation (Group B), and fiberglass casting techniques (Group C)**

Consumables	Cost		
	Group A (Naira)	Group B (Naira)	Group C (Naira)
Anaesthetics	250	300	200
Analgesics	200	200	200
Antibiotics	150	150	100
Stainman pins	2, 000	0	0
Gauze (rolls)	300	3000	500
Cotton wool (bundles)	200	200	300
Kirschner-Ehmer external fixative	0	30,000	0
Fiberglass cast	3,400	0	3,400
Adhesive plaster (10cm x 5cm)	50	300	50
Elizabethan collar	0	200	0
<b>NET TOTAL</b>	<b>5,950</b>	<b>33,700</b>	<b>4,250</b>
Service charge	5,000	20,000	3,000
<b>GRAND TOTAL</b>	<b>11,550</b>	<b>54,350</b>	<b>7,750</b>
<b>Ratio</b>	<b>1.5</b>	<b>7</b>	<b>1</b>

**Table 4.3: Cost-benefit analysis of radius and ulna fracture management in a breeding stud with pin-in-fiberglass casting(Group A), Kirschner- Ehmer external fixation (Group B) and fiberglass casting techniques (Group C)**

	Group A	Group B	Group C
Income /Week by breeder (IPW)	N20,000	N20,000	N20,000
Loss incurred by breeder/Week during morbidity period (LMP)	N20,000	N20,000	N20,000
Morbidity period (MP)	9 Weeks	8 Weeks	15 Weeks
Loss incurred during morbidity period (LMP)= (LMP X MP)	N180,000	N160,000	N300,000
Cost of immobilization (COI)	N11,550	N54,350	N7,750
<b>Profit-loss (LMP + COI)</b>	<b>N191,550</b>	<b>N214,350</b>	<b>N307,750</b>
<b>Ratio</b>	<b>1</b>	<b>1.1</b>	<b>1.6</b>

#### **4.2.6 Complications**

There was no early complication noted in all the groups within the first 2 weeks of surgery. Complication such as edema distal to the cast or external fixative was absent. Nerve and blood vessel injuries from pin tracts in pin-in- fiberglass cast and Kirschner-Ehmer external fixative groups were also absent. However, minor complications were seen in the later stage of healing.

In pin-in- fiberglass cast group, cast related complications were noticed. Cast sores were first noticed at the 6<sup>th</sup> week post-operative at the proximal aspect of the forelimb which was located caudally, just distal to the olecranon. The sore was treated by tucking in more cotton wool padding around the open end of the cast along with daily cleaning of the injury using 0.05% chlorhexidine gluconate (Purit<sup>®</sup> SaroLifecare Ltd, Ibadan, Nigeria). The sore healed after 4 days of treatment.

In the Kirschner-Ehmer external fixative group, there was serous pin tract drainage from pin holes especially those of the proximal segments at the 5<sup>th</sup> week post-operative. This was taken care of by loosening the clamps of the affected pins, squeezing the pins together and re-tightening the clamps under sedation. This was followed by daily cleaning of the Skin-pinhole interface with 0.05% chlorhexidine gluconate (Purit<sup>®</sup> SaroLifecare Ltd, Ibadan, Nigeria). Drainages resolved before the 6<sup>th</sup> post-operative week. Pressure sores were also noticed in this group. The sores were located around the cranial aspect of the elbow joint,

which were corrected by padding both ends of the connecting bar with cotton wool and wrapping it with adhesive plaster. The sores healed after 4 days of treatment.

Cast related complications were also seen in fiberglass cast group. Cast sores were seen at the distal end of the cast which was seen as a deep laceration around the paw. This was first noticed at the 8<sup>th</sup> week post-operative. Following the removal of cast after the fractures healed, cast sores were also seen around the cranial aspect of the carpal joint and the caudal aspect of the elbow. Stiffness of the elbow and carpal joint, and muscle atrophy of the operated limb were also observed after cast removal in this group. The operated limb was subjected to daily physiotherapy for 3 weeks while the joint stiffness and lameness resolved. Complications encountered in all the groups were considered to be minor.

#### **4.2.7 Haemogram**

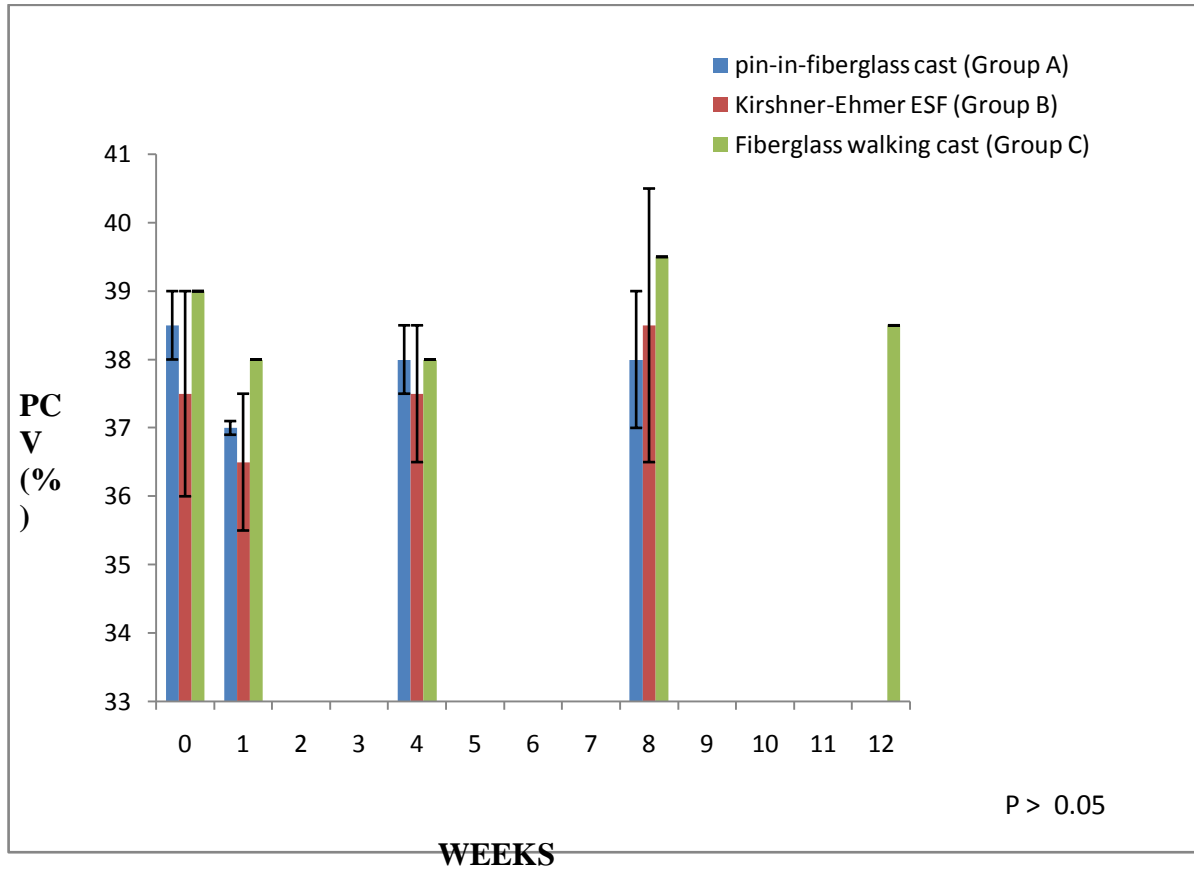
##### *4.2.7.1 Packed cell volume (PCV)*

The mean packed cell volume (PCV) of the pin-in-fiberglass cast group decreased slightly from  $38.5 \pm 0.5$  on the day of surgery to  $37 \pm 0.1$  on day 7 post-operative. By week 4 post surgery, the PCV of the group had risen to  $38 \pm 0.5$  which was maintained within the normal range until the termination of the study (Figure 4.1). The Kirschner-Ehmer external fixative group also showed a slight drop in mean PCV from  $37.5 \pm 1.5$  on the day of surgery to  $36.5 \pm 1$  on day 7 post-surgery. Improvement in the mean PCV of the group was noticed at week 4 post surgery with value at  $37.5 \pm 1$  which was maintained within the normal range until the termination of the study (Figure 4.1). Similarly, the fiberglass walking cast group showed a drop in mean PCV from  $39 \pm 0$  on the day of surgery to  $38 \pm 0$  on day 7 post surgery

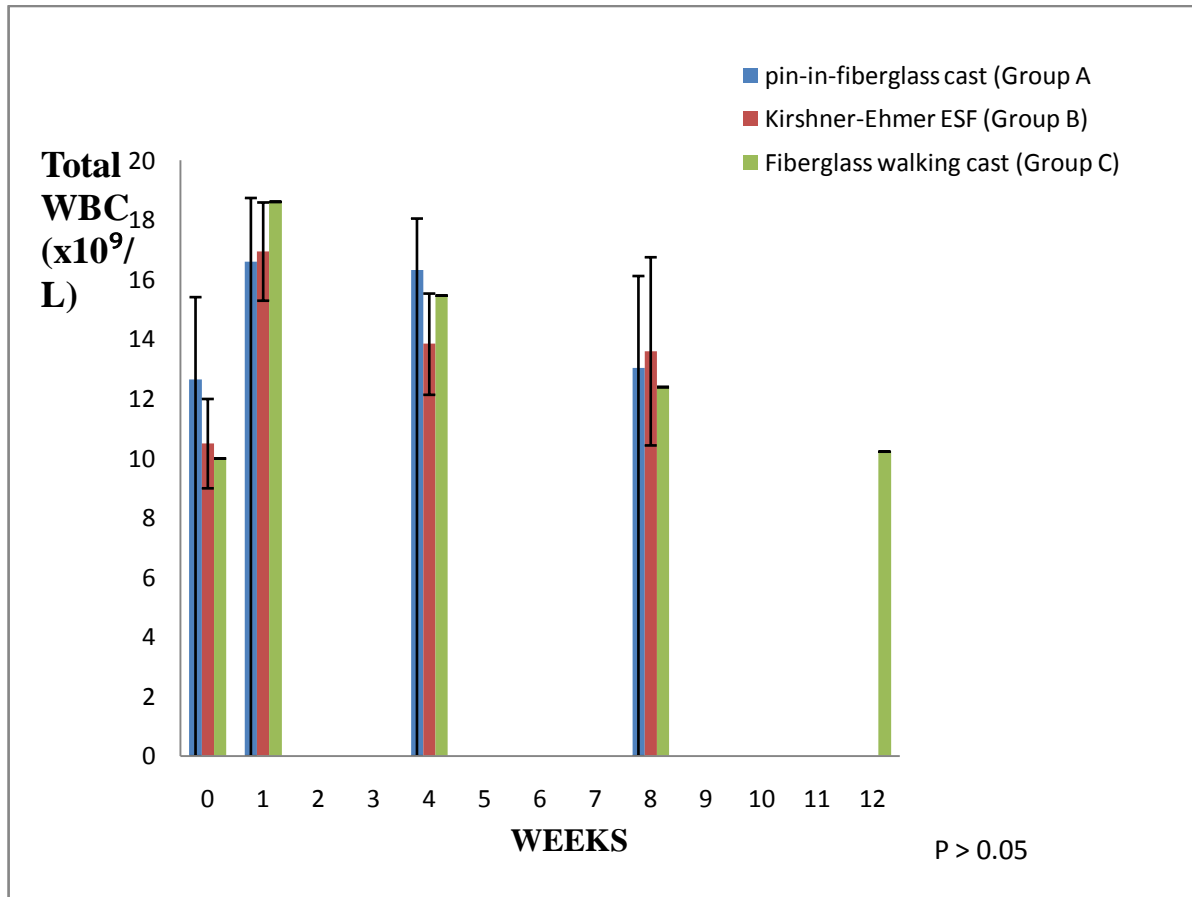
which later rose to  $39.5 \pm 0$  at week 8. The mean PCV of the group was maintained within normal range until the end of the study. There was no significant difference ( $P > 0.05$ ) in the mean PCV values between the three groups.

#### *4.2.7.2 Total white blood cell count (WBC)*

Generally, a sharp rise in mean WBC was noticed in all the groups within the first 7 days post-surgery from the initial values on the day of surgery (Figure 4.2). However in all the groups, this increase in the mean WBC was short lived as a decline in the mean WBC was later noticed which stabilised at week 4 to a normal range which remained stable within this normal range until the termination of the study.



**Figure 4.1: Mean Pre (week 0) and Post-operative pack cell volume (PCV) count plotted against the number of weeks for dogs of Group A, B, and C (Pin-in-fiberglass cast, Kirshner-Ehmer external fixative and fiberglass cast) respectively (Normal PCV value: 34-55 %)**



**Figure 4.2: Mean Pre (week 0) and Post-operative total white blood cell (WBC) count plotted against the number of weeks for dogs of Group A, B, and C (Pin-in-fiberglass cast, Kirschner-Ehmer external fixative and fiberglass cast) respectively (Normal WBC count: 6-17 X10<sup>9</sup>/L)**

## CHAPTER FIVE

### 5.0

### DISCUSSION

The dogs selected for this study were considered suitable based on the clinical and laboratory pre-operative evaluation findings. The parasitism noticed in all the dogs during their pre-operative evaluation was not an unusual finding due to the endemicity of these parasites as reported by Joshua *et al.*, (2013).

The differences observed in the vital parameters post-surgery when compared to the pre-surgical values could be ascribed to the inflammatory process that occurred, which is considered to be a normal finding following surgical trauma inflicted on the dogs (Slatter, 1985), which coincided with inflammatory response to the surgical trauma (Slatter, 1985). However, the rise was higher in the dog that underwent the fiberglass casting technique which was noninvasive compared to the other two techniques. This could be attributed to the inadequate stability offered by the fixative device at fracture site which resulted in higher degree of motion and pain at the fracture sites. The pain at the fracture site was evident by the prolonged period of non-weight bearing post-surgery on the operated limb. Thus, a prolonged physiological response in elevated vital parameters.

Since the primary aim of fracture treatment is to achieve the fastest possible healing and enable the patient to function normally by allowing early walking (Aron, 1998, Shahar,

2000), the healing of experimental bone defects of the radius and ulna managed by three reduction techniques were comparatively observed. On radiological evaluation, the evidence of earlier callus formation and fracture gap bridging in the pin-in-fiberglass and Kirschner-Ehmer external fixative groups could be ascribed to the less interfragmentary distance and a superior interfragmentary stability offered by these two techniques post fracture reduction when compared to the fiberglass group. However the Kirschner-Ehmer fixative group attained an earlier radiographic union at 7 weeks postoperative compared to the pin-in-fiberglass group and fiberglass cast group which attained radiographic union at 8 and 12 weeks respectively. Most uncomplicated fractures in adult dogs treated with external skeletal fixatives according to Harariet *et al.* (1996) attained radiographic union within 7 to 11 weeks. While it was reported (Harariet *et al.*, 1996; Permattei *et al.*, 2006) that fractures treated with external fixators heal via periosteal and endosteal callus formation, in this experiment, all the groups showed formation of both periosteal and endosteal callus; however, the size of the callus was smaller in the pin-in-fiberglass cast group. This can be attributed to the fact that indirect bone healing typically occurs in non-operative fracture treatment and in certain operative treatments such as; intramedullary nailing, external fixation, or internal fixation in which interfragmentary gap exceeds 0.01 mm (Kaderly, 1991) and some motion occurs at the fracture site (Peren., 2002). The more stable a fracture is, the less the size of callus formed around the fracture site (Gerstenfeld *et al.*, 2006).

On clinical observation post-operatively, it was observed that the dogs in the pin-in-fiberglass group were able to bear weight on the operated limb and had good joint mobility

within the first 24 hours post-operative and was functionally considered to be good by seven days after surgery. This was comparable to the Kirschner-Ehmer external fixative group in which it was also observed that the dogs were able to bear weight on the operated limbs and had good joint mobility within the first 24 hours post-operative and could use their legs to a great extent within 7 days postoperatively. In the fiberglass group, the dog could not bear substantial weight on the operated limb even up to week 6 postoperative. This early weight bearing observed in the pin-in-fiberglass and Kirschner-Ehmer external fixative groups could be attributed to the optimum stabilization and better load sharing ability of the fixative devices (Nnajiet *al.*, 2015). According to Ozsov and Altunatimaz (2003) early weight bearing observed in the groups are important development with respect to avoiding possible complications such as joint stiffness, bone and muscle atrophy, by allowing early return to function of the extremity.

The overall time requirement for operative and post-operative care for the three surgical techniques in the repair of radius and ulna fractures evaluated in this study revealed that the pin-in-fiberglass casting technique (5.5 hours) was less time consuming than the Kirschner-Ehmer external fixation (22 hours) and the fiberglass casting (8.5 hours) techniques. External skeletal fixation is a highly versatile and effective treatment modality, but it requires high technicality and experience in application in the theatre and also diligent care during the convalescent period. Animal owners are usually given some series of routine instructions on fixative care (Permattei *et al.*, 2006 ); daily inspection of apparatus, daily cleaning of crust and exudate around the pins, treatment of the pin sites with a topical antibacterial medicine, and a dressing to cover the splint as well as to compress and

immobilize soft tissues under the splint with gauze padding placed between the skin and the splint, were undertaken in this study. Hence, the longer man-hour required for undertaken in these techniques. As observed in the other groups however, the aftercare needed for the fixative device in the pin-in-fiberglass group was simple and minimal as it involved the placement of compressive modified Robert Jones bandage on the operated limb for a period of 7 days to prevent limb edema and dressing of cast sore observed on the operated limbs as the fracture heals. In the fiberglass cast group, meticulous attention was required to bring back the fractured limb back to function after cast removal because of the fracture disease (muscle atrophy and joints stiffness) observed in the group. This was achieved by subjecting the affected limb to daily physiotherapy for a period of 3 weeks after cast removal.

The operative and post-operative management cost analysis of the three techniques evaluated in this study revealed that the management of radius and ulna fractures with pin-in-fiberglass cast (N11,550) was more economical than using Kirschner-Ehmer external fixative (N54,350) but less economical when compared to using fiberglass cast (N7,750). Even though it may be argued that the Kirschner-Ehmer external fixatives are re-usable, the potential savings of such a program is 25% of the cost of new frames (Sung *et al.*, 2008). This therefore means that a Kirschner-Ehmer external fixative intended for re-use will cost N22,500 instead of N30,000 for a brand new one which may still be beyond the reach of clients in this environment. It is also good to know that the Steinman transfixation pins used in the pin-in-fiberglass fixative technique are also re-usable. The unavailability of these Kirschner-Ehmer external fixative is a serious challenge to a surgeon as was encountered in

this study as they were not available locally because most surgical equipment sales outlet do not keep such on their shelves due to their high cost and low patronage for them either by the human or the veterinary surgeons. Their high initial cost (N30,000) could also make it difficult for young practicing veterinary surgeons to add them to their arsenal of surgical equipment. Also based on our experience in clinical practice, the uncooperative attitude of most pet owners may get to an extent in which clients disappear with their pets or sold their pet off while a surgical implant which was implanted for fracture repair was still in the dog. Such experience may make a young veterinary surgeon reluctant to invest his/her hard earned money into purchasing and using such expensive device. Utilization of pin-in-fiberglass casting for repair of radio-ulna fractures in dogs was more costly than fiberglass casting alone as observed in this study. This was because transfixation pins were not required in the fiberglass casting. However, previous reports suggest that the use of cast alone for radius and ulna fractures management may not provide adequate immobilization (Tomlinson 1991; McLaughlin and Roush, 1999). Other reports documented delayed union, bone and muscle atrophy, joint stiffness, and presence of poor alignment of the limb after removal of cast (Slatter, 1985; Hassan and Hassan, 2003; Permattei *et al.*, 2006). When the results obtained in the dogs in the pin-in-fiberglass group were compared, the fiberglass group, the use of pin-in-cast for treatment of radius and ulna fractures appears to be superior in the preservation of joint mobility, ease of ambulation and early fracture union.

Evaluating the cost implications for the surgical and post-operative management mentioned above for the three techniques, one may be carried away by the economic benefit offered by the fiberglass casting technique over the other two techniques thus recommending it for the

repair of radius and ulna fractures in dogs. However, the cost-benefit analysis based on dog-hours lost in a high performing dog like a breeding stud as shown in table 4.3, the potential loss that would be incurred during the morbidity period for the three techniques was N191,550, N214,350, and N307,750 for the pin-in- fiberglass casting, Kirschner-Ehmer external fixation and fiberglass casting respectively. Thus, it was observed that overall, the highest loss will be incurred using the fiberglass casting technique even though such technique offered the most economical operative and post-operative management cost as previously shown (table 4.2). This was attributed to the longer morbidity period (dog-hour lost) of 15 weeks involved in managing the fractures with fiberglass casting. On the other hand, the pin-in-fiberglass casting technique offered the best economic sense when compared to the Kirschner-Ehmer external fixation and fiberglass casting. This was attributed to the shorter morbidity period (dog-hour lost) of 9 weeks when compared to the fiberglass casting technique. Even though the morbidity period for the pin-in-fiberglass casting group (9 weeks) was longer when compared to the Kirschner-Ehmer external fixation group (8 weeks), the technique still offered a less economic loss which was attributed to the lower surgical and post-surgical management cost offered by this technique when compared to the Kirschner-Ehmer external fixation technique.

The absence of any early complication in the first 2 weeks post-operative suggested an adequate and proper application of the fixative devices in the three groups. According to Tomlinson (1991), early complication such as edema distal to the cast was the most important indication of wrongly applied cast which we did not encounter in this study in the pi-in-fiberglass and fiberglass cast groups; however, the application of modified Robert Jones bandage to the pin-in-fiberglass cast and the Kirschner-Ehmer fixative groups post

fracture reduction may have prevented such edema in these two groups. Various complications which were considered to be minor were seen in the later stage of healing. The sores observed in the pin-in-fiberglass and fiberglass cast groups according to Permattei *et al.* (2006) was not an unusual finding as it constituted about 55% of complications seen following the application of cast even by a very prudent surgeon. The sores were as a result of the dogs spilling their drinking water on themselves which sores the cast padding thus causing rub sores by the cast edges. The serous pin tract drainage from pin holes especially those of the proximal fragments in the Kirschner-Ehmer external fixative group was as a result of pin loosening at the bone-pin interface which was the weakest link in the external skeletal fixation (Permattei *et al.*, 2006). Premature loosening of the bone-pin interface was the common limiting factor with the use of external fixators (McLaughlin and Roush, 1999) which can arise as a result of insertion of pins at high speed leading to thermal bone necrosis, and insertion of pins into muscle belly (Anderson *et al.*, 1997). However, the drilling speed employed in this study for the pin-in-fiberglass and Kirschner-Ehmer external fixative groups was the low speed (less than 150 Rotation/minute) advocated by several authors (Anderson *et al.*, 1997; McLaughlin and Roush, 1999; Permattei *et al.*, 2006). The fact that these complications occurred in the pins placed in the proximal fragments suggested that this may be a result of the area being covered with a more prominent muscle mass found in the proximal aspect of the forearm when compared to the distal part (Ozsoy and Altunatimaz, 2003; Sereda *et al.*, 2009). One would expect that such complication of pin loosening should be expected in the pin-in-fiberglass cast, but such was not observed post removal of the cast in this study. This could be attributed to the flexibility in pin positioning since all the four transfixation pins did not necessarily have to be inserted in a linear fashion

unlike in the Kirschner-Ehmer external fixator, which made it possible to identify safe corridor for pin insertion thus avoiding area with prominent muscle mass.

From the haemogram, all the groups showed just a slight drop in pack cell volume (PCV) after week 1 post-operative. This could be attributed to the negligible blood loss observed in less invasive surgery like external skeletal fixation and external coaptation as reported by Scalea *et al.* (2000). The moderate leukocytosis observed in all the groups 1 week post-operative was attributable to tissue damage and inflammatory response following surgery (Gerstenfeld, *et al.*, 2003), which according to Bush (1991) could manifest even as early as the first 12-36 hours after surgery. However the higher leukocytosis observed in the dogs that underwent fiberglass casting technique even though was the least invasive was attributed to the prolonged inflammatory response due to inadequate stability offered by the fixative device at fracture site which resulted in prolonged period of motion, and pain at fracture site. The prolonged inflammatory response at the fracture site was evident by the prolonged period of non-weight bearing post-surgery on the operated limb.

## CHAPTER SIX

### 6.0 CONCLUSIONS AND RECOMMENDATIONS

The study established the following about the comparatively evaluation of pin-in-fiberglass cast, Kirschner-Ehmer external fixation, and fiberglass cast in the management of experimental radius and ulna fractures:

- i. Minimal soft tissue swelling and periosteal tissue reaction was observed in all the groups
- ii. Maximum callus formation was achieved as follows: 6<sup>th</sup> week for pin-in-fiberglass casting (P.I.C), Kirschner-Ehmer external fixation (K-ESF) and 10<sup>th</sup> week for fiberglass casting (F.G.C).
- iii. P.I.C and K-ESF provided early ambulation within a period of 24 hours post-surgery. Complete fracture healing was attained at week 8, 7 & 12 for P.I.C, K-ESF and F.G.C respectively.
- iv. P.I.C and K-ESF offered an excellent functional and cosmetic appearance while it was fair in F.G.C
- v. The duration of repair was shorter in the P.I.C (5.5 Hours), than the K-ESF (22 hours) and the F.G.C group (8.5 hours).

- vi. Cost-benefit analysis favours the P.I.C against the K-ESF and F.G.C in the ratio of 1 : 1.1 : 1.6
- vii. Haematological changes were within the normal range for all the groups

## **6.1 Recommendations**

- i. Pin-in-fiberglass cast should be used as a satisfactory substitute to Kirschner-Ehmer external fixator in the management of stable radius and ulna fractures in dogs.
- ii. The possibility of using a preformed, removable, and bivalve cast in place of the cylindrical cast should be investigated as this would give room for the management of soft tissues trauma which often are present at fracture sites while the fracture heals.
- iii. Our local industries should be encouraged to go into the production of these fixative devices in order to help in reducing their cost and increasing their availability.

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## APPENDICES

**Appendix 1a: Mean Pre- and Post-surgery vital parameters of two dogs that were treated with pin-in-fiberglass casting.**

Parameters	Temperature ( <sup>0</sup> C) (38.5-39.4)	Pulse rate (Beats/min.) (65-90)	Respiratory rate (Cycles/min.) (15-30)
Days			
Pre-op(0)	38.85±0.35	115±3	28.5±1.5
1	39.5±0.1	130±2	33±3
2	39.5±0	131.5±2.5	33.5±1.5
3	39.2±0.2	128±2.0	30.5±1.5
4	39.15±0.25	121±2	29±0
5	39.65±0.25	119.5±0.5	29±1
6	38.85±0.45	117.5±2.5	28.5±0.5
7	39.25±0.15	118±1	27.5±0.5
8	39.3±0	113.5±1.5	30±0
9	39.1±0.2	114±1	29±0
10	39±0.1	117.5±0.5	28±0
11	39.1±0	118.5±1.5	28±1
12	39±0.1	116±0	28±0
13	39.2±0.1	118.5±0.5	29±1
14	38.8±0.1	114.5±1.5	24±2
15	39.2±0.2	118.5±1.5	27.5±1.5
16	39.1±0.2	116.5±2.5	28.5±3.5
17	38.9±0.3	119.5±0.5	28.5±0.5
18	38.75±0.05	114.5±2.5	27±3
19	39.3±0	119±0	31±3

20	$39.25 \pm 0.15$	$119.5 \pm 0.5$	$30 \pm 1$
21	$39.35 \pm 0.5$	$127 \pm 12$	$29.5 \pm 2.5$
28	$39.35 \pm 0.25$	$121.5 \pm 4.5$	$29 \pm 2$
35	$39.05 \pm 0.2$	$115.5 \pm 1.5$	$27.5 \pm 1.5$
42	$39.1 \pm 0.2$	$118.5 \pm 0.5$	$28.5 \pm 1.5$
49	$39.3 \pm 0.2$	$134.5 \pm 3.5$	$27 \pm 6$
56	$38.85 \pm 0.05$	$118 \pm 1$	$28 \pm 0$

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**Appendix 1b: Mean Pre- and Post-surgery vital parameter of two dogs that were treated with Kirschner-Ehmer external skeletal fixation.**

Parameters	Temperature ( <sup>0</sup> C)	Pulse rate (Beats/min.)	Respiratory rate (Cycles/min.)
	(38.5-39.4)	(65-90)	(15-30)
<b>Days</b>			
Pre-op(0)	38.6±0.2	114.5±4.5	25±4
1	39.05±0.25	153±	29.5±0.4
2	39±0.4	139±15	30.5±2.5
3	39.2±0.3	141±17	33.5±3.5
4	39.25±0.05	128.5±5	31.5±0.5
5	39.2±0.1	133±10	28.5±0.5
6	38.95±0.05	120.5±1.5	29.5±0.5
7	38.85±0.05	122±4	28.5±1.5
8	39.1±0.4	122±0	26±0
9	39±0.1	119.5±2.5	28.5±0.5
10	38.65±0.05	118.5±4.5	27.5±1.5
11	39.3±0	118±1	27.5±2.5
12	39±0.1	117.5±1.5	28±1
13	39.2±0.3	114.5±0.5	26±0
14	39.2±0.2	115±3	28.5±1.5
15	39.15±0.25	118±0	24.5±1.5
16	39.3±0.5	121.5±6.5	29±0
17	38.95±0.05	115±2	23±3
18	39.05±0.2	118.5±0.5	26±1
19	38.95±0.2	117±5	25±1
20	39±0.2	113.5±1.5	26±2
21	39.2±0	117±1	25±0

28	$38.85 \pm 0.05$	$120 \pm 1$	$24 \pm 3$
35	$39.25 \pm 0.05$	$117.5 \pm 1.5$	$26.5 \pm 1.5$
42	$39.75 \pm 0.4$	$130.5 \pm 14.5$	$21.5 \pm 3.5$
49	$39.25 \pm 0.2$	$129 \pm 2$	$28.5 \pm 0.5$
56	$38.9 \pm 0.1$	$116.5 \pm 1.5$	$26 \pm 1$

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**Appendix 1c: Pre- and Post-surgery vital parameters of a dog that was treated with fiberglass cast**

Parameters	Temperature (°C) (38.5-39.4)	Pulse rate (Beats/min.) (65-90)	Respiratory rate (Cycles/min.) (15-30)
Days			
Pre-op (0)	38.9	110	22
1	40	112	44
2	40	129	36
3	39.9	128	31
4	39.8	128	28
5	38.7	120	22
6	39.4	118	24
7	39.4	119	26
8	39.1	116	21
9	39.3	118	23
10	38.9	114	26
11	39.4	110	23
12	39.8	121	21
13	40.3	139	20
14	40.4	143	19
15	39.9	141	23
16	39.4	132	26
17	39	106	24
18	38.7	116	23
19	38.9	109	24
20	38.7	110	22
21	38.8	113	29

36	38.6	109	25
43	38.9	112	22
48	38.6	115	23
57	38.9	106	21
64	39.1	111	24
71	38.9	107	22

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**Appendix 2a : Pre (Day 0) and Post-surgery haematology mean values of dogs that were treated with pin-in-fiberglass cast, Kirshner-Ehmer external fixative and fiberglass cast**

Parameters measured	Groups	Before surgery	Weeks Post-Surgery											
		-1	1	2	3	4	5	6	7	8	9	10	11	
		Mean±SEM												
<b>Total Leucocyte Count</b>	A	12.65±2.77	16.6 ±,2.15			16.33±1.73				13.03±3.16				
	B	10.5±1.5	16.95±1.65			13.84±1.7				13.6±3.5				
	C	10±0	18.62±0			15.47±0				12.4±0			10.23±0	
<b>Neutrophils(X109/L)</b>	A	11.04±2.1	15.98±2.02			11.25±1.13				11.37±2.2				
	B	8.72±0.72	10.23±1.13			10.33±1.59				10.45±2.81				
	C	4.99	15.31			10.81				7.89			8.92	
<b>Lymphocytes (X109/L)</b>	A	0.71±0.11	1.15±0.01			2.34±0.02				0.82±0.2				
	B	1.115±0.89	0.9±0.01			1.13±0.02				0.91±0.19				
	C	4.3±0	0.93±0			2.36±0				1.94±0			0.93±0	
<b>Monocytes (X109/L)</b>	A	0.68±0.53	2.1±0.1			1.9±0.3				0.7±0.33				
	B	0.46±0.04	3.72±0.29			2.06±0.03				1.12±0.04				
	C	0.29±0	1.51±0			0.94±0				1.39±0			0.13±0	
<b>Eosinophils (X109/L)</b>	A	0.135±0.01	0.22±0.01			0.8±0.28				0.14±0.36				
	B	0.17±0.17	0.15±0.09			0.29±0.01				1.3±0.12				
	C	1.4±0	0.16±0			1.2±0				1.15±0			0.25±0	
<b>Bands (X109/L)</b>	A	0.08±0.02	1.13±0.01			0.03								
	B	0.09±0.02	1.92±0.14			0.03±0.04								
	C	0	0.71±0			0.16±0				0.03±0			0	
	A	38.5±0.5	37±0.1			38±0.5				38±1.5				

<b>Pack cell volume (%)</b>												
	B	37.5±1.5	36.5±1			37.5±1				38.5±2		
	C	39.0±0	38.0±0			38±0				39.5±0		38.5±0
<b>Total protein</b>	A	6.25±0.05	8.2±0			6.8±0.8				7.6±0.6		
	B	6.9±0.5	8.65±0.05			6.8±0.5				7.2±1		
	C	7.2±0	8.9±0			8±0				8±0		7.3±0

