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Comparative evaluation of various external skeletal fixator (ESF) device configurations for management of long bone fractures in cattle

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Abstract
The present clinical study aimed to investigate the comparative efficacy of various external skeletal fixator devices for long bone fracture management in cattle and its clinico-therapeutic outcome. A total 12 clinical cases of cattle with non-weight bearing limb, recumbency, abnormal angulations of fractured limb, pain with moderate to severe haemorrhage were presented to teaching hospital. Radiographic examination of all limbs showed comminuted, transverse and oblique fracture of long bones in present study with non-significant changes were recorded in haemato-biochemical values. However, values of SGOT and serum cortisol were fluctuating throughout the study. Epoxy ESF device showed, acceptable anatomical alignment and fracture reduction with adequate strength in animals weighing upto 120 kg body weight. Bilateral linear fixators, 6 mm pins (3 in each fragments) was found to be adequate and strong to hold the side bars after reduction of fractured fragment in metacarpal fractures which seems to be stronger, rigid and least cumbersome technique in heavy animals. Compound oblique fracture of tibia and metatarsal was stabilized with circular external fixators in three animals with early weight bearing. It was concluded that, epoxy pin ESF is more reliable, economical and lighter device which provide rigid fracture fixation in animals weighing upto120 kg body weight as compared to other two fixator devices having several postoperative complications due to movement and heavy weight of animals.

Keywords: Cattle, epoxy, fracture, pain, skeletal fixators

Introduction

In earlier decades, cattle and buffaloes affected with long bone fractures were either euthanized or treated with various conservative techniques owing to non-availability of suitable advanced fracture fixation techniques and poor awareness of farmers. However, fracture repair in cattle and buffaloes is receiving great attention in current veterinary practice to restore the consistent source of income and livelihood of poor farmers in rural India. The major drawback in the management of fractures in large animals is the non-availability of suitable fracture fixation devices and problems associated with postoperative care, management and rehabilitation. Various techniques of fracture fixation have been developed in the last two to three decades for the treatment of long bone fractures in large animals; however, their suitability and success rate are still debatable. In recent years, ESF is acquiring demand in large animal surgery too, because it is versatile, less invasive, provides better stability and allows drainage and dressing of open wounds (Kumar *et al*. 2018 and Aithal *et al*. 2019a) [25, 6].

Mechanical studies have further revealed that, hybrid fixator was most rigid and strong under compression, whereas bilateral linear ESF was strongest in cranio-caudal bending (Singh *et al.* 2007a) [39]. The epoxy-pin fixation is a free form fixation system, wherein the pin size and location of pin insertion is not dictated by the size of fixation bolts/clamps or the position of side bars/rings. The side bars can be constructed as desired and contoured to the shape of the limb. It is also easy to apply, economical and provide stable fixation of bone in light weight animals (Aithal *et al*, 2019b) [7]. External skeletal fixators made from mild steel for use in large ruminants could withstand about 300 kg load applied under compression and bending without any substantial adverse biomechanical effects on constructs.

Mechanical studies have further revealed that, hybrid fixator was most rigid and strong under compression, whereas bilateral linear ESF was strongest in cranio-caudal bending (Singh *et al.* 2007a) [39]. Comparison of mechanical strength of different designs of acrylic and epoxy pin ESF system (comprising of both two-point and three point fixation system per segment) revealed that constructs with three-point fixation per segment were significantly stronger than construct with two-point pin fixation and both acrylic and epoxy-pin ESF were sufficiently strong with no significant difference (Tyagi *et al*. 2014) [42]. Thus the present clinical study was undertaken to evaluate the efficacy of various external skeletal fixator devices for management of long bone fractures in cattle and its clinico-therapeutic outcome.

Materials and Methods

Animals: Total 12 cattle were included with the history of trauma and non-weight bearing affected limb and they were suffering with various long fractures referred from government veterinary dispensaries. All animals underwent for routine anamnesis, like cause of fracture, duration of fracture, body weight, degree of lameness and physiological status and type of fracture were considered its suitability for application of appropriate fracture fixation devices. Among the various long bone fracture in cattle, fracture of tibia, radius, metacarpus and metatarsal were considered as suitable patient for application of various external skeletal fixators in present study. Fracture of femur and humerus in cattle were excluded from the present clinical study due to its anatomical limitation as far as surgical approach was concern.

Fracture assessment: Animals were evaluated for type and location of fracture, the degree of soft tissue injury and they were graded and described as exposure of fracture fragments through small opening in skin with minor contamination and cellulitis (slight, +), large wound with gross contamination and relatively more soft tissue damage (moderate, ++) and very large skin wound with major contamination, torned soft tissue, necrosis and vascular compromise (severe, +++).

Haematological and biochemical study: Blood samples were collected from jugular venipuncture and subjected for haemoglobin (Hb), packed cell volume (PCV), total leukocyte count (TLC), differential leukocyte count (DLC), monocyte (M), lymphocyte (L), mean corpuscular hemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), and mean corpuscular volume (MCV) were estimated in automatic analyzer. Biochemical parameters include BUN (mg/dL), Serum Creatinine (mg/dL), SGOT (IU/L), and SGPT (IU/L). To assess the stress level in orthopaedic animals, serum cortisol (nm/L) was monitored on 0^{th} Day (preoperative); 3^{rd} Day (postoperative) and 7^{th} Day (postoperative) with the help of RIA technique.

Radiographic examination: After thorough clinico-laboratory investigation, all animals were subjected to orthogonal radiographic view or latero-medial and cranio-caudal view to determine the exact location, type of fracture and select appropriate diameter of pin and number of fixation pins to be used in present study.

Patient Preparation and anaesthetic protocol: All animals were kept off feed for 36-48 hours and water was withheld for 12 hours prior to surgery and fractures or wound site was prepared aseptically.

Prophylactic antibiotic (Inj. Dicrysticine-5gm) and analgesic-anti-inflammatory drug (Inj. Meloxicam^2 -10ml) was administered intramuscularly prior to the procedure. All animals were premedicated with inj. xylazine @0.1mg/ kg, intramuscularly and diazepam @ 0.2-0.4 mg/ kg, intravenously along with Inj. Butorphenol 0.02 mg/ kg intravenously as a premedication and induction was performed by using Inj. Propofol 4-6 mg/ kg intravenously till effect. Surgical anaesthesia was maintained on 2-3% isoflurane gaseous anaesthesia.

Animal positioning and fracture reduction: animals were positioned in lateral recumbency with the wound surface facing upwards; the open wound was thoroughly debrided before flushing with sterile isotonic solution. In fresh cases, attempts was made to close the fresh wound with simple interrupted suture by using nylon over the exposed fractured fragments by leaving enough space for postoperative drainage. All fracture fragments were reduced via manipulation method by applying traction and counter traction with the help of a rope tied at the fetlock. The free sharp pieces of bone at fracture site were removed and bone fragments were held in near anatomical alignment manually till complete fixation of fracture with recommended fixator device. In some cases, hemicerclage wiring (16G) were used to align the fractured fragments as a complimentary procedure before application of external skeletal fixator device.

Selection and configuration of external skeletal fixator devices: On the basis of body weight, appearance of wound (fresh or contamination), involved long bone, location of fracture and type of fracture (closed or open) all animals were randomly considered for epoxy pin fixation, bilateral linear fixators (BLF) and circular external fixators (CEF).The required instrumentation for preparation various external skeletal fixators devices as below.

1. **Epoxy pin external skeletal fixators:** Animals weighing less than 120 kg body weight with radius-ulna, metacarpal or metatarsal fracture were considered for this device, the pins (1.5-2.5 mm diameter) were passed using a low speed (250-300 rpm) electric drill under continuous dropping of cold normal saline at insertion point at two points both in proximal and distal bone fragments to immobilize fractured fragments. All the transcortical pins were passed; they were bent about 1-1.5 cm away from the skin, the bent pins in same plane were joined using cloth adhesive tape to make temporary scaffold of connecting bars. After making scaffold, the fracture reduction and alignment was re-examined and then the epoxy resin (M-seal) was thoroughly mixed with the hardener to make dough and applied long the pin scaffold taking it as guide and by incorporating the pins within the epoxy mold and allowed to harden for about 45 to 60 minutes.
2. **Bilateral linear fixator:** It comprising of pair of side bars with threads carved in opposite direction on both sides from centre and multiple fixation bolts were used. The side bars measured 14 mm in diameter and 22-45 cm in length (three different sizes). The centre of the side bar had a hexagonal flat surface for easy turning with wrench. The rectangular fixation bolts had an eccentrically placed threaded hole to get secured along the side bars and other side an 8 mm hole drilled perpendicular to the length of side bar to accept 6-7 mm pins. The thread in the fixation bolts were also carved in

opposite directions to secure along the corresponding side of side bar. After preparation of assemble, 2 fully threaded 6 mm pins inserted mediolateral in proximal and distal portion of diaphysis after pre-drilling each site with 5.5 mm drill bit. The ideal distance between two pins was kept at 40-60 mm. The pins were then fixed to the 22 cm long side bars using fixation bolts with the help of nuts at a fixed distance of 50 mm from the bone on either side.

3. **Circular external fixator:** In this technique, the rings were 14-20 cm in inner diameter, 2 cm in width and 5 mm in thickness was used. Ring dimensions were standardized and ring was large enough to accommodate soft tissues. Each full ring had 22 equidistant holes measuring 10 mm in diameter for connecting rods and fixation bolts. Connecting rods were 4-6inch long and 8 mm in diameter. The slotted bolts of 8 mm diameter were drilled to accept 3.5 mm K-wires. Assembled circular skeletal fixators were placed on centre of fractured tibia; about 4-5 rings were mounted 80 mm apart using 12 threaded connecting bars. Rings were fixed to the bone by 3.5 mm beaded K-wires driven through the bone using a low speed electric drill and then fastened to the fixator rings using slotted fixation bolts. 2 K wires were used per ring. 1 passed from craniolateral to caudo-medial and another from caudolateral to craniomedial direction. The wires crossed each other at an angle of 90degree. Wires were tensioned using a non-caliberated device and then secured by tightening the nuts on the fixation bolts manually using wrench.

Fracture healing and complications if any: Radiographs were also made in regular interval (15^{th}, 30^{th}, and 45^{th} days) to assess the status of bone fragments and fixation pins, degree of bone healing, osteolytic changes and any other complications. The fixation was maintained till complete healing evidenced by radiography and recorded as normal, delayed, Malunion and non-union. All animals were observed for postoperative complications associated with various external skeletal fixators' devices for 2-3 months.

Statistical Analysis
The present clinical data was analyzed with the help of IBM-SPSS-20.0 software package using t-test and one way ANOVA as per standard methods by described by Snedcor and Corchan (1994).

Results and Discussion
Incidence of fracture: Amongst the 12, 6 were Khillar breed followed by 5 Holstein Friesian and one Jersey aged between 9 months and 7 years (2.28±0.54 years) comprising of 8 females and 4 males (Table 1). The body weight of all affected animals ranged between 60 kg and 500 kg (207.33±43.5 kg) and majority of cattles were injured due to falling from height and slipped on slippery floor leading to long bone fractures (Table No.4.1). Similar incidence was documented by Aithal *et al.* (2019a) [6] in their review including 28 cases calves and 4 foals with open bone fractures (n=31) and open joint luxation (n=1) in animals aged between 4 days and 2 years with 45 to 105 kg body weight. They further reported that, the incidence of metatarsus fracture (n=15) was highest followed by fractures of metacarpus (n=6), tibia (n=5), radius and ulna (n=4) and phalanges (n=2).
In another study, with 28 long bone fractures or joint luxation in 25 goats and sheep (weighing 8-25 kg) aged between 2 months and 2.5 years, higher no of males (16) were affected than female.(Aithal *et al.*, 2019b) [7] and Lozier *et al.* (2018) [31] reported, long bone fractures of metatarsus (n = 16, 41%), metacarpus (n = 11, 28%), radius/ulna (n = 6, 15%), tibia (n = 5, 13%), and proximal phalanx (P1) (n = 1, 3%) in ruminants consisting of 27 closed (69%) and 12 open (31%) fracture. Majority of fractures in present study were recorded in the metacarpus (n=6), followed by tibia (n=5) and metatarsus (n=1) and the fractures were located at distal third of long bone (n=5) followed by middle third (n=6) and proximal third (n=1). Fractures of metacarpus or metatarsus were common in present study as also reported in earlier study (Nuss, 2014) [34] which could be due to less soft tissue coverage of distal bones making them more susceptible to open fracture as also reported by (Bramlage, 1983) [9] in his report.

Clinical observation
All animals showed non-weight bearing lameness, recumbency, shivering, congested conjunctivae, abnormal angulations of fractured limb, pain with moderate to severe haemorrhages at fracture site. Amongst 12 long bone fractures, eight were open fractures and remaining four were closed fracture with varying degree of pain on palpation. On the days of presentation, all the animals showed mild to moderate respiratory distress; open mouth breathing and slight tachycardia which could be due to the persistent pain associated with long bone fracture and transportation stress. The present findings were in accordance with Aithal *et al.* (2019a) [6], Gulaydin and Sarierler (2018) [20] and Aithal *et al.* (2019b) [7] who have recorded similar clinico-physical findings in cases of long bone fractures in ruminants. Non-significant changes were observed in heart rate, body temperature and respiratory rate in all animals (Table 2) at different intervals except for body temperature at 0minute showing significant difference between group-A (84.21± 16.85) and group B (101.18± 0.46) which could be due to some unnoticed metabolic disorder. Rubio-Martinez *et al.* (2007) [37] reported that, the 85- kg. 3-year-old male alpaca was lame and unable to bear weight on the left hind limb with metatarsus fracture with normal vital parameters.

Fracture assessment findings
In open fractures, the degree of soft tissue injury was severe (n=5) characterized by major skin loss at the site of fracture with broken fractured fragments, torn muscles and necrosed surrounding soft tissues indicating gross contamination (+++) and they were reported after 5 days from the occurrence of fracture. In three cases, the fracture site had a cellulitis with small opening and protrusion of sharp end of fractured bone (++) indicating soft tissue damage at fracture site. In four cases, fracture was closed and showed doughy swelling indicative of haematoma with palpable fractured fragments with minimal soft tissue damage. Similar grading system was used by Aithal *et al*. (2019a) and (2019b) [6-7] in their study and they allotted various grades to long bone fractures in cattle on the basis of degree of damage of soft tissues, gross contamination and type of fracture.

Radiographic findings
Preoperative radiographic examination in all animals revealed, comminuted fractures in five animals with three or more bone fragments followed by transverse fracture in three animals and spiral or oblique fracture in four animals which might be due to significant torsional force during slippage on slippery floor. The present radiographic findings of various

long bone fractures were in accordance with Aithal *et al.* (2019a and 2019b) [6-7] who have studied 32 cases and 26 cases, respectively via radiographic views and recorded comminuted, transverse and oblique or spiral fractures of various long bones.

Haematobiochemical findings: haemoglobin levels at 0min (preoperatively) and at 60th min showed mean of 10.13±0.59g % and 9.23±0.63g % respectively indicating non-significant changes within as well as between the groups (Table 3). In contrary, the values of total erythrocytic count at 45 min was 7.42 ±0.30x10^6/µland 8.00 ± 0.66 x10^6/µl whereas as at 60 minutes 7.97 ±0.21 x10^6/µland 8.19 ±0.46x10^6/µl indicating significant changes between the animals whereas non-significant changes were observed within different time intervals could be due to temporary effect of anaesthetic drugs. Kelawala *et al.* (1991) [24] reported non-significant decrease in total erythrocyte count during diazepam and ketamine anaesthesia in goats. Similar observations were recorded by Sannakki and Ranganath (2015) [38] in cattle and Alsobayil *et al.* (2015) [8] in camel during isoflurane anesthesia induced with ketamine.

Blood urea nitrogen and serum creatinine values were normal within the groups at different time intervals indicating non-significant changes (Table 4) suggesting minimal effect of anaesthesia on renal blood flow. Goyal (2015) [19] also recorded non-significant increase in BUN values during anesthesia maintained with isoflurane in bovines. The significant alterations of SGOT and SGPT values were observed in the present study could be attributed to the long duration of illness and prolonged treatment regimen. Hisaka *et al.* (2000) [22], Gill (2013) and Thangadurai *et al.* (2016) [41] studied liver enzymes in goats and bovine and they reported nonsignificant changes in serum AST and ALT level during isoflurane anesthesia. The cortisol values in all animals were fluctuating throughout the study period indicates significant changes which could be affected by pain originating from fractured bone, recumbency and surgical stress. In studies performed by Lefcourt *et al.*, (1993) [27] and Forslund *et al.* (2010) [15] in farm animals which had a history of mismanagement, travel, inappropriate environmental temperature, castration without local anaestheia altered serum cortisol level were recorded.

Thorough cleaning of open fracture wound with 0.2% povidone iodine was found to be more effective to prevent further contamination. Majority in all animals, bamboo splints were applied as external immobilization technique which was found effective to avoid further damage of soft tissue and gross contamination at the site of fracture. Many researchers like Hoerdemann *et al.* (2012) [23], Lozier *et al.* (2018) [31], Aithal *et al.* (2019a) and (2019b) [6-7] endorsed that, thorough cleaning of open wound at fracture site with 0.2% povidone iodine helps to minimize the infection at fracture site and early immobilization of fractured fragments will decide the fate of fracture repair in animals. Isoflurane produced excellent quality of anaesthesia with moderate to good muscle relaxation and complete loss of palpebral, corneal and swallowing reflexes with good depth of anaesthesia for 90 min all animals which could be due to smooth induction and recovery. Similarly Abrahamsen (2008) [1] reported that good to excellent cardiopulmonary function and stable plane of anaesthesia could be maintained by triple drip intravenous infusion as compared to ketamine-diazepam in large ruminants.

Fracture reduction findings: Fracture reduction was found to be excellent in seven cases of fractures in metatarsus or metacarpus by traction and counter-traction whereas greater efforts were required in cases with tibial fractures which could be due to its anatomical topography as well as presence of bulky muscles restricting the alignment of fractured fragments in large animals. Similar techniques of fracture reduction was used by Gulaydin and Sarierler (2018) [20], Aithal *et al.* (2019a) [6] and Aithal *et al.* (2019b) [7] in their study and they found it satisfactory for reduction of long bone fracture in animals. In five cases of open comminuted or oblique fractures of tibia, hemicerclage wiring done which was found to be excellent complimentary technique to facilitate the reduction of fractured bone whereas in one two year old HF having metacarpal fracture, lag screw was used for reduction of fracture fragments. Similar ancillary orthopaedic techniques were used by Aithal *et al.* (2010b) [5] in two cases of tibial fracture in calves and they reduced the bone fragments and temporarily stabilized using hemicerclage wire.

External skeletal fixator devices findings

Epoxy Pin ESF: Out of 12, 6 animals with average age 14.06±2.4months including four Khillar and two HF cattle weighing between 60 kg and120 kg (96.33±9.5 kg) underwent epoxy pin external skeletal fixation. The mean time required for wound cleaning, debridement and intraosseous drilling, fixation of pins and making final temporary scaffold was 45.3±8.3 minutes and total time required for construction of assembly was 61.2±3.5 min. Similarly Aithal *et al.* (2019a) [6] reported average time required for debridement and fixation of pins (as 25.3±4.1min) and construction of external skeletal fixators as (55.2±5.5min) in their study. The selection of fixation pins depends upon the type of fixators, size of bone and patient. Aithal *et al.* (2019a) [6] used fixation pins having diameter 2-3 mm in different animals. In other studies, 2-3 mm diameter fixation pins were found suitable in calves according to Aithal *et al.* (2007) and (2010b) [3, 5].

None of the cases showed iatrogenic fracture or any complication while drilling the pins in different long bones and pins were inserted into the bone at an angle of 60-90, however, in one case the angle between the crossed pins was 30-45^0. Bending of 2 mm to 2.5 mm pins was found to be easier it was easy to construct the connecting side rods and bend the pins to make temporary scaffold side bar using strips of cloth adhesive tape which provided temporary scaffold which provided temporary stability at fixation site, before the epoxy putty used. Handling of epoxy putty was easy and it was easy to apply it along the pin scaffold to construct the whole assembly. This finding is in corroboration with Aithal *et al.* (2019a) [6] who used epoxy dough around the pins aiming to achieve maximum stability and rigidity of fractured long bone.

The epoxy resin was kept more than 2 cm away from skin the surface during its application to fixation of pins so as to prevent possible thermal injury to the skin and none of the animals showed thermal injury to the skin. Leitch and Worth (2018) [30] reported that, maximum temperature recorded during curing of epoxy resin was less (43 °C) than that of PMMA (98.5 °C) whereas Butto *et al.* (2018) [11] stated that, heat transfer from epoxy putty to the pins reach 47 °C which did not cause thermal injury to soft tissue indicating epoxy was safe for use in external skeletal fixation. During the follow up period of cases treated with epoxy pin ESF showed excellent tolerance and stable fixation of fracture in animals weighing upto 120 kg body weight. Aithal *et al.* (2019b) [7] concluded that, epoxy pin external fixators is easy to apply, inexpensive, very versatile and provides better stability in animals weighing up to100 kg.

Bilateral linear fixator: Three animals aged between and 7 years (52.0±17.4months) weighing between 270 and 500 kg (420±75.05 kg) comprised of Khillar, HF and Jersey suffering with metacarpal fractures (2 communited and 1 transverse). In one case (Jersey), the fractured fragments of distal metatarsus were stabilized with lag screws and transarticular fixation by incorporating first phalanx. In HF breeding bull, the distal one third metatarsal fractures were reduced by transarticular fixation by incorporating first phalanx whereas in another case (Khillar), knee joint was incorporated. The 6 mm pins inserted in medio-lateral direction with electric drill was found to be adequate and strong to hold the side bars after reduction of fractured fragment in all cases. The distance between two transosseous pins was kept 4-5 cm in all cases and the bone was approached medially. While drilling of pins into the bone, few of them got stuck and it was withdrawn and re-drilled again.

Ideally 3-4 pin inserted into the proximal as well as distal fragments of fracture was found to be stiff and rigid fixation of fracture. Another benefit of these bilateral fixators was after fixation of pins to side bars with nuts realignment and reduction of fractured fragments could be done. All the nuts and screws were tightened in all three cases is in accordance with Lewis *et al.* (2001) [28]. All three animals stood up immediately after fixation with support and showed good weight bearing after 24 hrs. In all cases the distance between the skin surface and the side bar was kept about 4 cm. Newman and Anderson (2006) [33] suggested fixing the connecting bars at least 1 cm away from the skin to allow for post-operative oedema. In the present study, none of the animals showed bending of pins or side bars in metacarpus fracture reduction during follow up which seems to be stronger, rigid and least cumbersome technique. Similar observation was made by Singh *et al.* (2007a) [39] and Dubey *et al*. (2021) [12] who in their biomechanical study of various fixators concluded that, the fixator is strongest in cranio-caudal bending

Circular external fixators: Among 12, three animals (1 Khillar and 2 HF) aged between 10 months and 4 years (29.33±10.9 months) weighing between 180 kg and270 kg (216.6±88.4 kg) having compound oblique fracture of tibia and metatarsus underwent circular skeletal fixation (CEF) technique. Both tibial oblique fractures were reduced by hemicerclage wiring and they were near to anatomical alignment before application of CEF evidenced via postoperative radiographic examination. Aithal *et al.* (2019b) [7] and (2010b) [5] used circular fixators for treatment of long bone fractures in large animals weighing upto 250-275 kg. In another study, calves weighing upto 100 kg with unstable or compound tibial fractures were successfully treated with CEFs (Aithal *et al*., 2004) [2].

The diameter of inner rings found adequate for metatarsus and tibia were 13-14 cm and 17-18 cm, respectively in animals weighing 270 kg with no friction between ring and skin surface seen in the present study. Bronson (1995) [10] found 30% reduction in axial stiffness in ring diameter 120-160 mm whereas Gasser *et al*. (1990) [17] showed that, 4 cm reduction in ring diameter resulted in 77-86% increase in axial stiffness in different level of applied load. In another study, the inner diameter of ring for metatarsus and tibia was 130-150 mm and 170-190 mm, respectively and they recommend 2 cm distance between the skin and inner circumference of ring (Aithal *et al.*, 2004) [2]. The 3.5 mm pins were found to be stiff and no evidence of osteoporosis or reduction in bone strength. Similarly Aithal *et al*. (2004) [2] used 3.5 mm pins for fixation of CEFs and found adequate whereas in human 1.5-2 mm pins (Lewis *et al.*, 1998 and Kummar, 1992) [29] and in dogs and cat 1-1.6 mm (Ferretti, 1991) [13] pins were commonly used. In the present study, in case of metatarsus fixator ring was fixed at the centre of the ring whereas in tibia, centering of bone was not possible and it was fixed eccentrically relative to rings to avoid friction with skin surface. Similarly Fleming *et al.* (1989) [14] suggested the similar positioning of bone within ring which showed greater shear stiffness, whereas Podolsky and Chao (1993) [35] suggested eccentric positioning of bone within ring improve higher axial and rotational stiffness.

Assessment of fracture healing: Radiographic findings in cases treated with epoxy pin ESF showed very good bone reduction, alignment and fixation with proper placement of pins in all cases and presence of perisoteal callus formation 50 to 60 days. Similarly, researchers like Gamper *et al*. (2006) [16]; Gülaydin and Sarierler (2018) [20] and Aithal *et al.* (2019a) [6] have advised radiographs at regular intervals to assess the fracture healing. In cases of linear bilateral fixators showed good alignment of fractured fragments in metacarpal fracture with complementary screwing with slight gap with hard callus formation on 4th postoperative days. Many researchers (Gülaydin and Sarierler, 2018; Aithal *et al.*, 2019a and Rawat *et al*., 2020) [20, 6, 36] reported that, periodic postoperative radiographs help to assess the degree of callus formation at site of fracture and usually takes 45 to 60 days (mean ±SD:58.1±18.8 days) for complete healing.

Table 1: Incidence of long bone fracture in cattle in present clinical study (n=12)

Code. No	Breed	Age (Months / Years)	Sex	Body Weight (kg)	Involved long bone	Anatomical part of long bone	Type of fracture	Cause of fracture
1E2	HF	10 M	F	80	Right tibia	Midshaft	Oblique	Slipped on floor
2E3	HF	9 M	F	98	Left metacarpal	Distal two third	Closed communited	Falling from height
3E4	Khillar	2.5 Yr.	M	180	Right metatarsal	Midshaft	Compound/ multiple	Fell down in sewage gutter
4E5	HF	10 M	F	200	Right tibia	Midshaft	Compound oblique	Slipped on floor
5E6	Jersey	7 Yr.	F	270	Right metacarpal	Distal two third	Communited	Falling down on ground
6E7	HF	2 Yr.	M	490	Right metacarpal	Distal two third	Communited	Slipped on floor
7E8	Khillar	1.5 Yr.	F	120	Left tibia	Distal two third	Compound oblique	Slipped on floor
8E9	HF	4 Yr.	F	270	Left tibia	Midshaft	Compound oblique fracture	Slipped on floor
9E10	Khillar	4yr	M	500	Left metacarpal	Proximal two third	Transverse	Hyper excited due to fire cracker and fell down on ground
10E11	Khillar	1.2 Yr.	M	100	Right metacarpal	Midshaft	Comminuted	Fell down into the pit
11E12	Khillar	9 M	F	60	Right metacarpal	Midshaft	Transverse	Falling down on due to entrapped

								limb in the rope
12E13	Khillar	2 Yr.	F	120	Left tibia	Midshaft	oblique	Slipped on floor

Table 2: Mean average (±) values of physiological parameters recorded during preoperative (0th Min), intraoperative (15th, 30th, 45th, 60th and 75th Min) and postoperative (90th Min) period in long bone fracture repair in cattle (n=12)

Time (Min.)	**Rectal Temperature (^{0}F)**				**Heart Rate (Per Min)**				**Respiratory Rate (Per min)**			
	Before/After anaesthesia				**Before/After anesthesia**				**Before/After anesthesia**			
0	84.21± 16.85	101.18± 0.46	-1.01	0.03*	85 ± 8.06	63.16 ± 2.82	2.55	0.50^{NS}	35.33 ± 6.09	31.66 ± 3.02	0.53	0.25^{NS}
15	100.78 ± 0.39	101.33± 0.69	-0.69	0.42^{NS}	77 ± 7.11	75.16 ± 4.02	0.28	0.37^{NS}	32.50 ± 6.97	33.16 ± 4.96	-0.07	0.65^{NS}
30	100.10 ± 0.45	100.98± 0.73	-1.01	0.55^{NS}	71.50 ± 7.46	76.33 ± 3.11	-0.59	0.30^{NS}	29.83 ± 5.53	31.00 ± 5.50	-0.14	0.73^{NS}
45	99.58 ± 0.44	100.31± 0.64	-0.93	0.68^{NS}	71.16 ± 8.33	68.66 ± 4.20	0.26	0.39^{NS}	28.33 ± 4.66	29.83 ± 4.74	-0.22	0.55^{NS}
60	99.20 ± 0.51	100.47± 0.54	-1.69	0.91^{NS}	67.16 ± 7.25	68.83 ± 4.25	-0.19	0.25^{NS}	25.66 ± 3.10	31.66 ± 5.27	-0.98	0.12^{NS}
75	98.52 ± 0.30	99.93± 0.69	-1.86	0.29^{NS}	63.83 ± 6.23	67.66 ± 3.27	-0.54	0.69^{NS}	26.16 ± 3.66	29.50 ± 4.49	-0.57	0.56^{NS}
90	97.75 ± 0.24	99.98± 0.67	-3.10	0.11^{NS}	63.50 ±4.63	64.00 ± 3.82	-0.08	0.25^{NS}	27.33 ± 3.66	31.66 ± 4.31	-0.76	0.29^{NS}
F cal.	0.82	0.78			1.18	1.87				0.49	0.07	
P value (sig)	0.55^{NS}	0.58^{NS}			0.33^{NS}	0.11^{NS}				0.80^{NS}	0.99^{NS}	

(NS-Non-significant, If p value is (p>0.05); (***** - Significant, If p value is (*p*<0.05)

Table 3: Mean average (±) values of hematological parameters recorded during pre (0th) and intraoperative period during (10th, 20th, 30th, 45th and 60th) long bone fracture repair in cattle (n=12)

Time Interval (Min.)	**Haemoglobin (gm/dl)**				**Packed cell Volume (%)**				**Total Erythrocytic Count (x10^{6}/ul)**			
	Before Anaesthesia	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**
0	10.13±0.59	11.23±0.56	-1.35	0.84^{NS}	31.11 ±2.04	33.90±1.47	-1.11	0.80^{NS}	8.33 ± 0.46	7.78 ±0.44	0.86	0.87^{NS}
10	9.97±0.54	11.27±0.60	-1.60	0.94^{NS}	30.55 ±1.69	34.31±1.93	-1.46	0.66^{NS}	7.78 ± 0.49	7.38 ± 0.49	0.58	0.79^{NS}
20	9.83±0.52	10.97±0.57	-1.47	0.83^{NS}	29.60 ±1.75	32.88±1.42	-1.45	0.87^{NS}	7.85 ±0.50	7.38 ± 0.68	0.54	0.51^{NS}
30	10.04±0.57	9.63±0.51	0.53	0.52^{NS}	29.95±1.75	30.45±1.67	-0.20	0.86^{NS}	7.72 ±0.42	7.30 ±0.58	0.58	0.45^{NS}
45	9.48±0.59	9.92±0.74	-0.46	0.43^{NS}	29.50±2.18	30.20±2.58	-0.20	0.22^{NS}	7.42 ±0.30	8.00 ± 0.66	-0.80	0.02*
60	9.23±0.63	11.43±0.59	-2.53	1.00^{NS}	29.68±2.55	33.96±1.80	-1.36	0.50^{NS}	7.97 ±0.21	8.19 ±0.46	-0.44	0.02*
F cal.	0.37	1.64			0.09	0.98			0.53	0.44		
P value (sig)	0.86^{NS}	0.18^{NS}			0.99^{NS}	0.44^{NS}			0.74^{NS}	0.81^{NS}		

(NS-Non-significant, If p value is (p>0.05); (* - Significant, If p value is (*p*<0.05))

Time Interval (Min.)	**Total Leukocytic Count (x10^{3}/ul)**				**Platelets (Lacs/ul)**				**Mean Corpuscular Volume (fl)**			
	Before Anaesthesia	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (sig)**
0	12.04±2.13	7.62±0.66	1.98	0.87^{NS}	3.52 ±1.02	3.38 ±0.80	0.10	0.70^{NS}	41.50±2.49	48.00±4.15	-1.34	0.32^{NS}
10	10.58±1.80	8.07±0.71	1.29	0.79^{NS}	3.37 ±0.95	3.23 ±0.76	0.11	0.70^{NS}	42.83±2.39	50.33±4.77	-1.40	0.05^{NS}
20	10.70±1.58	8.54±0.66	1.25	0.51^{NS}	3.48 ±0.96	3.57 ±0.99	-0.06	0.94^{NS}	41.83±1.40	44.50±3.89	-0.64	0.09^{NS}
30	10.77±1.67	7.57±0.69	1.76	0.45^{NS}	3.40 ±0.96	3.70 ±0.99	-0.21	0.97^{NS}	39.33±3.18	44.50±4.17	-0.98	0.62^{NS}
40	10.65±1.50	8.27±1.30	1.20	0.02*	3.48 ±0.95	3.75 ±0.88	-0.20	0.90^{NS}	39.83±1.83	47.17±2.83	-2.17	0.33^{NS}
50	11.37±1.55	9.10±0.99	1.23	0.02*	3.55 ±0.93	3.40 ±0.89	0.11	0.95^{NS}	40.68±2.30	49.83±3.36	-2.24	0.19^{NS}
F cal.	0.11	0.45			0.00	0.05			0.31	0.41		
P value (sig)	0.98^{NS}	0.80^{NS}			1.00^{NS}	0.99^{NS}			0.90^{NS}	0.83^{NS}		

(NS-Non-significant, If p value is (p>0.05); (* - Significant, If p value is (*p*<0.05))

Time Interval (Min.)	**MCHC (gm/dl)**				**Neutrophil (%)**				**Lymphocyte (%)**			
	Before Anaesthesia	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (sig)**
0	33.82±1.62	34.37±1.48	-0.25	0.87^{NS}	43.83±7.02	40.67±3.09	0.41	0.06^{NS}	50.17±7.08	51.83±5.98	-0.18	0.46^{NS}
10	33.47±1.26	36.60±2.19	-1.24	0.46^{NS}	45.50±6.09	40.83±4.00	0.64	0.38^{NS}	52.17±7.10	49.83±5.92	0.25	0.43^{NS}
20	33.17±1.58	35.10±3.02	-0.56	0.40^{NS}	46.17±5.94	43.83±3.57	0.33	0.30^{NS}	53.33±7.00	52.17±5.27	0.13	0.43^{NS}
30	35.17±1.80	34.98±1.44	0.08	0.90^{NS}	48.33±5.91	43.92±3.40	0.64	0.21^{NS}	53.50±6.71	49.00±4.95	0.54	0.33^{NS}
40	33.83±1.80	34.65±2.18	-0.28	0.74^{NS}	49.67±4.74	44.08±2.18	1.07	0.25^{NS}	54.50±7.34	52.83±4.28	0.19	0.04*
50	33.58±2.12	33.58±1.92	-0.36	0.77^{NS}	50.50±4.20	47.00±2.77	0.69	0.38^{NS}	53.83±7.91	49.50±5.94	0.43	0.21^{NS}
F cal.	0.16	0.14			0.20	0.53			0.04	0.08		
P value (sig)	0.97^{NS}	0.98^{NS}			0.95^{NS}	0.74^{NS}			0.99^{NS}	0.99^{NS}		

(NS-Non-significant, If p value is (p>0.05); (* - Significant, If p value is (*p*<0.05))

Table 4: Mean average (±) values of biochemical parameters recorded during pre (0th min) and intraoperative period during (10th, 20th, 30th, 45th and 60th min) long bone fracture repair in cattle (n=12)

Time Interval (Min.)	**Blood Urea Nitrogen (mg/dl)**				**Serum Creatinine (mg/dl)**				**SGPT (IU/L)**			
	Before Anaesthesia	**After Anaesthesia**	**T-Cal**	**P. Value (sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**	**Before Anaesthesia**	**After Anaesthesia**	**T-Cal**	**P. Value (Sig)**
0	29.67±3.32	23.50±2.28	1.53	0.19^{NS}	1.25±0.11	1.07±0.05	1.50	0.06^{NS}	97.67±27.25	50.17±4.09	1.72	0.00*
10	28.83±3.23	23.17±1.64	1.56	0.06^{NS}	1.18±0.05	1.08±0.06	1.19	0.67^{NS}	100.83±27.36	52.83±4.42	1.73	0.00*
20	27.33±3.25	24.83±2.90	0.57	0.45^{NS}	1.07±0.06	1.11±0.11	-0.28	0.05^{NS}	103.67±26.71	54.67±4.30	1.81	0.00*
30	27.67±3.24	22.83±1.42	1.36	0.06^{NS}	0.97±0.04	1.17±0.06	-2.86	0.15^{NS}	106.50±26.13	54.17±5.00	1.96	0.00*
45	27.00±3.15	22.33±2.35	1.18	0.28^{NS}	1.11±0.06	0.95±0.07	1.67	0.77^{NS}	107.83±26.74	56.67±4.95	1.88	0.00*

60	28.50±3.28	22.83±1.64	1.54	0.11^{NS}	1.13±0.08	1.08±0.06	0.51	0.56^{NS}	112.83±26.84	60.33±4.70	1.92	0.00*
F cal.	0.09	0.17			1.84	1.08			0.04	0.56		
P value (sig)	0.99 ^{NS}	0.97 ^{NS}			0.13 ^{NS}	0.38 ^{NS}			0.99 ^{NS}	0.72 ^{NS}		

(NS-Non-significant, If p value is (p>0.05); (*-Significant, If p value is (*p*<0.05))

Time Interval	SGOT (IU/L)				Cortisol (nm/L)			
(Min.)	Before Anaesthesia	After Anaesthesia	T-Cal	P. Value (sig)	Before Anaesthesia	After Anaesthesia	T-Cal	P. Value (sig)
0	137.33 ±25.19	65.83 ±8.77	2.68	0.03*	54.50±2.99	50.00±5.60	0.70	0.07 ^{NS}
10	139.67 ±24.63	67.83 ±9.20	2.73	0.04*	63.50±4.20	54.00±4.90	1.47	0.58 ^{NS}
20	142.17 ±24.88	69.50±8.22	2.77	0.02*	69.67±3.05	58.83±5.49	1.72	0.14 ^{NS}
30	144.17 ±24.39	70.17±8.43	2.86	0.03*	78.67±5.19	85.67±16.31	-0.40	0.17 ^{NS}
45	152.50 ±23.55	71.67 ±8.65	3.22	0.12 ^{NS}	83.83±4.98	92.33±24.38	-0.34	0.11 ^{NS}
60	54.50 ±23.44	72.67 ±8.14	3.29	0.08 ^{NS}	92.17±5.05	88.50±12.80	0.26	0.20 ^{NS}
F cal.	0.08	0.08			10.15	2.00		
P value (sig)	0.99^{NS}	0.99^{NS}			0.00*	0.10^{NS}		

(NS-Non-significant, If p value is (*p*>0.05); (* - Significant, If p value is (*p*<0.05)

Complications if any

In epoxy pin skeletal fixators, serous discharge and the presence of debris at pin skin interfaces, bending of pins and epoxy putty side bar was broken, which could be due to self-mutilation. Aithal *et al.* (2019a) [6] and Rawat *et al.* (2020) [6] also reported pin track sepsis, osteolysis and breakage of epoxy column and disruption of scaffolds. In cases of CEFs, one animal showed loosening of fixator and bending of fixation pins on 48th observation days whereas in another case, pin track discharge and pus formation was seen which could be due to the presence of skin bacteria. Similar complications were recorded by Harari (1992) [21]; Marcellin-Little (1999) [32] and Aithal *et al.* (2004) [2] in their study. In bilateral fixator technique, loosening of side bars and pins was seen which could be due to excessive unrestricted movement of the animal during postoperative period and eventually fractured fragment showed non-union on 60 postoperative day radiograph. Similarly, Aithal *et al.* (2004) [2] and Gülaydin and Sarierler (2018) [20] reported that, slight loosening of some (2-3) of the pins was noticed in almost all the animals, especially in the proximal fragments, from the third week. The present study recommends that, Epoxy pin ESF device has excellent tolerance and stable fixation of long bone fracture in animals weighing upto 120 kg body weight with regaining of body weight on operated limb within 4-5 weeks with minimal complications. However, bilateral linear and circular skeletal fixators' devices showed cumbersome procedure accompanied with many complications due to heavy weight and movement of animals, postoperatively.

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