RESEARCH ARTICLE

# Clinical and Radiological Evaluation of Silver Fluorophosphate in the Treatment of Long Bone Fractures in Dogs

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## Abstract

The objective of this study was to evaluate clinical and radiological effect of silver fluorophosphate for repair of long bone fractures in dogs. Twelve clinical cases of long bone fractures were divided into two groups having six animals in each group. In group I, long bone fractures were immobilized using a locking compression plate (LCP), while in group II long bone fractures were immobilized using LCP along with additional use of silver fluorophosphate granules. Post-surgery, modified Robert Jones bandaging provided limb support. Antibiotics and analgesics were administered and owners were instructed on wound care and limited movement of dogs for minimum 20 days. Radiographic examination and functional outcome of affected bone examination was carried out on the day of surgery and then on the 15$^{th}$, 30$^{th}$, 45$^{th}$ and 60$^{th}$ day post-operatively. Good clinical outcome in terms of post-operative fracture healing and lameness score was observed in group I compared to group II. The poor outcome in group II might be due to fracture complexity, sex-specific and breed-specific behaviour, and limited post-operative care. Post-operative complications observed mainly in group II included self-mutilation of the wound, screw dislodgment, plate bending, and bone osteolysis.

**Key words:** Dog, Locking compression plate, Long bone Fracture, Radiography, Silver fluorophosphate granules, Surgical management.

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## Introduction

Domestic dogs (*Canis lupus familiaris*), often called "man's best friend", are adopted as companions by people both in cities and rural regions (Bhadesiya and Raval, 2014). They are highly prone to fractures from trauma, road accidents or fall from heights. Fracture stabilization can be accomplished through external coaptation (splinting the limb), internal fixation (stabilizing the bone), or external skeletal fixation (Tyagi and Singh, 2008). Various internal fixation techniques have been used to repair fractures with varying success (Fossum, 2007). Bone plating is a widely used internal fixation method for managing fractures and has been practiced since the late 1800s. Locking plates offer the advantage of requiring less contouring compared to standard plates. The locking plate functions as an internal fixator and prevents displacement of fracture segments during screw tightening, even if the plate contouring is not perfectly precise (Wagner, 2003). However, complications such as screw loosening, fixation failure, plate breakage, malunion, non-union, and stress protection have been associated with dynamic compression plates (Coutinho *et al*., 2015).

Treatment of bone defects is a continuous challenge in orthopedic surgery. Large defects that result from trauma, infection, resection of tumors, or other causes usually do not heal spontaneously, and surgical intervention is often required. The most widely used technique for the reconstruction of a bone defect is the use of an autogenous bone graft. However, the disadvantage of this technique is its limited availability and morbidity at the donor site. These disadvantages led to the use of allograft and xenograft. However, the usage of these materials for bone repair has been associated with the risk of rejection and transfer diseases. To overcome these drawbacks of endogenous and exogenous bone grafts, several synthetic bone grafts have been proposed.

Infection poses a significant challenge in surgery and should be a primary focus when designing biomaterials. Silver has regained importance due to its ability to enhance the

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effectiveness of antibiotics against resistant bacterial strains. To minimize the risk of long-term infections, the scaffold must continuously release silver ions throughout the healing process (Sean Hoover *et al*., 2017). Fluorine when added in low non-toxic concentration to phosphate-based glasses produce fluorophosphate glasses, which have a higher bioconversion rate. For increasing the mechanical strength various metal oxides are added to the fluorophosphate. Silver ions have antimicrobial properties and significantly reduce microbial colonisation leading to biomaterial-related infections. Scaffolding of the fluorophosphate glass is essential to bring the molecules for clinical use. Hence, in the present study, clinical and radiological evaluation of silver fluorophosphate in the treatment of long bone fractures in dogs was targeted.

## Materials and Methods

The present study was carried out at the Department of Veterinary Surgery and Radiology, College of Veterinary Science and Animal Husbandry, Kamdhenu University, Junagadh (Gujarat, India) in the year of 2024 following approval of IAEC of the institute. This clinical study was conducted on 12 cases of long bone fractures in dogs, randomly divided into two groups, each comprising six dogs.

### Radiographic Evaluation

In both groups, following a thorough clinical evaluation, the dogs underwent pre-operative radiographic examination using a mobile X-ray machine. Radiographs were taken in two orthogonal views, which were then processed using a Computed Radiography System. Standard mediolateral and cranio-caudal radiographs encompassing the relevant joints were obtained for diagnostic purposes. These measurements were crucial in selecting the correct size and length of locking compression plates (LCP) and screws for the surgical procedure.

### Pre-Operative Preparation, Anaesthesia and Surgical Procedure

The affected limb was immobilized with a Robert-Jones bandage until surgery, which was scheduled promptly. Animals were fasted for 12 h and deprived of water for 6 h pre-operatively. Aseptic preparation of the limb involved clipping the hair over a broad area around the fracture, shaving, and scrubbing with 7.5% povidone-iodine solution. Intravenous normal saline was administered as maintenance fluid during surgery.

Prophylactic antibiotics (Inj. Amoxicillin-sulbactam, 12.5 mg/kg) and analgesic (Inj. Tramadol, 2 mg/kg) were administered intravenously. Pre-anaesthetic Inj. Atropine sulphate, 0.04 mg/kg was administered subcutaneously along with Ketamine (10 mg/kg) and Diazepam (0.5 mg/kg) intravenously. Anaesthesia was maintained as needed using the same combination. Animals were positioned in lateral recumbency for the procedure.

All the dogs of group-I were operated by open reduction with locking compression plate (LCP), while those of group-II were operated with LCP plate along with Silver Fluorophosphate (procured from Pandian Advanced Medical Center (P) Ltd. Madurai, Tamil Nadu, India) for immobilization of bone fragments.

After surgical exposure of the fracture site, the fracture fragments were aligned and anatomically reduced to restore both the length and correct rotational alignment of the bone. A locking compression plate (LCP) was then positioned over the fracture site and temporarily held in place using a Lowman bone-holding clamp. Proper alignment was carefully verified before securing the plate. The bone was drilled using a low-speed high-torque electric drill employing a drill bit corresponding to the inner core diameter of the locking screws. The appropriate screw length for the application of the locking compression plate was determined by measuring the antero-posterior thickness of the bone at various points from the fracture site, as observed on preoperative radiographs. These measurements were confirmed intraoperatively using a depth gauge. Locking screws of the correct length were then inserted into the predrilled holes and tightened with a hexagonal orthopedic screw driver until the screw tip exited the trans cortex, securely affixing the plate to the bone. Attention was paid to ensure that the locking screws were inserted perpendicular to the plate holes to guarantee proper engagement between the screw threads and the plate. The screws were tightened with controlled force to prevent over-tightening. The locking compression plate was securely held at both ends of the fracture by inserting additional screws into the proximal and distal fragments, avoiding placement directly across the fracture site. The use of silver fluorophosphates in fracture fixation involved its application in a sterilized granular form. This material was introduced into the medullary cavity to aid in bone healing. In cases where a gap was present at the fracture site, additional silver fluorophosphate granules were inserted to bridge the defect and promote stabilization (Fig. 1). After the fracture fixation procedure, Vicryl (Polyglactin 910) was utilized for suturing the fascia lata and subcutaneous tissue using a continuous lockstitch suture pattern. The skin incision was subsequently closed with nylon, employing either a horizontal mattress suture or a simple interrupted suture pattern.

### Assessment of Fracture Repair and Bone Healing

For grading of fracture healing, scoring system based on callus formation, appearance of fracture line and stage union of bones was used as per Hammer *et al*. (1985).

The lameness grading scale as described by Vasseur *et al.*(1995) was recorded on the 0, 15$^{th}$, 30$^{th}$, 45$^{th}$ and 60$^{th}$ postoperative days. This included, Grade I: Normal weight bearing on all limbs at rest and when walking; Grade II: Normal weight bearing at rest, favours affected limb while walking; Grade III: Partial weight bearing at rest and while walking; Grade IV: Partial weight bearing at rest and does

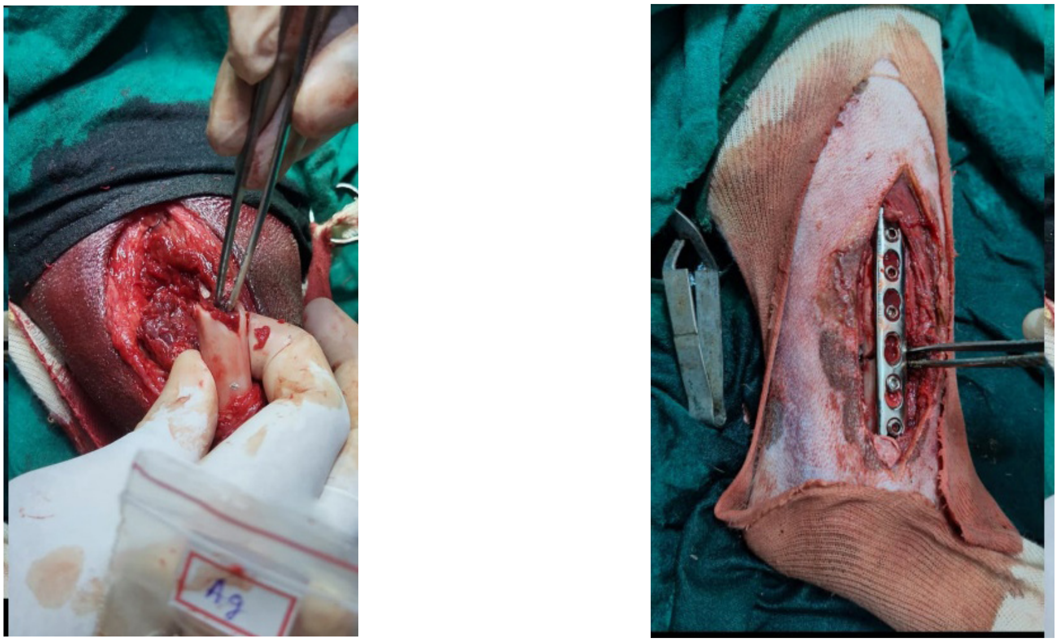



**Fig. 1:** Placement of the granules at the fracture site and both fracture ends of medullary cavity

not bear weight on affected limb while walking; and Grade V: Does not bear weight on the limb at rest or while walking.

## Results and Discussion

### Assessment of Fracture Healing in Group I

Radiographic examination revealed a closed, complete transverse mid-diaphyseal fracture of the left tibia in Case 1, and complete oblique proximal diaphyseal fracture of the right tibia in Case 2. Post-operative X-rays showed proper alignment and excellent apposition. By days 15, 30, and 45, X-rays indicated massive trabeculae crossing the fracture line, reduced fracture line visibility, and Grade 2 healing with stage of union achieved (Fig. 2A, 2B, 2C). By day 60, X-rays showed uniform bone structure and no visible fracture line, indicating complete healing and Grade 1 fracture healing in both the cases (Fig. 2D).

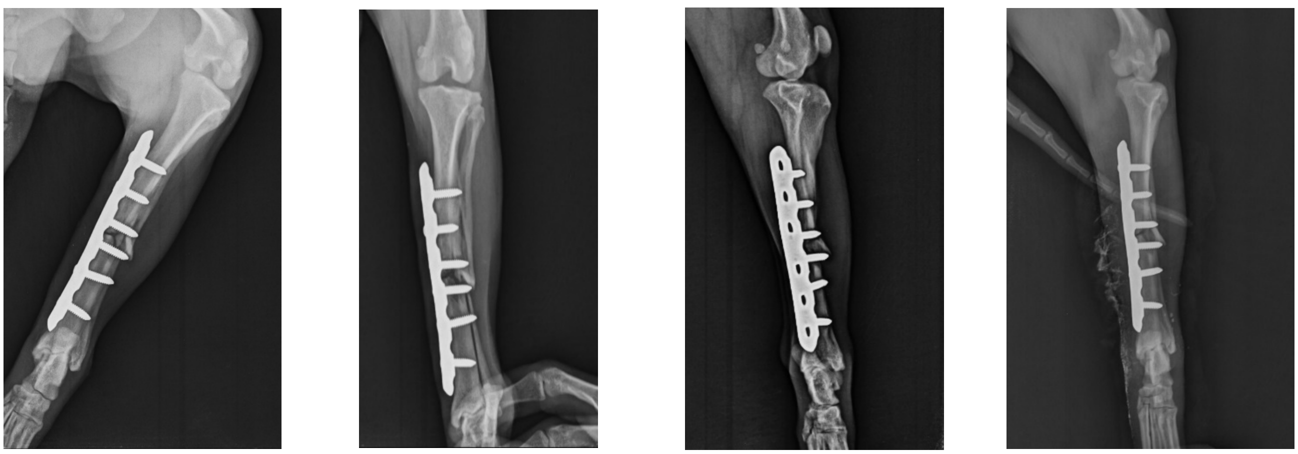
Radiographic examination of Case 3 revealed a closed, complete oblique mid-diaphyseal fracture of the right radius and ulna, with proper alignment and apposition post-operatively. However, by day 15, no callus formation or union was observed, with a distinct fracture line corresponding to Grade 4 healing. On days 45 and 60, bridging of the fracture line was noted, though the line remained discernible, with uncertain union and osteolysis, indicating Grade 3 healing. In case 4, radiographic examination revealed a closed, complete oblique mid-diaphyseal fracture of the right humerus. Post-operative X-rays showed proper alignment and apposition, with one screw slightly misaligned. By day 15, extensive callus formation and obliteration of the fracture line indicated Grade 2 healing. On days 30, 45, and 60, bridging of the fracture gap, obliterated fracture line, and achieved union indicated Grade 1 healing.

Radiographic examination of Case 5 revealed an open, complete transverse mid-diaphyseal fracture of the right tibia (Fig. 3A), with proper alignment and apposition in post-operative X-rays. By day 15, no bridging and a distinct fracture line indicated Grade 4 healing (Fig. 3B). By day 30, bridging of the fracture line was observed, though the fracture line remained discernible, indicating Grade 3 healing (Fig. 3C). On days 45 and 60, a homogenous bone structure with an obliterated fracture line and achieved union confirmed Grade 1 healing (Fig. 3D). In case 6 radiographic examination revealed a closed, complete transverse mid-diaphyseal fracture of the right radius and ulna, which showed proper alignment and apposition post-operatively. By day 15, no callus formation and a distinct fracture line indicated Grade 4 healing. Later, apparent bridging of the fracture line with a discernible fracture line and uncertain union suggested Grade 3 healing.

### Assessment of Fracture Healing in Group II

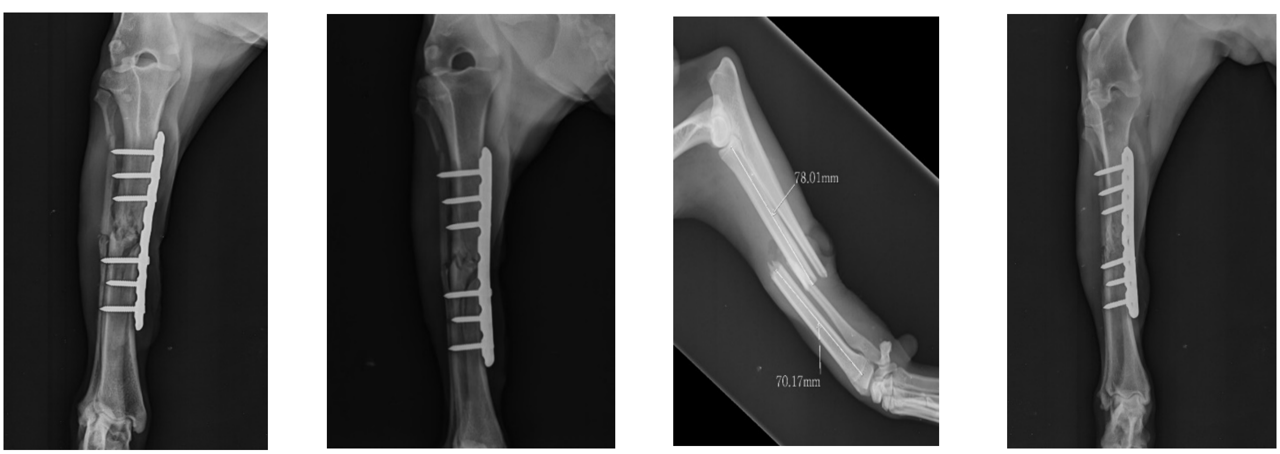
Radiographic examination in Case 1 revealed a comminuted diaphyseal fracture of the right femur, while in Case 2 and 3 a closed, complete mid-diaphyseal transverse fracture of the left tibia and right femur, respectively, were noticed. Post-operative X-rays showed proper alignment and apposition in all cases. In case 1, by day 15, no callus formation, a distinct fracture line, and lack of union indicated Grade 5 healing. By day 30, a dislodged screw and minimal or no bridging of the fracture line with visible fracture persisted, indicating Grade 4 healing. However, subsequent radiographs showed initial bridging callus formation, signaling progression toward healing. In case 2, on days 15 and 30, mild osteolysis and bridging of the fracture line were observed, with a discernible fracture line and uncertain union, indicating Grade 3 healing. By day 30, plate bending was noted, alongside healing progression. On day 45, callus formation was present but union was still uncertain. By day 60, exuberant callus formation and fracture line obliteration indicated Grade 2 healing. In case 3, by day 15, osteolysis and mild plate displacement were noted, with bridging observed but the fracture line was still discernible, indicating Grade 3 healing. By day 60, dislodgment of the plate and proximal screw, along with angulation of the fractured fragments and non-union, indicated Grade 4 healing with no progress (Table 1).

Radiographic examination of case 4 and 5 revealed a closed, complete distal diaphyseal transverse fracture of the right radius and ulna (Fig. 4A), and of the left tibia, respectively, while in case 6, an open, complete mid-diaphyseal transverse fracture of the right radius and ulna was noticed. Post-operative X-rays showed proper alignment and apposition in all three cases. In case 4, on days 15, 30, and 45, radiographs showed bridging of the fracture line, which remained discernible with uncertain union, indicating Grade 3 healing (Fig. 4B, 4C). By day 60, excessive callus formation, fracture line obliteration, with achieved union indicated Grade 1 healing (Fig. 4D). In case 5, mild plate bending, altered bone angulation, and absence of callus formation were observed. By day 15, no callus formation, a visible fracture line, and lack of union indicated Grade 5 healing. Progressive plate bending and subsequent infection necessitated implant removal, culminating in leg amputation one week later. In case 6, on



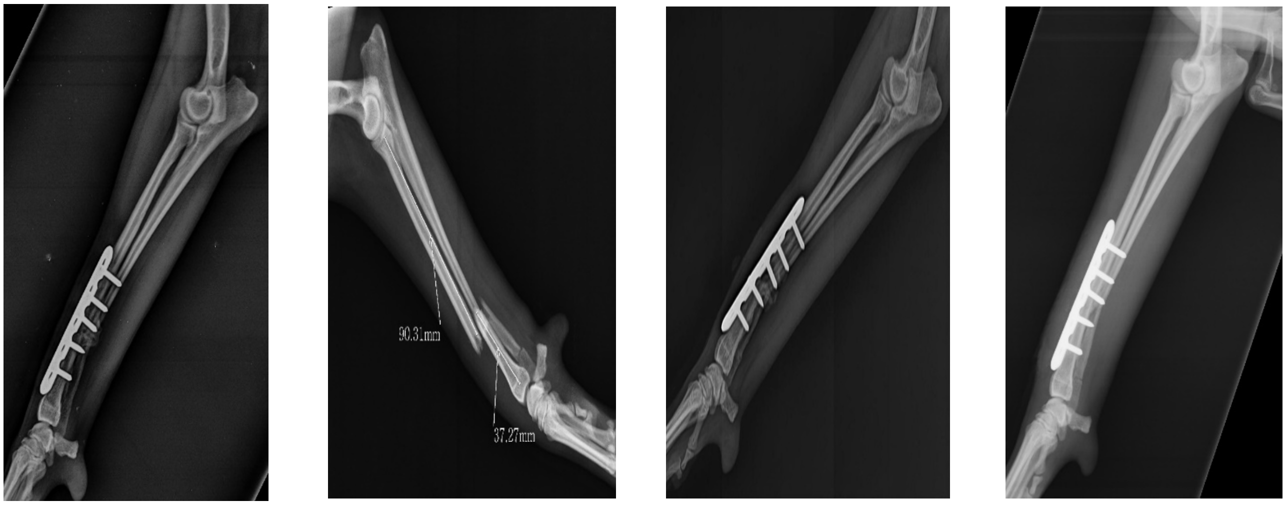
A. 15th day B. 30th day C. 45th day D. 60th day

**Fig. 2:** Radiographic evaluation of fracture healing of complete transverse mid-diaphyseal fracture of the left tibia in a case 1 treated with LCP alone




A. 15th day B. 30th day C. 45th day D. 60th day

**Fig. 3:** Radiographic evaluation of fracture healing of an open complete transverse mid-diaphyseal fracture of the right tibia in a case 5 treated with LCP alone




A. 15th day B. 30th day C. 45th day D. 60th day

**Fig. 4:** Radiographic evaluation of fracture healing of a closedcomplete distal diaphyseal transverse fracture of the rightradius and ulna in a case 4 treated with LCP along with SFP granules

**Table 1:** Mean (± SE) grade of fracture healing in group I and II dogs (n=6)

| Grade | Group | Day 0 | Day 15 | Day 30 | Day 45 | Day 60 |
|---|---|---|---|---|---|---|
| Fracture healing grade | I (LCP) | 5.0±0.0 | 3.0±0.4 | 2.2±0.4 | 1.7±0.3 | 1.5±0.3 |
| | II (LCP + SFG) | 5.0±0.0 | 3.5±0.5 | 3.3±0.4 | 3.3±0.3 | 3.0±0.5 |
| Lameness grade | I (LCP) | 5.0±0.0 | 3.2±0.5 | 2.7±0.3 | 2.0±0.4 | 1.3±0.2 |
| | II (LCP + SFG) | 5.0±0.0 | 3.2±0.7 | 3.7±0.6 | 3.7±0.7 | 3.2±0.9 |

day 15, apparent bridging of the fracture line with uncertain union indicated Grade 3 healing. By day 30, massive trabeculae crossing the fracture line, with the fracture line barely visible and union achieved, suggested Grade 2 healing. However, by days 45 and 60, radiographs showed bone loss at the fracture line and increased fracture line visibility, indicating poor healing and Grade 3 fracture healing.

Schwandt and Montavon (2005) reported relatively rapid fracture healing using a Locking Compression Plate (LCP) in a young dog with concomitant fractures of the radius-ulna and tibia-fibula. Complete bridging and callus remodelling were achieved 53 days post-surgery. Ayyappan *et al*. (2009) reported complete fracture union in various bones stabilized with ESF, as observed through radiographic examination. The humerus achieved complete union by 90 days, the femur by 75 days, the radius by 72 days, and the tibia by 68 days. Cabassu (2001) observed callus formation two weeks following the stabilization of fractures with cuttable plates, whereas Xue *et al*. (2016) reported that callus formationin most dogs from both groups (dynamic compression plate versus locking compression plate) four weeks post-surgery. By eight weeks, the excess callus had been reabsorbed, resulting in a decreased callus mass volume.

## Functional Outcome of Affected Bone

In all cases from group I and group II, the lameness grade was recorded as 5 on the pre-operative day. In group I, the post-operative recovery pattern was evaluated. On the 15th day following surgery, cases 1 and 2 exhibited lameness of grade III, characterized by normal weight-bearing at rest but evident lameness while walking, which improved to grade I by the 60th day. Cases 3 and 5 with initial grade II lameness on the 15th day, progressed to grade I by the 60th day. In contrast, case 4 displayed more severe lameness, graded IV on the 15th day, which ameliorated to grade II by the 60th day. The most severe lameness, grade V, was observed in case 6 on the 15th day, which improved to grade II by the 60th day.

In group II, Case 1 exhibited severe lameness, graded V, on the 15th day, which significantly improved to grade I by the 60th day. Case 2 presented with moderate lameness, graded II, on the 15th day. However, due to an intervening dog fighting incident, the condition worsened, resulting in grade V lameness on the 30th and 45th days. Following plate removal, the lameness gradually improved to grade IV on the 60th day and further to grade II on the 80th day. Case 3 displayed lameness graded III on the 15th day, which unexpectedly deteriorated to grade V on the 30th, 45th, and 60th days. Case 4 exhibited an initial grade I lameness on the 15th post-operative day, which transiently worsened to grade II on the 30th day, but subsequently improved back to grade I on both the 45th and 60th post-operative days. Case 5 exhibited persistent severe lameness, graded V, on 15th day. Case 6 presented with lameness graded III on the 15th day, which progressed to grade V by the 60th day, possibly due to osteolysis of the bone.

A.Banding of LCP plate day 30th

B. Self-mutilation of surgical wound

**Fig. 5:** Complications in healing of a closed complete distal diaphyseal transverse fracture of the rightradius and ulna in a case 4 treated with LCP along with SFP granules

Schwandt and Montavan (2005) reported that animals with comminuted fractures of the radius-ulna and tibia-fibula, treated with locking compression plating, were able to bear full weight by the 14th day post-surgery. By the 30th day post-operation, the animals were walking and running normally, placing their paw with each step. Yadav *et al*. (2016) reported complete weight bearing on the operated fractured limb with LCP by the 21th post-operative day. Yuvaraj *et al*. (2007) observed that dogs with femur and radial fractures, treated with dynamic compression plates (DCP), achieved complete weight-bearing starting from the second day post-operation. Al-Harby *et al*. (1996) observed that the dogs started bearing weight on the operated limb between 7 and 10 days after surgery. After 15 to 20 days post-operation, they were able to walk normally, showing no signs of pain or limping. Singh (2019) reported that out of 12 dogs, 11 had a pre-operative lameness grade of V. By the 45th post-operative day, 10 dogs demonstrated full weight-bearing while at rest and standing. However, one dog remained at lameness grade V, and another exhibited grade II. Marvaniya (2019) reported that all dogs had a pre-operative lameness grade V. By the 60th post-operative day, 11 dogs demonstrated full weight-bearing while resting and standing. However, one dog remained at Grade II, continuing to favour the affected limb while walking on the 60th post-operative day.

### Post-Operative Complications

Out of 12 cases, six cases showed normal surgical wound healing without complications within 2 weeks. Two cases exhibited inflammatory swelling for 2-4 days post-operatively, which subsided gradually. Implant-related complications were observed like dislodgment of screw, plate bending (Fig. 5A), and osteolysis of bone. Another dog showed discharge from the surgical site, open wound, non-healing wound and self-mutilation wound (Fig. 5B). Nojiri *et al*. (2015) noted four complicationsdue to implant failure (plate breakage or screw loosening), while five were attributed to biological failure (infection or refracture). However, two patients with antibiotic-resistant infections ultimately required amputation. Marvania (2019) noted complications like osteolysis at the fracture site, plate dislodgment, and plate bending resulting in bone angulation.

Overall, the results were not encouraging in group II treated with LCP along with silver fluorophosphates granules since the mean fracture healing grades were poor with higher lameness scores on all days of post-operative evaluation, over LCP alone (Table 1), probably due to fracture complexity, sex-specific and breed-specific behaviour, and limited post-operative care by the owners. Post-operative complications observed were also more in this group and included self-mutilation of the wound, screw dislodgment, plate bending, and bone osteolysis.

## Conclusion

The present study concludes that while both locking compression plating (LCP) alone and LCP combined with silver fluorophosphate granules can be used for long bone fracture repair in dogs, the outcomes were significantly better in the LCP-alone group. The inferior healing responses in LCP combined with silver fluorophosphate granules (group II) can be attributed to the inclusion of more complex fractures (such as comminuted types), a higher proportion of active, free-roaming male and non-descriptive dog breeds, and challenges in maintaining strict post-operative care and immobilization. These factors led to increased incidences of complications like screw dislodgment, plate bending, and osteolysis, and ultimately delayed healing.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