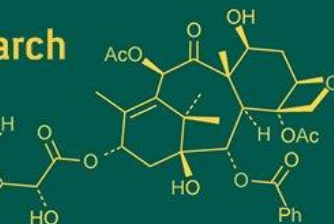
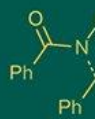


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Clinical and radiological evaluation of Titanium Tie-In Fixation (TTIF) for Tibiotarsus fracture repair in pigeon

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Abstract

Tibiotarsus is anatomically vulnerable because of its thin cortices, large medullary cavity, relative paucity of surrounding musculature in the distal two-third predisposes it to high-energy trauma. Six pigeons with confirmed mid-diaphyseal tibiotarsus fractures were repaired using titanium tie-in fixation (TTIF). The construct comprised a titanium intramedullary (IM) K-wire combined with two titanium transcortical K-wires connected by a polymethylmethacrylate (PMMA) bar moulded within an endotracheal tube. General anaesthesia was induced with midazolam (0.5 mg/kg IM) and ketamine (30 mg/kg IM). Fractures were reduced by closed technique. Clinical assessment including weight-bearing scoring and lameness scoring was performed pre-operatively and on 0th, 7th, 14th, 21th, and 30th post-operative days. All six birds were achieved excellent weight-bearing by 30th post-operative day. Radiographically, callus formation progressed from absent pre-operatively to extensive in all cases by 30th post-operative day, with five of six birds achieving primary bone union. Minor complications included post-operative swelling, transient knuckling, and one case showed patient-induced implant disruption. Titanium tie-in fixation is an effective, lightweight, and well-tolerated orthopaedic technique for tibiotarsus fracture repair in domestic pigeons.

Keywords: Titanium tie-in fixation, TTIF, tibiotarsus fracture, pigeon, avian orthopaedics, K-wire, PMMA

Introduction

Tibiotarsus fractures are the most frequently encountered long bone injury in domestic pigeons, accounting for 51% (Kayikci *et al.*, 2019) [9], 50% (Kothamdi and Shilpa, 2016) [11], and 43.82% (Sindhu *et al.*, 2023) [13]. The avian tibiotarsus is anatomically vulnerable because of its thin cortices, large medullary cavity, relative paucity of surrounding musculature in the distal two-thirds, and load-bearing role during perching and locomotion—predisposes it to high-energy trauma (Westfall and Egger, 1979; Coles, 2007) [18, 4]. Successful fracture management in birds demands a construct that is lightweight, rigid enough to allow early weight-bearing and easily removable without secondary surgery. Tie-in fixation, combining an intramedullary (IM) pin with an external skeletal fixator (ESF), achieves multi-planar stability and has been demonstrated to yield good functional outcomes in raptors (Bueno *et al.*, 2015) [3] and pigeons (Kaya and Ozsoy, 2017) [8]. The substitution of stainless steel with titanium alloy implants offers additional biomechanical benefits: a modulus of elasticity approximately half that of stainless steel reduces stress shielding, while superior biocompatibility and osseointegration potential reduce peri-implant reactivity (Uhthoff *et al.*, 1981; Disegi, 2000; Skripitz and Aspenberg, 1998) [16, 6, 14]. The present study evaluated the clinical and radiological efficacy of titanium tie-in fixation (TTIF) using a PMMA connecting bar moulded within a commercial endotracheal tube for the management of tibiotarsus fractures in six domestic pigeons.

Materials and Methods

Six pigeons presenting to the Department of Veterinary Surgery and Radiology, Veterinary College, Hebbal, Bengaluru, with clinically and radiographically confirmed tibiotarsus fractures were enrolled.

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Cases were included regardless of age, sex, fracture morphology, or duration of illness. The study was conducted following institutional ethical guidelines. Complete physical examination was performed in all cases. Pre-operative orthogonal radiographs (cranio-caudal and medio-lateral views) of both the affected and contralateral tibiotarsus were

obtained. Radiometric data from the contralateral limb: mean tibiotarsus length 5.30 ± 0.9 cm; mid-diaphyseal bicortical diameter 0.33 ± 0.01 cm; medullary canal diameter 0.23 ± 0.01 cm. These measurements guided implant selection. Case anamnesis is summarised in Table 1.

Table 1: Anamnesis and fracture details of the six pigeons enrolled in the study

Case	Age	Wt (g)	Sex	Aetiology	Duration (d)	Fracture Type
1	1 yr	250	F	Ceiling fan injury	1	Transverse
2	1.5 yrs	280	M	Falcon attack	1	Transverse
3	1 yr 8 mon	280	M	Mishandling by owner	2	Transverse
4	7 mon	240	M	Cage entrapment	1	Transverse
5	9 mon	200	F	Mishandling by owner	1	Oblique
6	2 yr 1 mon	380	M	Cage entrapment	2	Transverse

Pre-operative Preparation and Anaesthesia

On the day of surgery, feed was withheld for 3 hours and water for 1 hour. Enrofloxacin (10 mg/kg IM) and butorphanol (0.1 mg/kg IM) were administered into the pectoral muscles as pre-medication. General anaesthesia was induced with midazolam (0.5 mg/kg IM) followed by ketamine (30 mg/kg IM) five minutes later; maintenance was achieved with supplemental ketamine at half the induction dose as required. Induction was achieved within 2-3 minutes in all cases. Recovery was smooth, with all birds alert within 45-120 minutes of the last ketamine dose. No anaesthetic complications were recorded. Feathers over the fracture site and below the hock were manually plucked following induction. A sterile bandage was applied to the

hock, and the bird was positioned in lateral recumbency with the affected limb uppermost on a heating pad. The surgical field was prepared with 5% povidone-iodine scrub followed by sterile draping.

Implant Selection

Intramedullary K-wire diameter was selected to occupy approximately 50% of the medullary canal (≤ 1.5 mm titanium K-wire). Two transcortical titanium K-wires (≤ 0.8 mm, approximately 25% of medullary canal diameter) were used per case. The connecting bar was fabricated by filling a commercial endotracheal tube (diameter equal to or slightly greater than the bicortical diameter of the tibiotarsus) with self-curing dental acrylic (1:2 liquid: powder ratio) (Fig 1).

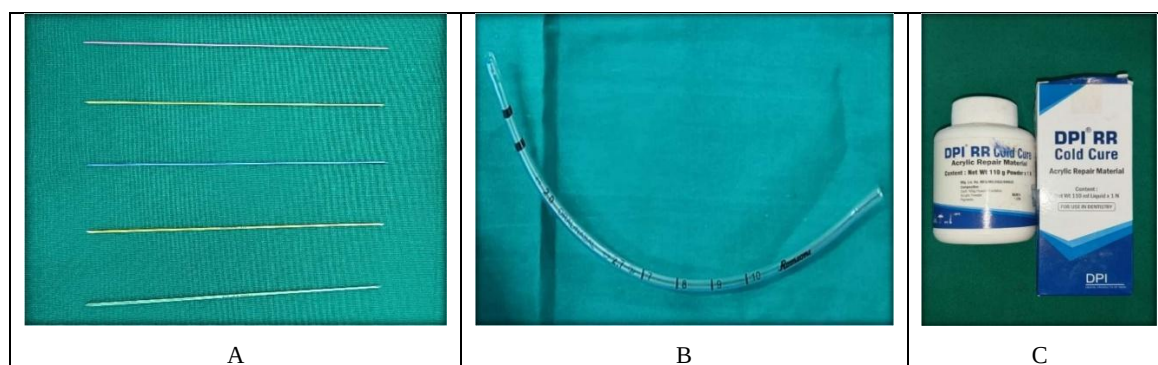


Fig 1: Implants used in TTIF: (A) Titanium K-wires of varying diameters, (B) Commercial endotracheal tube used as mould for the PMMA connecting bar and (C) Self-curing dental acrylic

Surgical Technique

All fractures were reduced by closed technique. The IM K-wire was inserted normogradely at the tibial plateau, with the patellar tendon deflected laterally, and advanced through the medullary canal to just proximal to the extensor canal and supratendinal ridge. Two transcortical K-wires were inserted from the lateral cortex perpendicular to the bone's long axis: the proximal wire at the level of the cnemial crests (directed caudomedially, anterior to the fibula,

engaging both cortices), and the distal wire proximal to the supratendinal ridge (directed lateromedially, parallel to the proximal wire). The external portion of the IM K-wire was bent 90° and aligned with the transcortical pins. Wet cotton gauze was placed at all K-wire skin entry points to prevent thermal injury during acrylic polymerisation. The ET tube was filled with PMMA mix and placed over all K-wires; the pigeon's feet were held in slight valgus alignment for approximately 10 minutes until the acrylic cured (Fig 2).

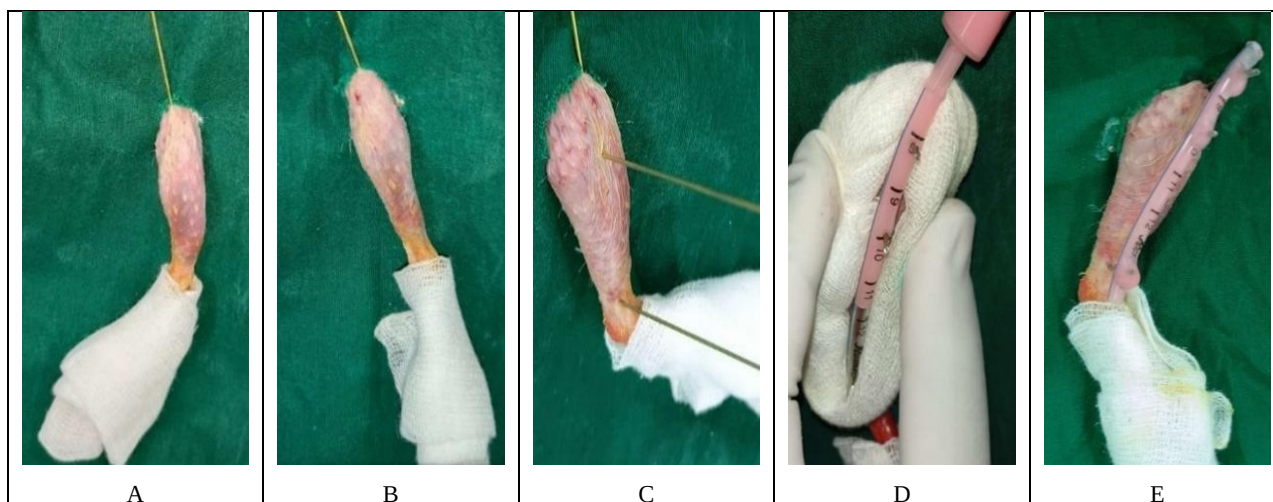


Fig 2: Surgical Procedure. A-IM K-wire was inserted normogradely proiml fragmnt, B-IM K-wire was advanced to distal fragment, C-Two transcortical K-wires were inserted, D-ET tube was filled with PMMA, and E-TTIF apparatus.

Post-operative Care and Staged Implant Removal

Post-operative care comprised daily antiseptic dressing (5% povidone-iodine) of K-wire entry points for one week, extended to alternate-day dressing thereafter. Enrofloxacin (10 mg/kg, SID, orally for 5 days), meloxicam (0.2 mg/kg, SID, orally for 3 days), oral calcium, and multivitamin supplementation (one drop daily for 14 days) were administered. Alternate-day passive physiotherapy was initiated 72 hours post-operatively to prevent knuckling, muscular spasticity, and joint rigidity. On day 14th post-operative day, staged destabilisation was performed: the PMMA-IM K-wire link was severed and both transcortical K-wires were removed following radiological confirmation of adequate callus. The IM K-wire was removed by manual traction on day 21th post-operative day after confirming sufficient consolidation (Fig 3).



Fig 3: Staged implant removal: transcortical K-wire removal on 14th post-operative day (left) and intramedullary K-wire removal on day 21 (right)

Clinical and Radiological Evaluation

Clinical parameters (body weight, swelling, wound condition, lameness) were recorded pre-operatively and on 0th, 7th, 14th, 21th, and 30th post-operative days. Weight-bearing was graded using the Fox *et al.* (1995) [7] four-point scale (Excellent = full weight-bearing; Good = slight

lameness only after exercise; Fair = slight to moderate lameness but consistent weight-bearing; Poor = intermittent or consistent non-weight-bearing). Lameness was scored on the Kestin gait scale (0 = no detectable abnormality; 5 = complete lameness, bird cannot walk) (Kestin *et al.*, 1992) [10]. Radiological evaluation followed the Tunio *et al.* (2014) [15] scoring system using orthogonal views. Data were analysed using one-way ANOVA.

Results

The midazolam and ketamine protocol produced reliable induction in 2-3 minutes in all six birds with smooth recovery. All fractures were successfully managed by closed reduction. One intra-operative iatrogenic cortical splinter was noted in Case 2; this was evident on the day-0 radiograph and healed uneventfully by 30th post-operative day (Fig 7b).

Weight-Bearing

All birds showed poor weight-bearing pre-operatively and on day 0. By day 7, five birds improved to fair weight-bearing (one remained poor). By day 14, three birds achieved good and three remained fair. All six birds showed good weight-bearing by day 21 and excellent weight-bearing by day 30 (Table 2) (Fig 4).

Table 2: Weight-bearing scores

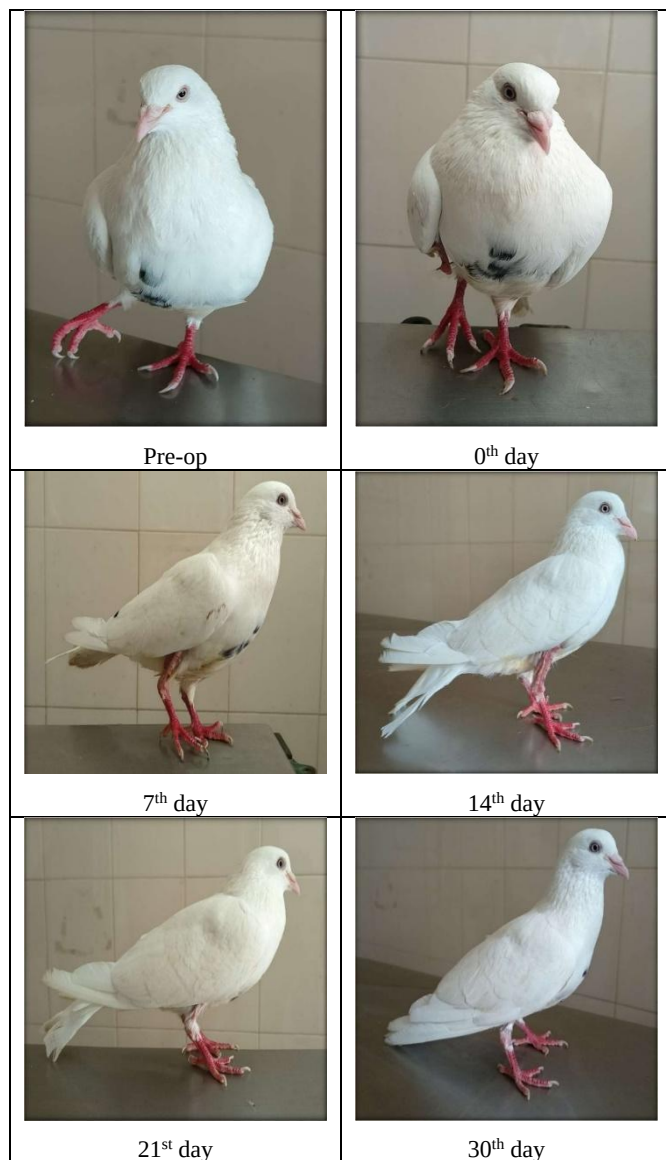
Case	Pre-op	Day 0	Day 7	Day 14	Day 21	Day 30
1	Poor	Poor	Fair	Good	Good	Excellent
2	Poor	Poor	Poor	Fair	Good	Excellent
3	Poor	Poor	Fair	Fair	Good	Excellent
4	Poor	Poor	Fair	Fair	Good	Excellent
5	Poor	Poor	Fair	Good	Good	Excellent
6	Poor	Poor	Fair	Good	Good	Excellent

Lameness Scoring

Mean lameness scores declined progressively and highly significantly ($P < 0.01$) from 5.00 ± 0.00 pre-operatively to 0.33 ± 0.21 on 30th post-operative day (Table 3), confirming near-complete restoration of ambulatory function.

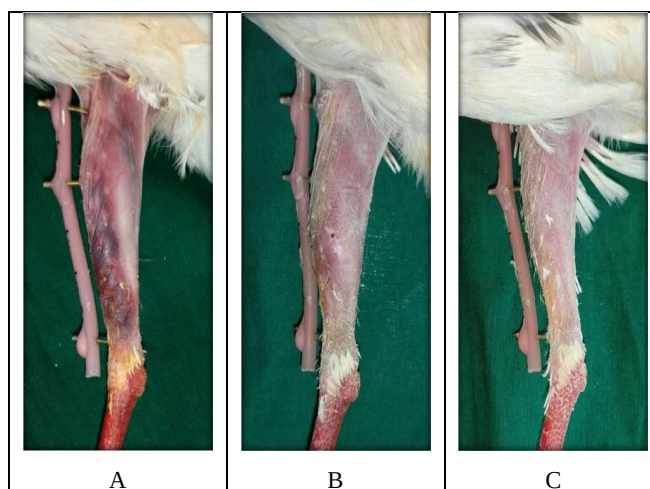
Table 3: Mean $\pm$ SE lameness scores

Case	Pre-op	Day 0	Day 7	Day 14	Day 21	Day 30
1	5	5	4	3	2	1
2	5	5	4	4	2	0
3	5	5	4	3	2	0
4	5	5	4	2	2	0
5	5	5	4	4	3	1
6	5	5	4	3	2	0
Mean $\pm$ SE	5.00 $\pm$ 0.00	5.00 $\pm$ 0.00	4.00 $\pm$ 0.00	3.17 $\pm$ 0.31	2.17 $\pm$ 0.17	0.33 $\pm$ 0.21

**Fig 4:** Weight bearing pattern on pre-operative and post-operative days**Post-operative Swelling and Wound Healing**

Post-operative swelling and greenish discolouration of the

operated limb were observed in all birds from day 0, peaking on day 1. Swelling and discolouration resolved completely by day 14 in all cases (Fig 5). No pin tract infections were recorded. The wound at the IM K-wire insertion point showed delayed healing due to continuous contact with the skin during locomotion (Fig 7A), but healed uneventfully following IM K-wire removal.

**Fig 5:** Post-operative swelling and greenish skin discolouration of the operated limb: (A) day 0, (B) day 7, and (C) day 14, demonstrating progressive resolution**Radiological Evaluation**

All four radiological parameters scored by the Tunio *et al.* (2014)^[15] system showed highly significant improvement ($P < 0.01$) from pre-operative to day 30 (Table 4). Pre-operatively, the fracture line was visible in all cases and no callus was present. On day 7, a partially visible fracture line was noted in three cases, periosteal reaction was evident in all, and minimal callus formation was present. By day 14, four cases had a partially visible fracture line, all showed minimal-to-moderate callus formation, and all had progressed to secondary union. By day 21, four cases showed an absent fracture line and extensive callus, with four achieving primary union. By day 30, the fracture line was absent in five cases, extensive callus was present in all six, and five cases had achieved primary union (Fig 6).

Table 4: Mean $\pm$ SE radiological scores (Tunio *et al.*, 2014)^[15]

Parameter	Pre-op	Day 0	Day 7	Day 14	Day 21	Day 30
Fracture Line	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.50 $\pm$ 0.22	0.67 $\pm$ 0.21	1.67 $\pm$ 0.21	1.83 $\pm$ 0.17
Callus Formation	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	1.00 $\pm$ 0.00	1.83 $\pm$ 0.17	1.83 $\pm$ 0.17	2.00 $\pm$ 0.00
Bone Union	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.17 $\pm$ 0.17	1.00 $\pm$ 0.00	1.67 $\pm$ 0.21	1.83 $\pm$ 0.17
Axial Alignment	0.50 $\pm$ 0.22	1.00 $\pm$ 0.26	1.17 $\pm$ 0.17	1.33 $\pm$ 0.21	1.33 $\pm$ 0.21	1.83 $\pm$ 0.17

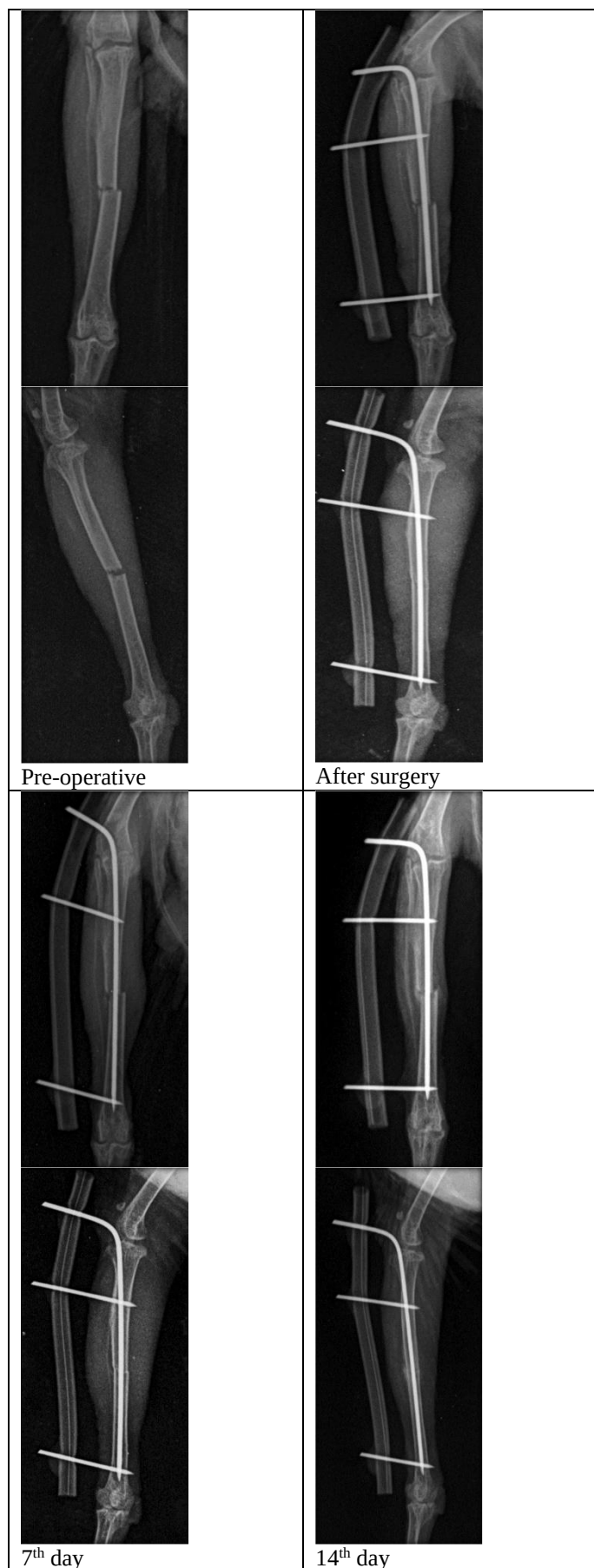


Fig 6: Cranio-caudal and medio-lateral radiograph of affected limb on pre-operative and post-operative days

Implant Performance

The TTIF construct remained stable in five of six birds throughout the study period. No loosening of transcortical K-wires was observed and the 90°-bent IM K-wire maintained secure connection to the external PMMA bar in all intact cases. After staged transcortical K-wire removal on day 14, the adhesive bond between PMMA and the IM K-wire could be overcome with considerable manual force, confirming PMMA integrity until that point. No metallic implant breakage or migration was recorded.

Complications

Complications recorded during the study included one case of intraoperative iatrogenic cortical splinter, which was evident radiographically on day 0 (Fig 7) and healed uneventfully by day 30. Post-operative swelling and greenish skin discolouration were observed in all six cases on day 0 and resolved by day 14 (Fig 5). Skin widening at the intramedullary (IM) K-wire insertion site was noted in all cases due to continuous locomotion (Fig 7a). and healed after K-wire removal.

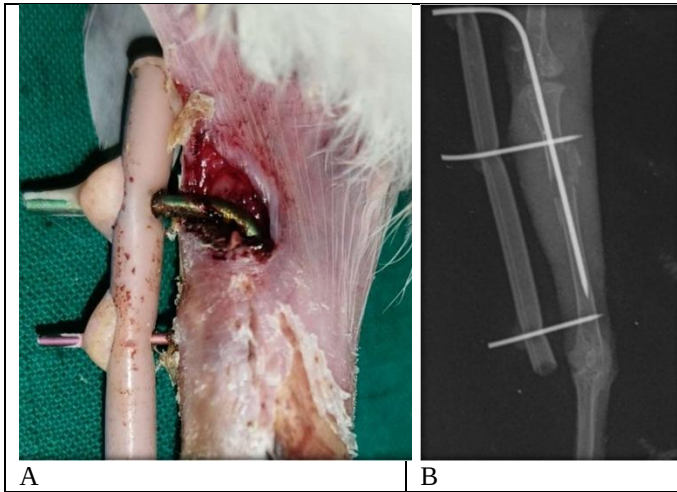


Fig 7. Complications, (A): Skin widening at the IM K-wire insertion point due to continuous locomotion, (B): iatrogenic cortical splinter evident on day-0 radiograph (arrow).

Discussion

The midazolam-ketamine protocol used in this study provided reliable induction, adequate surgical depth, and smooth recovery consistent with the recommendations of Atalan. (2002) ^[1] for domestic pigeons. The closed reduction approach preserved periosteal vascularity, which is critical in avian fracture healing (West *et al.*, 1996) ^[17], and avoided the iatrogenic trauma associated with open reduction. All six birds achieved excellent weight-bearing by day 30 which is in consistent with Bueno *et al.* (2015) ^[3], who reported 84% clinical success (mean ~38 days) with ESF-IM tie-in fixation in 37 raptors with tibiotarsus fractures, and with Kaya and Ozsoy (2017) ^[8], who documented comparable outcomes in tie-in fixation for tibiotarsal fractures in chukar partridges and pigeons. The significant progressive decline in lameness scores ($P < 0.01$) from 5.00 ± 0.00 to 0.33 ± 0.21 reflects the rapid restoration of weight-bearing mechanics that this construct affords. Radiologically, the pattern of secondary healing, periosteal reaction by day 7, callus bridging by day 14-21, and extensive callus with remodelling by day 30, is consistent with the established avian fracture healing timeline of 3-4 weeks for small birds in accordance with Bennett and Kuzma (1992) ^[2] and Tunio *et al.* (2014) ^[15]. Axial alignment improved to good in five of six birds by day 30, confirming that the TTIF construct maintained adequate fracture reduction despite functional weight-bearing throughout the healing period. The endotracheal tube PMMA bar provides a lightweight, customisable, and easy-to-fabricate connecting bar. Its hollow construction reduces overall construct weight, a critical consideration in avian patients where body weight is a major flight parameter. The bar remained rigid and effectively immobilised all implants until day 14, at which point staged removal proceeded without complication in five of six cases. In one case of patient induced pin removal underscores the limitation of smooth (non-threaded) transcortical K-wires in an awake, biting bird; threaded transfixation pins have been recommended (Redig, 2005) ^[12] and should be considered in future cases. The biomechanical advantages of titanium over stainless steel have been well documented. Uthoff *et al.* (1981) ^[16] demonstrated that titanium plates (modulus of

elasticity $\sim 6 \times$ cortical bone) produce less stress shielding than stainless steel ($\sim 12 \times$ cortical bone), thereby preserving periosteal callus formation and facilitating earlier radiological consolidation. Disegi (2000) ^[6] further established titanium's superior fatigue resistance and biocompatibility. Skripitz and Aspenberg (1998) ^[14] confirmed enhanced osseointegration at the titanium-bone interface. These properties collectively explain the absence of peri-implant osteolysis and pin tract infections observed in the present study.

Conclusion

Titanium tie-in fixation using a PMMA connecting bar moulded in a commercial endotracheal tube is an effective, lightweight, and well-tolerated method for the repair of tibiotarsus fractures in pigeons. It provides rigid multi-planar stabilisation, supports secondary fracture healing with predictable callus formation, and permits progressive early weight-bearing. The biomechanical advantages of titanium over stainless steel implants, reduced stress shielding, superior biocompatibility, and osseointegration potential make TTIF particularly suited to avian orthopaedics. The use of threaded transcortical pins is recommended to prevent patient-induced implant disruption.

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