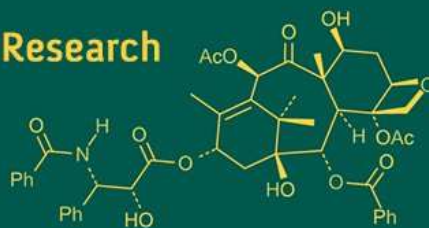
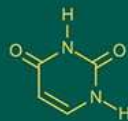
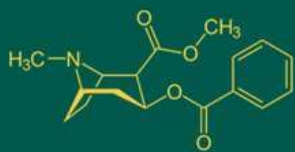


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Computed tomographic evaluation of tibiotarsus fracture healing following titanium tie-in fixation in a pigeon: A case report

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Abstract

Computed tomography with three-dimensional reconstruction was used to evaluate tibiotarsus fracture healing following titanium tie-in fixation in a two-year-old male domestic pigeon that sustained a transverse mid-diaphyseal tibiotarsal fracture due to a cage entrapment. The fracture was reduced by closed reduction technique and stabilized using a titanium intramedullary Kirschner wire together with two titanium transcortical Kirschner wires connected by a polymethylmethacrylate bar. Computed tomographic examinations with three-dimensional reconstruction were performed on 7th, 14th and 30th post-operative days, along with concurrent plain radiography. On day 7th post-operative day, the fracture line was clearly visible with minimal callus formation, and both implants were in satisfactory position without migration or osteolysis. By day 14th post-operative day, the fracture line showed partial blurring with progressive periosteal and endosteal callus and partial cortical bridging; the transcortical wires were removed on this day, and the resulting pin tract channels were visualized as low-density defects without surrounding osteolysis. By day 30th post-operative day, complete cortical continuity was evident with the fracture line largely absent, confirming solid three-dimensional bony union, and the intramedullary wire tract showed early endosteal remodelling. No implant migration, osteolysis or adverse peri-implant reaction was observed at any stage. Computed tomographic findings corroborated the concurrent plain radiographic scores and additionally provided superior visualization of cortical continuity and implant-bone interface integrity. This case demonstrates that computed tomography with three-dimensional reconstruction is a valuable adjunct imaging modality for objectively confirming tibiotarsus fracture healing in three-dimensional view following titanium tie-in fixation in pigeon.

Keywords: Computed tomography, tibiotarsus fracture, pigeon, titanium tie-in fixation, fracture healing

Introduction

Conventional orthogonal radiography has been the standard imaging modality for monitoring fracture healing in birds; however, its inherent limitations, including anatomical overlap of cortices, inability to resolve subtle trabecular bridging, and restricted three-dimensional assessment of callus architecture, can render interpretation ambiguous, particularly in the later stages of healing (Berry and Thrall, 2017) ^[1]. Computed tomography (CT) addresses these limitations by eliminating superimposition, providing cross-sectional anatomical detail, and enabling multiplanar and three-dimensional (3D) reconstruction of the fracture zone (Gumpenberger and Henninger, 2001) ^[3]. In avian medicine, CT has gained increasing acceptance for evaluating complex fractures, implant positioning, and fracture union status (Huynh *et al.*, 2019) ^[5]. The ability to accurately characterise callus formation, cortical bridging, and residual fracture gaps in three dimensions makes CT particularly valuable when radiographic evidence of union may be obscured by callus density, cortical overlap, or implant shadow (Nicholson *et al.*, 2021) ^[7]. CT also provides advantages in stress-reduction for avian patients compared to multiple radiographic repositionings (Gumpenberger and Scope, 2012) ^[4]. Despite these advantages, dedicated CT evaluations of post-operative fracture healing following titanium tie-in fixation (TTIF) in domestic pigeons have not been formally reported.

The present case was undertaken to document the CT appearance of tibiotarsus fracture healing, specifically the sequence of callus formation, cortical bridging, fracture line resolution, and implant-bone integration, following TTIF in a domestic pigeon at post-operative days 7th, 14th and 30th post-operative days, and to compare CT findings with concurrent plain radiographic scores.

Materials and Methods

A two-year-old male domestic pigeon, weighing 380 g, was presented with a confirmed transverse mid-diaphyseal tibiotarsus fracture of two day duration, sustained due to cage entrapment. Titanium intramedullary (IM) Kirschner wire (≤ 1.5 mm, approximately 50% of medullary canal diameter) and two titanium transcortical Kirschner wires (≤ 0.8 mm, approximately 25% canal diameter) were connected by a polymethylmethacrylate (PMMA) bar moulded within a commercial endotracheal tube. The fracture was reduced by closed technique under midazolam-ketamine anaesthesia. Staged implant removal was planned on 14th post-operative day (transcortical K-wires) and day 21 (IM K-wire). Computed tomographic examinations of the

operated tibiotarsus were performed on post-operative days 7th, 14th and 30th post-operative days. The bird was anaesthetised with the same midazolam-ketamine protocol (0.5 mg/kg, 30 mg/kg IM, respectively) used for surgery to minimise motion artefact (Orosz and Toal, 1992) [8]. CT scans were acquired using a standard small-animal protocol. Three-dimensional reconstructions were generated from the acquired CT data set for each time point and evaluated for sagittal multiplanar reconstructions. The CT images were assessed qualitatively for the following parameters at each time point: visibility of the fracture line; callus formation (absent, periosteal reaction only, partial cortical bridging, complete cortical bridging); bone union (non-union, partial union, complete union); implant position and integrity (K-wire alignment, cortical contact, absence of migration or breakage); and peri-implant bone reaction (osteolysis, sclerosis). CT findings were compared with concurrent plain radiographic scores documented using the Tunio *et al.* (2014) [10] system. Serial orthogonal radiographs (cranio-caudal and medio-lateral views) were obtained alongside CT at days 7, 14, and 30.



Fig 1: Cranio-caudal and medio-lateral radiograph of affected limb (A) and 3D CT image (B) on 7th post-operative day

Results and Discussion

Computed tomography with 3D reconstruction was successfully visualised the fracture site and TTIF construct at all three post-operative time points, and findings are summarised in Table 1.

7th post-operative day

On the 7th post-operative day, 3D CT images demonstrated a clearly visible fracture line, consistent with the early inflammatory phase of fracture healing. Minimal callus formation was evident at the fracture margin in the form of a subtle soft-tissue density bridging the outer cortex. The IM K-wire was visualised in satisfactory position within the medullary canal, as were both transcortical K-wires, with no implant migration or cortical perforation beyond intended purchase. A minimal periosteal reaction was noted at the transcortical K-wire entry points, and no osteolysis was observed at any implant-bone interface.

14th post-operative day

By the 14th post-operative day, CT demonstrated partial blurring of the fracture line, indicating early callus

mineralisation bridging the cortical gap, with partial cortical bridging by callus visualised on multiplanar reconstructions. The external callus volume had increased notably and the periosteal callus could be distinctly characterised as continuous across the fracture site. Following removal of the transcortical K-wires on this day, the pin tract channels were clearly visualised on CT as low-density linear defects traversing the cortex, with no surrounding osteolysis, confirming the absence of pin tract infection. The adhesive bond between the PMMA sleeve and the IM K-wire was disrupted at this stage, as documented clinically, with separation of the PMMA sleeve from the IM K-wire evident on 3D CT reconstruction.

30th post-operative day

On the 30th post-operative day, CT demonstrated complete cortical continuity on 3D reconstruction, with the fracture line largely absent and callus bridging forming a uniform cortical architecture in the healing zone, confirming solid three-dimensional bony union. Early remodelling of the external callus was evident, characterised by progressive smoothing of the periosteal contour on 3D views. The

former IM K-wire tract within the medullary canal was closed, with endosteal remodelling partially filling the

former pin channel. No late osteolysis, medullary osteomyelitis, or implant fragment retention was detected.

Table 1: Computed tomographic findings of the case at post-operative days 7, 14 and 30

CT Parameter	Day 7	Day 14	Day 30
Fracture line	Clearly visible; sharp fragment margins	Partially visible; blurring of margins	Largely absent; obliterated by callus
Callus formation	Initial periosteal callus; minimal volume	Progressive periosteal and endosteal callus; partial cortical bridging	Extensive callus with complete cortical bridging; early remodelling
Bone union	Non-union	Partial union	Complete union
Implant position	IM and transcortical K-wires in satisfactory position	IM K-wire in position; transcortical K-wires removed	IM K-wire tract closed; normal remodelling at former sites
Peri-implant bone reaction	Mild periosteal reaction at K-wire entry points	Mild periosteal reaction at entry points; no osteolysis	No osteolysis

Comparison with plain radiography

CT findings were concordant with concurrent plain radiography at all time points; however, CT provided complementary information not fully available on plain films. On 7th post-operative day, plain radiography demonstrated periosteal reaction consistent with CT but was unable to clearly delineate callus architecture or confirm cortical continuity in cross-section. On day 14th post-operative day, plain radiography showed callus formation and partial bridging, but CT more precisely characterised the degree of cortical continuity and revealed pin tract anatomy. On day 30th post-operative day, CT confirmed solid three-dimensional union, corroborating plain radiography, which showed extensive bridging callus and early remodelling. The findings in this case followed the established pattern of secondary bone healing appropriate for TTIF: initial periosteal callus (day 7), progressive cortical bridging (day 14), and near-complete union with early remodelling (day 30). These observations are consistent with the CT-based fracture healing timeline reported by Braunstein *et al.* (1986) [2], who demonstrated CT's superior sensitivity for detecting incomplete union and residual fracture gaps compared to plain radiography, and with the clinical observations of Karajagi (2022) [6], who reported complete three-dimensional bony union on CT by the 30th post-operative day in birds. A key finding of this case was that CT provided complementary information beyond plain radiography at all three time points. On 7th post-operative day, CT delineated callus architecture and

implant-bone interface integrity with greater precision than radiography, which was limited by cortical superimposition of the TTIF construct. On 14th post-operative day, CT provided unambiguous evidence of partial cortical bridging that was not fully assessable on plain films due to callus density. On 30th post-operative day, CT confirmed solid three-dimensional union in a case where radiographic interpretation could have been complicated by extensive callus masking residual gaps, consistent with Nicholson *et al.* (2021) [7], who demonstrated CT's superiority for confirming bridging callus and union when radiographic findings were inconclusive. Gumpenberger and Henninger (2001) [3] noted that CT is particularly valuable in birds for overcoming the limitations of conventional radiography related to anatomical overlap of the spine, pelvis, and limb structures. In the present case, the lateral placement of the TTIF construct introduced additional metallic artefact on plain films that CT multiplanar reconstruction could partially circumvent by selecting imaging planes that minimised beam-hardening interference. The visualisation of the pin tract channel on day-14 CT as a discrete low-density linear cortical defect, without surrounding osteolysis, confirmed the absence of subclinical pin tract infection, consistent with the clinical absence of purulent discharge. Titanium's superior osteointegration properties (Skripitz and Aspenberg, 1998) [9] and biocompatibility likely contributed to the favourable peri-implant response observed throughout the case.



Fig 2: Cranio-caudal and medio-lateral radiograph of affected limb (A) and 3D CT image (B) on 14th post-operative day



Fig 3: Cranio-caudal and medio-lateral radiograph of affected limb (A) and 3D CT image (B) on 30th post-operative day

Conclusion

Computed tomography with three-dimensional reconstruction provided reliable, detailed, and complementary evaluation of tibiotarsus fracture healing following titanium tie-in fixation in this domestic pigeon. The CT healing sequence, periosteal callus at day 7, partial cortical bridging at day 14, and near-complete three-dimensional bony union at day 30, corroborated plain radiographic findings and confirmed the efficacy of TTIF for supporting secondary fracture healing. CT is particularly valuable when radiographic interpretation is limited by callus density, metallic artefact from the fixation construct, or cortical superimposition, and its use is recommended as a confirmatory imaging adjunct in avian fracture cases where radiographic union status is equivocal.

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