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Case Report

Biologically Oriented Plate Fixation for Avian Long-Bone Fractures: A Case Series

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Abstract

Avian long-bone fractures are challenging because of the distinctive anatomy and biomechanics of avian bone and the need to preserve local biology while restoring function. The aim of this study was to evaluate the clinical application of biologically oriented plate fixation in avian long-bone fractures. A retrospective descriptive case series was performed using six avian fracture cases with complete records of species, bone, fracture type, fixation method, complications, and radiographic follow-up. The population included two domestic chickens, one peafowl, one hyacinth macaw, one bald eagle, and one sulphur-crested cockatoo. Fractures involved the tibiotarsus (4/6), femur (1/6), and radius/ulna (1/6), with transverse and comminuted configurations. Internal plate fixation was used in all six cases. Radiographic union was achieved in all cases, with healing times of 60–92 days. One femoral fracture treated with a 3.5 mm locking plate was complicated by plate failure; no complications occurred in the remaining cases. Because outcomes were assessed only by radiographic union and documented complications, with no functional outcome data, these findings should be interpreted cautiously. Biologically oriented plate fixation may be a viable option for selected avian long-bone fractures, though larger prospective studies are needed to define indications, construct selection, and outcomes.

Keywords: avian orthopedics; fracture repair; minimally invasive plate osteosynthesis; biological osteosynthesis; plate fixation; long-bone fracture; tibiotarsus; birds

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1. Introduction

Appendicular fractures are frequently encountered in avian patients and present substantial therapeutic challenges because of the distinctive anatomy and biomechanics of avian bone. Thin cortices, relatively limited soft tissue coverage, and the functional requirement for early restoration of limb use complicate fracture stabilization and postoperative management, particularly in species with high activity demands [1–5]. In addition, preservation of the local biological environment is especially important in birds, as further disruption of periosteal and surrounding soft tissues may adversely affect bone healing and functional recovery [1–3].

Biological osteosynthesis has become a central principle of modern fracture management by emphasizing mechanical stability while minimizing surgical trauma to the fracture site. Within this framework, minimally invasive plate osteosynthesis (MIPO) aims to preserve fracture hematoma, periosteal perfusion, and soft tissue integrity through indirect

reduction and bridging fixation techniques [6–10]. In the present report, the term "biologically oriented plate fixation" denotes minimally invasive plate osteosynthesis (MIPO) applied according to biological osteosynthesis principles—that is, plate stabilization that prioritizes preservation of the fracture hematoma, periosteal blood supply, and surrounding soft tissues. All cases in this series were managed using this minimally invasive approach. In canine and feline orthopedic surgery, MIPO has been associated with satisfactory alignment, favorable clinical outcomes, and timely radiographic healing in selected long-bone fractures [6,11–14]. Although direct extrapolation from mammalian patients to birds should be made cautiously, the underlying biological rationale is highly relevant to avian fracture repair, particularly when stable fixation is required without excessive disturbance of fragile osseous and peri-fracture tissues.

In avian orthopedics, fracture management has traditionally relied on external coaptation, intramedullary pinning, or external skeletal fixation, with technique selection influenced by species, body size, fracture configuration, anatomic location, and the need to limit implant burden and soft tissue injury [1–5,15,16]. Published avian reports have described treatment of tibiotarsal fractures with tape splints, external skeletal fixation, tie-in constructs, and hinged external fixation strategies in selected birds [3–5,15–17]. By contrast, clinical information on locking plate fixation and MIPO-inspired biological fixation strategies in birds remains comparatively limited, although isolated case reports, small avian case series, and additional reports in the broader avian fracture literature suggest that plate-assisted stabilization and minimally invasive osteosynthesis may be feasible in selected fractures [18–22], and broader reviews of avian wing-fracture assessment and management provide additional context for these approaches [23]. Reports describing radioulnar osteosynthesis in wild birds and radiographic and functional evaluation of external fixation models in pigeons further support continued investigation of avian internal and external fixation strategies [17,19,20]. This relative lack of evidence is clinically relevant because plate-based fixation may offer potential advantages in selected cases, including improved stability, preservation of alignment, and support for early functional limb use, while still respecting the biological requirements for fracture healing.

Accordingly, the aim of this study was to evaluate the clinical use of biologically oriented fracture fixation for avian long-bone fractures and to provide additional information on fixation strategy, fracture healing, and short-term outcomes. By examining plate-assisted fracture stabilization within the broader framework of biological osteosynthesis, this report seeks to expand the limited body of literature addressing internal fixation techniques in birds, complement existing avian reports focused primarily on coaptation and external skeletal fixation, and further assess the role of these methods in achieving satisfactory radiographic and clinical healing [1–7,11–20].

2. Materials and Methods

This study was conducted as a retrospective descriptive case series of avian appendicular long-bone fractures managed using biologically oriented fixation principles. Cases were drawn from clinical records over the period 2015 to 2020. Birds were eligible for inclusion if they presented with a long-bone fracture considered amenable to management by minimally invasive plate osteosynthesis (MIPO). Cases were identified from the clinical records available in the present dataset and were included when sufficient information was available regarding species, bone affected, fracture configuration, fixation method, complications, and radiographic follow-up. All birds underwent general anesthesia and received perioperative analgesia according to institutional and case-specific protocols. The study population comprised domestic chickens (*Gallus gallus domesticus*) (Figures 1–5), a hyacinth macaw (*Anodorhynchus hyacinthinus*) (Figures 6–9), a peafowl (*Pavo cristatus*)

(Figures 10–13), a bald eagle (*Haliaeetus leucocephalus*) (Figures 14–16), and a sulphur-crested cockatoo (Cacatua galerita). Preoperative and postoperative radiographs of the second domestic chicken case are shown in Figures 17 and 18.

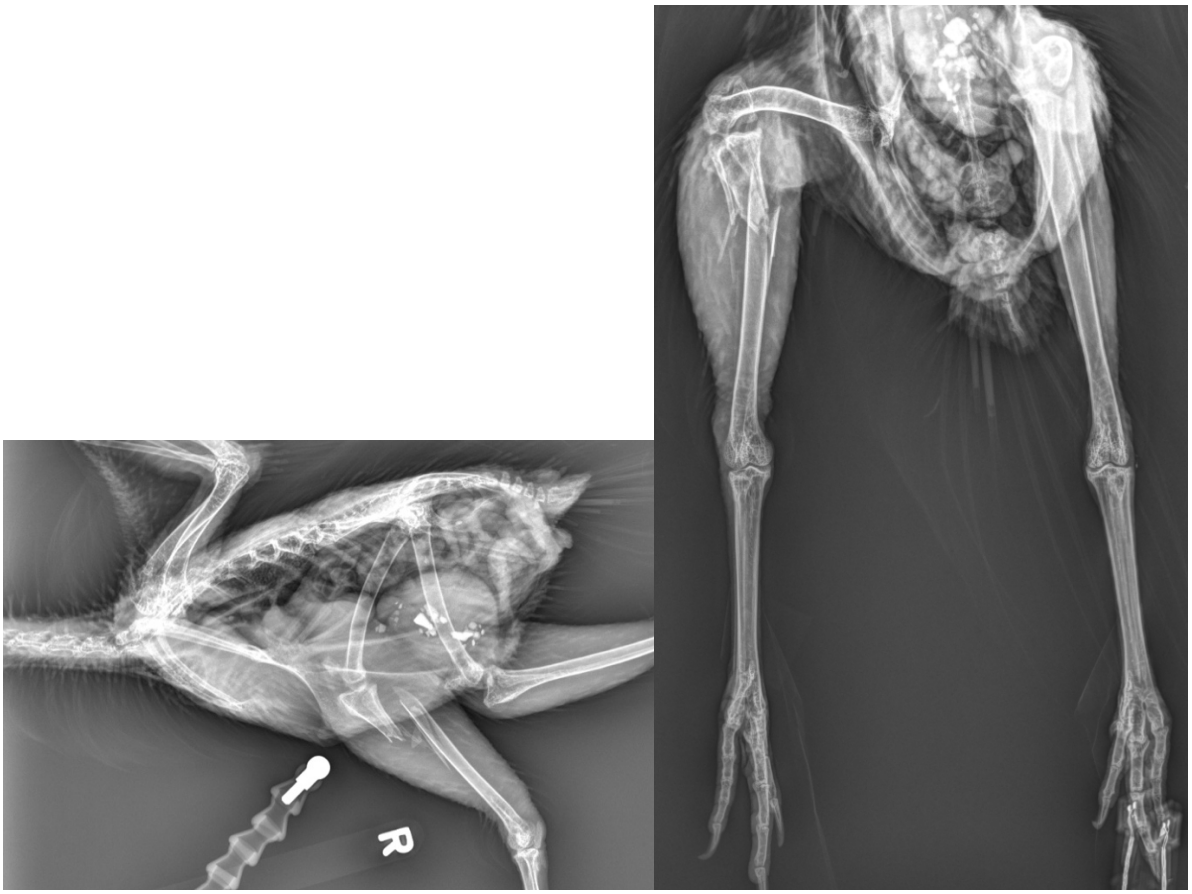


Figure 1. Case 2 (*Gallus gallus domesticus*): preoperative radiographs of the right tibiotarsus demonstrating a proximal comminuted fracture with caudal–medial displacement. The letter R in the figure is marking the right side of the patient.

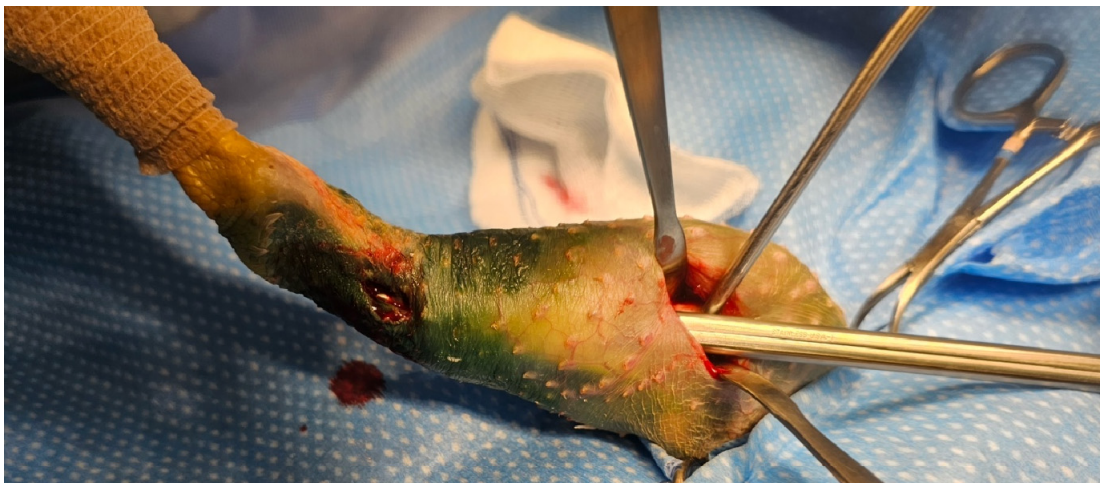


Figure 2. Intraoperative photograph of Case 2 (*Gallus gallus domesticus*) illustrating the minimally invasive approach to the tibiotarsus: proximal and distal skin incisions are visible, with a submuscular epiperiosteal tunnel created medially beneath the tibialis cranialis and gastrocnemius muscles to allow plate passage while preserving the fracture hematoma and surrounding soft tissues.

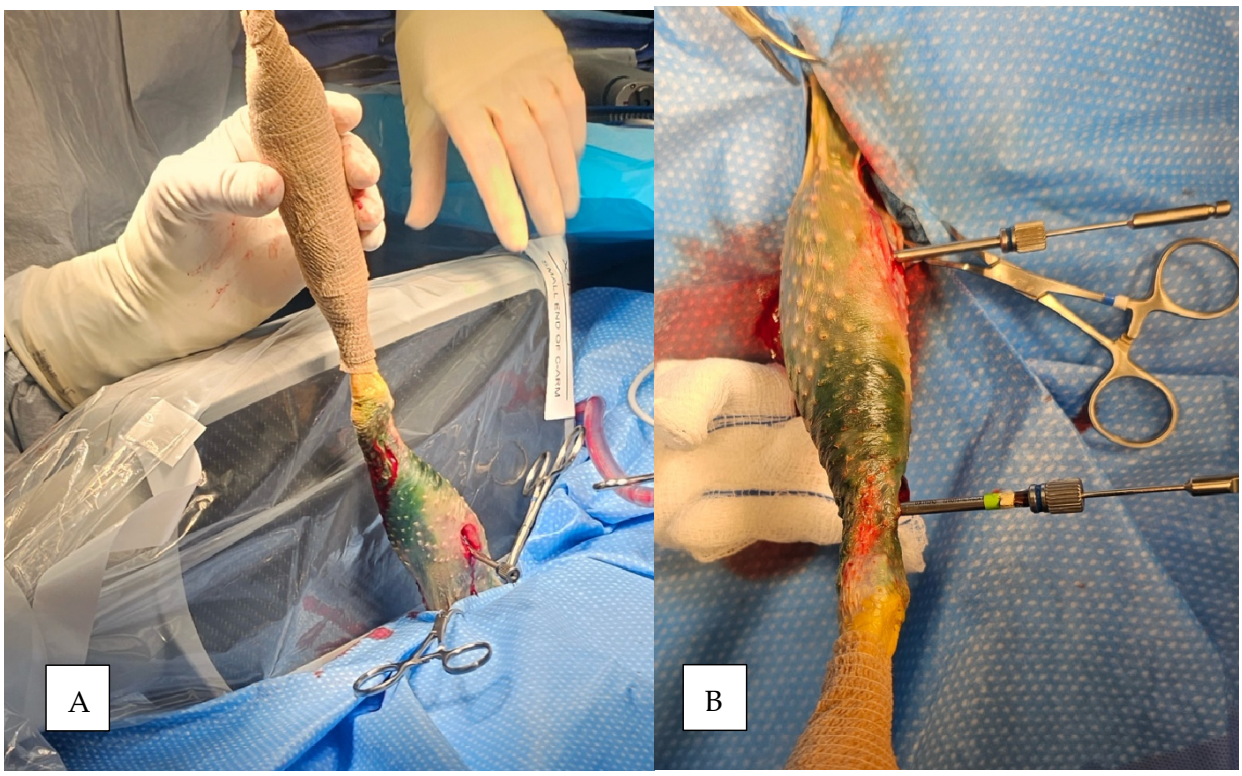


Figure 3. Case 2 (*Gallus gallus domesticus*), proximal comminuted tibiotarsal fracture treated with a 2.0 mm locking Synthes plate applied through a minimally invasive approach. (**A**) Intraoperative view of the limb positioned over a mini C-arm, used to guide indirect reduction and confirm correct plate placement under fluoroscopic control. (**B**) The plate is provisionally secured to the bone with two 1.5 mm drill bits inserted through the locking drill guides; at this stage, limb alignment is verified in the sagittal and frontal planes before definitive screw placement.



Figure 4. Case 2 (*Gallus gallus domesticus*), final intraoperative view following minimally invasive plate osteosynthesis. The 2.0 mm locking Synthes plate is applied along the medial aspect of the tibiotarsus and secured with two proximal and two distal 2.0 mm locking screws. The fracture site itself was not surgically approached, preserving the fracture hematoma and surrounding soft tissues consistent with biological osteosynthesis principles.

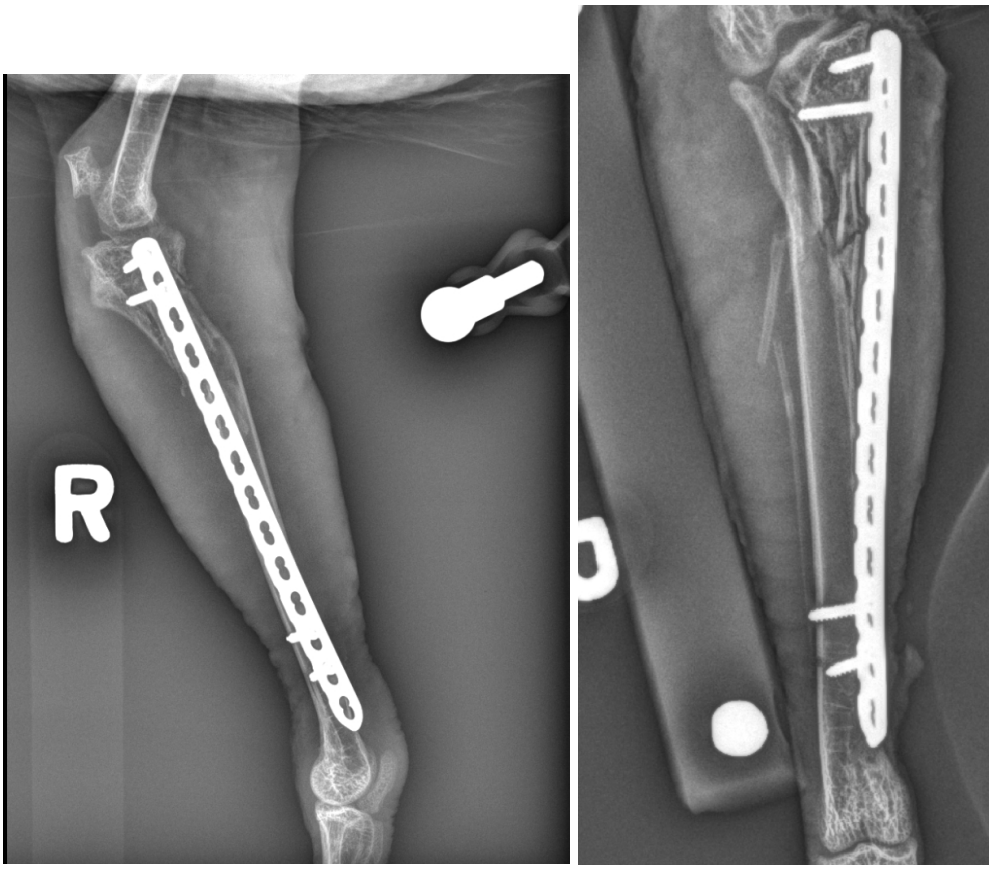


Figure 5. Case 2 (*Gallus gallus domesticus*), immediate postoperative radiographs demonstrating satisfactory alignment and restoration of the limb axis of the proximal comminuted tibiotarsal fracture and correct medial positioning of the 2.0 mm locking Synthes plate, secured with two proximal and two distal locking screws.

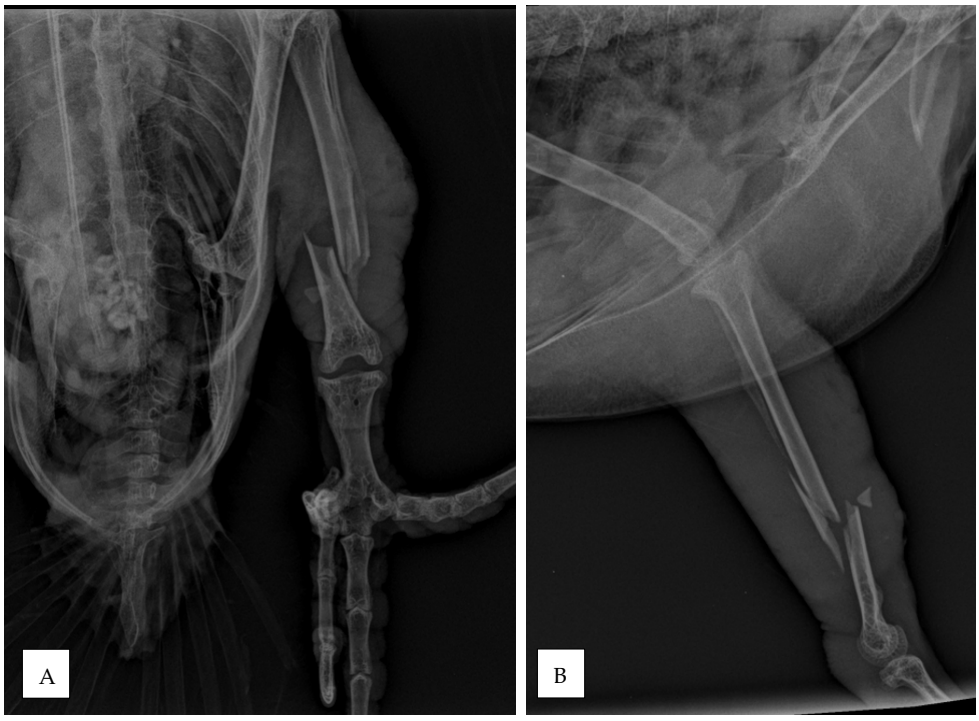


Figure 6. Case 4 (*Anodorhynchus hyacinthinus*), multifragmentary diaphyseal fracture of the tibiotarsus. (**A**) Craniocaudal view and (**B**) lateral view.

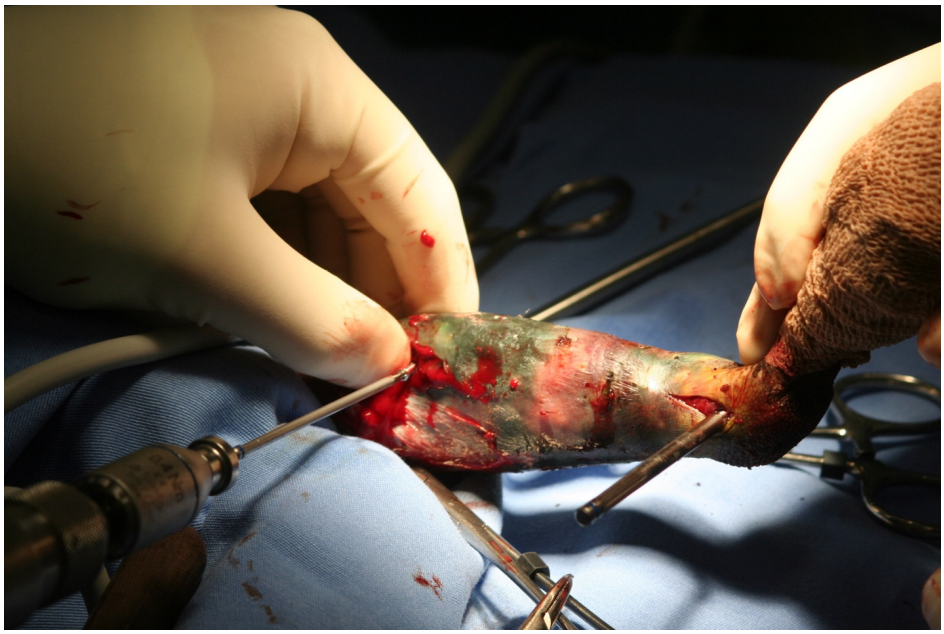


Figure 7. Case 4 (*Anodorhynchus hyacinthinus*), intraoperative view showing placement of a locking screw in the 2.0 mm locking Synthes plate. Note the small proximal and distal approaches used to insert the screws, with the fracture site left unapproached to preserve the fracture hematoma and surrounding soft tissues.

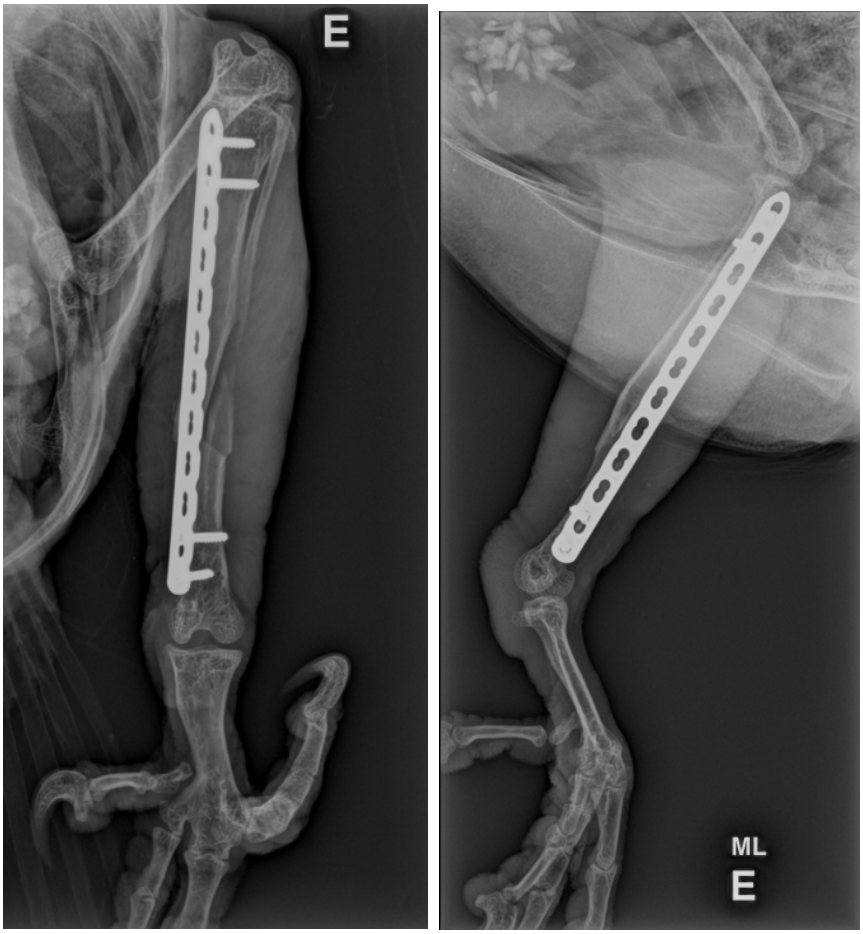


Figure 8. Case 4 (*Anodorhynchus hyacinthinus*), immediate postoperative radiographs demonstrating a reduction in the tibiotarsal fracture and correct medial positioning of the 2.0 mm locking Synthes plate, secured with two proximal and two distal locking screws.

Data extracted for each case included species, bone affected, fracture type, fixation method, presence or absence of documented postoperative complications, and time to radiographic union. The age and sex of the birds were not determined in the available clinical files and are therefore not reported. Fractures involved the tibiotarsus, femur, and radius/ulna. Based on the available case records, fracture configurations were categorized as transverse or comminuted, and additional localization descriptors were recorded when provided, including proximal or distal tibiotarsal involvement.

Definitive stabilization was achieved using internal fixation in all cases. Internal fixation constructs included a 2.0 mm Steelvet plate, 2.0 mm locking Synthes plates, a 2.0 mm Synthes plate, a 2.5 mm Carmelo plate, and an Intrauma 3.5 mm locking plate, selected according to the species, bone dimensions, and fracture characteristics documented in the records. Fracture repair was performed according to biological osteosynthesis principles, with the objective of obtaining adequate mechanical stability while minimizing unnecessary disruption of the fracture environment and surrounding soft tissues. A minimally invasive approach with epiperiosteal tunneling and indirect reduction was used in all cases, including the comminuted radius/ulna case; all fractures were therefore managed according to the MIPO technique. Because of the retrospective nature of the study and the variable level of detail available in the source records, further procedural standardization could not be evaluated.

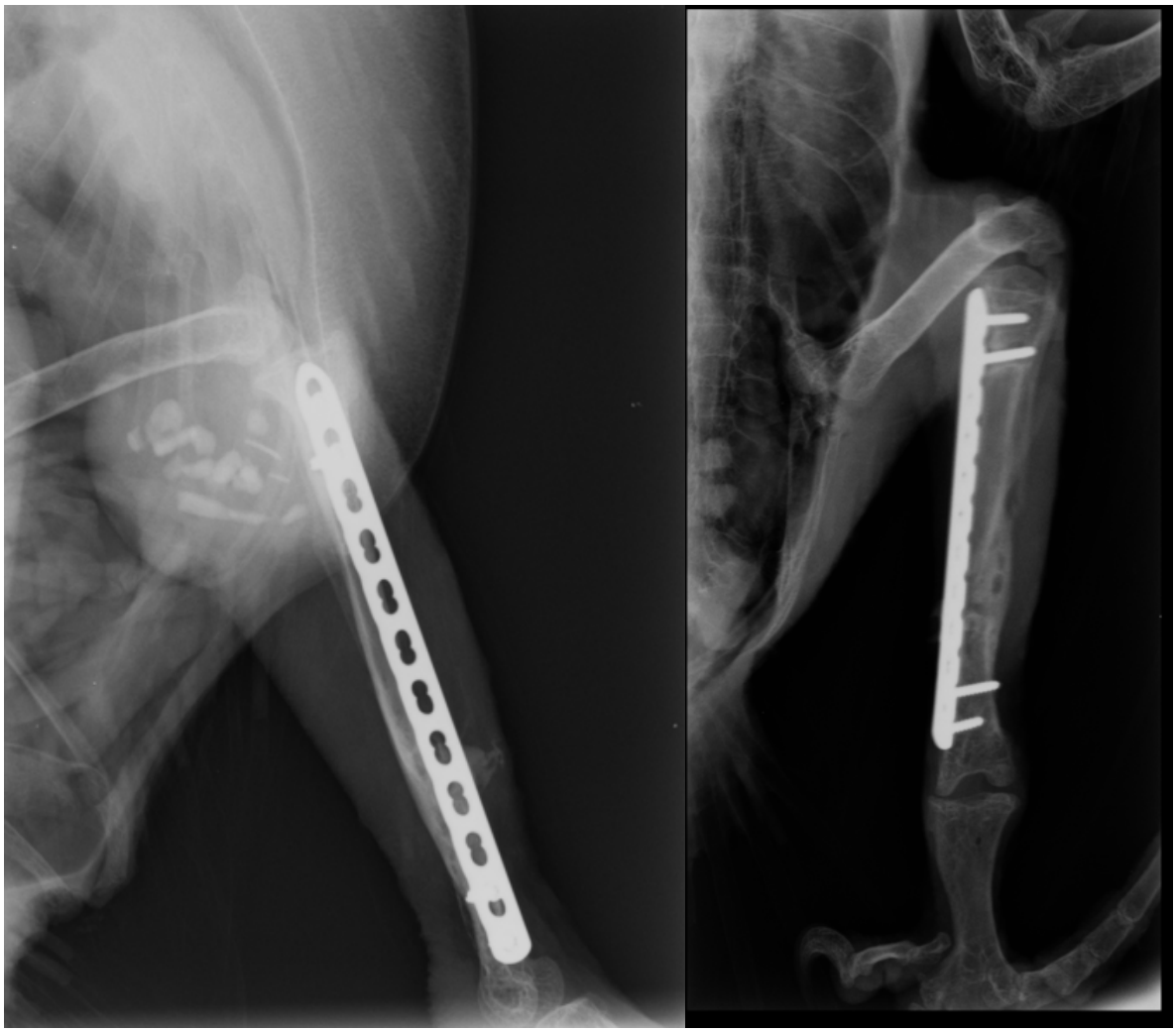


Figure 9. Case 4 (*Anodorhynchus hyacinthinus*), radiographs obtained 60 days postoperatively, showing bridging callus and progression toward radiographic union of the tibiotarsal fracture.

Steelvet plate system: The Steelvet plates (Steelvet, Mogi Mirim, Brazil) are titanium locking-plate implants available in five plate lines ranging from 1.5 mm up to 4.5 mm (equine); the 2.0 mm line was used in the present series. The plates feature both fixed-angle locking holes, which accept either locking or non-locking cortical screws.

Carmelo plate system: The Carmelo plates (Intrauma S.p.A., Bruino, Italy) are likewise a locking-plate system—the polyaxial "MultiAx" system—comprising silver-coated titanium plates; the 2.5 mm (Mini) series was used in the present series. The locking (Multiax) screws thread into conical threaded holes to form an angularly stable construct that maintains fracture alignment without relying on plate-to-bone friction; the Multiax design additionally permits screw angulation of up to ±15° in any direction (a 30° cone), while separate compression holes accept reduced-head cortical (non-locking) screws. This angular stability is well suited to the small-diameter, thin-walled long bones encountered in avian orthopedic surgery.

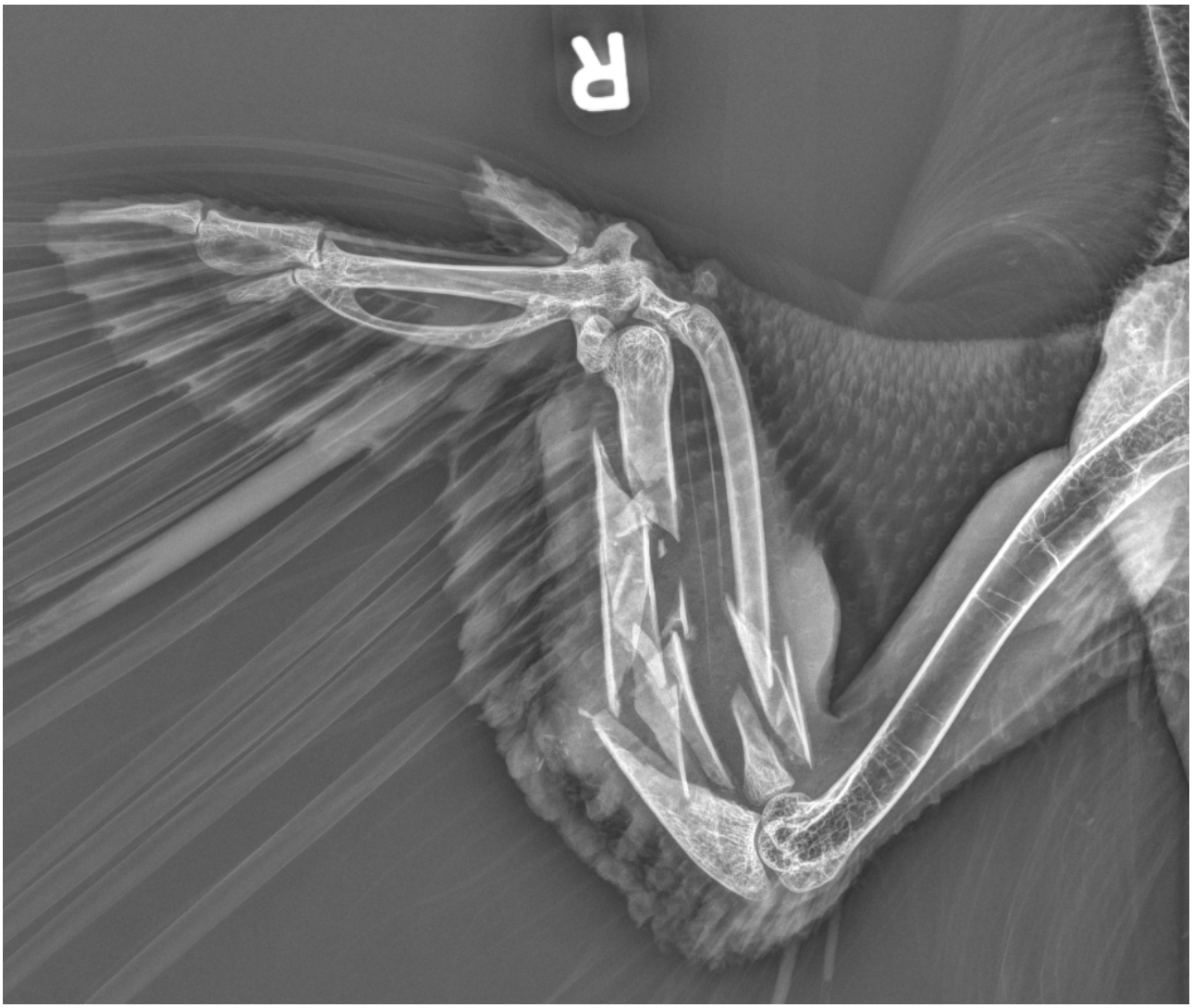


Figure 10. Case 3 (*Pavo cristatus*): preoperative radiograph of the right wing (antebrachium) demonstrating a comminuted fracture involving both the radius and ulna.

All fractures were stabilized using minimally invasive plate osteosynthesis (MIPO) [6,7,9,10]. In every case, two skin incisions were made remote from the fracture, and a freer elevator or long Metzenbaum scissors was used to create a submuscular epiperiosteal tunnel close to the periosteum for plate passage. Care was taken not to

increase the override of the fracture during tunneling and reduction. Indirect reduction was performed, and in all cases a C-arm was used to check implant positioning and bone reduction; a less-than-anatomic reduction was accepted in all cases, consistent with biological osteosynthesis principles that prioritize preservation of the fracture hematoma and periosteal blood supply over exact anatomical reconstruction. Although the MIPO technique has been described in detail in dogs and cats rather than in birds, the underlying biological principles are similar and were applied here to avian long bones [24].

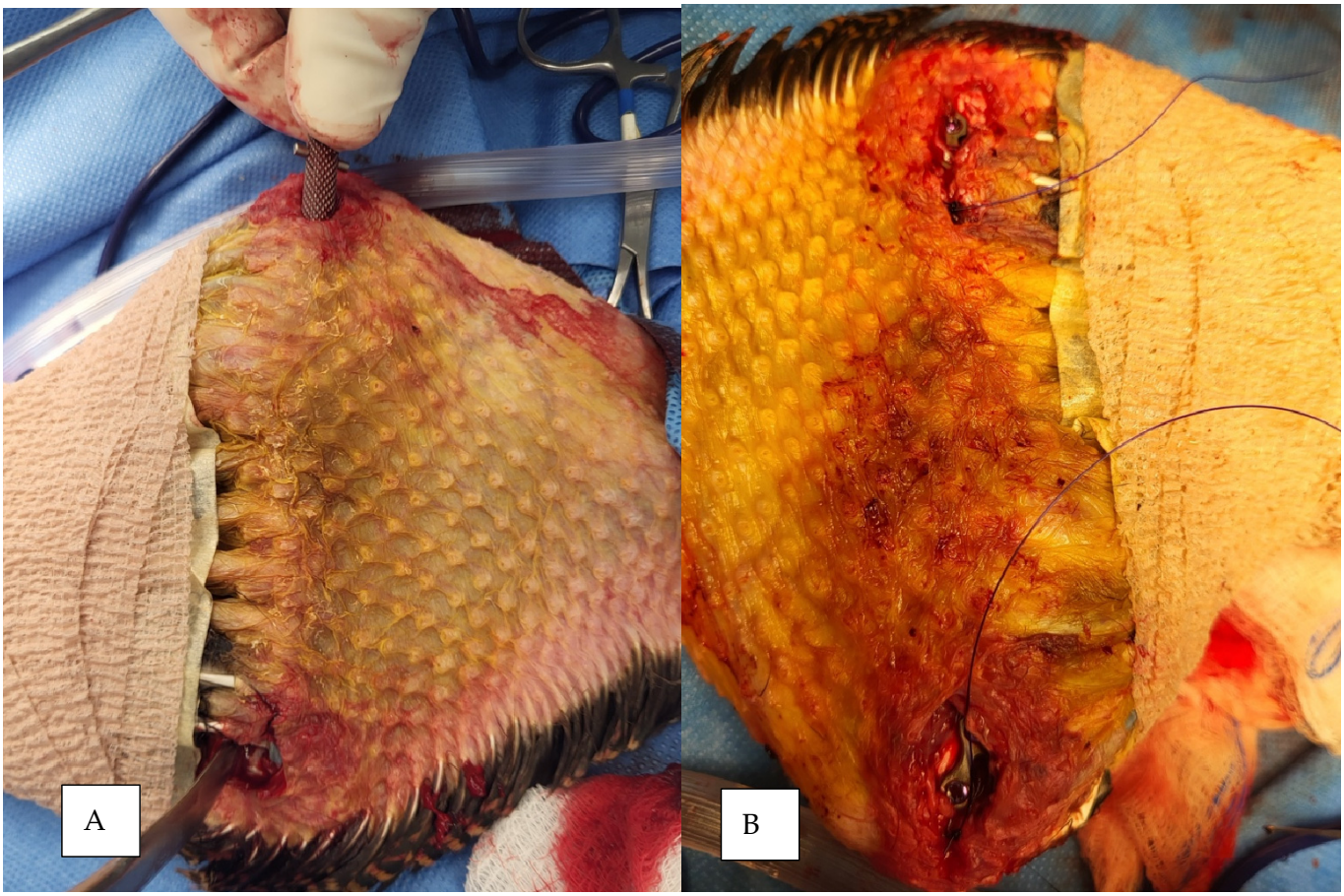


Figure 11. Case 3 (*Pavo cristatus*), intraoperative photographs of the right wing during minimally invasive plate osteosynthesis of the comminuted radius/ulna fracture. (**A**) Limited approach with a soft tissue tunnel of the antebrachium. (**B**) The plate was placed in the soft tissue tunnel.

In Case 1 (*Gallus gallus domesticus*, distal transverse tibiotarsal fracture), a 2.0 mm Steelvet plate was applied to the medial aspect of the tibiotarsus. In Case 2 (*Gallus gallus domesticus*, proximal comminuted tibiotarsal fracture), the submuscular epiperiosteal tunnel was created medially beneath the tibialis cranialis and gastrocnemius muscles, and a 2.0 mm locking Synthes plate was applied medially and secured with two proximal and two distal locking screws (Figures 1–5). In Case 3 (*Pavo cristatus*, comminuted radius/ulna fracture), a 2.5 mm Carmelo plate was applied to the ulna through a soft-tissue tunnel of the antebrachium; only the ulna was stabilized because it was the larger of the two bones and no available implant or plate could be accommodated by the radius, and the radius was left to heal alongside the stabilized ulna (Figures 10–13). In Case 4 (*Anodorhynchus hyacinthinus*, multifragmentary tibiotarsal fracture), a 2.0 mm locking Synthes plate was secured along the medial tibiotarsus with two proximal and two distal locking screws (Figures 6–9). In Case 5 (*Haliaeetus leucocephalus*, comminuted femoral fracture), the femur was stabilized with an Intrauma 3.5 mm locking plate; this construct was subsequently complicated by

plate failure. In Case 6 (*Cacatua galerita*, transverse tibiotarsal fracture), a 2.0 mm Synthes plate was applied to the medial tibiotarsus. Anesthesia time was recorded in four cases: 45 min (Case 2), 1 h 13 min (Case 3), 58 min (Case 4), and 2 h 18 min (Case 5); anesthesia time was not recorded for Cases 1 and 6.



Figure 12. Case 3 (*Pavo cristatus*), immediate postoperative radiographs of the right wing demonstrating fixation on the ulna of the comminuted radius/ulna fracture with a 2.5 mm Carmelo plate. Surgery was performed approximately 10 days after the initial radiographs (Figure 10). (**A**) Lateral view and (**B**) horizontal-beam cranial–caudal view.

Outcome assessment was based on the occurrence of documented postoperative complications and the time to radiographic union reported for each case. A complication was defined as any implant-related or surgical complication—such as implant failure, infection, or loss of reduction—identified during the postoperative period or on follow-up radiographs; both major and minor complications were recorded. Radiographic union was defined as the presence of bridging callus across the fracture with progressive obliteration of the fracture line on orthogonal radiographic views. As avian fractures heal predominantly by secondary bone healing, with callus derived principally from the periosteal surface, union was judged by the development of periosteal bridging callus [1,2,25]. Radiographic union was recorded between 60 and 92 days in cases for which follow-up data were available. Clinical and radiographic follow-up extended at least until radiographic union was documented in each case, corresponding to 60, 75, 92, 60, 90, and 63 days for Cases 1 to 6, respectively. Given the descriptive nature of this series and the limited sample size, results were summarized qualitatively, and no statistical analysis was performed.

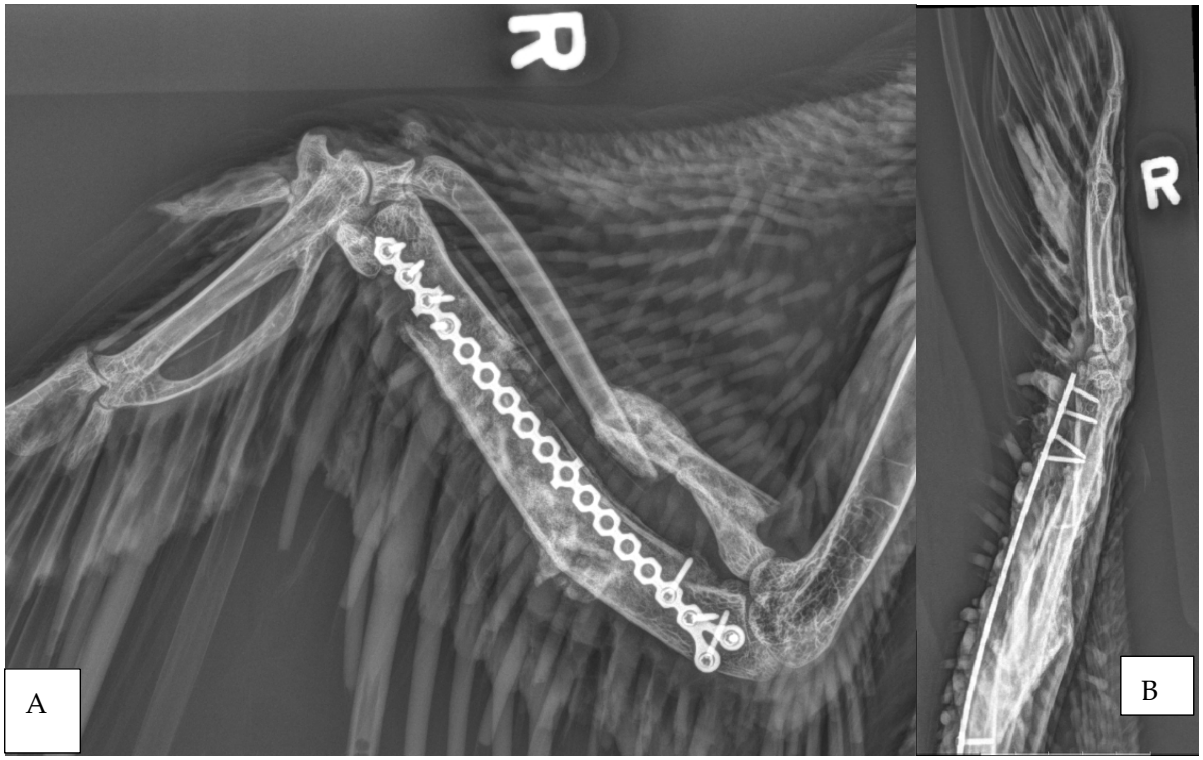


Figure 13. Case 3 (*Pavo cristatus*), follow-up radiographs of the right wing at 92 days postoperatively, showing bridging callus and progression toward radiographic union of the radius/ulna fracture. (**A**) Lateral view and (**B**) horizontal-beam cranial–caudal view.



Figure 14. Case 5 (*Haliaeetus leucocephalus*): preoperative orthogonal (craniocaudal and mediolateral) radiographs of the left femur showing a comminuted mid-diaphyseal femoral fracture with medial–caudal displacement.

Postoperatively, no external coaptation was used in any case; no cast or bandage was applied to any fracture. Activity was not restricted. In the birds with tibiotarsal fractures, perching was permitted as soon as the surgery was completed. In the peafowl with the radius/ulna (wing) fracture, no bandage was applied, and in the bald eagle with the femoral fracture, no bandage or activity restriction was used. An Elizabethan collar was placed in all patients to prevent interference with the surgical site.



Figure 15. Case 5 (*Haliaeetus leucocephalus*): immediate postoperative radiographs of the left femur showing stabilization of the comminuted femoral fracture with an Intrauma 3.5 mm locking plate secured with two proximal and two distal locking screws. The two most proximal screws appear short, and fracture reduction is suboptimal on the sagittal view, with pronounced procurvatum.



Figure 16. Case 5 (*Haliaeetus leucocephalus*): follow-up radiographs at 90 days postoperatively demonstrating plate failure. The two most proximal screws have pulled out of the bone and away from the plate, and a large callus formation can be seen in the vicinity. Compared to the postoperative radiographs, the procurvatum in this set of radiographs is more pronounced, with greater override of the distal segment caudally. Despite the implant failure, the bone shows a large bridging callus.

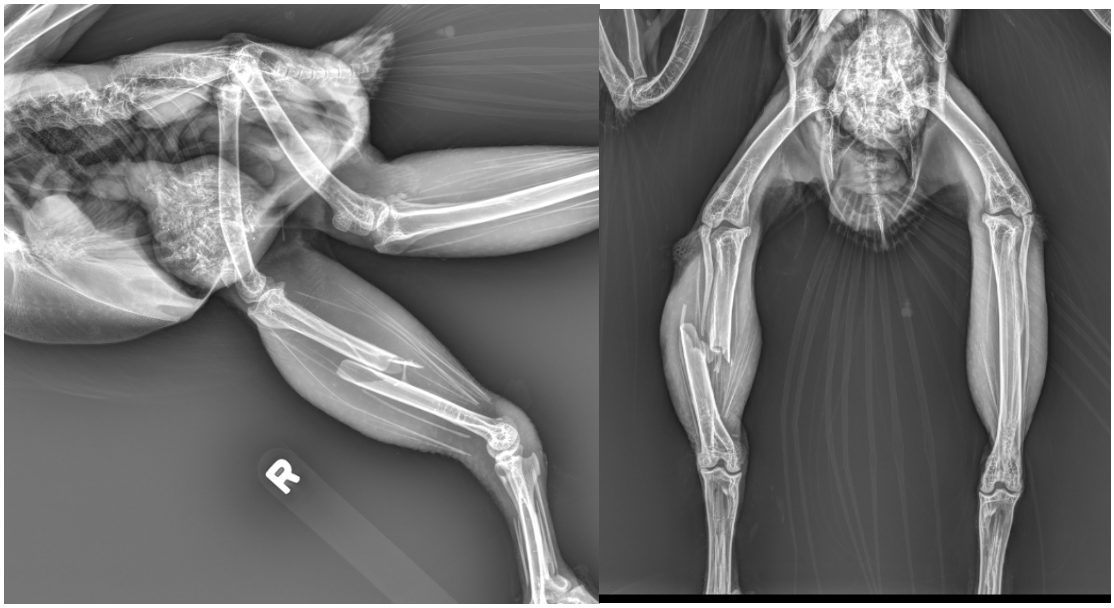


Figure 17. Case 1 (*Gallus gallus domesticus*): preoperative radiographs of the right tibiotarsus in lateral (**right**) and craniocaudal (**left**) projections, demonstrating the diaphyseal comminuted fracture with cranial–lateral displacement.

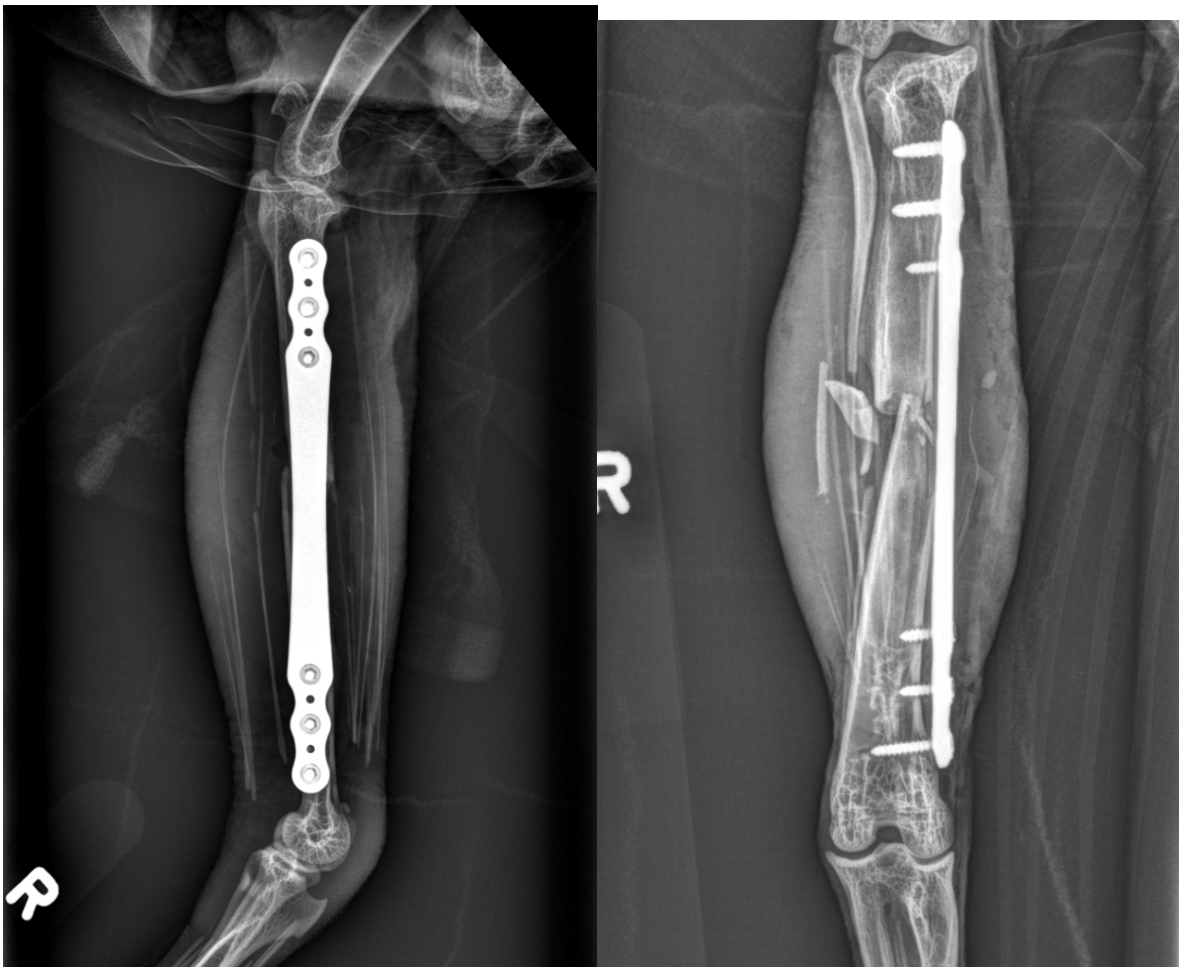


Figure 18. Case 1 (*Gallus gallus domesticus*): immediate postoperative radiographs of the right tibiotarsus in lateral (**right**) and craniocaudal (**left**) projections, showing the 2.0 mm locking plate bridging the diaphyseal comminuted fracture.

3. Results

Six avian fracture cases were included in this series (Table 1). The study population comprised two domestic chickens (*Gallus gallus domesticus*), one peafowl (*Pavo cristatus*), one hyacinth macaw (*Anodorhynchus hyacinthinus*), one bald eagle (*Haliaeetus leucocephalus*), and one sulfur-crested cockatoo (*Cacatua galerita*). The tibiotarsus was the most frequently affected bone (4/6), followed by the femur (1/6) and radius/ulna (1/6). Fracture configurations included one distal transverse fracture, one transverse fracture, one proximal comminuted fracture, two comminuted fractures, and one multifragmentary fracture; fracture classification was not further specified beyond the table terminology. Internal fixation was used in all six cases and consisted of a 2.0 mm Steelvet plate, two 2.0 mm locking Synthes plates, one 2.0 mm Synthes plate, one 2.5 mm Carmelo plate, and one Intrauma 3.5 mm locking plate. Radiographic union was reported in all cases, with healing times of 60, 75, 92, 60, 90, and 63 days. No complication was recorded in five cases, whereas one femoral fracture (Case 5, bald eagle) treated with a 3.5 mm locking plate was associated with plate failure, which was identified on recheck radiographs at 34 days postoperatively; at that time the eagle was clinically well and perching normally.

Table 1. Species, bone affected, fracture type, fixation method, complications, and time to radiographic union in six avian long-bone fracture cases treated with biologically oriented fixation principles. NR = not recorded.

Case	Species	Bone	Fracture Type	Fixation Method	Anesthesia Time	Complication	Radiographic Union/ Follow-Up	Figure(s)	Functional Outcome
1	*Gallus gallus domesticus*	tibiotarsus	diaphyseal comminuted	2.0 mm locking Steelvet plate	NR	No	60 days	—	Returned to owner; normal limb use
2	*Gallus gallus domesticus*	tibiotarsus	Proximal comminuted	2.0 mm locking Synthes plate	45 min	No	75 days	Figures 1–5	Returned to owner; normal limb use
3	*Pavo cristatus*	radius/ulna	Comminuted	2.5 mm Carmel locking plate	1 h 13 min	No	92 days	Figures 10–13	Normal wing extension/ flexion, no patagial damage; living well per owner; flight not formally assessed
4	*Anodorhynchus hyacinthinus*	tibiotarsus	Multifragmentary	2.0 mm locking Synthes plate	58 min	No	60 days	Figures 6–9	Maintained at São Paulo Zoo; flying within enclosure
5	*Haliaeetus leucocephalus*	femur	Comminuted	Intrauma 3.5 mm locking plate	2 h 18 min	Plate failure (identified on recheck radiographs at 34 days)	90 days	—	Transferred to sanctuary; flying within enclosure
6	*Cacatua galerita*	tibiotarsus	Transverse	2.0 mm locking Synthes plate	NR	No	63 days	—	Returned to owner; normal limb use

Functional outcomes were assessed qualitatively on the basis of owner or caretaker reports following the final radiographic evaluation. Cases 1, 2, 3, and 6 were followed until the final radiographs confirmed union; these birds were privately owned and were returned to their owners, with normal use of the affected limb reported. In Case 3 (*Pavo cristatus*, radius/ulna fracture), wing extension and flexion were normal with no patagial damage, and the owner reported the bird living well without restriction; however, flight was not formally assessed by the authors or the owner. Case 4 (*Anodorhynchus hyacinthinus*) was maintained at the São Paulo Zoo following surgery and was reported to be doing well and flying within its enclosure. Case 5 (*Haliaeetus leucocephalus*), following the final radiographs, was transferred to the Dolly Parton Eagle Mountain Sanctuary and was likewise reported to be doing well and flying within the enclosure. As these outcomes were based on subjective observation rather than standardized functional assessment, they should be interpreted with caution.

4. Discussion

The present case series suggests that plate-assisted fracture fixation based on biological osteosynthesis principles can be successfully applied in selected avian long-bone fractures. Radiographic union was achieved in all cases, with healing times ranging from 60 to 92 days, despite variation in species, bone involved, and fracture configuration. These findings are consistent with the general premise of biological fixation, in which preservation of the local vascular and soft tissue environment may support callus formation and progression to union while maintaining adequate construct stability [7,9,10]. Similar advantages have been reported in canine and feline MIPO literature, where minimally disruptive plate fixation has been associated with satisfactory healing and favorable short-term clinical outcomes [6,11–14]. As this series lacked a control group and objective comparative outcome measures, it demonstrates feasibility and satisfactory radiographic healing but cannot establish the superiority or specific biological advantages of the technique, which remain supported by the prior experimental and clinical literature rather than by the present data [6,7,9–14].

Most fractures in the present series involved the tibiotarsus, which is a frequent site of injury in birds and a well-recognized therapeutic challenge because of limited soft tissue coverage and the functional importance of early limb use [1–5,15–20]. Published avian studies have described successful management of tibiotarsal fractures using tape splints, external skeletal fixation, external skeletal fixator–intramedullary pin tie-in techniques, and hinged transarticular fixation strategies in selected birds [3–5,15–17]. In contrast, reports of avian locking plate fixation and minimally invasive osteosynthesis remain comparatively sparse and are largely limited to isolated case descriptions, small case series, and a small number of additional reports in the avian orthopedic literature [18–22], with broader avian wing-fracture assessment and management reviewed elsewhere [23]. The report of radioulnar osteosynthesis in a Savanna Hawk, the experimental articulated external fixator study in pigeons, and the use of hinged transarticular fixators in young birds illustrate the diversity of avian fixation strategies currently described and highlight the ongoing need to refine constructs that preserve function while promoting fracture healing [17,19,20]. In this context, the use of locking plate constructs in several of the current cases is noteworthy. As detailed in the Materials and Methods section, all six cases were managed using a true minimally invasive plate osteosynthesis technique—a two-incision approach remote from the fracture, submuscular epiperiosteal tunneling, indirect reduction confirmed under C-arm guidance, and acceptance of a less-than-anatomic reduction consistent with biological osteosynthesis principles. Compared with coaptation alone, plate fixation may provide improved resistance to bending and torsional forces and may better preserve axial alignment, particularly in unstable or comminuted fractures [26,27]. The successful union observed in the plated tibiotarsal cases of this series

supports the view that internal fixation can be a useful option in appropriately selected avian patients, although direct comparison with other fixation methods cannot be made from the present dataset.

The three most directly comparable avian plate reports each address a different facet of the approach used here. Bennert et al. experimentally evaluated two miniplate systems for stabilization of induced ulnar and radial fractures in pigeons, demonstrating that plate constructs can be applied to the small, thin-walled bones of the avian wing [21]; this parallels the comminuted radius/ulna fracture in the present peafowl (Case 3), which achieved radiographic union at 92 days with a 2.5 mm Carmelo plate and supports the feasibility of plate fixation for antebrachial fractures despite limited bone stock. In this case, only the ulna was stabilized because it is the larger of the two antebrachial bones and no available implant could be accommodated by the radius. Furthermore, early callus formation was already present at the time of surgery, and fixation of the radius would have risked damaging the patagial membrane; the radius fracture was therefore left without fixation to heal alongside the stabilized ulna. Davidson et al. described plate fixation of a coracoid fracture in a bald eagle, illustrating internal fixation of a load-bearing bone in a large raptor [22]; this contrasts instructively with the bald eagle femoral fracture in the present series (Case 5), in which a 3.5 mm locking plate failed, raising the possibility that in this individual high-demand raptor, implant selection and load distribution—rather than the biological approach itself—may have contributed to construct failure, although this observation derives from a single case and cannot be generalized. Finally, the review by Nacar et al. of avian wing-fracture assessment and management situates these individual reports within the broader clinical decision framework for the antebrachium [23], reinforcing that plate fixation is one of several options whose selection depends on species, fracture configuration, and functional demand. Taken together, these reports are congruent with the present findings: plate-based fixation is achievable across a range of avian species and bones, and its success may depend on matching implant size and mechanical capacity to the loading environment of the specific bone, as suggested by the single failed case.

In the bald eagle (Case 5), minimally invasive plate osteosynthesis of the femur proved technically very demanding, and the reduction achieved was less than optimal; this suboptimal reduction is likely to have contributed to the plate failure. In contrast, the tibiotarsal procedures were technically straightforward, whereas the femoral repair in the eagle was considerably more difficult, reflecting the deeper soft-tissue envelope and more challenging surgical access to the avian femur.

One case in this series was complicated by plate failure following femoral fracture repair. This finding is clinically important because it highlights that biological fixation principles alone do not eliminate the risk of mechanical failure if construct design, implant size, loading environment, or postoperative demands exceed the capacity of the fixation system. The veterinary MIPO literature similarly emphasizes that success depends on an appropriate balance between biology and mechanics, rather than on limited surgical exposure alone [6,8–10]. In birds, this balance may be even more critical because body size, activity level, cortical thickness, and available implant dimensions vary markedly among species. Thus, although the overall results of the present series were favorable, the implant failure observed here supports cautious case selection and careful implant planning when plate fixation is used in avian patients.

This study has several limitations, including its retrospective design, small sample size, and heterogeneous case population. In addition, the absence of standardized functional outcome assessment restricts interpretation to radiographic healing and documented complications. Nonetheless, the qualitative follow-up available for these cases is encouraging:

the privately owned birds were reported to regain normal use of the affected limb, and both the hyacinth macaw maintained at the São Paulo Zoo and the bald eagle transferred to a sanctuary were reported to be flying within their enclosures. Because return to flight and normal limb function are often more clinically relevant than radiographic union alone in birds, these observations are important, although they were subjective and were not obtained through standardized functional testing and should therefore be interpreted with caution. Nevertheless, the series contributes useful preliminary clinical information to an area in which published avian data remain limited and still consist largely of retrospective series, case reports, and reports centered on external fixation methods [3–5,15–20]. Overall, the findings support the potential value of biologically oriented plate fixation for selected avian long-bone fractures and indicate that further studies with larger case numbers, standardized follow-up, and more detailed reporting of implant selection and surgical technique are warranted [1–5,15–20].

5. Conclusions

In this case series, minimally invasive plate osteosynthesis (MIPO) produced radiographic union in all six avian long-bone fractures, with healing times of 60–92 days. These findings suggest that MIPO is a feasible and possibly useful technique for selected avian long-bone fractures, particularly of the tibiotarsus. However, because the study lacked a control group and comparative outcome measures, it cannot be concluded that MIPO is superior to, or the best of, the available fixation options. Prospective comparative studies with standardized functional follow-up are needed before broader recommendations can be made.

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Institutional Review Board Statement: This study was a retrospective review of clinical records from privately owned animals treated at the University of Tennessee College of Veterinary Medicine and Knox Veterinary Surgery for clinically indicated fractures. No experimental procedures were performed, and no animals were treated outside of clinical necessity. Under institutional policy, retrospective use of de-identified clinical records does not require Institutional Animal Care and Use Committee review. The bald eagle was treated under applicable wildlife rehabilitation permits.

Informed Consent Statement: Written informed consent was obtained from the owners of the animals involved in this study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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