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Plate Fixation of a Coracoid Fracture in a Bald Eagle (*Haliaeetus leucocephalus*)

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Abstract: An adult female bald eagle (*Haliaeetus leucocephalus*) was presented with a history of being unable to fly. Physical examination revealed crepitus in the left shoulder, and radiographs revealed a middiaphyseal coracoid fracture with overriding fragments. The fracture was surgically stabilized with 2 bone plates. The eagle was rehabilitated and successfully released 5 months after presentation. This case demonstrates the use of bone plating of the coracoid bone in a raptor, resulting in early return to full function and release.

Key words: coracoid, fracture, surgery, bone plate, avian, bald eagle, *Haliaeetus leucocephalus*

Case Report

An adult, 4.2-kg, surgically sexed, female bald eagle (*Haliaeetus leucocephalus*) was presented to the Wildlife Hospital of Louisiana (Louisiana State University, Baton Rouge, LA, USA) after being found tangled in chicken wire and unable to fly. On presentation, the bird was bright, alert, and responsive. Physical examination revealed a 3-cm crust in the right axillary region, and crepitus was present in the left shoulder. The bird was in fair body condition (body score, 2/5) and appeared hydrated. Based on the bird's presentation, the injury sustained by the eagle appeared to be a recent event. The bird had a voracious appetite and ate approximately 350 g of frozen-thawed rats or quail per day.

A blood sample was collected from the right jugular vein and submitted for a complete blood count (CBC) and plasma biochemical analysis. Results of the CBC revealed a stress leukogram (17.2×10^3 cells/μl; reference range, $12–21 \times 10^3$ cells/μl)[1] and was characterized by a heterophilia (90%, 15.5×10^3 cells/μl; reference range, 52%–80%),[1] lymphopenia (4%, 0.7×10^3 cells/μl; reference range, 18%–34%),[1] and a monocytosis (4%, 0.7×10^3 cells/μl; reference range, 0%–3%).[1] Results of the plasma biochemical analysis revealed high concentrations of creatine kinase (CK) (495 IU/L; reference range, 234–485 IU/L)[1] and aspartate aminotransferase (AST) (894 IU/L; reference range, 153–370 IU/L).[2] The high CK and AST concentrations were attributed to the injury and muscle damage in the left shoulder. However, because the AST concentration was relatively higher than the CK concentration, hepatic disease or injury could not be ruled out. A fasting bile acid test was performed and found to be unremarkable (40 μmol/L; reference range, <100 μmol/L) (Clinical Pathology Laboratory, Louisiana State University, Baton Rouge, LA, USA).

Based on the results of the physical examination and blood tests, the bird was considered a good candidate for anesthesia and survey radiographs. The eagle was induced with 5% isoflurane administered by facemask. Once anesthetized, the eagle was intubated with a 23-cm, 5-mm internal diameter, noncuffed endotracheal tube and maintained on 1.5% isoflurane. Positive-pressure ventilation was provided every 10 seconds, and the heart rate was monitored with an ultrasonic Doppler flow detector. Whole-body lateral and ventrodorsal radiographs revealed an oblique fracture of the middiaphysis of the left coracoid bone resulting in overriding and mild ventral and lateral displacement of the distal fracture fragment (Fig 1). Bone margins were sharp, indicating an acute fracture. Additionally, a minimally displaced triangular bone fragment and mild soft-tissue swelling were present at the fracture site. Recovery from anesthesia was uneventful.

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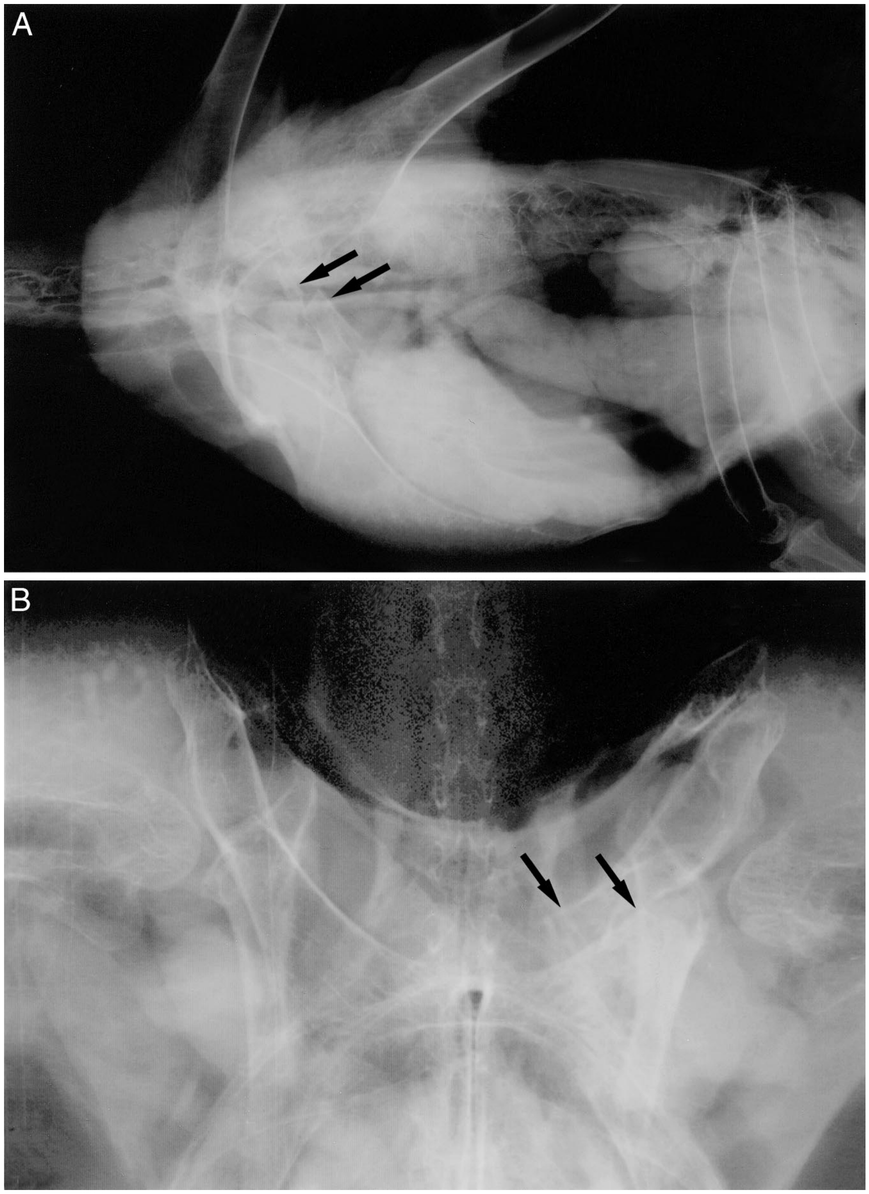

Figure 1. Radiograph revealing an oblique fracture of the middiaphysis of the left coracoid bone in an adult bald eagle. The bone end fragments are overriding, and the distal fragment is displaced laterally and ventrally (arrows). (A) Lateral view. (B) Ventrodorsal view.

Based on the radiographic findings, surgical correction of the fractured coracoid with cortical plates was considered the best option for return to full flight ability. Antibiotic therapy with enrofloxacin (15 mg/kg PO q24h; Baytril, Bayer Corporation, Shawnee Mission, KS, USA) was begun 24 hours before surgery and continued for 8 days. The eagle was premedicated with butorphanol tartrate (2 mg/kg IM; Torbugesic, Fort Dodge Animal Health, Ft Dodge, IA, USA), and anesthesia was induced with isoflurane as described above. During the surgical procedure, the bird was maintained on 2.5% isoflurane and ventilated by positive pressure every 10 seconds. The heart rate (Doppler) and body temperature were monitored, and heat was maintained by a recirculating water heating pad.

The eagle was placed in dorsal recumbency with the left wing was extended. The feathers were removed from the pectoral region and ventral aspect of the proximal wing. The surgical site was prepared routinely for sterile surgery and the remainder of the wing was wrapped in cellophane before applying sterile drapes. The surgical approach to the coracoid has been described.[3,4] The skin was incised over the clavicle and along the lateral edge of the keel. A combination of sharp and blunt dissection through the pectoral muscles exposed the coracoid bone. Hemorrhage was controlled with bipolar electrocautery. The fracture was difficult to reduce anatomically because of small comminuted fragments of bone at the ends of the bone fragments. A 6-hole, 2.0-mm Straight Mini Plate (Synthes, Paoli, PA, USA) was applied, but the third hole from the proximal end was left open because cortical bone was insufficient for screw placement. A 6-hole, 1.5/2.0-mm Veterinary Cut-to-Length Plate (Synthes) with 2.0-mm screws was placed next to the first plate. The third hole of the second plate also had to be left open over the fracture site. All screws were tightened. The plates spanned most of the length of the bone. The pectoral muscles and skin were closed routinely with an absorbable monofilament suture (4-0 PDS, Ethicon Inc, Sommerville, NJ, USA) in a simple continuous pattern. The duration of the surgical procedure was 2 hours and 15 minutes.

Postoperative lateral and ventrodorsal whole-body radiographs revealed the fracture was reduced by using the two 6-hole bone plates and associated screws placed side by side on the ventral aspect of the left coracoid bone (Fig 2). Moderate soft-tissue swelling was present at the fracture site. A figure-of-eight bandage was placed on the left wing, and the wing was bandaged to the body to decrease the likelihood of injury during recovery. Recovery from anesthesia was uneventful.

The figure-of-eight bandage and body wrap were used for 4 weeks after surgery to immobilize the left pectoral girdle and minimize the likelihood of injury. Every 3 days, the bandages were changed and physical therapy was applied to the left wing. Butorphanol tartrate (2 mg/kg PO q12h) was continued for 15 days after surgery. Three weeks after surgery, additional survey radiographs were taken and the implants appeared stable. The eagle was cage rested for a total of 52 days, after which it was transferred to an outdoor flight cage (100 × 20 × 14 ft) to complete its rehabilitation. Flight training lasted an additional 64 days. The eagle was released near the site it was originally located 121 days after presentation.

Discussion

Early return to full function with eventual release to the wild was the goal of fracture repair for this eagle. To our knowledge, this is the first report of successfully rehabilitating and releasing a bald eagle with a coracoid fracture that was repaired with cortical bone plates.

Coracoid fractures are not uncommon in birds, and usually occur when the bird flies directly into a solid object or is hit by a moving vehicle.[5–8] Diagnosis of a coracoid fracture on physical examination can be difficult. Birds with coracoid fractures usually cannot fly or are only capable of flying short distances with minimal lift. There may be a slight wing droop and an inability to lift the wing above the horizontal plane.[7,9] Survey radiographs are required to confirm the presence of a coracoid fracture. Birds with fractures of the scapula or clavicle may present with a similar case history and can be differentiated from those with coracoid fractures on survey radiographs.

The coracoid articulates proximally with the sternum and distally with the humerus, clavicle, and scapula.[9] The coracoid functions as a strut between the wing and the sternum. It prevents collapse of the thorax when the pectoral muscles contract during the wing downstroke. The coracoid also helps to suspend the sternum during gliding. Because the coracoid is subjected to compressive forces both at rest and during pectoral muscle contraction, diaphyseal fractures are often overriding.

The prognosis for flight in birds with severely dislocated coracoid fractures is guarded to grave. Healing without internal fixation often leads to malunion and a shortened bone. Coracoid fractures may be stabilized with intramedullary pins or cortical plates.[5,6,10] The time for birds to return to full flight after intramedullary pinning of the coracoid is 6 months.[11] Howard[10] was the first to describe bone plating of a coracoid fracture in a raptor; however, the bird died during the anesthetic recovery and the success of the surgery could not be evaluated.

Small birds with coracoid fractures may recover well with the wing bound to the body, but prolonged immobilization is associated with patagial contraction and elbow stiffness. When fractures are managed conservatively, problems with soft-tissue healing may develop, such as joint ankylosis, muscle atrophy, tendon contracture, or entrapment of tendons or ligaments within the callus.[12,13] Surgical repair of coracoid fractures is generally recommended for birds that need to regain full flight ability.[5,6] In general, internal fixation provides the best opportunity to obtain accurate anatomic reduction and alignment of fractures. Open reduction with intramedullary pinning of the coracoid provides better stability and results in better return to function than conservative management.[6] Excessive callus around nonsurgically treated coracoid fractures can impinge on the esophagus and prevent the passage of food, resulting in death.[14]

In birds that require full flight function, the recommended surgical repair for coracoid fractures is a single intramedullary pin to provide alignment

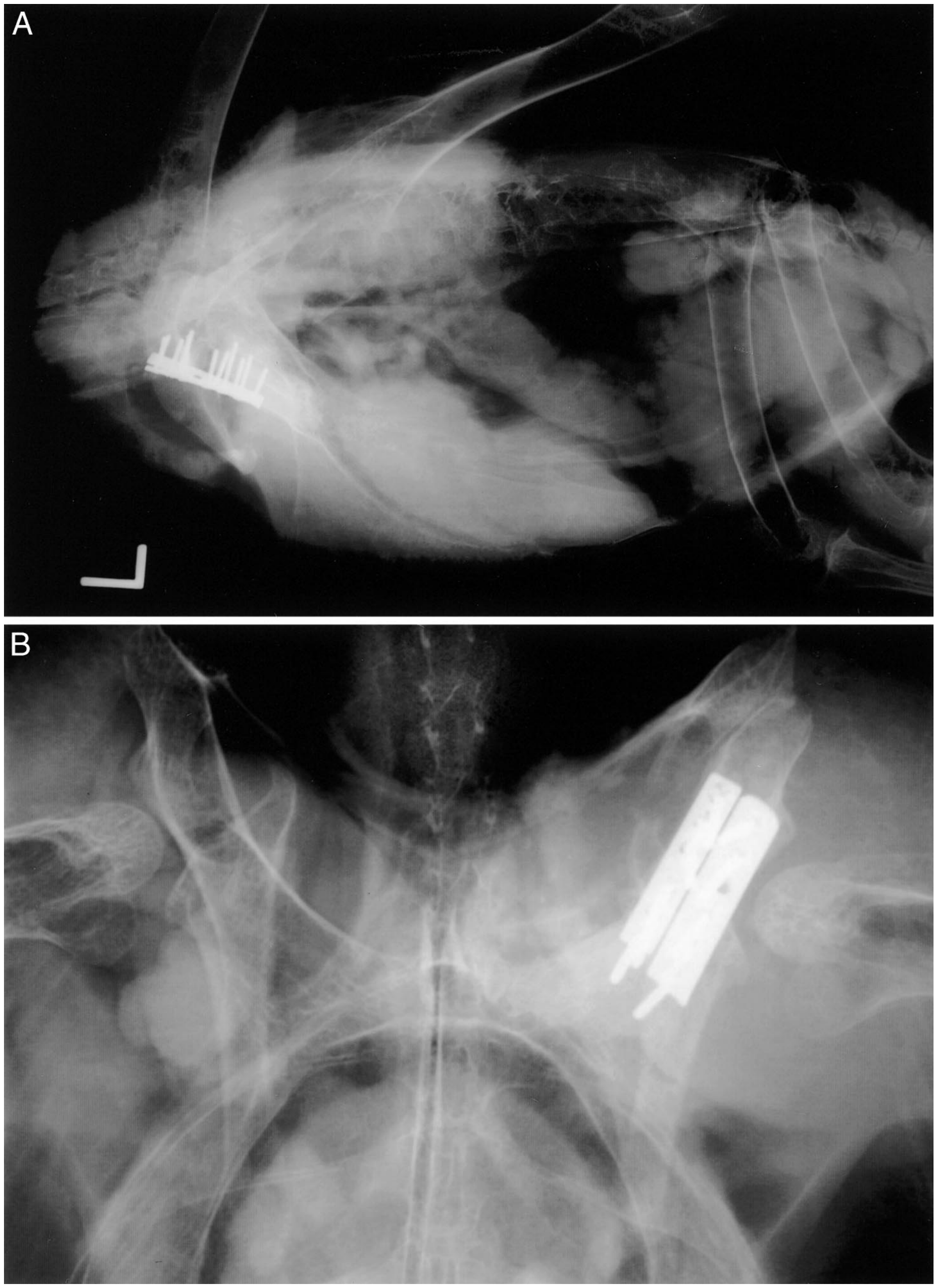

Figure 2. Postoperative whole-body radiograph of the eagle described in Figure 1. The left coracoid bone was reduced by using bone plates and screws. (A) Lateral view. (B) Ventrodorsal view.

and prevent excessive motion.[8] After surgery, the wing is supported with external coaptation to prevent rotational forces. A potential complication of pin placement is advancement of the pin into the coelomic cavity.[4] A potential disadvantage of intramedullary pin fixation is damage to the shoulder joint by the pin, which can result in periarticular fibrosis, shoulder joint ankylosis, and impaired function.[8,12] Excessive callus, which is frequently seen after internal pinning and external coaptation, can impinge on the soft tissues and affect normal function.[13,15] In addition, the postoperative coaptation necessary after pinning may promote joint stiffness, muscle atrophy, and prolonged rehabilitation.

In mammals, bone plates provide rigid stability with minimal callus formation. Potential advantages of plates are the ability to maintain anatomic alignment, lack of interference with joint movement, and early return to limb function. Plates prevent bending, rotational, shear, and compression forces. In this case, all of these forces were a concern. In particular, the desire to maintain bone length made plating a superior option over intramedullary pinning. Contraction of the pectoral muscles causes the coracoid fragments to override and would result in a shortened bone. Because bone plates are internal, they are well tolerated by birds. The size and weight of the plates were not thought to be an issue for a bird this size, particularly in such a proximal location.

Avian bones are often described as being brittle with thin cortices.[3,9,12,14] Avian long bones tend to shatter on impact, resulting in comminuted fractures.[9] The thin cortices of avian bone are thought to have limited holding power for pins and other hardware.[9,13] Holding strength of screws in avian bone has not been reported. However, in 1 study, several plates failed by bending rather than by screw pull out, suggesting adequate screw holding strength.[10]

There are no reports in birds to suggest the preferred plate size based on the bone and the size of the animal, as there are in dogs.[16] In this case, the 2.0-mm plate seemed to be the most appropriate size. Although a 2.7-mm plate may have fit the bone, the smaller threads of the 2.0-mm screws were more appropriate for the thin cortices. In addition, a 2.0-mm plate is lighter weight and easier to contour than a 2.7-mm plate. As the plate was applied, small comminutions with loss of cortical bone made it impossible to place a screw in the third hole. Leaving a plate with an unfilled hole over the fracture creates a weak area in the bone plate system and is undesirable. Cuttable plates can be stacked to provide increased stiffness.[16] However, in this case a second plate was placed adjacent to the first to get more purchase of cortical bone with the additional screws.

In the absence of rigid stability, both mammalian and avian fractures heal by secondary bone healing with callus formation. Fractures with greater stability have less callus formation.[15] Primary bone healing is characterized by direct growth of Haversian systems across the fracture line with minimal callus production. Although primary bone healing has not been documented in birds, avian fractures repaired with bone plates form minimal callus, suggesting that primary bone healing occurs when the bones are rigidly stabilized.[13]

As in mammalian bone, disrupting the soft tissues can compromise the blood supply and result in delayed healing of avian bone. The approach for plate application requires elevating the muscle along the entire aspect of the bone where the plate is to be placed. The coracoid is located within heavy muscle, so the potential for the bone to revascularize is probably higher than it would be for a more distal bone with less soft-tissue coverage. The motion associated with unstable fracture fragments can also compromise blood supply.[7] In this case, the benefit of rigid plate fixation was thought to enhance bone healing sufficiently to justify disrupting the soft tissues.

Stable fractures appear to heal more rapidly in birds than in mammals.[12,15] Pin stabilization in birds results in faster union compared with external coaptation (sling, splint, or bandage).[15] In uncomplicated cases, bone healing in small birds is usually completed by 3–6 weeks.[9,12,15] Time to bony union may be affected by factors such as fracture stability, blood supply, and the presence of infection.[16] In birds, radiographs are recommended at 3 weeks after surgery and then every 2 weeks until the bone is healed.[7,8] In this eagle, radiographs were taken 3 weeks after surgery and again an additional 2 weeks later. In both radiographs, the implants were stable and the fracture was healing.

After fracture stabilization, limiting activity while the bone is healing is important.[7] However, physical rehabilitation should begin within several days after surgery.[7] The benefits of controlled activity include improved vascular supply to the damaged tissues and enhanced bone healing.[8] The goals of rehabilitation are to maintain or improve cardiovascular condition, joint range of motion, and muscle strength.[3] Because of the aggressive nature of this eagle and our concern that it might injure itself, a figure-of-eight bandage and body wrap were placed during its recuperation. Long-term placement of these bandages can lead to patagial tendon contracture, muscle disuse atrophy, and joint stiffness. To counter these negative effects, the bandages were changed every 3 days and physical therapy was applied to the left wing. When the bird was transferred to the flight cages, the left wing appeared normal.

In small mammals, plates are generally not removed unless they cause a problem.[16] Plates with little soft-tissue coverage can conduct cold and lead to deep bone pain. For this reason, removing the plate may be advisable in a bird that will be exposed to cold temperatures. However, this is not always necessary.[13] In this eagle, the plate was imbedded under the pectoral muscles so conduction of cold would be unlikely. Plate removal necessitates general anesthesia and an extensive surgical approach. After a plate is removed, a physical rehabilitation program must be instituted until the underlying bone returns to normal strength. If normal activity is resumed too quickly, the bone may refracture. In this eagle, a second major surgery and the increased time that would be required in captivity seemed to be more detrimental than the risk of the plate causing cold conduction. Louisiana does have a native population of bald eagles. Whether this particular bird remained in Louisiana, a warm year-round climate, is not known.

The potential disadvantages associated with use of plates are the specialized equipment and hardware required for the surgery, the expense associated with the hardware, and the longer anesthesia time required for the surgery. The cost of the hardware alone in this case was about $200. An intramedually pin would have cost about $10. Although placing bone pins may have been faster than applying a plate, the superior stability offered by plate fixation was thought to be justification for any increase in surgical time and expense. Because birds are able to tolerate long anesthesia times,[13] the potential difference in anesthesia time was not considered a major concern.

At the time of surgery, the bald eagle was still listed as a federally endangered species. In Louisiana, there are approximately 151 breeding pairs of bald eagles.[17] Because the population of these birds remains small, the genetic contribution of each animal remains important, and we elected to perform the procedure that would provide the best prognosis for the bird.

Bone plates were used to repair a coracoid fracture in a mature bald eagle. The advantages of bone plating are rigid stability with minimal callus formation and early healing with return to full function. Pin fixation with external coaptation may have resulted in longer healing time and more dysfunction of the soft tissues because of the increased immobility. The plates had sufficient soft-tissue coverage so that cold conduction necessitating plate removal was not a concern. Also, because the plates were light and placed proximal, weight was not a concern. Although we were unable to track this eagle after release, we believe that the surgery was a success as evidenced by the flight training during rehabilitation.

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