Wing Injuries- Approach to Diagnosis and Treatment- Kimberly A McMunn MS, MPH, DVM, CWR, CPH

Birds are highly adapted to flight, and preservation of flight capabilities is integral to the rehabilitation process. Each rehabilitator needs to work closely with a veterinarian to diagnose and treat the cause of an inability to fly. Rehabilitators are vital to the recovery of birds, providing necessary care and physical therapy during and after treatment/surgery. This talk will cover aspects of diagnosing and treatment of wing injures, from the perspective of the veterinarian. It will cover best approaches to various types of wing injures, as well as after-care and physical therapy recommendations.

Wing injuries are extremely common in wild avian patients, often secondary to trauma. Early identification of wing injuries is critical to optimize the long-term prognosis, as is getting the bird to a veterinarian for care as soon as it is stabilized. Veterinarians are responsible for animal welfare, and are the experts best suited to evaluate a patient's long-term prognosis.[5] The goal of rehabilitation is to return our patients to the wild, which requires return to normal function. If a wild bird is unable to fly, forage, migrate, attract a mate, breed, and avoid predators, euthanasia may be the kindest option.[5] Normal avian anatomy must be understood before it is possible to recognize and identify wing injuries.

As mammals, we generally have a good comparison of human to mammalian anatomy. Birds are different in that they are highly adapted for flight, and the wing is most comparable to the mammalian forelimb.

Wing skeletal anatomy- From the tip of the wing in, we have the digits, similar to the digits in mammals though there are fewer. Next are the major and minor carpometacarpals, which are separate in mammals but fused in birds, and the alula (essentially the "thumb"). In birds the large bone of the wing is the ulna (which is the small bone in terrestrial mammals) and the small bone is the radius (which is the large bones in mammals), and the upper bone between the elbow and shoulder is the humerus in both birds and mammals. The shoulder girdle in birds is made up of the scapula (shoulder blade), coracoid, furcula/clavicle, and sternum (keel).

Wing musculature- The ventral (underside) wing musculature includes all the flight muscles, with little muscle in the distal (furthest from the central body) wing. The dorsal (topside) wing has a lack of muscle on the leading edge of the patagium (wing membrane), and in the distal wing. The pectoral (chest) muscles provide the downstroke of the wing, they are the superficial (outermost layer) muscles that go from the sternum (keel) to the humerus. The supracoracoideus muscle actually lies underneath the pectorals, but provide the upstroke of the wing by reaching around and over the triosseal canal of the shoulder and attaching to the upper side of the humerus.

Wing vasculature- There is only one major blood vessel to the wing (brachial), with a few branches. The distal wing has very little vasculature. This is important to note, as the blood supply plays a large role in wound healing.

Bird bones vs mammal bones

In birds the bone cortices (walls) are thin and brittle but very strong, with high calcium content.[2,4] Any defect in the wall greatly reduces their strength. The thinness means less holding power for fixation hardware.[2] The limited amount of soft tissue (muscles, etc)[2,4] over many long bones and very thin skin means bone fragments exteriorize easily causing closed fractures to become open, exposing the ends of fractured bones through the skin. The humerus in all birds and the ulna in some species (Pelicans and California condors) are pneumatic bones, which means they are hollow and provide air space for the respiratory system, making them connected to the lungs. The majority of callus tissue (the callus is what bridges the fractures) in healing in birds is derived from the periosteal surface (the outermost layer of the bone), and the blood supply to the periosteum from surrounding soft tissues is very important. The intramedullary circulation (within bone circulation) appears to be of less significance in avian bone healing than in mammals.

In wild birds primary bone healing (under conditions of rigid fixation, through direct growth of Haversian Systems across the fracture with minimal to no external callus formation) does not occur. We rely on secondary bone healing, characterized by induction, inflammation, soft callus formation, hard callus formation, and bone remodeling. [1,2] The last stage, remodeling, provides the return to function and strength of the bone.[1,2]

Radiographic positioning

If you have access to radiographic equipment, the proper training, and in some cases anesthesia, radiographs during initial exam can help determine prognosis and help guide treatment. A quick survey radiograph can be useful to get a "big picture" of the bird and make sure there is nothing major before the more complete physical exam. In this case, the bird is literally "plopped" onto the x-ray table with no specific positioning. Major injuries can often be noted, despite the less than ideal conditions. However, if an orthopedic problem is suspected, then anesthesia may be more appropriate and tape or other methods used to hold the animal, and protect the human appropriately. You must work closely with a veterinarian in order to stabilize the animal for anesthesia and plan treatment once radiographs are obtained.

In a normal VD view (animal on its back), the legs are stretched back to try to get a "flat" view of the femurs, and the wings fixed slightly outstretched to get a clear view of all of the bones. In the Lateral view (animal on its left or right side) the "down" leg and wing are usually placed slightly forward. Orthogonal views (getting both a VD and a lateral) is important, as a bone that seems to be well-aligned from one angle can prove to be very badly aligned when viewed from another angle. The orthogonal views can also be important in determining if something seen on a radiograph is truly internal vs on the body surface. Radiographs of the non-affected limb are often helpful for comparison[2] as bilateral symmetry can often provide a "normal" limb to look at and compare to the "affected" limb.

Evaluation of the patient

Many of the decisions made during the initial examination of a patient with a fracture have an impact on the case's eventual outcome. Good initial triage, and a holistic view of the patient will result in better outcomes.[4] The goal is to utilize the body's healing potential while minimizing secondary morbidity. Early stabilization of the fracture and preservation of soft tissues are high priorities, the clinician must first and foremost address the critical care needs of the traumatized patient.[4] Initial fracture stabilization (often a splint), usually addressed on presentation of the patient, is very dependent on the patient's overall condition.[4] Definitive fracture repair (surgical fixation, long-term splint/wrap, etc) should be delayed until the patient is stable.[4]

To determine diagnosis and prognosis, the veterinarian must evaluate signalment, history and physical and orthopedic exams. First is a hands-off observation for mentation, posture, respiration and general appearance. Once this is complete, and depending on the patient and circumstances, anesthesia or sedation may be considered prior to the hands-on exam. Consider co-morbidities, including eye, head or intracoelomic trauma in wild birds, or malnutrition and associated poor bone condition in companion birds. During the comprehensive exam, any wounds associated with open fractures should be cleaned, necrotic soft tissue and bones should be debrided.[1]

Differential diagnosis for wing droop/fractures

When a bird is presented for a wing droop or suspected fracture, the actual wing injury may not be the only problem, or in fact a problem at all. The list of possible causes of a wing droop include: Infections (bacterial, fungal- aspergillosis), metabolic (gout), nutritional (Calcium deficiency, Ca/P imbalance, Vit D deficiency, excess protein), toxicosis (lead, zinc), physical (TRAUMA, brachial plexus avulsion), neoplasia, and others.[8] In rehabilitation, the most likely of the causes is trauma, however other possibilities should be considered and ruled out prior to diagnosis and determination of prognosis. Lead toxicity could also be more prevalent in certain species, or in certain parts of the country.

Diagnostic plan- First stabilize! Provide supportive care. Evaluate dietary factors in long-term captives. Swollen joints may be aspirated for cytology.[8] Radiology can evaluate for fractures and signs of osteoarthritis. With recent fractures the bone segments will be distinct, sharp and well defined.[8] Older fractures will show fuzzier bone edges and filling in of the bone at the bone ends.[8] If a fracture is suspected but cannot be seen radiographically, repeat radiographs in 10-14 days[8], when endosteal response can be seen. Osteolytic lesions can be osteomyelitis or neoplasia.[8] A focal increase in medullary opacity may indicate granuloma formation.[8]

Clinical Signs of Fractures

Presenting signs of wing fractures include wing droop, local swelling, apparent loss of limb function, localized pain, altered limb positioning, inability to elevate wing above the horizontal plane (key clinical finding in coracoid fractures), and inability to fly.[4] In an open fractures, bone ends may be visible protruding from the skin.

Factors contributing to fractures

Outside factors that may contribute to fractures should be taken into account, especially in determining long-term prognosis. Poor bone integrity, especially in captive birds, due to malnutrition (inadequate calcium), lack of exercise (loss of bone mass), or lack of Vitamin D must be corrected in order to assure long-term quality of life and to prevent further fractures. In female birds, reproduction may lead to calcium deficit, especially in cases of malnutrition. There may also be some kind of underlying bone disease such as neoplasia or osteomyelitis that could predispose to fracture.

When considering fracture management, keep in mind the basic orthopedic principles: Establish early and complete rigidity, maintain normal longitudinal and axial alignment as well as bone length, promote load-sharing with the bone when possible, return the limb to normal function and range of motion (ROM) as soon as possible, reduce morbidity, and promote patient mobility and comfort.[4,5,6]

Approaches to Fracture Management

The method of fixation selected should suit the patient's injury, natural behavior, activity levels and future needs. The skills and abilities of the veterinarian and rehabilitator should also be taken into consideration. If an animal is valuable (like an endangered species) you may consider referralConfinement/cage rest, external coaptation, and surgical fixation are the main approaches, and may be used independently, simultaneously, or successively depending on the situation. Regardless of method, fractures require active management in order to ensure the optimal outcome. The rate of fracture healing depends on the amount of displacement, integrity of blood supply, presence of infection, and degree of motion at the fracture.[1,8]

Prognosis and choosing best approach will depend on the:

- Goal of Repair- wild birds require flight, while captive birds may not. Breeding birds require function for courtship and breeding[8]
- Site of the fracture- fractures near joints often result in decrease of joint function (ROM) [8]
- Size of the bird- coaptation splints are often more successful with small birds[8]
- Acute vs Chronic injury- acute fractures have a better prognosis than chronic injuries[8]
- Simple vs comminuted- simple fractures are more straightforward to fix[8]
- Open vs Closed, and presence/absence of infection- open fractures and those with bacterial contamination have much poorer prognosis, and necrosis of bone can occur. Avoid placement of implants in infected sites; use external fixators for contaminated fractures[8]
- Comorbidities such as aspergillosis or bumblefoot mean a poorer prognosis[8]
- Age of the bird- young birds heal quickly, but outgrow coaptation splints rapidly[8]
- Extensive soft tissue trauma has a poorer prognosis, as does extensive fly strike

Other factors to prognosis

- Companion and aviary birds rarely require full mobility, and generally have excellent prognosis[3]
- Wild birds must have near perfect wing function to survive in the wild. Any slight rotation in the distal wing can alter flight. If synostosis (bridging between the radius and ulna) occurs, the bird may not be able to fly[3]
- There have been suggestions that pneumatic bones heal slower than medullary bones[3]
- Clinical stability may precede radiographic evidence that the bone is healed[3]
- Open fractures- exposed bone readily separates form blood supply and has a high risk of bone infection, therefore a poorer prognosis.[8] If there is ANY skin wound present than assume it is an open fracture
- High-energy forces are more likely to shatter a bone, resulting in comminuted fracture, often with significant soft tissue damage. Fractured bone cannot contribute to load-sharing, therefore these types of injures have a poorer prognosis
- Low-energy forces (collision with a stationary object) often result in simple transverse or oblique fracture, which are often easier to repair, with better prognosis
- Proximity to a joint- if flight is required, factures involving elbow or carpus have poor prognosis[8,9]
- Comorbidities should be evaluated- on x-rays check air sacs, lungs, etc.[1] If trauma is suspected, carefully check the eyes, ears and oral cavity

Amputation as an option

In the United States, in Federally protected species you legally cannot amputate above the elbow, though in companion birds amputation may be an option. The ability of the bird to adapt to amputation depends on their size, demeanor and required return to function. Amputation through bone is preferred to disarticulation, as the bone end will atrophy and maintain adequate soft tissue coverage. Parrots have been shown to adapt to wing amputation at the proximal 1/3 of the humerus.

Approaches to fracture management based on bone involved:

The best approach to fracture management will be determined by the veterinarian based on the bone involved, and the location and type of fracture. For best chance of return to flight, fractures must be repaired such that the bone retains normal length, rotation and angular orientation.[1] Compression, rotation, bending and shear forces must be neutralized to promote fracture healing.[1] Examples of approaches used based on the bone include[4]:

- Coracoid – Splinting/wrapping and cage rest
- Humerus - External skeletal fixator-intermedullary pin (ESF-IM) tie-in, intermedullary (IM) Pin, Type I external skeletal fixator (Type I ESF)
- Ulna – ESF-IM tie-in, IM Pin, Type I ESF
- Radius- IM pin
- Metacarpus- Type I ESF, curved-edge splint
- Femur- ESF-IM tie-in, IM Pin
- Tibiotarsus- ESF-IM tie-in, Type II ESF
- Metatarsus- Splint, Type III ESF

Cage rest is suitable in a very small number of situations, including very small birds and injuries not amenable to bandaging or surgery.[4] The bird should be kept in a small cage, as quiet as possible[1], with no wing flapping or walking around.

Splinting/bandaging/wrapping (external coaptation) requires less skill/experience than surgical fixation, is most common for initial or temporary stabilization, and is the preferred method for shoulder girdle fractures and metacarpal fractures. It may be considered for other types of fractures if full return to function is not required, if fractures are pathologic as a result of metabolic bone disease processes, if the bones are too soft to hold hardware, if the patient is too small for internal fixation alternatives, if fractures are minimally displaced, and/or if the surgical or anesthetic risk is judged to be too great.[1,2,3] Bandages/splints must be monitored carefully for tissue abrasions, tissue swelling, or slipping of the of the bandage, and must be padded well to prevent pressure necrosis. With bandaging there is a higher incidence of synostosis especially in the distal third of the radius/ulna, and prolonged use can decrease ROM or cause patagial contracture. The chances of achieving and maintaining functional alignment are generally poor when managed by splints/bandages alone.

A body wrap, provides temporary stabilization of wing fractures, and can be used as definitive treatment of shoulder girdle problems such as coracoid fractures or shoulder luxations.[5] They can be used with- or without a Figure-of-8 wrap. They can also be used to stabilize the radius OR ulna fracture,[4] though there is increased risk of bridging between the two bones (synostosis) and non-union compared to surgical repair.[5] Body wraps are also used with a metacarpal splint to treat distal wing fractures.[5] Whenever applying a body wrap, **be careful to allow respiratory movements** (VERY IMPORTANT!).

A figure-of-8 wrap alone can be used to stabilize the wing when a fracture is located distal to the elbow, or on reduced elbow luxations.[4,5] Longer term use (>7-10 days) increases the risk of complications including fibrosis and decreased ROM due to hyperflexion of carpus, and fibrosis and contracture of the patagium.[5] Keep these wraps lightweight with minimal bulk.[5] Physical therapy is recommended at least twice a week, with passive range of motion exercises, and may be needed more frequently if any decrease in ROM is noted.[5]

A curved edge split made of moldable thermoplast or SAM splint provides support for metacarpal fractures.[4,5] It is placed on the ventral surface of the wing and curved up along the leading edge of the wing and sandwiched with tape, then a body wrap. The lateral edge bends up at 90 degrees, and the splint does not extend above the plane of the dorsal surface of the wing[4] and does not wrap around the carpus. These also must be carefully monitored for soft tissue swelling.[4,5]

Robert Jones bandages are not recommended for wing injures as they are difficult to apply, uncomfortable for the patient, and generally too heavy for the wing. They are sometimes used on legs in birds.[5]

Tape splints are commonly used in very small birds (<300g) for leg fractures,[4] but have less use for wings except in extremely tiny birds for which no other options are generally available.

Surgical fixation usually provides better functional alignment, increased capacity for normal use of limb during healing, prevents loss of ROM due to soft tissue or tendon contracture, as well as improved fracture healing. Fixation devices should be rigid, lightweight, versatile and removable.[4] Fixators should stabilize the forces that apply tension, torsion, shearing and bending movements to bone, and provide load-sharing with the fracture where possible and load-bearing when not.

Types of Surgical Fixation include IM pin, ESF, hybrid fixator ESF-IM, plates and nails, cerclage wires, and shuttle pins.

IM pins provide excellent opposition to bending forces of a long bone[4,5,9] and good alignment[8,9], and are applied relatively easily.[5] They do NOT provide resistance to torsional, compressive and tensile forces,[1,3,4,9] therefore are typically used with bandages/splints or with ESF[5,9]. You must secure the pin so it does not fall out, or patient does not pull it out. The most common use of single pin is in a simple radial fracture.[4,5] Single pins should fill ½ to 2/3 of the medullary cavity.[1,8,9]

ESF resist rotational movement, compressive and tensile forces[3], and moderate bending.[4,5] It can be difficult to get good end-to-end alignment of the bone fragments.[9] It is critical to ensure that each ESF pin engages both bone cortices.[4] ESF may be used alone when an IM pin cannot be used to do joint impingement,[1,4] or in highly comminuted fractures with significant soft tissue compromise.[1] If used alone, ESF require 2 ESF pins in each fracture segment, one close to the end of the bone and the other as close to the fracture as possible. They are often used for metacarpal or ulnar fractures.

Hybrid fixators (ESF-IM tie in) are highly versatile. They can be inexpensive, easily learned, lightweight, adaptable, and are often very effective.[4,5] They can provide incredible strength and integrity, resisting all forces on bone[4], allowing for good bone alignment.[8] They consist of an IM pin, 2 ESF pins, and an external connector to join them.[9] Additional ESF pins can be used if load-bearing needs to be handled by the fixator. Sequential dismantling of the fixator allows transfer of load bearing to the bone, promoting bone healing. Make sure to verify pin placement with intra-op radiographs[5], and check rotational alignment of the fracture with comparison to the other wing. Check that the bone length is correct, especially in comminuted fractures. External connectors can be the FESSA system, metal bars, acrylic bars, rubber tubing (Penrose drain, IV tubing PVC tubing, straw) filled with methylmethacrylate (ie hoof repair material) or car body filler, thermoplastic (sheets or pellets, formed around the bent pins), or methylmethacrylate putty used as the thermoplastic.

Plates and nails/screws are mostly used for leg fractures in larger birds. Limitations include lack of suitably sized plates and nails/screws to accommodate the wide range of bone sizes, lack of strength in small plates to accommodate applied forces, morbidity associated with placement including ischemic necrosis of the skin pulled over the plate at closure, and expense. The stress junction at the end of the plate is susceptible to fracture. Due to the added weight of a plate on a bone, they are generally not able to be used in wings.

Cerclage, hemicerclage and interfragmentary wires can be used with IM pins and/or bandaging to neutralize rotational and shear forces.[3] These techniques are most useful for adding stability to long oblique and spiral fracture and for holding fragments of bone in apposition during the application of other fixation devices[2] such as IM pins. They can be used in conjunction with IM pins for long oblique and spiral fractures.[1,3] Risks include loss of bone viability and sequestrum formation.[4]

Shuttle pins are biological inert plastic and acrylic rods, lighter than IM pins, that provide stable fracture repair and do not require removal. They provide little rotational stability when used alone.[9] They allow rapid post-fixation exercise (7-10d) and most birds are able to fly in 14-21 days post-surgery. Shuttle techniques are technically difficult, the length of the pin is limited to the longest fracture segment, and the pin may not be passed into the shorter fragment segment to a sufficient depth to provide adequate stability. Foreign material remains in the medullary canal, which may alter the biomechanical response of a portion of the wing to stresses induced by flight.

Surgical approaches: In general it is best to identify and follow the natural separations between muscles and along facial planes. Ideally, avoid muscles completely to reduce the surgically induced soft tissue damage. Incision or bruising of the propatagium (the leading edge of the wing membrane) should always be avoided.

Post-surgery the bird should likely have a body wrap for several days until they can support the wing themselves. Usually the wrap can be removed within a week and the patient is allowed to return to normal ROM on its own. Dress wounds, pad any ESF, and give antibiotics as indicated[1] by the veterinarian. Antibiotics should be used for any open fractures, and anytime there is a protruding pin or ESF. Nutritional support, including calcium, vit A and D, is also important, and pain management is critical (USE APPROPRIATE ANALGESICS). Keep in mind that it is common for pin tracts to drain for a day or two post-surgery, but they should be clean and dry by day 5-7.[9] Consider prophylactic antifungals for birds of any highly susceptible species.

Physical therapy (PT) should be used as needed to promote mobility and joint ROM, improve circulation to the injured limb, maintain soft tissue integrity, and reduce the recovery time required after surgery or trauma.[4] Generally start PT post-operative day 3, examine and perform passive ROM, stretching and massage. Do this 2-3 times per week in the first 2-3 weeks, then taper.[9] For very painful injuries or in dangerous birds, this should be done under anesthesia. A goniometer can be used to actually measure the ROM. Elbow extension is usually 140 degrees plus, while the wrist is generally 180 degrees plus.

Healing can be monitored by recheck radiographs at 10-14d and 20-24d postop[5], and every other week thereafter until healed.[4] Staged deconstruction of a fixator can begin when early signs of callus formation are seen radiographically.[4] Any pins showing signs of loosening should be removed first.[4] Remove hardware when the fracture is stable and there is good evidence of bone healing. Most can be removed in 4-6 weeks, in young birds it can be more rapid (10-14 days if < 4 weeks old).

Common complications of surgical fixation include loose pins, which can be a concern if exudate is seen, or a radiolucent halo at the intersection of a fixation pin and bone.[4] Radioulnar synostosis can occur, and it can be removed. Afterwards, a fat pad (from coelomic subcutaneous fat) is placed in the space to deter recurrence.[4] Sequestration of bone fragments can also occur, especially in comminuted fractures. Evidence can be seen after approximately 3 weeks with a radiolucent area around a bone fragment or segment of bone; surgical removal is recommended.[4] Osteomyelitis can occur and is often seen with exudate around pins, signs of inflammation, draining tract- C&S, clindamycin, may require removal of IM pin, AIPMMA bead implantation. On radiographs, periosteal reaction, sclerosis, increased radiodensity in medullary canal can be seen.[3] Despite surgical intervention, non-unions can occur secondary to osteomyelitis, from inadequate fixation/instability at the fracture site, or due to a compromised blood supply. The treatment is to remove scar tissue, freshen bone ends, and attempt repair again. Poor ROM is best prevented by repairing fractures as soon as the patient is stable enough for the anesthesia/procedure, attempting to get rigid fixation, and performing PT early and often. Retrograde placement of pins through the distal humerus, nomograde placement from lateral or medial epicondyle of the humerus, placement through the distal ulna, or retrograde placement from the elbow can cause severe periarticular fibrosis and wing dysfunction, and should be avoided if possible.

After implants are removed, flighted birds should start exercising; wild birds can be creanced or exercised in flight cage. Start at 2-3 cage lengths daily, gradually work up to 14-15 cage lengths once or twice a day over a 2 week period.[9] When determining return to full flight, look for the ability to glide the final 30-40% of the length of the cage, there should be no labored/open-mouthed breathing, no asymmetry from front, side or behind, and it should take only a few wing beats to get into a smooth flight pattern.[9] Level flight should be maintained in hawks there should be no excessive feather noise, and owls should be silent after the first few wing beats.[9]

Summary:

Best outcomes will be achieved when close attention is paid to soft tissue preservation, when there is early and rigid stabilization of the fracture, and when the fixation maximizes opportunity for the patient to maintain range of motion and use of the limb.[5] Cage rest, bandaging/splints and surgical fixation may be used, depending on the characteristics of the individual situation and the desired outcome. Work closely with a veterinarian to determine the best treatment and prognosis, and assist with pre-, during, and post-surgical care to best set your patient up for success. Learn proper physical therapy techniques, and exercise birds properly so they are conditioned for release.

Bonus information concerning specific injuries:

Common patagial injuries include perforation and tears. Healing often results in contracture, altering the conformation and restricting extension of the wing.[2] In many cases sutures do not hold well in the patagium.[2] It is possible to suture a cardboard splint over the area, replacing it every 7-10 days until the defect is healed. The support of the cardboard allows extension of the wing during healing, preventing patagial contracture.[2]

Coracoid fractures are very common after blunt force trauma. They cause the inability to fly and wing droop. Treatment is a wing-body wrap if minimally displaced, or strict cage rest in a very small enclosure to prevent much wing movement. The odds of return to flight with this type of injury are generally very high. An IM pin may be necessary if it is a markedly displaced coracoid fracture.[8] One proposed protocol for corocoid fractures is to use oral meloxcam and tramadol for 10d, body wrap with PT 2x/wk for 2 week, then move to a small cage without wrap for 2 weeks, then a flight cage 2 weeks (or strict cage rest for 3 weeks, no body wrap/PT).

Clavicle/scapula fractures are less common than coracoid fractures. The same protocol can be used, generally with good prognosis.

Birds with shoulder luxations often also have an avulsion fracture of the ventral tubercle of the proximal humerus.[3] This can be stabilized with a Figure-of-8 bandage and body wrap to immobilize the wing to the body for 10-14 days.[3] Surgery may be needed to reduce the luxation and reattach the ventral tubercle with wires or lag screws.[3] If addressed soon after the injury occurs, shoulder luxations do not necessarily mean poor prognosis for return to complete function.[3]

Humeral fractures are very common[9], and very commonly displaced due to contraction of the pectoralis and biceps brachii muscles.[2] The prognosis is poor if torsion occurred at fracture site, causing massive soft tissue swelling distal to the elbow.[9] ESF-IM tie is needed if return to normal function is required.[8] The IM pin is normally placed retrograde into the proximal bone fragment. Usually a dorsal approach is used, avoiding the radial nerve. Proximal humeral fracture often have minimal displacement, and can heal well with a Figure-of-8 wrap combined with a body wrap. Displaced fractures, or minimally displaced fracture but wanting to maximize chance of flight, require internal fixation. A tension band technique has been described.[7] Mid-diaphyseal humeral fractures tend to be oblique, and are best managed with an ESF-IM tie-in. The radial nerve crosses the dorsal aspect of the humerus at ~1/2 the length, and must be identified and preserved. Distal humeral fractures can be problematic if within 2-3 bone diameter of the distal humeral condyles, as there is insufficient space for an IM pin to gain purchase in the distal fragment. A cross-pinning technique has been described.[7]

Elbow luxations present with wing droop, a very swollen joint, and poor ROM. Acute luxations can be non-surgically reduced, the joint immbolized with a Figure-of-8 bandage for 7-10 days[8] to 2 weeks. In these cases it is safest to skip PT (which can cause re-luxation), then cage rest another 2 weeks without wrap. To reduce, flex and extend the elbow while applying pressure to the dorsal aspect of the radius to force it back into articulation with the humerus. If repositioned properly, the joint should regain full ROM. Prognosis for return to function fair to good if treatment is prompt (within days of initial injury). If there is severe ligament disruption, imbrication or trans-articular fixation have been described (Redig 2000), though the prognosis for return to function is poor. In one report 5/9 raptor with elbow luxations were successfully returned to the wild following closed reduction and support with external fixators or bandages for 7-10 days.

Single fractures of the radius or ulna may be treated with bandaging/splinting small companion birds when displacement is minimal.[2] Potential complications include patagial contraction due to prolonged immobilization and formation of synostosis between displaced fragments and the other bone.[2] If return to normal function is required an IM pin, ESF, or combination should be used. The prognosis for diaphyseal fractures are good. A very proximal radius/ulna fracture may be managed only by transarticular ESF with very poor prognosis for return to flight.

Fractures of both the radius and ulna require IM pins or ESF (or combination) to optimize chances of return to flight, and given the greater rigidity obtained and shorter healing time, fixation of both the radius and ulna is recommended. Shuttle pins may also be used in place of IM pins. Avoid the radial nerve and artery, in the intraosseous space between the radius and ulna.

For fixation of radial fractures use a dorsal or ventral surgical approach. IM pins in radius are normally placed retrograde in the distal bone fragment or normograde from the carpus. This penetrates the carpal joint and may not allow full ROM; remove pin early.

For ulnar fractures, if bone ends overlap by at least 50%, a Figure-of-8 wrap (and PT) may be effective. Waiting a few days can improve the situation, as bone fragments can be pulled back into place. For surgical fixation, use a dorsal surgical approach to the ulna. IM Pins are normally placed normograde from the proximal end. Retrograde placement is contraindicated as it risks exiting the pin at the olecranon and damaging the joint.[2]

Carpal and carpometacarpal fractures can be tricky. If the single artery and vein located between the 3rd and 4th metacarpal bones are damaged, avascular necrosis to the distal portion of the wing can occur.[3] There is little soft tissue to protect and provide blood supply, and the high incidence of open comminuted fractures means a lower rate of successful fixation than other avian fractures and a longer time to heal.[2] A dorsal surgical approach is most direct. If closed and minimally displaced, a Figure-of-8 bandage[7] or curved edge splint may be useful. If not, IM pins and/or ESF can be done, with retrograde pin placement in the proximal fragment. Proper rotational alignment of the distal wing is critical, as only a few degrees of axial malalignment may prevent normal flight.[1]

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