

**N**umerous approaches have been used to repair fractures and luxations in avian species. Typically, these techniques have been adapted from those used for small mammals and humans. Regardless of the specific techniques employed in fracture repair, it is important to:

- Treat contaminated and infected wounds.
- Preserve soft tissue structures.
- Appose, align and control rotation of fractures and reduce luxations.
- Rigidly immobilize the fracture site.
- Maintain range of motion in all joints affected by the fracture or fixation technique.
- Return the affected limb to “normal function” as soon as possible.

The presence of a fracture certainly suggests major trauma, and a thorough physical examination should be performed to determine other injuries.

Subcutaneous emphysema may be noted in birds with ruptured air sacs or with fractures of the humerus, thoracic girdle or some ribs (the pneumatic bones). The emphysema will generally resolve within a few days. In many cases, birds may require several days of stabilization with fluids, steroids, antibiotics or supportive alimentation before anesthesia and surgery can be safely performed (see Chapter 40).

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CHAPTER

**42**

**ORTHOPEDIC  
SURGICAL  
TECHNIQUES**

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**Howard Martin  
Branson W. Ritchie**

It is common for subtle injuries to occur that are difficult to detect by physical examination. Survey radiographs of affected skeletal areas as well as the abdomen and thorax are needed to assess any bony or soft tissue changes that may have occurred during a traumatic episode. Recommendations for other evaluation procedures are similar to those described in soft tissue surgery (see Chapter 41).

Fracture stabilization techniques used in free-ranging birds must be designed to increase the likelihood that a rehabilitated bird can be released. Repair of a wing fracture, particularly near a joint, must be nearly perfect with no ankylosis and minimal soft tissue damage to ensure return to full flight. For these avian patients, maintenance and protection of soft tissues is the single most important aspect of successful surgery. The degree and type of soft tissue damage may be more critical in determining the potential for postsurgical return to function than specific osseous injuries. Native avifauna with injuries that will prevent their release must be repaired to a functional level that allows them to adapt to a zoo, breeding program or educational facility. Injured native birds that cannot be repaired to sufficiently achieve one of these goals may require euthanasia.

Birds that are maintained in aviary situations or in breeding facilities must have adequate postoperative use of a fractured limb to allow them to function effectively in their respective environments. Most companion birds can tolerate a substantial loss of function of the wings and still function normally. Leg injuries that alter weight-bearing in one or both feet can predispose a bird to bumblefoot or arthritis. Some birds will tolerate postoperative surgical hardware while others will not.

## Therapeutic Strategies

The fracture should be classified as to anatomy, shape, whether it is open or closed and its chronicity. The type of fracture will frequently dictate the type of specific therapy and stabilization procedures that are used. Patient preparation for surgery, preparing the surgical site and draping are discussed in Chapter 40.

**TABLE 42.1** Types of Fixation

- **External coaptation** - Sling, splint, bandage
- **Internal fixation** - IM pins, cerclage wires, bone plates
- **External fixation** - pins passed through bone from skin surface and connected to stabilizing bars

**TABLE 42.2** Principles of Fracture Stabilization<sup>31,30,38,39</sup>

- Minimal soft tissue damage
- Maintenance of length, rotation, angular orientation
- Anatomic alignment
- Rigid stabilization
- Minimal disturbance of callus formation
- Neutralization of forces:
  - Rotation, bending (transverse fractures)
  - Shear, rotation, bending (oblique or spinal fractures)
  - Compression, shear, rotation, bending (comminuted fractures)

### Developing a Surgical Plan

The method of fixation selected should suit the patient's injury, natural behavior, activity levels and future needs (Tables 42.1, 42.2). A thorough understanding of the location of major nerves, arteries and veins ensures that the surgeon can properly perform any necessary stabilization procedure. Bipolar radiosurgery is necessary to control blood loss and allow thorough visualization of a relatively small surgical field (see Chapter 40).

Avian bones have a high calcium content, and a thin, brittle nature.<sup>31,35</sup> In addition, portions of the medullary canal of the humerus in many birds are connected to the air sacs (pneumatic), which reduce the weight of the bone and are believed to contribute to the respiratory cycle during flight (see Anatomy Overlays). It is best to cover the medullary canal of the proximal fragment of a humeral fracture before irrigating the surgical site. Fluids or necrotic debris that are flushed into the pneumatic bones may cause asphyxiation, air sacculitis or pneumonia.

The distal legs and wings of birds have relatively little soft tissue (ie, tendons, ligaments, skin and muscles). Bone in these areas are, therefore, particularly susceptible to impact-related injuries (see Anatomy Overlays). Aggressive tissue manipulation can cause increased damage of already compromised blood supply and soft tissues, which increases the healing time and likelihood of unsuccessful function post-repair.



**FIG 42.1** Primary and secondary remiges (arrows) are attached to the periosteum of the metacarpal bones and ulna, respectively. Periosteal stripping and damage to the primary and secondary feather follicles should be avoided during a surgical procedure (courtesy of Laurel Degernes).

Gentle manipulation and frequent irrigation of soft tissues and bones with sterile saline will help maintain the integrity of vascular and neural structures and speed return to normal function. If exposure of a fracture site requires the transection of a muscle, it is best to do so near the muscle's origin or insertion in order to minimize trauma and hemorrhage and to facilitate reattachment. Periosteal stripping and damage of soft tissue attachments to the bone should be avoided, particularly in the wings, where the primary and secondary feathers are attached to the periosteum (Figure 42.1).

#### Open Versus Closed Reduction

Thin skin, scarce soft tissues and sharp bone fragments frequently result in open fractures in birds. Even if bones are not protruding from the skin at the time of presentation, the presence of any wound associated with the fracture would indicate previous

violation of the skin barrier. If any skin wound is present, the fracture should be considered open.

Closed reduction involves the manipulation of the fracture through application of traction and counter-traction to stretch the soft tissues and appose and align the bone fragments. It is difficult to achieve adequate alignment and reduction of fractures with closed reduction techniques without causing significant soft tissue trauma, except in those fractures that are minimally displaced.

The advantages of open reduction include reduced soft tissue trauma (as traction is applied directly to the bones), visualization of the fracture site (and therefore the ability to attain optimal reduction as well as cleansing of the fracture site) and removal from the fracture site of interposed soft tissues, contaminated or infected debris and necrotic or devitalized bone.<sup>11</sup>

#### Prognosis

Companion and aviary birds rarely require full mobility following fracture repair, and the post-fracture prognosis for return to function with these birds is generally excellent. By comparison, free-ranging birds (particularly raptors), which can be viewed as finely tuned athletes, must have near perfect wing function in order to survive in the wild. A slight rotation in the wing (particularly in the distal wing) can alter flight. The ulna and radius normally slide by each other longitudinally. If trauma causes the ulna and radius to fuse (preventing this sliding motion), a bird will be unable to properly supinate or pronate the carpus and may not be able to fly.<sup>21,41</sup>

Fractures near a joint usually result in ankylosis, which prevents normal limb function. Open comminuted fractures are more likely to be infected, resulting in secondary osteomyelitis.<sup>21</sup> A 20 to 30% decrease in leg function may be acceptable in birds released to the wild as long as the dysfunction does not dramatically affect the flexion or extension of the foot or the prehension of food.

#### Postoperative Care

Postoperative radiographs should be taken at two- to four-week intervals to assess bone healing. The radiographic changes associated with bone healing can appear similar to those that occur with osteomyelitis including periosteal reaction, sclerosis and increased radiodensities in the medullary canal (Figure 42.2).

To improve vascular supply to damaged tissue and to speed the bone healing process, active and passive



**FIG 42.2** A minimally displaced mid-diaphyseal tibiotarsal fracture in a Green-winged Macaw was stabilized with a cast. Radiographs three weeks after the fracture occurred show a loss of detail at the fracture ends and a smooth, well defined periosteal response characteristic of a normal healing process. This lateral radiograph indicates slight malalignment and over-riding of the fragments (courtesy of Marjorie McMillan).

rehabilitative techniques should be instigated as soon as possible after an orthopedic surgery. The physical therapy program should be based on the bird's injury, behavior and required degree of post-surgical function. Initial physical therapy may involve only a bird's daily activities of perching and prehending food. Physical therapy should evolve to include a variety of regimented exercises designed to maintain or increase cardiovascular endurance, to maintain or increase range of motion of joints and to maintain or increase muscular flexibility tone and fitness.<sup>10</sup> The physical therapy program is dictated by the exact nature of the injury and species of injured bird.



**FIG 42.3** Radiographic findings suggest that primary bone healing occurs in birds if a fracture is properly aligned and rigidly stabilized. An adult Amazon parrot was presented with a history of having fractured the right tibiotarsus three months before presentation. This fracture was repaired with a Robert Jones bandage. Three weeks before presentation, the bird had fractured the left tibiotarsus and the limb was cast. The bird had not improved during the three-week period, and the case was referred for evaluation. The severely displaced right tibiotarsal fracture was stable and a substantial periosteal callus was evident radiographically. At presentation, the left tibiotarsus was displaced (bone ends were not touching) and there was excessive soft tissue swelling. The fracture site was approached medially, and a large amount of fibrous connective tissue was removed to allow the bone ends to be reduced. The fracture was stabilized using positive profile threaded pins connected with methylmethacrylate. The bird was placed in a light Robert Jones-type bandage and was using the leg several hours after surgery. Radiographs taken four weeks postsurgery indicated a bony union with minimal callus formation.

### ■ Bone Healing

Controlled studies evaluating the healing process of avian bone are scarce. In general, it is assumed that the rate of fracture repair is dependent on the displacement of the bone fragments, the amount of damage to the blood supply, whether an infectious agent is present and the amount of motion at the fracture site.<sup>14</sup> In mammals, primary bone healing (bone growth through the Haversian system with minimal callus formation) occurs with rigid fixation and does not occur if there is a gap or motion at the fracture site. In these cases, secondary bone healing characterized by maximum callus formation occurs (Table 42.3). In birds where fractures were repaired with bone plates (maximum stabilization), callus formation was found to be minimal, suggesting that primary bone healing had occurred (Figure 42.3).<sup>19</sup>

Callus formation appears to be similar in birds and mammals.<sup>19</sup> Endosteal callus provides rapid stabilization in bones that are properly aligned. Periosteal



**FIG 42.4** In comminuted fractures, bone fragments that maintain a blood supply heal rapidly. Devitalized, uninfected fragments should be left at the fracture site to provide additional support for callus formation (courtesy of Laurel Degernes).

callus formation is minimal if the bones are rigidly fixed. The blood supply to the bones is believed to arise from periosteal (originating from soft tissues and muscles), medullary (originating from nutrient artery), metaphyseal and epiphyseal vessels.<sup>7</sup>

Stable, properly aligned fractures appear to heal more rapidly in birds than in mammals.<sup>6,7,30,31,45</sup> It has been suggested, but not confirmed, that pneumatic bones heal slower than medullary bones.<sup>31</sup> Clinical stability of a fracture (two to three weeks) may precede radiographic evidence that the bone is healed (three to six weeks).<sup>7,31,45</sup> The healing of unstabilized humeral fractures in pigeons was characterized by increased radiolucency in the medullary canal and endosteal and periosteal calluses that were present histologically by nine weeks. Poorly aligned fractures changed little between four and twelve weeks,<sup>31</sup> while properly stabilized bones remodeled rapidly during that time period.

Minor forces that cause undetectable levels of movement can damage the growth of small capillary beds and impede fracture stabilization. Fracture stabilization is most likely to fail in comminuted fractures that have the greatest number of forces that must be neutralized.<sup>30</sup> In these fractures, bone fragments that maintain a blood supply should heal as rapidly as the intact distal and proximal fragments. Devitalized, uninfected fragments should be left in place to provide structural support for callus formation (Figure 42.4).<sup>33</sup>

**TABLE 42.3 Secondary Bone Healing**

**Induction and Inflammation**

- Fibroblasts proliferate
- Osteogenic cells migrate from periosteum and endosteum and proliferate at fracture site

**Callus Formation**

- Collagen and mucopolysaccharide produced
- Calcium deposited in callus
- Soft callus becomes bone (endochondral ossification)

**Remodeling**

- Accelerated deposition and resorption of bone
- Change in shape of bone
- Function and strength restored

### Osteomyelitis

Avian heterophils lack the proteinase necessary to liquify necrotic tissue, and birds tend to form granulomas that wall off infectious agents and necrotic material. Consequently, osteomyelitis is characterized by caseous, dry, non-draining lesions that are frequently restricted to the site of infection and rarely induce secondary systemic infections.<sup>33</sup> With mild infections, it is common for the host defense mechanism to wall off the necrotic debris and form callus around the infected tissue. However, these granulomatous osteomyelitis lesions can serve as a nidus for infection that can cause a fatal septicemia if a bird becomes immunosuppressed.

Large quantities of necrotic debris may prevent bone healing and should be surgically removed if successful fracture stabilization is expected to occur.<sup>33,46</sup> Debridement and flushing should be used to remove necrotic tissue and debris from all open fractures to reduce the chances of postoperative osteomyelitis. Samples for culture and sensitivity should be collected from the fracture site at the time of surgery. The use of intraoperative, broad-spectrum antibiotics with good tissue penetration (trimethoprim-sulfa, cephalosporins, chloramphenicol, tetracyclines) should be considered in these cases.

Placement of stabilizing hardware at or near an open fracture site should be avoided to decrease the likelihood of osteomyelitis and improve the speed of bone healing. External fixators are recommended in these cases. It has been suggested that fractures in pneumatic bones would be predisposed to osteomyelitis from contaminated air entering the fracture site. There is no evidence to support this theory.<sup>7,31</sup>

### Malunions

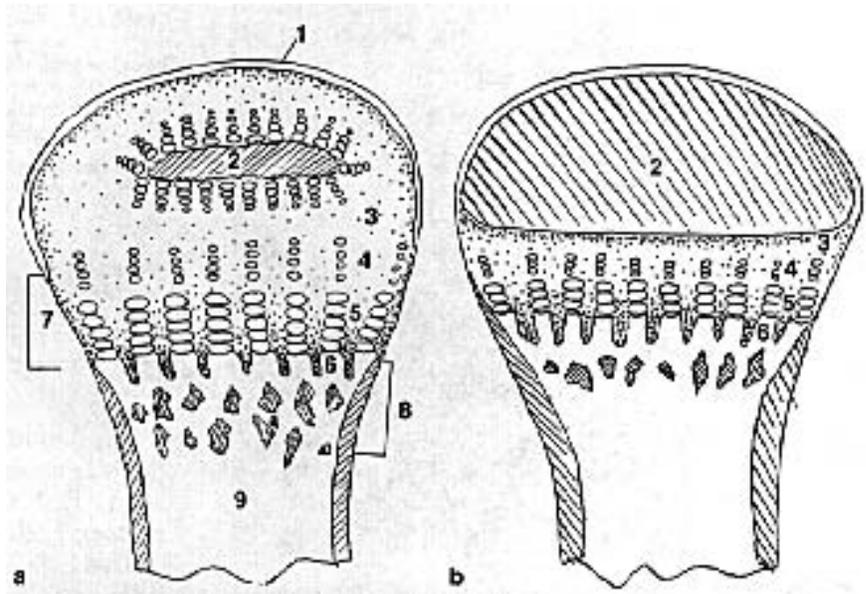
Viable and nonviable malunions can occur in birds (Table 42.4). Malunions occur when the ends of fractured bones heal but not to each other. Stabilization

requires removing necrotic debris, freshening the bone ends and compressing and rigidly stabilizing the fracture site.<sup>41</sup> Electrical current stimulation was used to repair a non-union fracture (six months' duration) in the radius and ulna of a Rough-legged Hawk. A direct-current stimulator<sup>a</sup> was implanted and delivered 0.83 volts at 20  $\mu$ A to the fracture site. Callus formation was evident radiographically at 21 days post-implantation and the fracture was healed by 80 days post-implantation.<sup>27</sup>

### Ossification<sup>13</sup>

The maturation process of the long bones of birds is different from that of mammals. In the majority of raptors, ossification of the limb bones occurs within 60 days of hatching and bones appear to mature thereafter. The diaphysis, or shaft, is that portion of a long bone between the ends (Figure 42.5). The metaphysis is the wider part of the extremities of the shaft, adjacent to the epiphyseal disc (physis). The epiphysis is the end of a long bone and is formed from a secondary center of ossification. The physis, or growth plate, is that segment of tubular bone concerned with growth. It is divided into four distinct zones:<sup>11</sup>

- **Zone of resting cartilage:** Small chondrocytes are dispersed in an irregular pattern.
- **Zone of cell proliferation:** Chondrocytes are somewhat larger and tend to form columns; this is the area of chondrocyte proliferation and mitotic figures are usually present.
- **Zone of cell maturation:** Cells are larger still and arranged in columns. As the cells enlarge and mature, they accumulate glycogen and begin producing phosphatase, which initiates calcification.
- **Zone of calcification and ossification:** With maturity, the columns of chondrocytes die and disintegrate, leaving spaces between partitions within the cartilage. Capillaries invade the spaces and osteoblastic activity takes place on the surface of the partitions. Longitudinally oriented bony trabeculae develop, which give a jagged appearance to this zone on histologic and radiographic preparations.



**FIG 42.5** a) Mammalian long bone ossification during early development and b) after the epiphysis has reached maximum size. 1) articular cartilage 2) secondary center of ossification 3) zone of resting cartilage 4) zone of cell proliferation 5) zone of maturation 6) zone of calcification and ossification 7) physis 8) metaphysis and 9) diaphysis (modified with permission from Fowler<sup>13</sup>).

**TABLE 42.4** Types of Malunions<sup>3</sup>

**Viable** – Sufficient blood supply

**Hypertrophic**

- Abundant callus and blood vessels
- Fractures filled with fibrocartilage
- Caused by inadequate fixation or premature loading

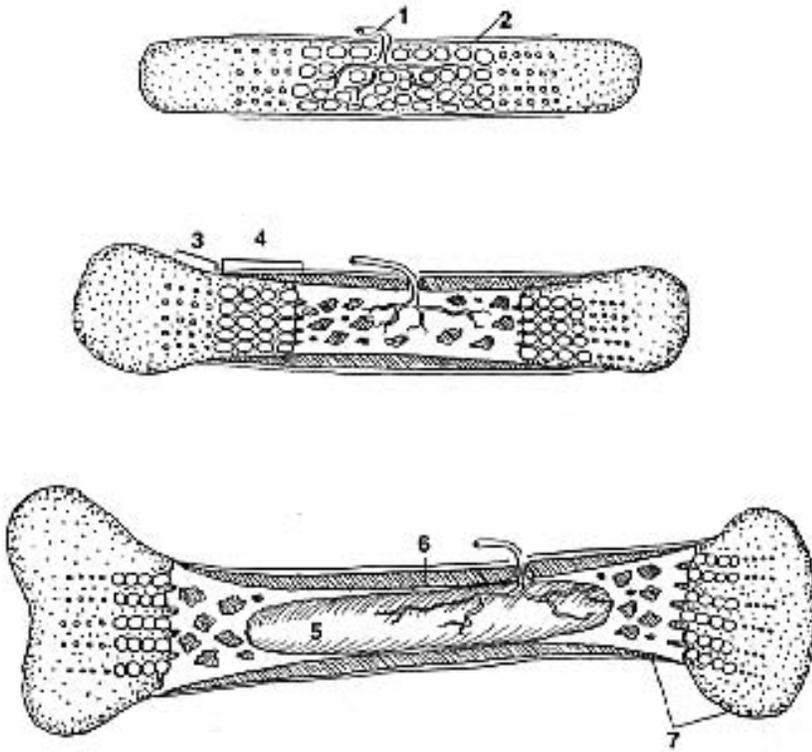
**Oligotrophic**

- No evidence of callus
- Biologically, fracture can heal
- Hypervascularized fragments
- Rounded, decalcified fragment ends

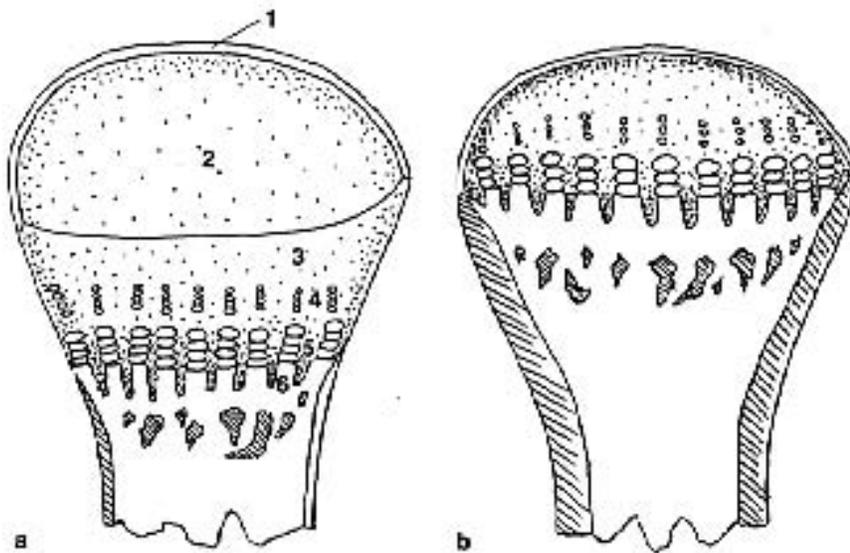
**Nonviable** – Insufficient blood supply

In mammals, most long bones have one or more epiphyseal or secondary centers of ossification. Their formation is similar to endochondral ossification with proliferation occurring in all directions until a predetermined size is reached. The epiphyseal center is covered distally by hyaline articular cartilage and proximally by an epiphyseal plate or physis until the animal reaches maturity.

The tibiotarsus of birds appears to follow a classic mammalian ossification pattern. The ends of the bones grow rapidly and establish secondary centers of ossification (epiphyses). The growth in length takes place at the epiphyseal layer, and when growth ceases, the layer of cartilage ossifies. The avian hu-



**FIG 42.6** Ossification of avian long bones from day 9 to day 13. 1) nutrient artery 2) periosteum and initial bone plate 3) zone of proliferation 4) zone of maturation 5) marrow cavity 6) cortex and 7) physis (modified with permission from Fowler<sup>13</sup>).



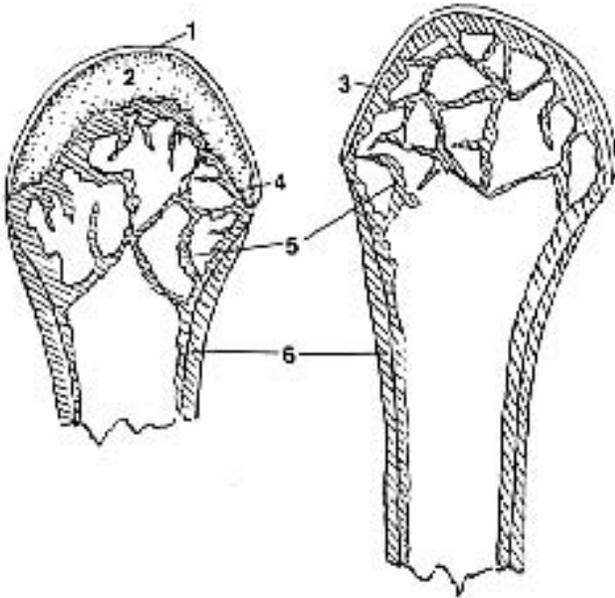
**FIG 42.7** **a**) In contrast to mammals, the epiphyseal center of the avian long bone remains cartilaginous (day-old chick). **b**) After the maximum bone size is reached (in this case a 155-day-old chick), the epiphyseal cartilage undergoes endochondral ossification. 1) articular cartilage 2) epiphyseal cartilage 3) zone of resting cartilage 4) zone of proliferation 5) zone of maturation and 6) zone of calcification and ossification (modified with permission from Fowler<sup>13</sup>).

merus, radius, ulna and femur appear to have different patterns of ossification.

The basic progression of ossification in long bones has been described in chickens (Figure 42.6). In the femur of a 9-day-old embryo, a sheath of bone has begun to form beneath the perichondrium of the original hyaline cartilage. At 13 days, the central diaphyseal cartilage has been replaced by bone, and the marrow cavity has formed. Endochondral ossification progresses toward both extremities.

In the day-old chick, the diaphysis has elongated by replacement of the cartilage model at the metaphysis. There is also a cartilage model analogous for the mammalian epiphyseal center of ossification (Figure 42.7), but the epiphyseal cartilage does not undergo endochondral ossification in the femur of chickens as it does in mammals. Instead, it persists as a wide basophilic hyaline zone covered by a narrow strip of eosinophilic articular cartilage. Elongation of the cartilage model is accomplished by interstitial growth of chondrocytes.<sup>11</sup>

At a predetermined time (may be controlled by age, species, nutrition), the growth cartilage becomes exhausted. The invading marrow tissue then enters the epiphyseal cartilage (Figure 42.8). Individual chondrocytes undergo hypertrophy allowing final endochondral ossification of the epiphyseal cartilage. By 190 days, ossification is essentially complete. At each end of the bone, a dense terminal bone plate is covered by an articular hyaline cartilage. It is possible for slight elongation of a long bone to take place by cartilage proliferation and ossification at the junction of the bone and articular cartilage. This is typical of the long bones of the humerus, radius, ulna and femur.

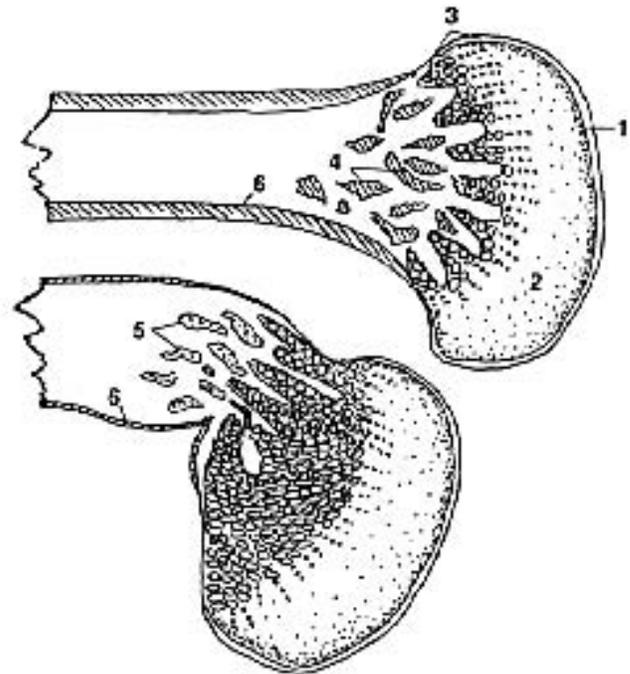


**FIG 42.8** Progression toward mature bone in a 190-day-old chick. 1) articular cartilage 2) epiphyseal cartilage 3) dense layer of bone beneath articular cartilage 4) physis 5) bone trabecula and 6) cortex (modified with permission from Fowler<sup>13</sup>).

The ossification of the tibiotarsal and tarsometatarsal bones is different. The epiphyseal center of ossification of the proximal end of the tibiotarsus becomes visible radiographically at 35 days in the chicken. The fibular and tibial tarsal bones, which make up the hock of mature mammals, fuse in avian embryos to the tibial cartilaginous model and appear as two epiphyseal centers in the seven-day-old chick. Likewise, the epiphyseal center at the proximal end of the tarsometatarsus corresponds to the distal row of tarsal bones in mammals. The carpals, metacarpals and phalanges of the wing ossify from a diaphyseal center in the same manner as long bones of the wing.

### Metabolic Bone Disease

Metabolic bone disease in the tibiotarsus and tarsometatarsus (bones with epiphyseal centers of ossification) appears similar to that described in mammals. If growth of the long bone continues by interstitial cartilaginous growth in the zone of proliferation without a sufficient supply of calcium and phosphorus, calcification of the intracellular substance between the mature cells ceases. Without calcification, the chondrocytes continue to live, causing thickening of the whole growth zone (Figure 42.9). Osteoblastic activity continues with the production of unmineralized osteoid tissue in the metaphysis. The stimulus for osteoid production is intensified because



**FIG 42.9** Comparison of normal avian ossification and ossification in a bone affected with metabolic bone disease. 1) articular cartilage 2) epiphyseal cartilage 3) physis 4) bone spicules 5) osteoid spicules 6) cortex, and folding fracture (modified with permission from Fowler<sup>13</sup>).

of the relative structural weakness of the unmineralized growth zone. This excessive osteoid production occurs subperiosteally, resulting in knobby growth centers. The radiographic changes are characterized by rickets, increased width of the physis, increased trabeculation in the metaphysis, lipping of the metaphysis and swollen distal extremities.<sup>40</sup>

The femur and wing bones lack epiphyseal centers of ossification. However, histologically, the same pattern of abnormal development takes place in the growth zone of a femur or wing bone in a bird with metabolic bone disease. The epiphyseal cartilage in birds corresponds to the epiphyseal ossification center in mammals.<sup>13</sup>

### Bone Grafts

Bone grafts promote fracture healing through osteogenesis (production of new bone), osteoinduction (recruitment of mesenchymal cells that differentiate into chondroblasts and osteoblasts) and osteoconduction (osteoblast ingrowth from the host into the graft providing structural and mechanical support). In general, cancellous bone is better than cortical bone

for grafting because the former has a larger surface area and a large number of viable cells for stimulating new bone production.

Autogenous medullary bone (collected from the tibiotarsus), corticocancellous bone (collected from the sternum or ribs) and cortical bone (devitalized fragments from the fracture site) have been shown to augment bone healing in birds.<sup>33,35,41</sup> Cortical allografts (same species, different individual) and xenografts (different species) were not found to stimulate nor inhibit bone healing when applied in an overlay fashion to humeral fractures in pigeons. There was less callus formation in the fractures supported by a graft but these birds also had a significantly higher occurrence of dehiscence, sequestration and foreign body reactions than birds with no grafts.<sup>28</sup> These findings suggest that the positive effects of cortical bone grafts in birds are limited to added fracture stabilization.

## Fracture Repair Techniques

It is best to have a command of a variety of fracture fixation techniques and to be ready with alternative plans at the time of surgery (see Table 42.1). Reassessment of the injury intraoperatively may necessitate a change in the surgical procedure. Each avian fracture is unique and may require a variety of maneuvers, techniques and instruments to achieve optimal reduction and immobilization.

Many closed fractures may heal without any type of coaptation or fixation. However, with unsupported long bone fractures, excessive callus formation, malalignment of the bone ends and shortening of the limb (overridden fractures) will dramatically reduce normal function. Non-displaced fractures of the pelvic girdle, coracoid, clavicle and scapula will generally heal with minimal support.<sup>21,39,46</sup> Displaced fractures of the coracoid must be surgically repaired or the fracture will usually result in an inability to fly.<sup>46</sup> Fractures of the radius or ulna, in which the other bone is intact, can generally be repaired with external coaptation and forced rest (Figure 42.10).<sup>38</sup>



**FIG 42.10** Minimally displaced fractures of the radius or ulna in which the other bone is intact can generally be repaired with a figure-of-eight wing-body wrap and forced rest; **a)** before and **b)** after coaptation (courtesy of Laurel Degernes).

### External Coaptation: Bandages and Splints

External coaptation is an inexpensive and rapid method of providing increased comfort to a patient (decreased movement of bone ends) and minimal stabilization of a fracture. Bandages and splints should be made of the lightest weight materials with the minimal amount of padding needed to compensate for swelling of damaged soft tissue. External coaptation is acceptable as a primary stabilization technique only when a limited post-fracture range of motion is satisfactory, a patient is too small to facilitate surgical repair, a fracture is minimally displaced or anesthesia and surgery would jeopardize the patient's life (eg, liver failure, kidney failure, heart disease, head trauma).

Fracture disease (malalignment of bone ends, muscle atrophy, joint ankylosis, shortened bone length and tendon contraction) is common in fractures repaired by external coaptation (Figure 42.11). In general, external coaptation should be considered an emergency method of stabilizing fractures until surgery can be performed or for providing additional support for fractures repaired by other methods.

Some companion birds may not require full return to flight; in these patients, some wing fractures can be effectively managed with external coaptation. Bandages or splints can be used to repair fractures of the distal legs and feet if the fracture can be properly



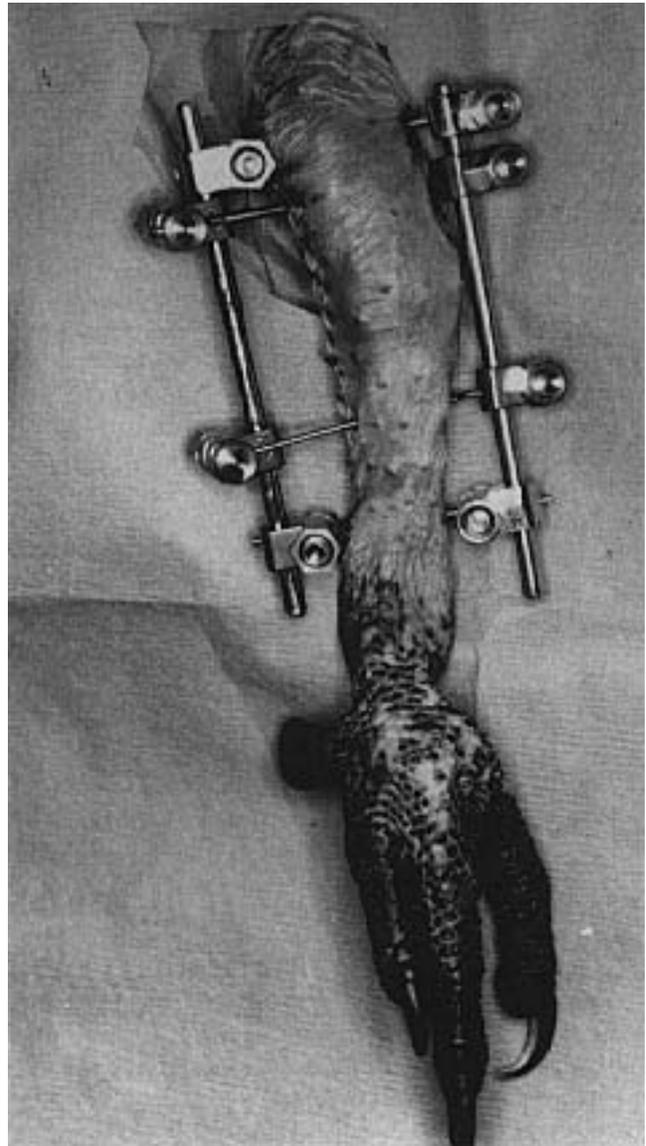
**FIG 42.11** VD radiograph of a falcon with post-traumatic degenerative joint disease of the elbow. Improper fracture repair techniques are frequent causes of fracture disease in birds.

aligned and if any decrease in bone length does not alter the weight-bearing capacity of either limb and predispose the patient to arthritis or pododermatitis (see Chapter 16). Additionally, if leg function is altered, the companion bird may not be able to ambulate or adequatelyprehend food.

### External Fixators

Bony injuries in the avian patient tend to heal in a reasonable manner and are amenable to a variety of fixation methods. In contrast, maintenance of soft tissues and joint mobility, the most vital components of return of full function for birds, may be hindered by many of the techniques used for immobilization of fractures and luxations. External fixators are generally considered the best stabilization technique for immobilizing fractures in birds that require a full return to function.

Numerous types of external fixation devices have been described for use in birds (Table 42.5). A variety of Kirschner wires and Steinman pins may be passed into the bones, and a variety of connecting bars and acrylic cements can be used for stabilizing the pins.<sup>6,16,25,26,37,45</sup> These devices are inexpensive, lightweight, easy to remove and are well tolerated by many avian species. An external fixator can be easily removed from a calm patient without anesthesia. When properly used, external fixators provide rigid stabilization and preserve joint and periarticular structure, while neutralizing rotational, bending and shear forces.<sup>14,21,24,25,26,35,46</sup> The approach to the surgical site can be minimal and, therefore, decreases soft tissue damage and reduces post-fixation dysfunction of the limb.<sup>16,18,19</sup> In many cases, external fixators



**FIG 42.12** An external fixator is an ideal way to repair many fractures in birds. Either KE connectors, various cements or casting materials can be used to connect the stabilizing pins. In this case, a valgus deformity of the tibiotarsus was corrected with a dome osteotomy and stabilized with a Type II external fixator. The connecting bars should be as close to the skin edge as possible.

allow a bird to use a repaired limb within several days of surgery (Figure 42.12).

External fixators can be applied in conjunction with IM pins to further neutralize rotation and increase stability.<sup>43</sup>

Type II (through-and-through) fixators are more stable and stronger than Type I fixators, which tend to loosen rapidly (Table 42.5).<sup>6</sup> The use of positive-profile threaded pins in a Type I fixator configuration is

particularly useful in repairing fractures of the proximal humerus and femur, where interference with the body wall makes it difficult or impossible to place a Type II fixator (Figure 42.13).

External fixators are ideal for corrective osteotomies and open, comminuted fractures. In the latter situation, the fixator can be placed so that an infected wound can remain open for several days for flushing and evaluation.

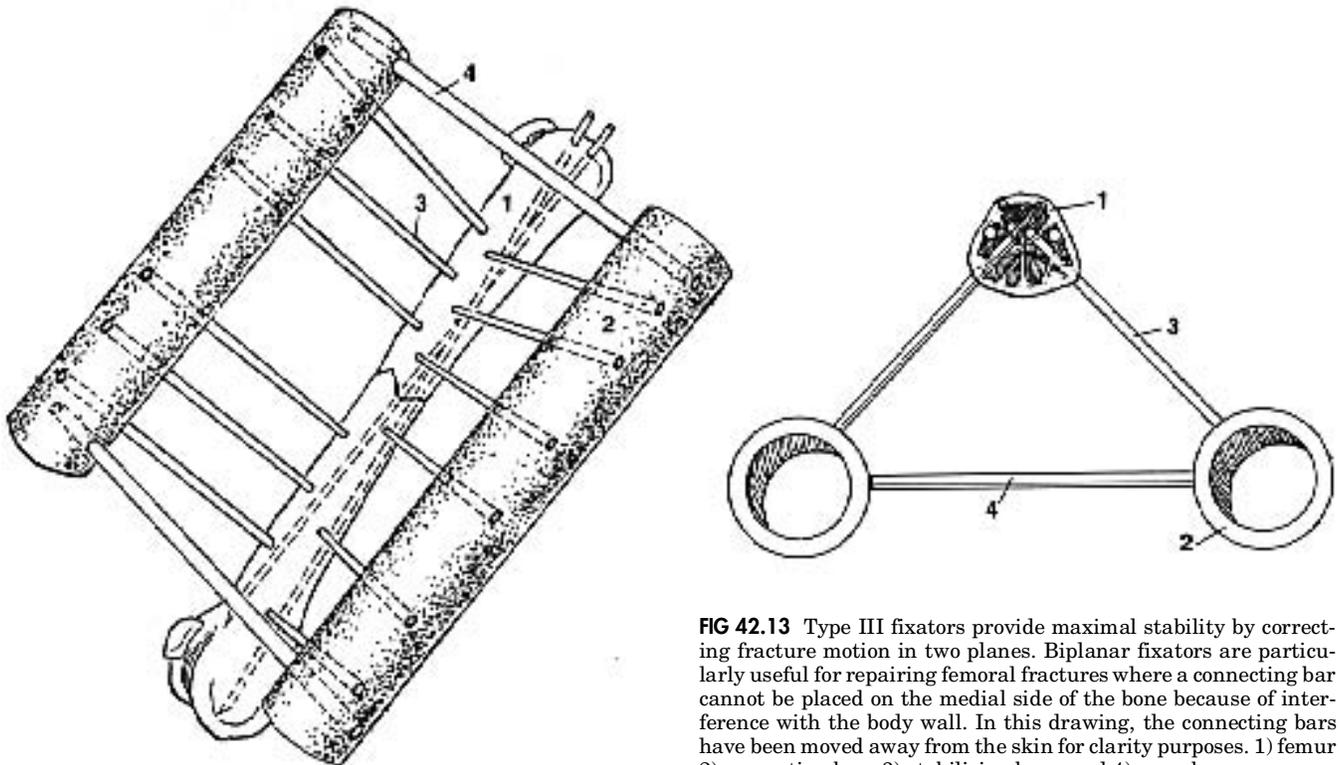
#### Application of an External Fixator

External fixator pins should be placed by making a small incision in the skin, and should not be placed through a primary incision site or open wound. This placement technique will decrease the likelihood that the pins will promote an infection at the surgical site. Pins should be inserted so that they avoid large muscle masses (minimizes loosening) and should be passed through pre-drilled holes to decrease wobble (improperly increases the size of the hole) and increase pin purchase on the cortices. It is best to place from three to four pins on each side of a fracture to decrease the stresses on any one pin. A minimum of two pins must be placed in each bone segment to ensure that the fixator will provide adequate fixation without rotation.

**TABLE 42.5** Fixator Types Listed in Increasing Strength

<b>Type I</b>	Half-pin splint - Pins penetrate one skin surface and both cortices. Connecting bars only on one side of the limb.
<b>Type II</b>	Full pin splint - Pins pass through both skin surfaces and both cortices. Connecting bars on both side of the limb in one plane.
<b>Type III</b>	Type I and Type II splints placed at a 90° angle to each other. Fixators are connected to each other. Creates a three-dimensional frame.

Positive-profile threaded pins inserted through pre-drilled holes have been found to maintain solid bone-to-pin interfaces for prolonged periods (up to three months) in some birds (Aron DN, unpublished). By comparison, other types of threaded or unthreaded pins are frequently loose in the cortex within three to six weeks of insertion. The diameter of positive-profile threaded pins is not reduced by the threading process and these pins are less likely to fail from the stress-riser effect than other types of threaded pins.<sup>2</sup> Placing unthreaded pins at an angle (35 to 55°) perpendicular to the bone will decrease the chance that the fixator will slip from side to side, but



**FIG 42.13** Type III fixators provide maximal stability by correcting fracture motion in two planes. Biplanar fixators are particularly useful for repairing femoral fractures where a connecting bar cannot be placed on the medial side of the bone because of interference with the body wall. In this drawing, the connecting bars have been moved away from the skin for clarity purposes. 1) femur 2) connecting bars 3) stabilizing bars and 4) cross bar.

would not be expected to be as effective as positive-profile threaded pins.

The connecting bar for the fixator pins should be placed as close as possible to the skin (taking into account anticipated swelling) to increase the strength of the apparatus. Standard Kirschner-Ehmer (KE) fixator hardware can be used to stabilize fractures in medium- or large-bodied birds. Their primary limitations are their size and weight.

It is extremely difficult to properly align a group of stabilizing pins that are passed free-hand. If they are not properly aligned, the pins cannot be attached to the connecting bars by KE fixator hardware. The easiest way to apply a KE fixator is to place the most proximal and distal stabilizing pins through the bone. The connecting bar is equipped with the desired number of clamps (minimum of four), and the first and last clamps are connected to the already inserted proximal and distal pins. The interior clamps are then used as a drill guide for placement of the remaining stabilizing pins.

In addition to KE clamps, stabilization pins can be connected with polymethylmethacrylate,<sup>b</sup> cast material<sup>c</sup> and dental acrylic.<sup>26,29,36,38,45</sup> In comparison to KE clamps, these materials are inexpensive, lightweight and are malleable so that pins that are not in perfect alignment can be easily connected. The tips of the stabilizing pins can be carefully bent parallel to the long axis of the bone to increase their holding strength in the connecting material. During the bending process, the pin should be stabilized to ensure that no forces are applied to the fracture site, the bone pin interface or associated joints.

Polymethylmethacrylate (PMM) can be attached to the stabilizing pins by mixing the material until it is the consistency of dough and then molding it around the stabilizing pins. The material can also be used by passing the stabilizing pins through a hole in a clear plastic tube (eg, clear straw). The plastic tubes used for a mold should be thin-walled to ensure that the methylmethacrylate column is of adequate diameter (approximately equal to that of the bone). When the pins are properly positioned (fracture site reduced and in proper alignment), the PMM is placed in a syringe and injected into the straw while it is still liquid. The fracture is held in place until the PMM hardens (generally ten minutes).

A soft metal connecting bar with numerous holes has recently become available.<sup>d</sup> The stabilizing pins are passed through the holes in the connecting bar, which

is then crimped to firmly secure the pins. These connecting bars are light-weight and inexpensive.<sup>16</sup>

In birds that weigh less than 200 g, hypodermic needles can be used as stabilizing pins and these can be attached with cyanoacrylate glue (SuperGlue) to other needles or tooth picks that function as temporary connecting rods. An index card can be fashioned into a V-shaped trough and placed over the pins. Five-minute epoxy cement is then poured into the trough to firmly bind the stabilization pins and connecting bars.

## ■ Intramedullary Fixation

### Intramedullary Pins

Generally, intramedullary pins neutralize bending forces and provide adequate fracture alignment, but they do not protect the fracture from rotational or shear forces.<sup>6,21,33,46</sup> Minimal rotational deformities in the wing bones can inhibit flight by altering the dynamics of the wing aerofoil.<sup>9,19,46</sup> Techniques that use IM pins in combination with external coaptation have been frequently discussed in the literature; however, the combination of these two fixation techniques should be avoided to prevent ankylosis of the associated joints.<sup>6,8,14,16,19</sup> Because of the relatively thin cortices of birds, the use of threaded IM pins has been suggested to provide better bone purchase than non-threaded pins.<sup>36,37,42</sup> However, IM pins are primarily used to counter bending force which would not be influenced by the degree of purchase in the cortex.<sup>21</sup>

*Editors' note: Intramedullary pins have several disadvantages when compared to external fixators. They have the inherent potential to cause articular and periarticular damage resulting in ankylosis of the joints. Even properly placed pins that exit near a joint can cause sufficient tendon or ligament damage, resulting in a partially dysfunctional limb. Unless an IM pin can be placed so that it does not exit through or near a joint, it is best not to use this method of internal fixation in birds that require full post-fixation use of a limb. Even pins that do not exit near a joint can still injure the vasculature and significantly alter the growth pattern of the bone.<sup>13</sup>*

*Retrograde placement of pins through the distal humerus, normograde placement from the 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.<sup>17,46</sup>*

The use of IM pins, with or without interfragmentary wires, is effective for stabilizing some fractures in companion birds when clients are not concerned with postsurgical return of flight. When IM pins are used, they should be of sufficient size to fill about one-half to two-thirds of the medullary canal.<sup>12,36-38</sup> In mammals, current theories suggest that the pin should occupy approximately 60% of the medullary canal; however, in birds, excessively large pins can interfere with endosteal blood supply, which may cause avascular necrosis or iatrogenic fractures.<sup>6,8,14</sup> In order to compensate for these problems, stack-pinning, cross-pinning or Rush-type pinning with multiple, small-diameter pins has been recommended for use in birds. However, placement of the pins with any of these techniques induces excess cortical damage.

Cerclage, hemicerclage and interfragmentary wires can be used as an adjunct to internal or external coaptation to neutralize rotational and shear forces. They are most useful for adding stability to long oblique and spiral fractures and for holding fragments of bone in apposition during the application of other fixation devices.<sup>41</sup>

Long bone fractures fixed with intramedullary pins alone are often immobilized with bandages or splints for 10 to 21 days. A significant loss in post-surgical range of motion should be expected when bandages are used in combination with intramedullary pinning.<sup>3</sup>

#### Intramedullary Polymer Pins

Several techniques have been described for the insertion of high-density polymer rods, polypropylene welding rods or polymethylmethacrylate into the medullary canal.<sup>17,24-26</sup> Plastic and acrylic rods have been successfully used in combination with external fixators for additional stability. The polymer rods are lighter than IM pins, inexpensive, biologically inert, provide for stable fracture repair and do not require removal when the fracture is healed.<sup>4,21,24</sup>

In one study, fractures of the wing repaired with IM polymer rods allowed rapid post-fixation exercise (seven to ten days) and most birds were able to fly 14 to 21 days postsurgery.<sup>24</sup> However, because the rods must be inserted using a shuttle technique (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.<sup>24-26</sup> Additionally, these techniques dictate that a foreign material remain in the medullary canal, which is likely

to alter the biomechanical response of a portion of the wing to stresses induced by flight.<sup>24</sup>

#### Intramedullary PMM

Polymethylmethacrylate has been used in the intramedullary canal of birds to aid in fracture stabilization. This material comes as a liquid monomer and a powdered polymer that, when mixed together, undergoes polymerization that is exothermic (100°C).<sup>16,19</sup> The high temperatures associated with polymerization do cause bone necrosis, and application of cool water has been suggested as a method of dissipating heat.<sup>18,35</sup> The material generally hardens in ten minutes. This method of fracture fixation does have the advantage of being fast and inexpensive, providing rapid stability and allowing almost immediate return to function without joint insult.

The inhibition of endosteal callus formation, endosteal blood supply (that is theorized to occur) and the intramedullary bone necrosis (that is known to occur) have not been shown to interfere with the clinical outcome of fracture healing.<sup>18,19,21,35</sup> The most significant interference with healing occurred when polymethylmethacrylate was allowed to pass between the bone ends and inhibit callus formation. If the humerus or femur are overfilled with PMM, the material may enter the connecting air sacs.

Methylmethacrylate should not be used in open wounds where infectious agents are likely. If the methylmethacrylate is contaminated with bacteria, the material can serve as a chronic source of infection.<sup>18,19</sup> The necrosis that occurs during the polymerization process and the damage to the endosteal blood supply would theoretically predispose an affected limb to osteomyelitis.<sup>35</sup> In humans, heat-stable antibiotics (cephalothin, potassium penicillin) have been added to the polymer to provide up to five years of bacteriostatic activity.<sup>35,44</sup> The effects of long-term exposure of birds to these antibiotics have not been investigated.

Given the uncertainties about the long-term effects of IM PMM (particularly in the wing bones of free-flighted birds), this technique should be used with caution. Techniques have also been reported using polymer rods in conjunction with IM PMM.<sup>10,22,23</sup> The advantages and disadvantages of these techniques are similar to those described with either technique alone.

## Bone Plates

Bone plates have been infrequently discussed for use in birds because of their thin cortices (undetermined whether a real or perceived concern) and their relative lack of soft tissue.<sup>6,14,24,41,46</sup> In addition, traditional bone plating equipment is expensive and the technique requires specialized training and prolonged anesthesia times.

The availability of small, lightweight bone plates has made these devices more worthy of consideration for repairing some avian fractures. Small finger plates designed for humans, cuttable metal plates<sup>e</sup> and acrylic plates are available in sizes useful for fractures of long bones in birds of 350 g or more.<sup>5,15,19</sup>

Bone plates have been successfully used to achieve what clinically and radiographically appear as primary bone healing in larger birds (ratites).<sup>20,41</sup> When they are used, bone plates have the advantage over other fixation techniques of providing rigid fixation with minimum callus formation and joint involvement.<sup>18,19,33,35</sup> Another advantage of plates is that they are completely internal and therefore are well tolerated by birds.

The stress junction at the end of the plate is susceptible to fracture. In raptors, plates used for the repair of closed fractures resulted in long healing times and rehabilitation periods, but produced excellent reduction and alignment of the fractures and a high level of return to full function.<sup>9</sup>

Some avian fractures are not conducive to being repaired with bone plates. Plates can serve as a nidus for infection and are not recommended for use in open fractures. Plates usually require a relatively long healing and rehabilitation time because of the “shielding effects” the plate induces with respect to underlying bone. After a plate is removed, the underlying bone may fracture (usually through the screw holes) if normal use is resumed immediately. Therefore, gradual physical therapy programs should be instituted. Movement should be limited for the first seven to ten days following removal of the plate, and then the bird should be allowed to gradually return to normal function. Plates

### CLINICAL APPLICATION

- The long-term effect of infusing polymethylmethacrylate into the medullary canal of birds has not been determined. The presence of any foreign material in the medullary canal of a bone would be expected to change its response to applied forces (particularly those involved with flight).

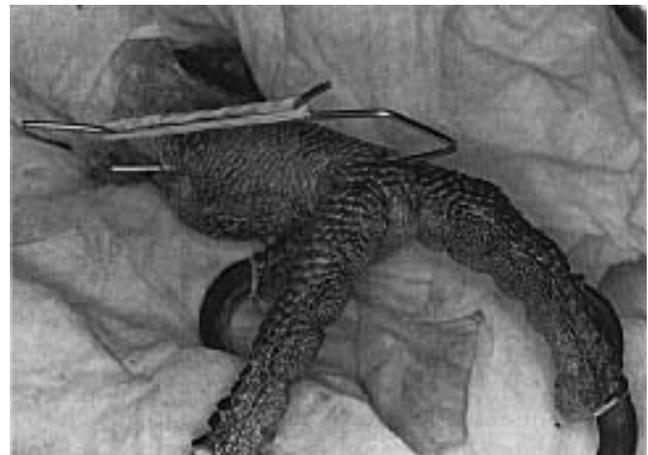
can conduct cold and lead to deep bone pain as well as frostbite of surrounding tissues and should generally be removed in birds that will be released to the wild. Plates can remain in place if the bird is not exposed to freezing temperatures or the plate does not cause any specific problems.

## Doyle Technique

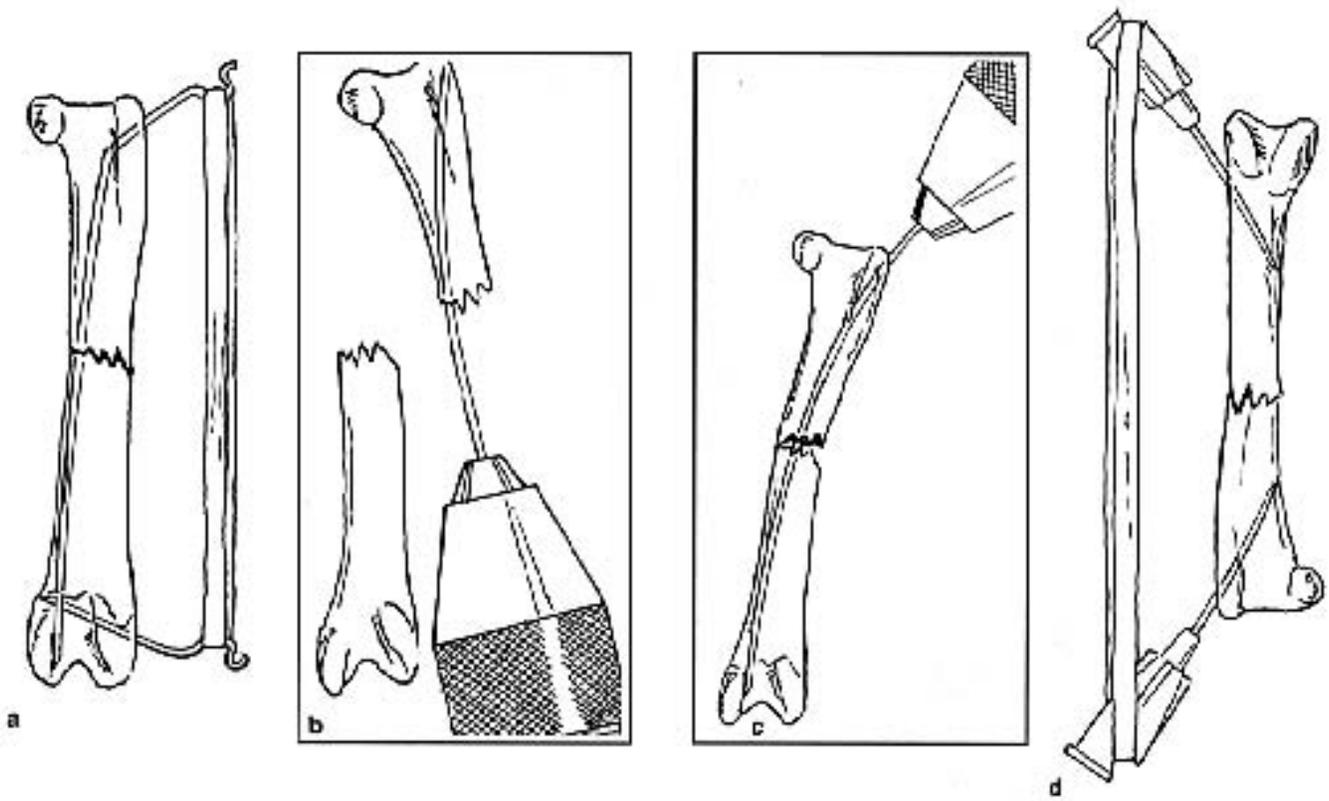
A fracture fixation method has been developed (Doyle JE, unpublished) that combines intramedullary pinning concepts with those of external fixation (Figure 42.14). In both the distal and proximal fracture segments, a pin is placed through one cortex and angled to bounce off the opposite cortex and remain in the medullary canal (Figure 42.15). Hooks are fashioned on the external end of each pin, and the fracture site is then compressed and stabilized by stretching a dental impact type rubber band<sup>f</sup> over the hooks of each pin. The technique requires that the smallest fracture segment be of sufficient size for the safe placement of a stabilizing pin. Kirschner wires (0.028, 0.035, 0.045 or 0.062 cm) are adequate for most avian fractures. In small birds, various-sized catheter needles or hypodermic needles can be used in place of the K wires.

This technique compensates for several problems that typically occur with intramedullary pinning techniques:

- The pins placed in the medullary canal do not damage periarticular tissue.
- Smaller pins can be used in order to prevent trabecular damage and excessive fixator weight.
- Maximum compression of the fracture site is achieved.



**FIG 42.14** Use of the Doyle technique to repair a diaphyseal tarsometatarsal fracture in a cockatoo.



**FIG 42.15** a) Doyle technique to repair long bone fractures. This technique allows for the use of intramedullary pins while reducing the degree of perivascular and trabecular damage and providing the maximum compression of the fracture site. Note that the longest pin does not penetrate the cortex of the bone, and that the shortest pin is placed into the cortex. b,c) A battery- or air-driven drill is used to place the pins. A dental rubber band attaches the cupped ends of the pins. d) In small birds, side cutters are used to notch the hubs of hypodermic needles, which are used in place of intramedullary pins.<sup>14a</sup>

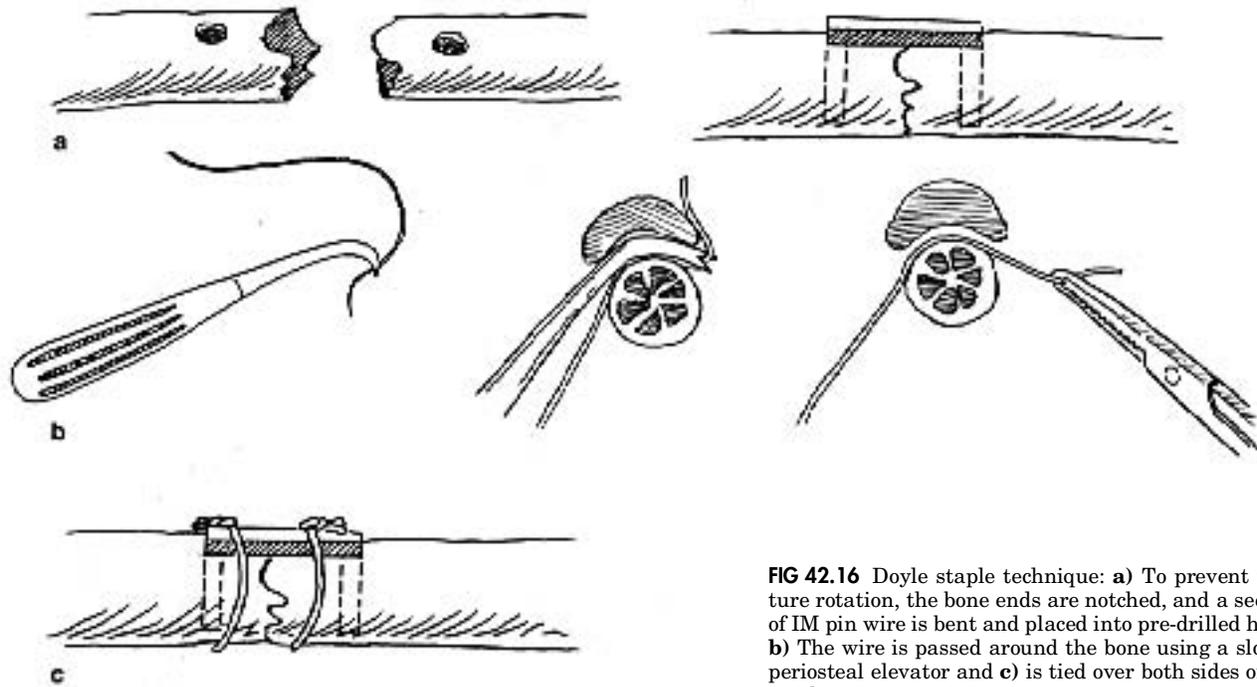
- The joint is not involved in the repair process.
- The bird will have less of a problem with fixation-induced fracture disease.

As with any pin that is placed through the cortex, the stabilizing pins used in this technique should be inserted through pre-drilled, appropriately sized holes (smaller than the pin size). The pin is inserted as far away from the fracture as possible without compromising the periarticular tissues. Once the pin has entered the cortex, the angle is changed so that the pin bounces off the opposite cortex and can be threaded into the medullary canal, past the fracture site and as deep as possible into the smaller fracture segment (the long pin should not penetrate through the cortex in the smaller segment) (Figure 42.15).

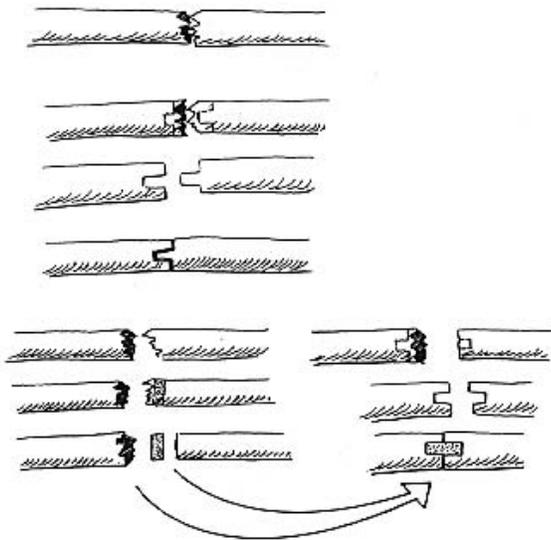
The exterior portion of the pin is bent in two places using locking pliers. A right angle bend is placed in the pin as it exits the skin so that the pin is relatively perpendicular to the bone. A semicircle (hook) is fashioned in the end of the pin about 1 cm from the skin. A

second pin is placed in the smaller fracture segment. This pin is inserted at a 45° angle to the long axis of the bone and parallel to the initial pin. This pin should penetrate but not exit the opposite cortex. A rubber band is placed around the hooks to compress the fracture. Postoperatively, several opened gauze pads are placed between the skin and the rubber band to prevent irritation. The affected appendage is placed in an appropriate bandage (leg: Robert Jones; wing: figure-of-eight body wrap). The rubber bands can generally be removed within 10 to 21 days, and the pins between 21 and 40 days after surgery.

Fractures that are minimally displaced and have recently occurred can be repaired in a closed fashion. Fractures that are several days old or that are displaced must be repaired in an open fashion, and any tissue debris or fibrous connective tissue should be removed from the bone ends. Either cerclage wires or fracture transversing staples can be used to minimize over-riding or rotation in oblique and comminuted fractures (Figure 42.16). Transverse fractures



**FIG 42.16** Doyle staple technique: **a)** To prevent fracture rotation, the bone ends are notched, and a section of IM pin wire is bent and placed into pre-drilled holes. **b)** The wire is passed around the bone using a slotted periosteal elevator and **c)** is tied over both sides of the staple.



**FIG 42.17** Doyle technique for slotting the end of fractures to reduce rotation. The bone ends are most easily notched using a sagittal saw. For additional stability, a section of the bone end can be removed (arrow) and placed in a slot created in the end of both fracture segments.



**FIG 42.18** a) A bite wound to the mandible in a conure resulted in rhamphothecal damage. A Doyle apparatus was applied to stabilize the fracture. The defect in the beak was covered with calcium hydroxide and a hydroactive dressing before being sealed with cyanoacrylate. b) The pins and cyanoacrylate were removed in four weeks and the mandible and beak were healed.

are most likely to rotate. This rotation can be reduced by notching the ends of the bone fragments with a sagittal saw and then applying a Doyle compression apparatus (Figure 42.17).

The Doyle technique can be used in combination with cleaning, calcium hydroxide and acrylics to repair the beak and fractures of the mandible. Pins are placed into the fracture segments and connected with rubber bands. The fracture site and beak defect are covered with calcium hydroxide paste to prevent dental acrylic from entering the defect and causing a malunion. The fracture is then covered with dental acrylic or a hydroactive dressing. The defect and fracture will generally require six weeks to heal (Figure 42.18).

## Surgical Approaches

During a surgical procedure, every attempt should be made to identify and follow the natural separations between muscles and along fascial planes. In most instances, surgical approaches can be planned to avoid muscles completely, which will reduce the degree of surgically induced soft tissue damage. Inci-

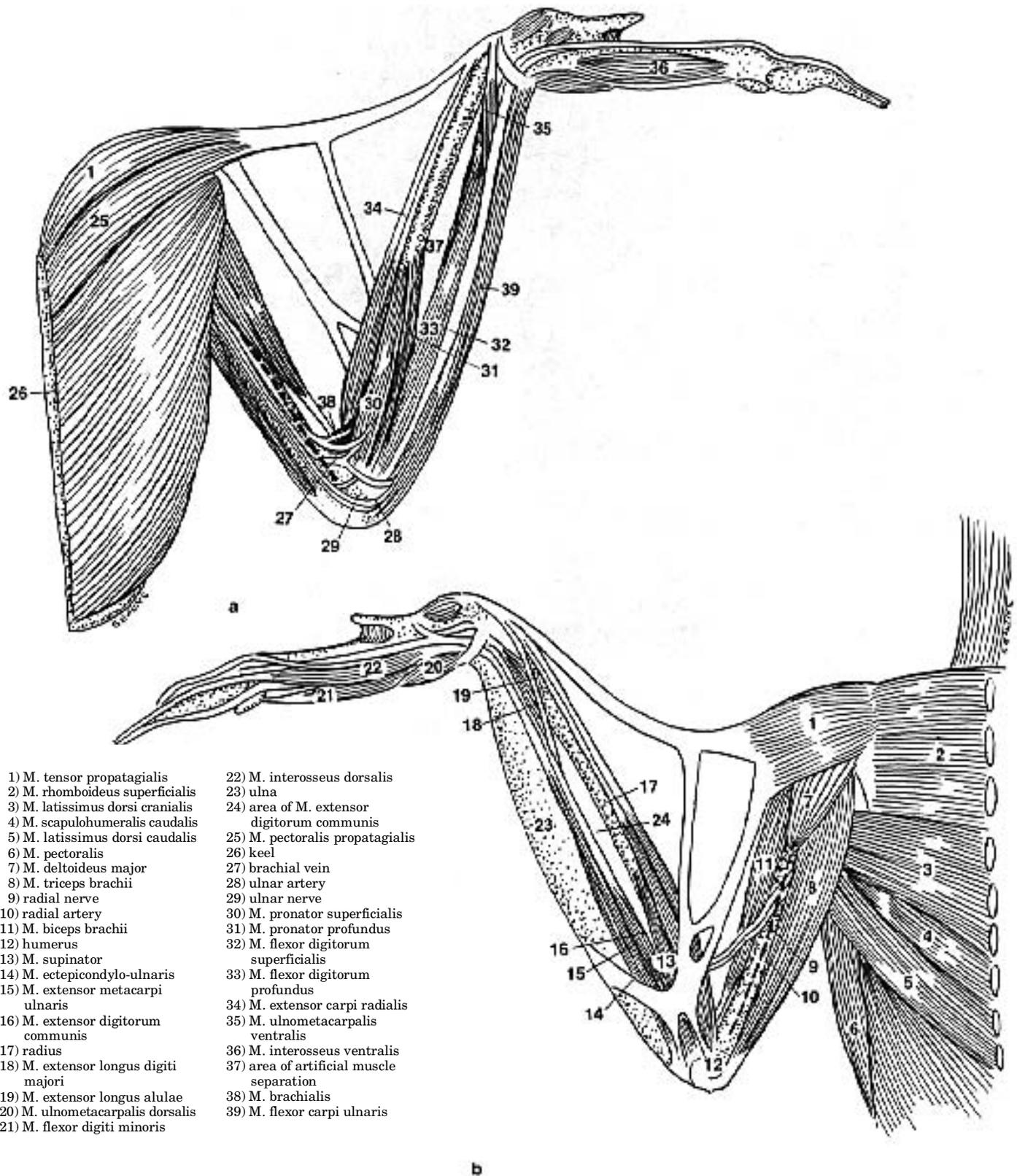
sion or bruising of the proptagium should always be avoided.

### The Wing

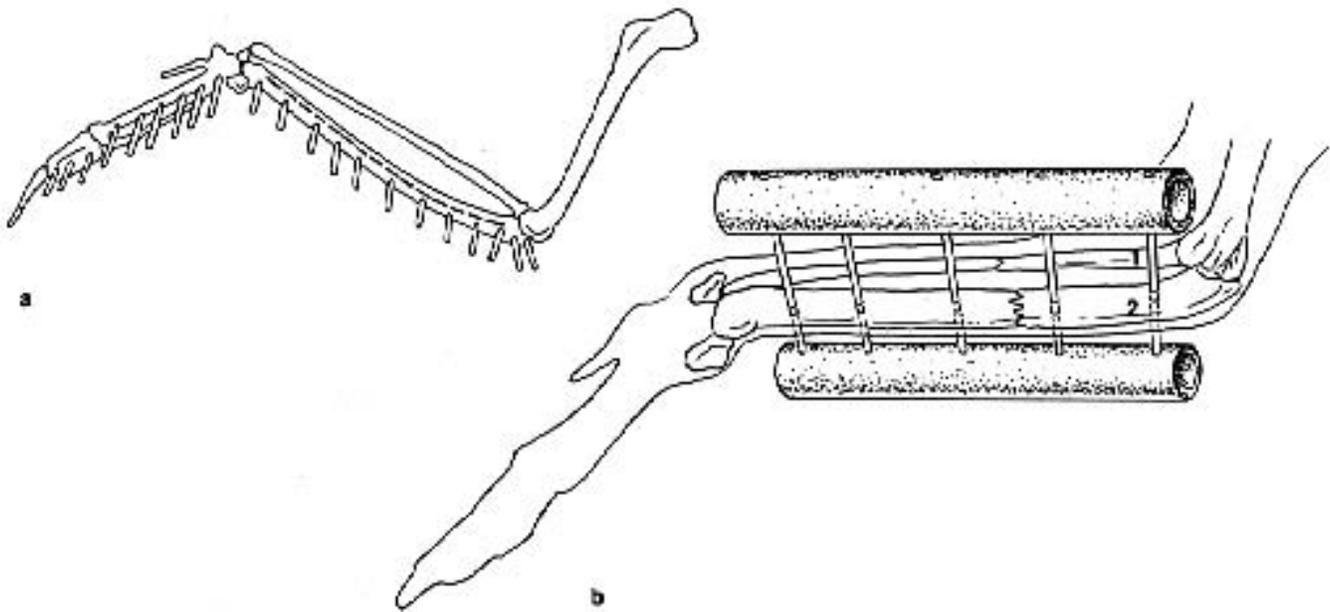
#### The Carpometacarpus

Figure 42.19 illustrates the anatomy of the wing. Repair of metacarpal fractures is meticulous. If the single artery and vein located between the third and fourth metacarpal bones are damaged, avascular necrosis to the distal portion of the wing can occur.<sup>41</sup> The most direct approach to fractures of the carpometacarpus is the dorsal approach. The bone can be visualized immediately beneath a dorsal skin incision. A ventral approach requires that soft tissues, tendons and blood vessels be separated in order to approach the main, or primary, metacarpal bone. Minimally displaced closed fractures of the carpometacarpus may be repaired with a figure-of-eight bandage (see Chapter 16). The clinical drawback to bandages is the loss in range of motion of the carpal joint while the fracture is healing.

Fractures of the carpometacarpus are ideally suited for small, lightweight external fixators that allow freedom of movement in the carpal joint. These are usually applied using small K wires or hypodermic needles and then attached by a connecting bar composed of plastic tubing filled with methylmethacry-



**FIG 42.19** Overview of surgically important anatomic features of the left wing. Dotted lines represent surgical approaches to the humerus. **a)** Ventrodorsal view and **b)** Dorsoventral view.



**FIG 42.20** Dorsal approach to the radius and ulna. **a)** An incision (dotted line) is made in the dorsocranial aspect of the ulna just cranial to the insertion point of the secondary feathers. **b)** A type II fixator is preferable for stabilization of the ulna. The ventral connecting bar should be padded to reduce damage to the body wall. The dorsal connecting bar has been elevated away from the skin margin for clarity purposes. 1) radius and 2) ulna.

late cement. IM pins may be added to help with alignment; these are usually placed through the fracture site and normograded distally and then retrograded back to the proximal fragment. Passing IM pins normograde from the carpus reduces the damage to the carpal joint.<sup>41</sup>

In larger birds, small plates may also be used; however, wound closure may be difficult due to the lack of subcutaneous tissues.

### The Radius and Ulna

Occasionally, birds are presented with fractures of the radius alone. Given the larger size of the ulna, radial fractures are often anatomically stabilized and splinted by the larger ulna. Bandages or simple enclosure rest may result in adequate fixation of minimally displaced radial fractures. If displaced, IM pins introduced through the fracture site and normograded out toward the carpus (avoiding the joint) and then retrograded back through the proximal fragment may be useful in reducing the fracture. External fixators may be used alone or in combination with IM pins. External fixators are easily applied to ulnar fractures.

Traumatic injuries frequently cause fracture of both the ulna and radius. For minimally displaced mid-shaft fractures, bandaging or external coaptation

(figure-of-eight to immobilize the elbow and carpus) may be adequate. However, given the resulting decrease in range of motion of the elbow and carpal joints, it is preferable to repair these fractures with external fixators. Concomitant use of intramedullary or shuttle pins to provide alignment and increased stability is helpful. Plates may also be used on fractures that are closed.

The dorsal approach to the radius and ulna is preferred. An incision is made on the dorsocranial aspect of the ulna just cranial to the insertion point of the secondary feathers (Figure 42.20). In some cases in which both bones are broken, repair of the ulna alone is sufficient. However, with severely displaced fractures, the surgeon may need to stabilize the radius to allow proper healing. The same incision may be useful for stabilizing both bones depending on the location of the radial fracture. The intraosseous space between the radius and ulna houses the radial nerve and the radial artery, both of which should be avoided. The ulna can be easily identified and exteriorized for debridement and repair through the dorsal incision. If intramedullary pins are used, they are introduced through the fracture site and retrograded out the olecranon (avoiding the elbow) and then normograded into the distal fragment.

To approach the radius separately, an incision is made over the dorsal aspect of the radius between the extensor metacarpi radialis muscle anteriorly and the extensor digitorum communis over the intraosseous space. IM pins placed in the radius can be retrograded out through the distal radius and then normograded back into the proximal fragment. Badly displaced radial and ulnar fractures can usually be repaired by applying an external fixator or shuttle pin in the ulna, and placing a simple intramedullary shuttle pin in the radius. Plates can be used to repair ulnar fractures.

### The Humerus

Humeral fractures usually require open fixation because contraction of the pectoralis and biceps brachii muscles pulls the distal bone fragment proximally, creating a displaced fracture (Figure 42.21). A dorsal approach is recommended for most fractures of the humerus (Figure 42.22). This procedure avoids transection of the basilic vein and artery over the ventral aspect of the bone, as well as the medianoulnar nerve. However, the surgeon must cautiously incise dorsally over the midsection of the humerus to avoid the radial nerve. Once the incision is made through the skin, the radial nerve should be immediately identified and retracted. The humerus is exposed immediately beneath the skin. Proximally, the muscles of the biceps and deltoids will overlie the humerus. For a ventral approach, the surgeon makes an incision over the cranioventral aspect of the humerus, taking care to avoid the medianoulnar nerve and the brachial artery and basilic vein. The easily separable muscles of the biceps and the triceps converge proximally (see Figure 42.19).

A variety of methods may be used to repair fractures of the humerus. The choice of fixation technique is based on the nature of the fracture, the type of patient and the surgeon's experience. External fixators in combination with shuttle pins or intramedullary pins are preferred for free-ranging birds. Type II external fixators should be carefully applied to prevent pins and connecting bars from inducing soft tissue trauma medially on the trunk of the animal. Threaded pins in a Type I or biplanar Type I external fixator will reduce the chances of fixation-induced injuries to the animal. Stabilizing splints and bandages must immobilize the shoulder joint as well as the elbow and, therefore, must be wrapped around the body of the bird. Some birds may be highly intolerant of this type of bandaging.

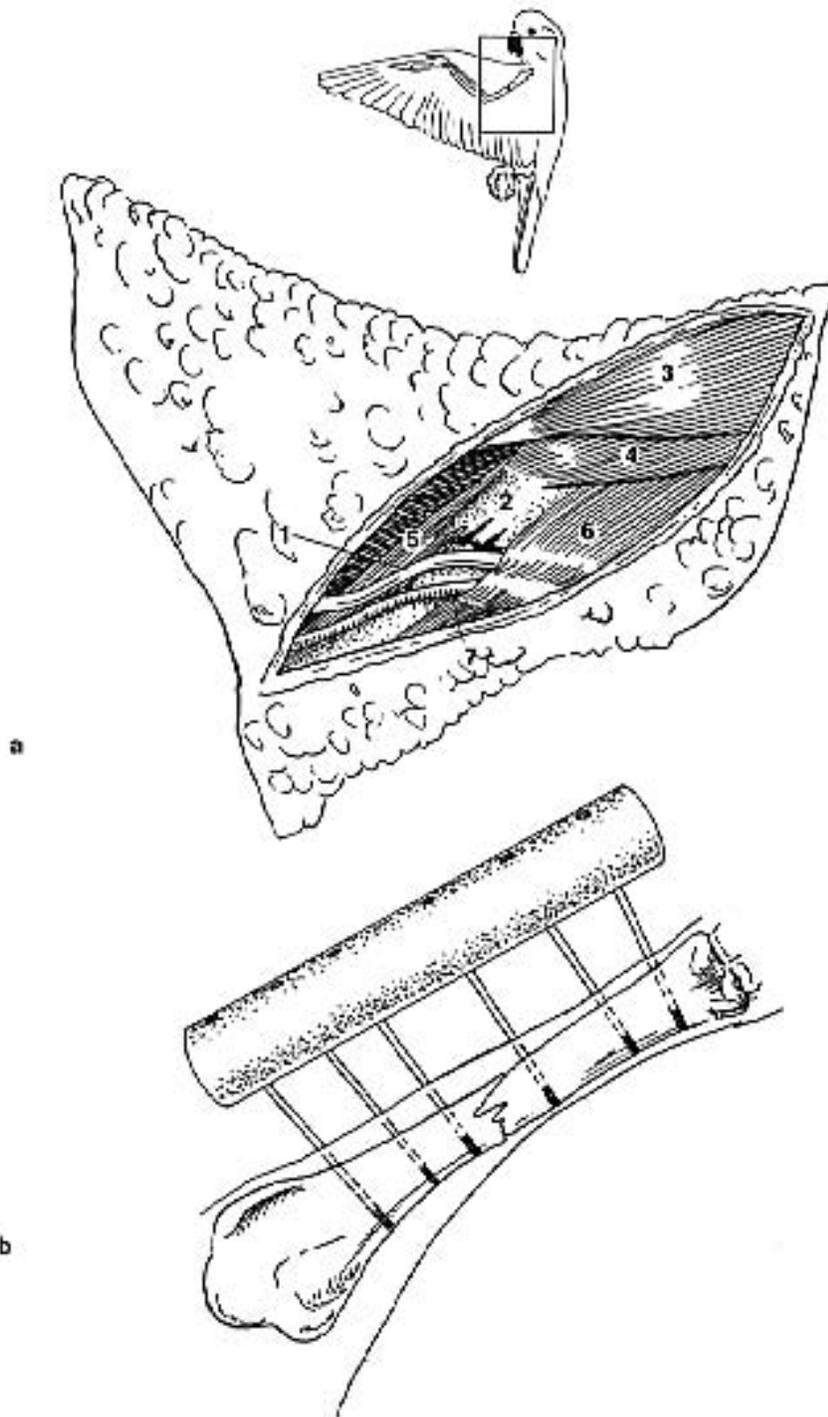


**FIG 42.21** Contraction of the pectoralis and biceps brachii muscles usually pulls the distal fragment of a humeral fracture proximally. The resulting displacement of the bone necessitates open reduction and repair (courtesy of Laurel Degernes).

### The Coracoid

Birds can fracture the coracoid by flying into large, solid objects such as walls, windows or cars. Minimally displaced fractures may be stabilized successfully by bandaging the wing to the body. Surgical correction is necessary if the fracture is markedly displaced. A skin incision is made along the caudal edge of the furcula starting laterally and then continuing medially along the lateral edge of the keel for the first one-fifth or one-sixth of the length of the keel bone (Figure 42.23).

The superficial pectoral muscle is encountered, and an incision is made through the superficial pectoral muscle along the caudal edge of the furcula. This muscle can then be elevated from the keel bone medially. Radiosurgery is necessary to control hemorrhage from the clavicular artery, which supplies part of the pectoral muscle. This vessel is usually encountered at the caudal midpoint of the furcula. An incision or blunt dissection is used to penetrate the deep pectoral muscle. The coracoid is located immediately beneath the deep pectoral muscle and runs from the point of the shoulder at approximately a 45° angle to



**FIG 42.22** Dorsal approach to the left humerus. **a)** The skin over the dorsal humerus should be carefully incised to avoid cutting the 1) radial nerve. The 2) humerus is visible immediately beneath the incision. Exposure to the proximal humerus is prevented by the 3) *M. tensor propatagialis* and the 4) *M. deltoideus*. The 5) *M. biceps brachii* is seen on the cranial edge of the humerus and the 6) *M. triceps scapularis* is located caudally. The 7) radial artery runs caudal to the nerve. **b)** A Type I external fixator in conjunction with positive-profile threaded pins can be used for stabilization of humeral fractures. The connecting bar has been raised from the skin edge for clarity purposes.

the cranial aspect of the sternum. Trauma associated with a fractured coracoid can be significant, resulting in massive soft tissue damage and hematoma formation. Because of the location of the coracoid, the surgeon works in a small, deep hole, and radiosurgery as well as irrigation are mandatory to keep the surgical field clean.

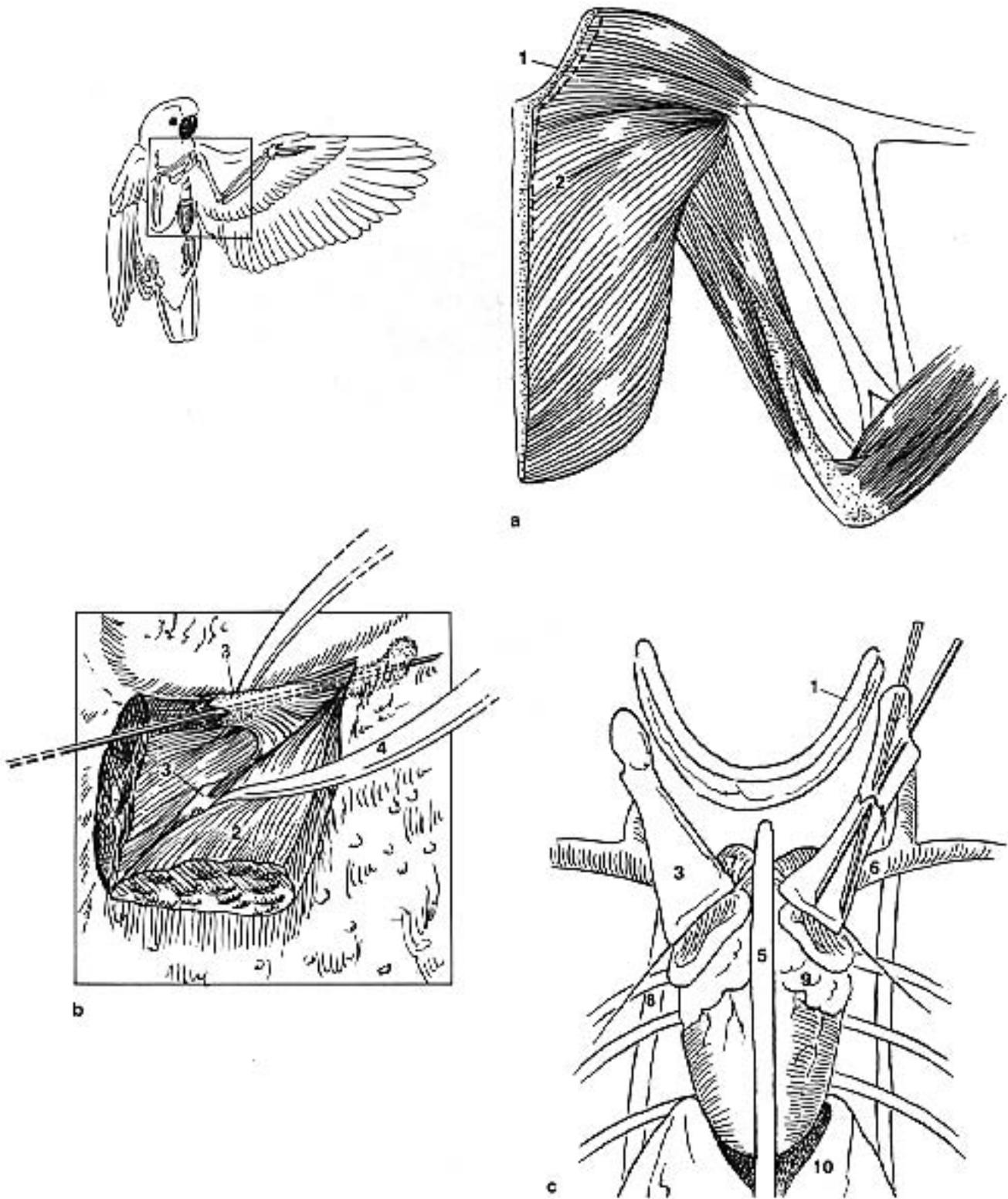
The proximal fragment of the coracoid should be grasped and rotated into the incision. Following cleaning and debridement, multiple small intramedullary pins are introduced at the fracture site and exteriorized through the point of the shoulder. The distal fragment is rotated up into view and cleaned, and the fracture is aligned. Intramedullary pins must be carefully normograded back into the distal fragment. If the pins are advanced too far caudally and penetrate the sternum, the pins may perforate the pericardium and the heart. This problem can be prevented by carefully measuring the length of the distal fragment and using this distance to advance the pins. Muscle bellies are re-approximated using a simple continuous pattern and absorbable suture material. The superficial pectoral muscle may also be secured to the furcula. The wing should be wrapped to the body for five to ten days following surgery.

### ■ The Leg

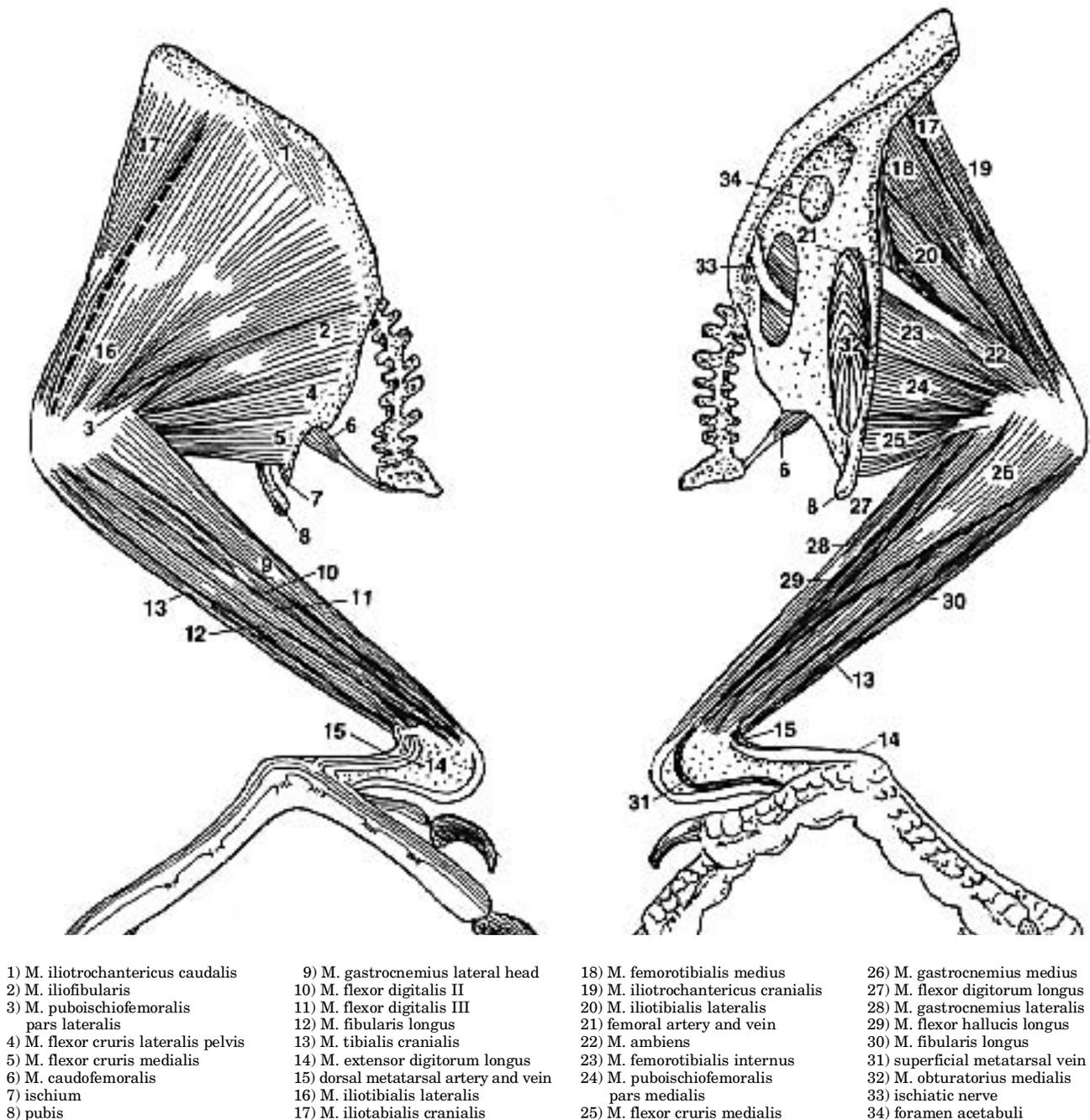
Fractures of the tibiotarsus, tarsometatarsus and phalanges are best repaired using external fixation techniques (Figures 42.25, 42.26).

#### The Tarsometatarsus

The approach to the tarsometatarsus is simple because of the lack of soft tissues in this area. A lateral dorsal or medial dorsal approach may be used. A straight dorsal approach is generally not used because of the scutes overlying this area and the extensor tendons beneath. The sur-



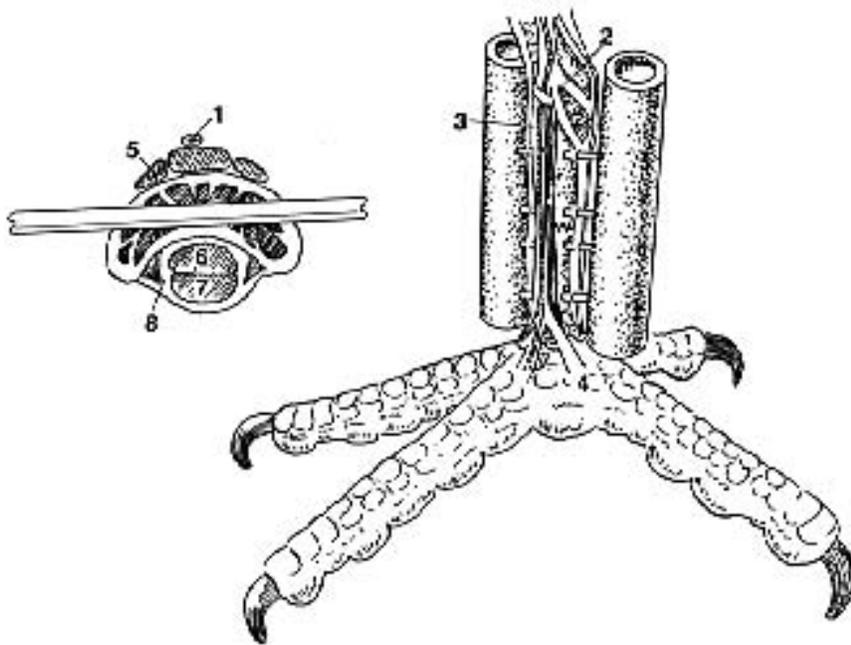
**FIG 42.23** Surgical approach to the coracoid. **a)** A skin incision is made along the caudal edge of the 1) clavicle starting laterally and continuing medially along the lateral edge of the keel. **b)** The 2) pectoralis muscle is incised along the caudal edge of the clavicle and the 3) coracoid can be identified beneath the deep pectoral muscle coursing at a 45° angle to the cranial aspect of the sternum. **c)** Multiple, small intramedullary pins are passed retrograde out the cranial part of the shoulder. The pins are then carefully passed normagrade back into the distal fragment taking care not to have the pins pass through the caudal end of the coracoid and into the heart. 4) retractors 5) keel 6) left brachiocephalic trunk 7) aorta 8) scapula 9) heart and 10) liver.



**FIG 42.24** Overview of important surgical anatomy of the leg. a) Lateral view and b) Medial view.

geon should be aware of the concave nature of the caudal aspect of the tarsometatarsus (Figure 42.25). A groove, which houses the flexor tendons of the foot as well as the dorsal metatarsal artery, runs dorso-medially along with the vein and should be avoided when approaching the tarsometatarsus.

Any number of fixation methods may be utilized for fractures in this area (Figure 42.26). However, external fixators are ideally suited, and Type II configurations are easy to apply and provide excellent stability. If IM pins must be used, they are generally introduced through the fracture and exteriorized in a



**FIG 42.25** Type II external fixators are ideal for repairing tarsometatarsal fractures. The clinician should be aware of the concave nature of the tarsometatarsal bone. 1) dorsal metatarsal artery 2) M. fibularis longus 3) M. extensor digitorum longus 4) M. extensor brevis digiti IV 5) M. extensor hallucis longus 6, 7) M. flexor digiti II, III, IV and 8) M. gastrocnemius.

retrograde fashion laterally or medially to the joint, then normograded back into the distal fragment. Small plates may also be used; however, there are scant soft tissues or skin in this area that can be used to cover the plate.

### The Tibiotarsus

A skin incision over the craniomedial aspect of the tibiotarsus provides access to the distal two-thirds of the underlying bone (Figure 42.27). The medial belly of the gastrocnemius muscle may have to be retracted from the cranial tibial muscle and fibularis longus craniolaterally to achieve access to some fractures. The cranial tibial artery, which runs over the mid to distal tibiotarsus in a craniolateral position, should be avoided when making this approach.

External fixators are ideally suited and easy to apply in this area. IM pins may be introduced from the tibial crest and normograded down through the proximal and then into the distal fragments. This positioning prevents the pin from penetrating the stifle. Plates may be used in midshaft closed fractures. External fixation can be used to repair metaphyseal fractures by placing stabilizing pins on both sides of the affected joint.

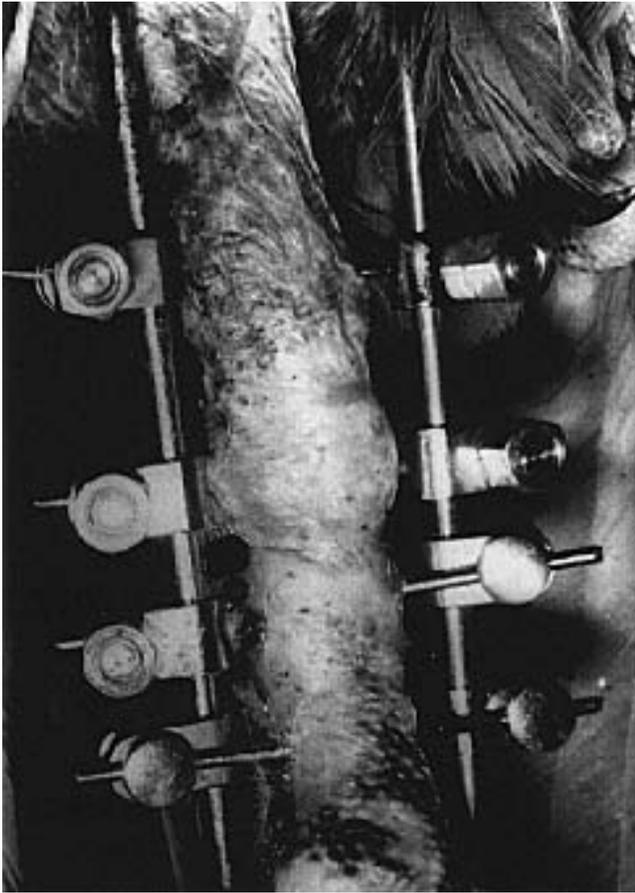
### The Femur

The lateral approach to the femur is initiated by making a craniolateral skin incision (Figure 42.28). The greater trochanter proximally and the stifle joint distally can be used as landmarks. The cranial and caudal bellies of the iliobtibialis muscle are separated using blunt and sharp dissection. The iliofibularis muscle is located caudally. With this approach, the femorotibialis medialis muscle will be located craniolateral and ventral to the pubo-ischio-femoralis muscle will be located caudally. Distally, a branch of the lateral genicular artery may require attention when working around the epicondyles and condyles.

Branches of the femoral artery may be encountered in the cranial proximal region of the femur. However, the femur is generally easy to approach except in those species that have a well developed femorotibialis medialis muscle that originates on the lateral aspect of the femur (eg, Anseriformes). In these species, the muscle is transected and elevated cranially and caudally to expose the femur.

A variety of fixation methods may be used for femoral fractures. Plates provide excellent stabilization especially in closed fractures. Type I or biplanar external fixators may be used alone or in combination with intramedullary pins. IM pins are passed through the fracture site and retrograded out through the greater trochanter laterally and then normograded back through the distal fragments. Shuttle pins are also ideally suited for this area.

Some surgeons have described a medial approach to the femur (Figure 42.29).<sup>3,16</sup> With this procedure, care must be taken to avoid the ischiatic nerve, artery and vein, which lie caudomedially. The bone is approached by separating the pubo-ischio-femoralis muscle medially. IM pins can be successfully used to repair proximal and metaphyseal fractures of the femur.<sup>21,41</sup> Retrograde insertion through the trochanteric fossa and normograde insertion from the same anatomic area can be accomplished.



**FIG 42.26** Type II external fixators are ideal for repairing tibiotarsal or tarsometatarsal fractures. A recently imported Military Macaw was presented with an open comminuted fracture of the distal tibiotarsus. The fracture was reduced through an open approach and stabilized using an external fixator. Two pins were placed in the large proximal fracture segment, one pin was placed in the small distal fracture segment and a pin was placed in the metatarsal bone, with the joint in a normal flexed position to ensure stability of the fracture. The bird was using the limb within 24 hours after surgery and healing was uneventful. The medial side of the KE apparatus was removed in three weeks, and the entire KE apparatus was removed six weeks after surgery.

### ■ Dome Osteotomy

Several techniques have been described for correcting angular limb deformities including transverse, oblique, wedge and dome osteotomies. Dome osteotomies have been successfully used to correct angular limb deformities in Psittaciformes, Falconiformes and Strigiformes, and offer several advantages over other osteotomy techniques. These include ease of planning and implantation, maintenance of maximum bone length and maximum bone-to-bone contact to facilitate healing. In addition, the dome osteotomy technique allows three-dimensional correction of the deformity while ensuring bone-to-bone contact

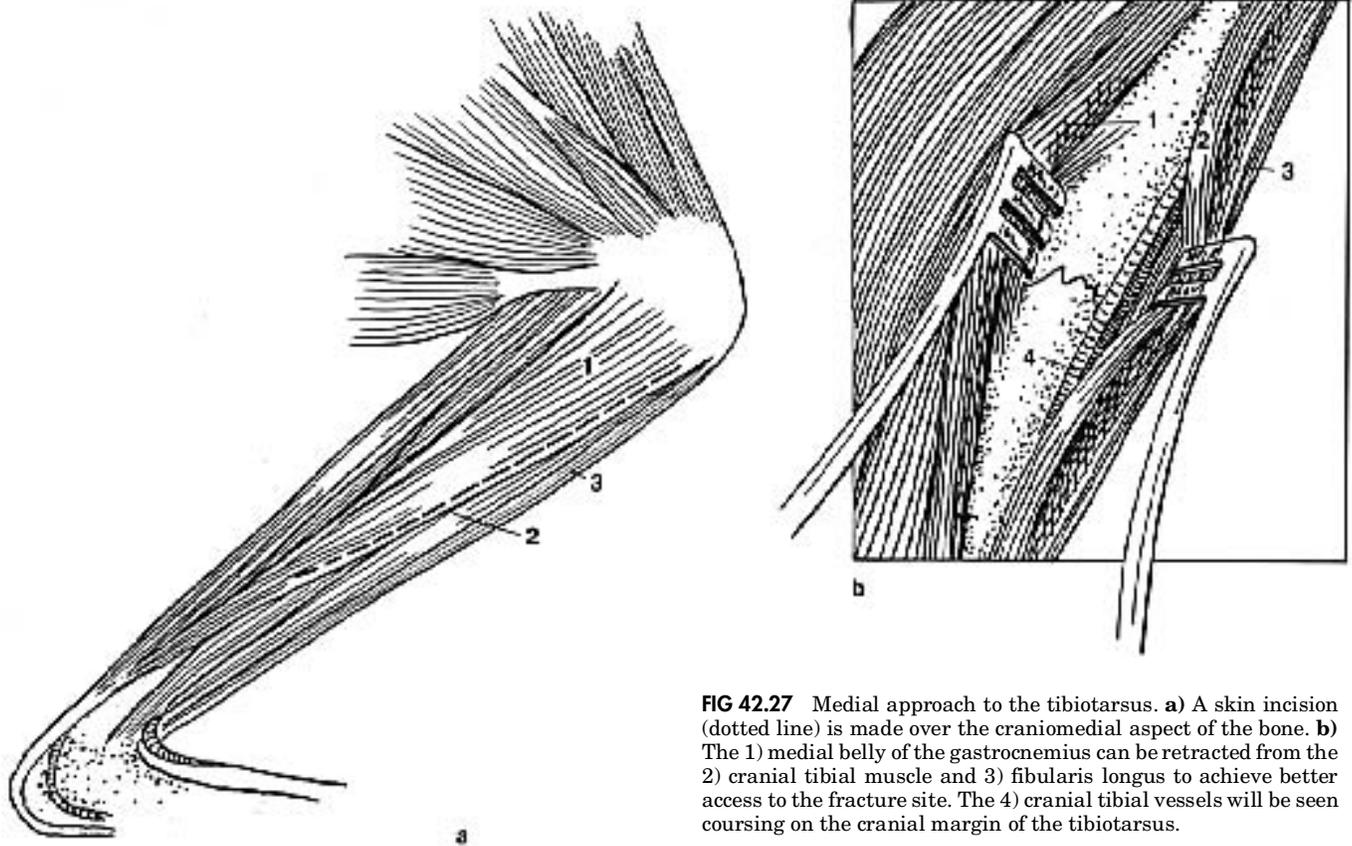
in all three planes. This technique can also be used to successfully repair fractures that have healed, producing an incorrect bone angle.

The procedure is planned from a tracing of a radiograph of the affected limb. The radiographic view that indicates the most severe angular deformity should be used for planning the procedure. Lines are drawn sagittally through the center of the distal and proximal ends of the bone. The point where the two lines intersect is the location for the dome osteotomy. The osteotomy is performed by using a drill to make a series of small holes in a half-circle fashion at the osteotomy site. The holes are then connected using a high-speed air drill and a side cutting bit. The distal bone segment can then be rotated freely in the proximal segment to allow proper bone alignment.<sup>42</sup> Appropriate fixation, generally an external fixator, is then used to stabilize the fracture during healing. Radiographic findings in birds suggest that when properly applied, a dome osteotomy site will undergo primary bone healing with minimal to no callus formation (Figure 42.30).

### ■ Repair of Luxations

Luxations have been infrequently reported in birds. Those that have been reported usually involve coxofemoral luxations secondary to a companion bird getting a leg trapped in enclosure accessories or as a consequence of struggling during restraint. Luxations of the elbow are probably the most common luxation in free-ranging raptors and are the result of trauma to the distal wing while in flight. Repair requires reduction of the luxation and stabilization of the joint. The sooner the luxation is detected, the better the chances for reduction without secondary joint damage.

Femoral head luxations are generally craniodorsal to the acetabulum. Open reduction may be successful in repairing acute cases. A femoral head osteotomy has been recommended for repair of chronic luxations of the hip. Coxofemoral luxations may be approached laterally or medially for stabilization. Spica-type splints are recommended, as well as supporting sutures, which are placed from the greater trochanter to the ilium and to the ischium. These sutures, usually of nonabsorbable materials, support the reduced hip in its normal location and are recommended in those avian species with a gliding hinge-type coxofemoral joint (noncursorial species such as most psittacine birds and raptors). It is important to remember that some cursorial species of birds (eg,



**FIG 42.27** Medial approach to the tibiotarsus. **a)** A skin incision (dotted line) is made over the craniomedial aspect of the bone. **b)** The 1) medial belly of the gastrocnemius can be retracted from the 2) cranial tibial muscle and 3) fibularis longus to achieve better access to the fracture site. The 4) cranial tibial vessels will be seen coursing on the cranial margin of the tibiotarsus.

ratites), have a ball and socket-type coxofemoral joint and these sutures would not be appropriate.

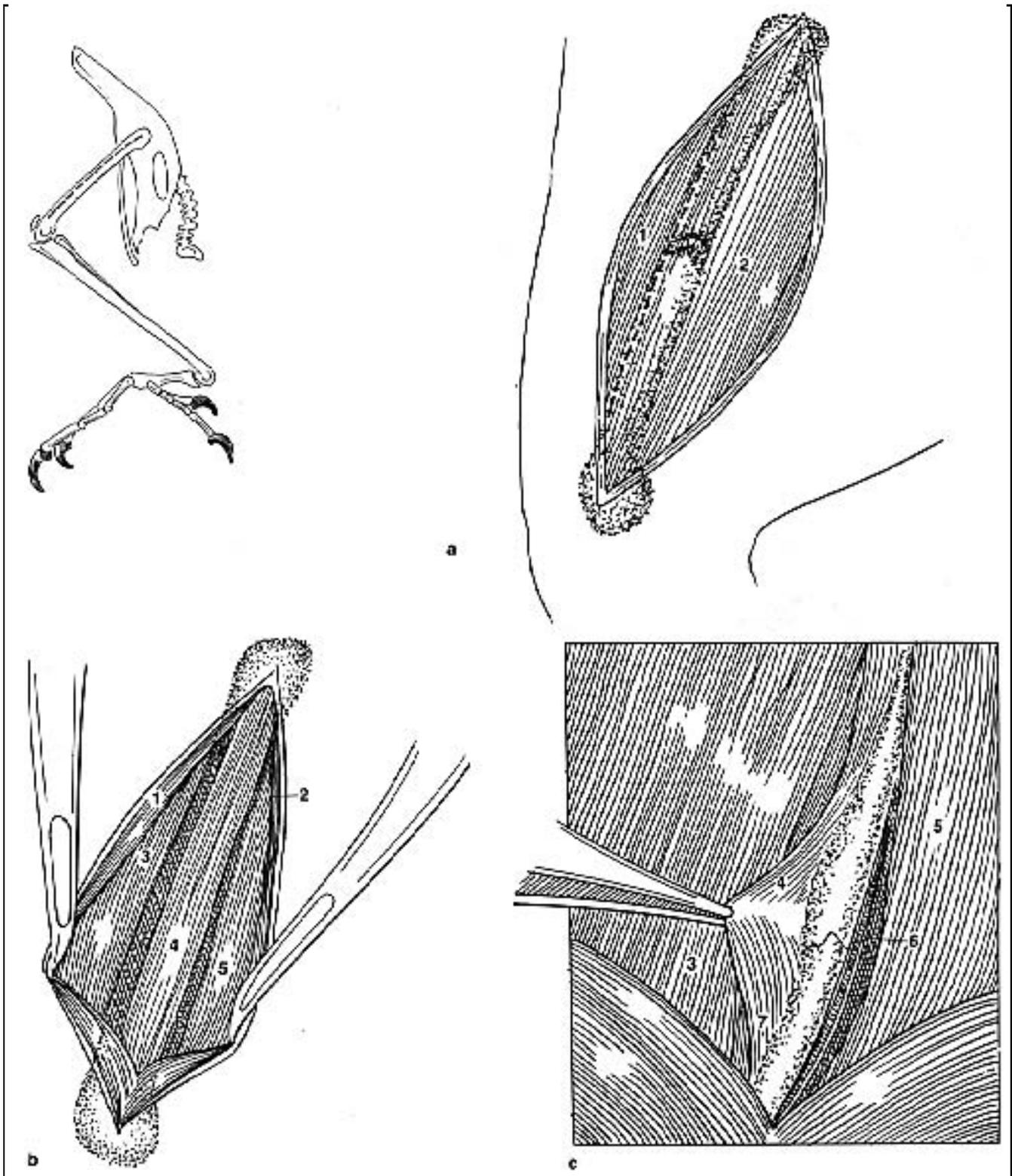
Elbow luxations in raptors usually result in a straight caudal or dorsocaudal displacement of the ulna. If treated early, closed reduction of these luxations can be made and then supported with external fixators or bandages. In one report, five of nine raptors with elbow luxations were successfully returned to the wild following closed reduction and support with external fixators or bandages for seven to ten days.

Luxations of the shoulder have also been reported in raptors. These are usually accompanied by an avulsion fracture of the ventral tubercle of the proximal humerus. These can be stabilized by application of a figure-of-eight bandage to immobilize the wing to the body for 10 to 14 days. A surgical approach may be warranted to reduce and reattach the ventral tubercle with wires or lag screws. It is important to note that luxations do not necessarily suggest a hopeless prognosis for return to complete function, particularly if addressed soon after the injury occurs.

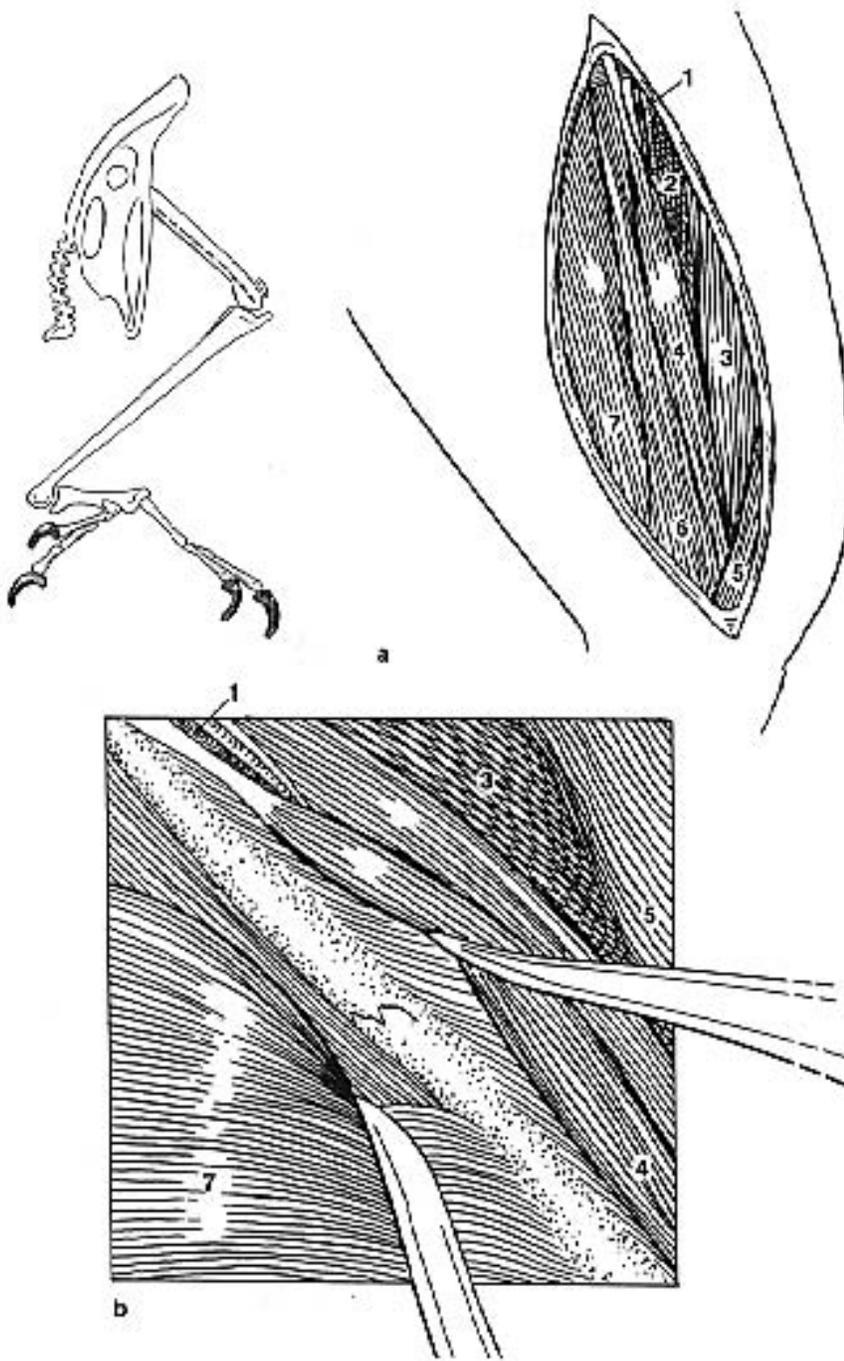
The collateral ligaments of the knee may be damaged following many traumatic events. A positive drawer sign is characteristic. Techniques used to repair collateral ligament damage in mammals can also be used for birds.

### ■ Repair of the Beak

A healthy beak is critical to the everyday survival of a bird, and minor injuries to this tissue can be serious depending upon the degree of associated soft tissue damage. Initially, therapy for any beak injury should be provided to control hemorrhage, maintain nutritional support and prevent secondary infection. Several approaches may be used to correct these injuries, and the therapeutic plan is chosen based upon the size of the patient and the nature of the fracture. Birds with beak injuries that result in defects can also readily adapt to soft diets. Prosthetic beak devices require continuous replacement as the beak grows, and must be carefully monitored to prevent bacterial or fungal infections.



**FIG 42.28** Lateral approach to the femur. **a)** A skin incision is made from the greater trochanter to the stifle joint as needed. The 1) cranial and 2) caudal bellies of the iliotibial muscles are separated, using blunt dissection. **b)** The 3) M. iliotibialis cranialis, 4) M. femorotibialis externus, 5) M. iliofibularis and 6) M. pubo-ischio-femoralis will be in view. **c)** The 7) M. femorotibialis medialis is seen on the cranial edge of the femur.



**FIG 42.29** Medial approach to the femur. 1) femoral artery, vein and nerve 2) *M. femorotibialis medius* 3) *M. iliotibialis* 4) *M. ambiens* 5) *iliotibialis cranialis* 6) *M. femorofibialis internus* and 7) *M. pubo-ischio-femoralis medialis*.

### Fractures

Mandibular fractures are the most common injury and should be addressed in two stages: repair of the bone,

and repair and realignment of the keratinized beak. Fractures through the beak will not heal side-to-side. Forces encountered by the beak must be neutralized or they will be transferred to the underlying bone and interfere with healing (Figure 42.31).

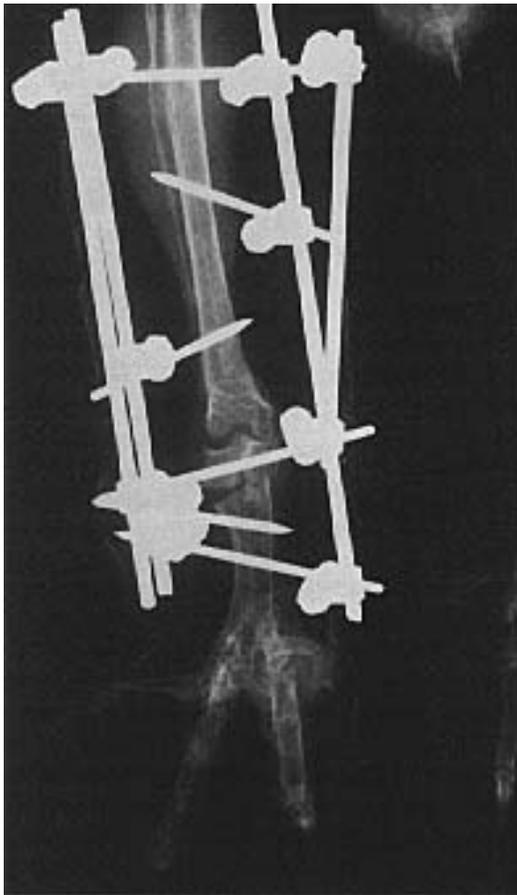
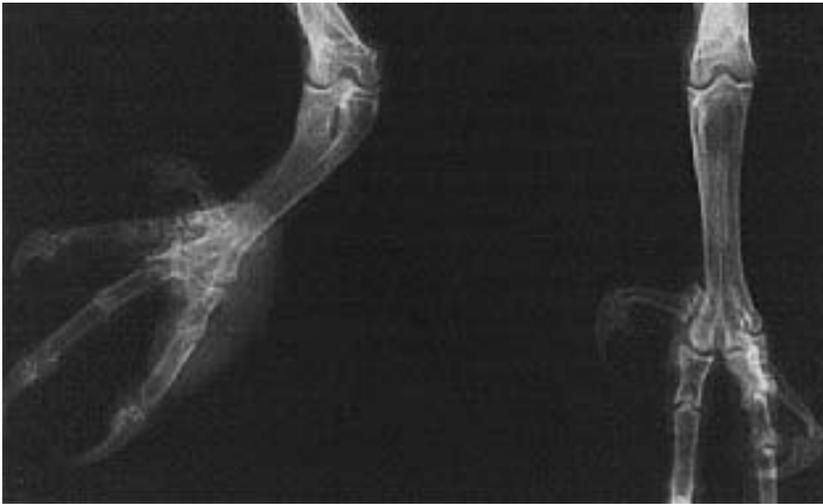
Depending upon patient size and the location of the fracture, pins, wires, cements, screws and plates may be useful in repairing mandibular fractures. For most smaller birds, hypodermic needles and cerclage wires are useful. The primary goals are realignment and stabilization of the fracture site. Pins and hypodermic needles may be inserted into the body of the mandible, antegraded across the fracture site from the rostral point of the beak, and stabilized with cerclage wires (plus or minus cements) (Figure 42.32).

Once the fracture is repaired, soft tissue injuries must be treated. If the injury is of a degloving type, every attempt should be made to reappose the displaced skin. Tissue glues are useful for facilitating this repair. If glues are not applicable, the fracture site should be dressed with a self-adherent wet/dry type dressing.<sup>8</sup>

Fractures of the upper beak are generally more difficult to manage due to the presence of small bones and the kinetic nature of the maxilla. These fractures frequently involve the quadrate and jugal bones, which are thin structures that are difficult to immobilize. The use of small hypodermic needles is usually necessary to facilitate repair, but their effectiveness is limited. Healed fractures often result in beak abnormalities such as lateral deviation of the maxillary beak.

### Beak Deformities

Beak defects that require repair may occur secondary to trauma, nutritional deficiencies or congenital abnormalities. The beak is constantly growing and any prosthesis that is applied will migrate and loosen over time. The beak



**FIG 42.30** A free-ranging Great-horned Owl neonate was presented with a valgus deformity of the right tarsometatarsus. Note the soft tissue swelling on the medial side of the foot induced by improper ambulation. A dome-shaped cut was made in the metatarsus at the point of maximum deformity. The angle of the limb was so severe that even though a dome-shaped cut was made, it appears on radiographs as an oblique osteotomy site. The osteotomy site was stabilized with a Type III external fixator. The bird had full postsurgical use of the foot and was released.

is similar in structure to a hoof, with sheets of protein overlying a substantial vascular supply and bone. The keratin layers of the bone can regenerate only if the underlying vascular bed is viable. If the vascular tissue is destroyed, a permanent defect will be present in the beak.

Two common defects in psittacine neonates are scissors beak (lateral deviation of the upper beak) and mandibular prognathism. The etiology of these problems is only speculative. If mandibular prognathism is recognized early, it can be corrected by applying gentle outward pressure to the beak for ten minutes, six to eight times daily. The same technique can be used to correct some early cases of scissors beak. If cases are allowed to progress, they must be corrected using various beak prostheses or surgical techniques to redirect the forces applied to the beak and its underlying bones.

#### Scissors Beak

A severe case of scissors beak can prevent the prehension of food and will cause abnormal wear on both sides of the gnathotheca. The gnathotheca on the side of the deviation will wear excessively, and the gnathotheca on the contralateral side will grow unabated. This problem may occur in most species of psittacine birds but appears to be most common in cockatoos and macaws. In poultry, scissors beak can be caused by inappropriate egg incubation temperatures, fungal toxins, vitamin D<sub>3</sub> toxicosis, teratogens and genetic defects.<sup>1</sup>

In theory, any slight injury to the cere or germinal beds during early development could cause scissors beak (Figure 42.33). The theory that scissors beak is caused by constantly feeding a neonate from the same side of the mouth has been disproven.<sup>1</sup> Keratin normally migrates rostrally along the surface of the beak and laterally from the vascular bed. Any change in the rate of keratin migration between these two sites, any change in the premaxilla that changes the orientation of the tip, or a malformation of the frontal bone could cause the beak to deviate laterally.

Correction procedures are designed to change the forces that direct the anterior growth of the rhinotheca (Figure 42.34). Redirected growth is achieved by applying a prosthesis to the lower beak on the affected side or by placing pins in the calvarium and



**FIG 42.31** a) An adult Blue and Gold Macaw was presented with a malaligned beak after attempting to bite a large wooden dowel. Radiographs indicated a dislocated palatine bone dorsal and rostral to the vomer bone. b,c) The dislocation was repaired by placing a pin through the frontal sinus over the maxilla and pushing caudally. The dislocation was stabilized for healing by placing wire sutures around the suborbital arch and the jugal bone ventral to the globe. The bird returned to normal function.

using rubber bands to apply pressure to the tip of the beak (similar to orthodontic techniques used in humans).

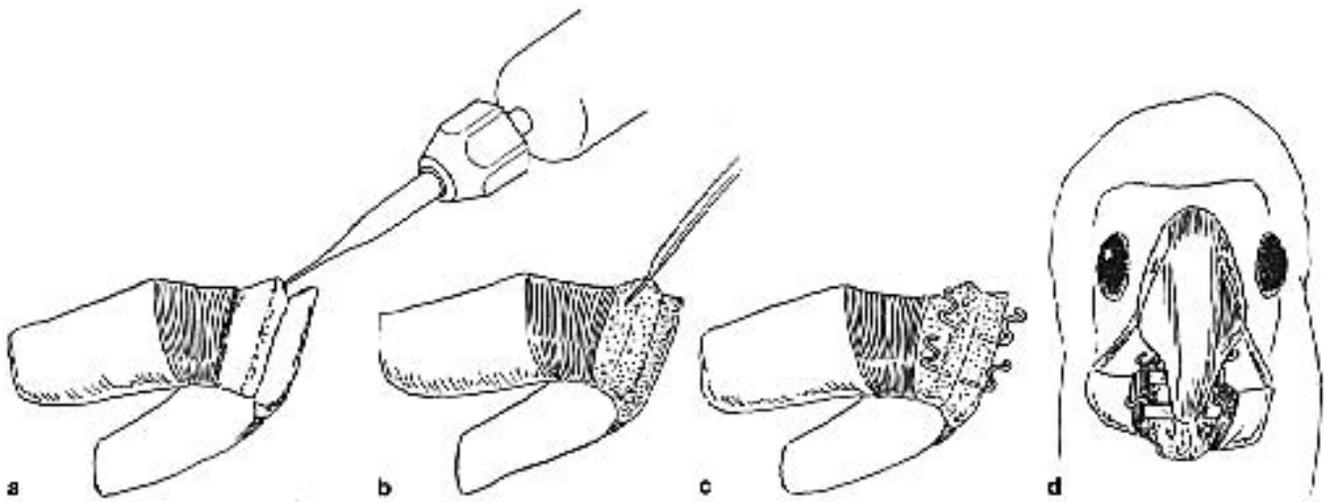
Scissors beak is easiest to repair in a young bird because the bones and beak are actively remodeling. The prosthetic device must be sufficiently anchored to the lower beak to prevent normal beak occlusion from dislocating the prosthesis. The keratin of the gnathotheca on the affected side is grooved with a Dremel tool. The grooves should be deep enough to increase the surface area for prosthetic attachment but should not be so deep as to induce hemorrhage.

The scored gnathotheca is cleaned and disinfected, and a light coat of cyanomethacrylate is applied to the area and allowed to dry. Stainless steel or nylon dental screen mesh is molded to the gnathotheca. The mesh should be extended to create a ramp that redirects the beak tip to the midline with each bite. The ramp is covered with cyanoacrylate and

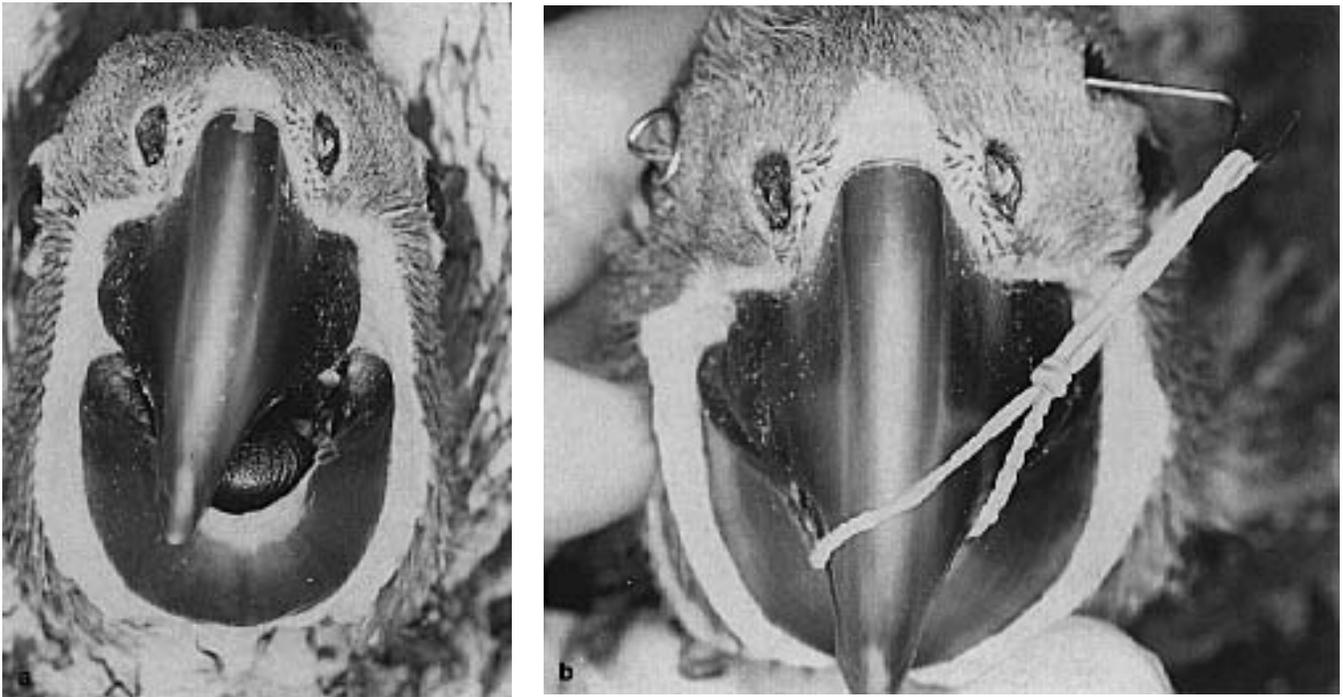
smoothed with a Dremel tool. When the defect is corrected, the implant is removed.

### Bragmathism

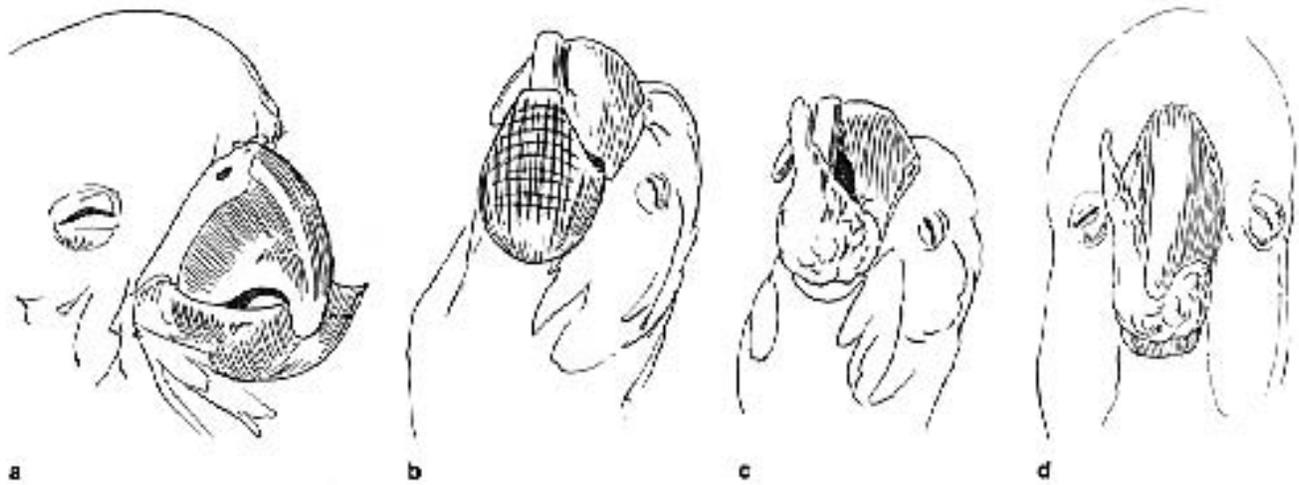
Bragmathism can be repaired by placing a KE wire into the frontal bone just caudal to the maxilla joint and caudal to the nares (Figure 42.35). A caudally directed hook is bent into the external portion of the pin. A second pin is placed in the maxilla midway down the beak at the point at which the internal rotation of the maxilla is most severe. Acrylic is applied to the area, incorporating the pins to supply extra support. A rubber band placed between the two pins will pull the beak tip into proper apposition. When the rhinotheca is properly positioned on the outer surface of the gnathotheca, the rubber band can be removed. The pins can remain in place for several more days until it is apparent that the bragmathism will not recur. When it is apparent that the problem is permanently corrected, the acrylic and pins can be removed.



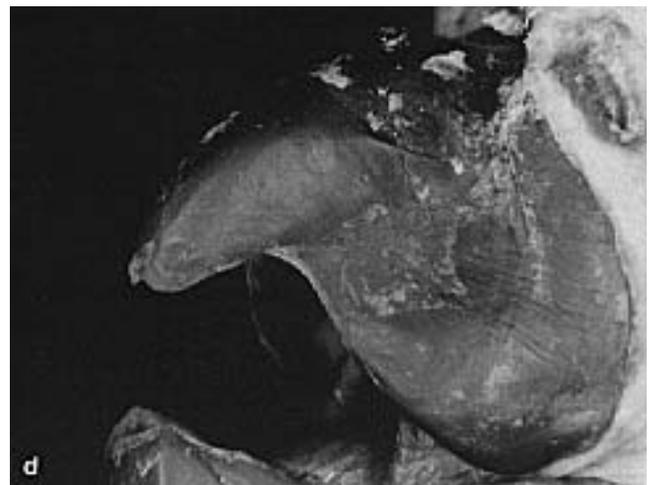
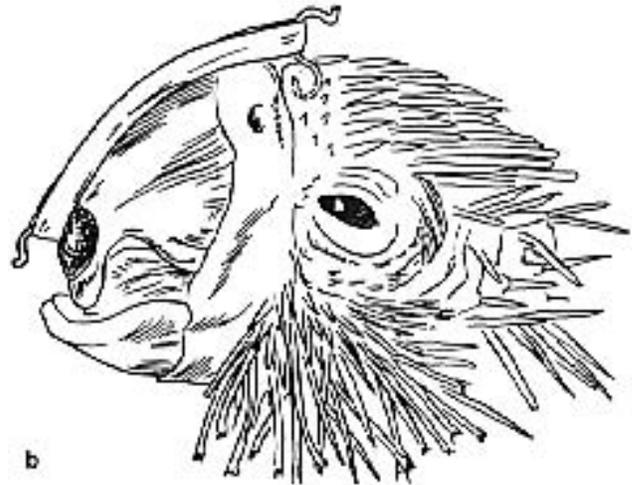
**FIG 42.32** Doyle technique for repair of a mandibular symphyseal fracture. **a)** The gnathotheca is scarified with a dental burr. **b)** The scarified area is coated with calcium hydroxide. **c)** Pins are placed through the mandible and hooks are fashioned in their ends. **d)** Rubber bands are placed around the hooks and the hardware is coated with methylmethacrylate.



**FIG 42.33** **a)** Scissors beak in a Hyacinth Macaw chick. **b)** The defect was corrected by placing a KE wire through the frontal bone and using a rubber band to place correcting pressure on the beak tip. The upper beak was properly aligned within seven days of applying the apparatus.



**FIG 42.34** a) Scissors beak can be corrected by using pins placed through the frontal bone or by using a prosthetic device attached to the gnathotheca. b) The gnathotheca is scarified with a dental burr and cleaned and covered with a light coat of dental acrylic. c) Nylon dental mesh is covered with dental acrylic to create a ramp that pushes the tip of the beak into proper alignment. d) The prosthesis after being shaped with a Dremel tool.



**FIG 42.35** a) Brachygnathism in a cockatoo neonate before repair. b,c) Repair of brachygnathism using a principle (modified Doyle technique) similar to those used in human orthodontics. A KE wire is passed through the frontal bone and hooks are fashioned in both ends. A second pin is placed into the maxilla midway down the beak. The pin in the maxilla is supported with dental acrylic. The tip of the beak is pulled into proper apposition using a rubber band. d) Patient after correction of brachygnathism.

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- a. Osteostim, Englewood, CO or Surgical Simplex-P, Howmedica Inc, Rutherford, NJ
- b. Non-sterile hoof repair material, Technont, Jorgensen Labs, Loveland, CO
- c. Hexcelite, Hexcel Medical Co, Dublin, CA
- d. Manuflex, Trade-Coop, Budapest, Hungary
- e. American Society of Internal Fixation cuttable plates, Synthes, Paoli, PA
- f. A-508 Associated Rubber Bands, Boise Cascade Co, Chicago, IL
- g. DuoDerm, Convatec (Squibb), Princeton, NJ

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## ■ C H A P T E R S

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**VII**

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**SECTION SEVEN**

**COMPARATIVE  
MEDICINE AND  
MANAGEMENT**

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**VII**

