

Pancarpal and Partial Carpal Arthrodesis

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At a Glance

► **Anatomy**
Page 180

► **Indications**
Page 182

► **General Principles of Arthrodesis**
Page 182

► **Preoperative Evaluation**
Page 184

► **Partial Carpal Versus Pancarpal Arthrodesis**
Page 185

► **Postoperative Management**
Page 189

► **Complications**
Page 190

Abstract: Arthrodesis can be an effective procedure to restore acceptable function and alleviate pain when other medical or surgical treatments are not possible. A thorough knowledge of carpal anatomy and strict adherence to the principles of arthrodesis are essential to success. The most important factor in determining whether a partial carpal arthrodesis can be performed is the stability of the antebrachio-carpal joint. Multiple techniques, including plating, pinning, and external skeletal fixation, have proven successful, and this article discusses these techniques and the complications of each.

Arthrodesis—the surgical elimination of joint motion and, ultimately, bony fusion of joint surfaces—is considered a salvage procedure for patients in which other surgical or medical treatment will not restore normal, pain-free joint function.¹⁻⁵ It can relieve pain and restore reasonable limb function. *Ankylosis* is the pathologic immobilization of a joint by a combination of osteophytosis, enthesiophytosis, intraarticular fibrosis, periarticular fibrosis, capsular adhesion, and musculotendinous contracture.⁵ Spontaneous ankylosis rarely results in bony fusion of a joint and often causes the joint to be painful. For certain joints, such as the hip, elbow, or stifle, total joint replacement or excision arthroplasty can be an alternative to arthrodesis. There have been reports of success with splinting or casting of dogs with minor hyperextension injuries; if the injury is severe, however, conservative treatment is unlikely to achieve functional results.^{6,7} In some patients, amputation may be the only feasible alternative to arthrodesis.^{2,4,5,8} The carpus and tarsus are the most common joints in which arthrodesis is performed in small animal patients.²⁻⁵

Despite some degree of gait alteration, the procedure typically results in a comfortable, functional limb. Currently, there are two broad categories of carpal

arthrodesis: partial arthrodesis (the fusing of only the distal two joints) and pancarpal arthrodesis (the immobilization of all three carpal joints). This article reviews partial and pancarpal arthrodesis in dogs and cats.

Anatomy

In both dogs and cats, the carpus has seven bones arranged in two rows, which creates three distinct joints (**FIGURE 1**). The first row consists of the radiocarpal, ulnar carpal, and accessory carpal bones. The accessory carpal bone articulates caudally with the ulnar carpal bone (**FIGURE 2**). The second row comprises four carpal bones (C1, C2, C3, and C4).

The carpal joint has three levels and is classified as a hinged (ginglymus) joint. The most proximal joint is the antebrachio-carpal (ABC) or radiocarpal joint, where the radiocarpal and ulnar carpal bones articulate with the distal articular surfaces of the radius and ulna, respectively. The middle or intercarpal (MC) joint consists of the distal articular surfaces of the radiocarpal and ulnar carpal bones and the proximal articular surfaces of C1 through C4. The carpometacarpal (CM) joint is the most distal and is made up of the distal articular surfaces of C1 through C4 and the proximal articular surfaces of metacarpals one through five. The ABC joint does

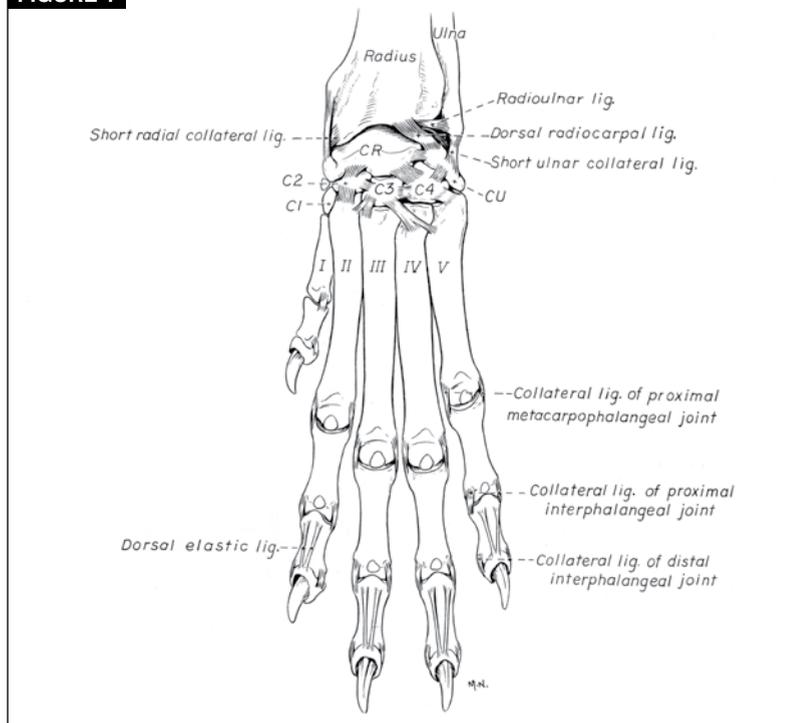
^aDr. Radasch discloses that he has received financial support from IMEX Veterinary, Inc.

not communicate with either of the other two joints, but the MC and CM joints communicate between the distal row of carpal bones.^{3,9}

Soft tissue structures responsible for supporting the carpus include ligaments, tendons, the flexor retinaculum, and the palmar fibrocartilage (FIGURES 2 AND 3). The medial and lateral collateral ligaments consist of the short radial collateral ligament and short ulnar collateral ligament, respectively (FIGURE 1). The short radial ligament originates on the tubercle of the radius above the styloid process and inserts on the most medial aspect of the radiocarpal bone. The short ulnar ligament originates on the styloid process of the ulna and inserts on the ulnar carpal bone. Palmar support is provided by the flexor retinaculum proximally and the palmar fibrocartilage distally (FIGURE 3). Two accessory ligaments originate from the free end of the accessory carpal bone and insert onto the palmar surface of the fourth and fifth metacarpal bones. These two ligaments act as a stay apparatus (i.e., a system of ligaments and tendons acting in concert to stabilize a particular joint in a physiologic position with minimal muscular energy) to stabilize the carpus. The only tendon significant to carpal stability in extension is the flexor carpi ulnaris, which originates on the caudomedial surface of the olecranon and the medial epicondyle of the humerus and inserts on the accessory carpal bone.^{3,5,10}

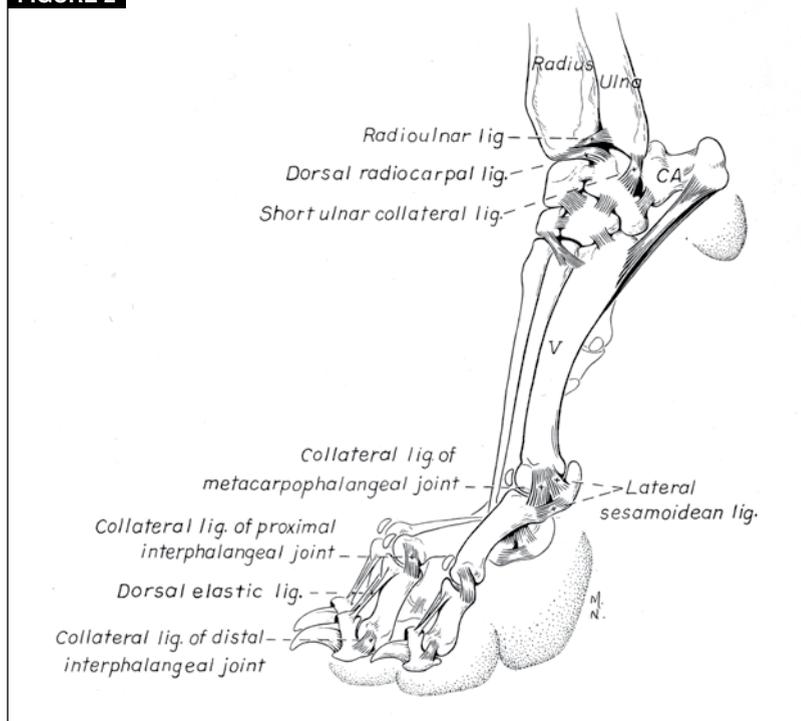
In dogs and cats, each forelimb carries approximately 30% of the weight during a normal stride.^{11,12} This weight bearing, combined with high-impact forces from running, jumping, or trauma, can predispose the carpus to hyperextension injuries. Flexion and extension in the carpus are primarily at the ABC joint and, to a lesser degree, the MC joint. The relative contribution of the ABC, MC, and CM joints to carpal range of motion is 85% to 90%, 10% to 15%, and 0%, respectively.^{5,10} The normal range of flexion is approximately 100° for the ABC joint, 40° for the MC joint, and 10° for the CM joint.⁵ The normal standing angle of the carpus is approximately 140° to 180° in dogs and 160° to 180° in cats. One study revealed a significant difference in the metacarpophalangeal joint angle when the contralateral limb was elevated, with the angle becoming more acute under increased load.¹³ However, variation exists between breeds and individuals.

FIGURE 1



Bones and ligaments of the left forepaw, dorsal aspect. C1–C4 = first, second, third, and fourth carpal bones; CR = radiocarpal bone; CU = ulnar carpal bone; I–V = metacarpals; lig = ligament. (Reprinted with permission from Evans HE, ed. *Miller's Anatomy of the Dog*. 3rd ed. Philadelphia: WB Saunders; 1993:240.)

FIGURE 2



Bones and ligaments of the forepaw, lateral aspect. CA = accessory carpal bone; lig = ligament; V = fifth metacarpal bone. (Reprinted with permission from Evans HE, ed. *Miller's Anatomy of the Dog*. 3rd ed. Philadelphia: WB Saunders; 1993:242.)

Indications

The most common indications for carpal arthrodesis are ligamentous injuries, carpal bone fracture, and carpal joint luxations or subluxations^{5,10,14-17} (FIGURE 4). Hyperextension of the carpus, which can result from either acute trauma or repetitive chronic trauma, often damages the palmar ligaments and palmar carpal fibrocartilage, leading to instability of one or more joints within the carpus^{6,8,18,19} (FIGURE 5). Shearing injuries to the medial or lateral collateral ligaments or carpal bones often cause substantial carpal instability and subsequent osteoarthritis.^{2,3,20}

Other potential indications for carpal arthrodesis include:

- ▶ Carpal joint instability due to loss of articular cartilage or injury to supporting ligamentous structures, such as that associated with erosive and nonerosive immune-mediated joint disease and septic or fungal arthritis²¹⁻²³
- ▶ Chronic osteoarthritis that is nonresponsive to medical management²⁴
- ▶ Loss of carpal bones or supporting ligamentous structures due to resection of neoplastic conditions²⁵
- ▶ Congenital malformations of the carpus

resulting in luxations or complete or partial agenesis of carpal bones²⁶⁻²⁸

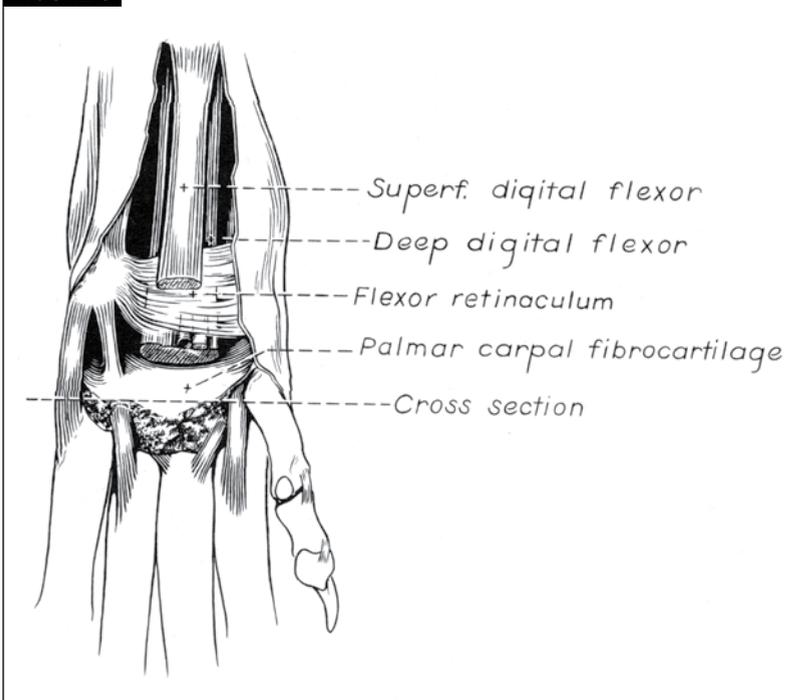
Carpal arthrodesis may also be used in patients with high radial nerve injury; however, arthrodesis is not recommended in patients that have lost cutaneous sensation in the palmar region because of the potential for self-mutilation.^{2-5,10}

General Principles of Arthrodesis

To successfully achieve partial or complete arthrodesis of the carpus, the following basic surgical principles must be strictly observed:

- ▶ Remove articular cartilage from all bones of the joint(s) to be fused. This is generally accomplished with a pneumatic bur or rongeur (FIGURE 6). Drilling multiple small holes into the subchondral bone of the joints to be fused is called *forage*, which may help stimulate early joint fusion by providing vascular access channels and additional blood supply to the newly forming bone⁵ (FIGURE 7).
- ▶ Place the joints being fused into a normal standing angle before rigid stabilization is applied. Achieving the proper fusion angle is of paramount importance; the angle is

FIGURE 3



Superficial ligaments of the left carpus, palmar aspect. (Reprinted with permission from Evans HE, ed. *Miller's Anatomy of the Dog*. 3rd ed. Philadelphia: WB Saunders; 1993:239.)

FIGURE 4



Lateral radiograph of a carpus showing an obvious antebrachiocarpal luxation.

measured on the contralateral limb while the dog or cat is standing but may need to be modified if arthrodesis is expected to shorten the limb. The more obtuse the angle is, the straighter and longer the limb will be after surgery; conversely, the more acute the angle, the shorter the limb length. In most cases, the fusion angle is slightly less (i.e., closer to 0°) than the contralateral normal angle to make up for loss of cartilage and bone. The angle most commonly used to contour the plate for a pancarpal arthrodesis is 10° to 15° of hyperextension.¹³

- ▶ Cut contact surfaces flat to produce the proper angle and increase bone contact. Unlike the stifle, the carpus is a congruent joint and does not require resection of bone end plates. As a result, carpal arthrodesis does not typically result in substantial limb shortening.
- ▶ Provide rigid stabilization of the joints to be fused, using plates or screws, internal pins and wires, tension bands, ring fixators, or external skeletal fixation (ESF) frames. Often, postoperative external coaptation is used as an adjunct to internal implants to reduce the risk of implant failure. Fixation must be rigid, and compression is preferred. Plates are most commonly used for their superior stability. Use of lag screws and Kirschner wires as the sole method of fixation is not recommended because these devices are more flexible than plates and not as well secured to bone on each side of the arthrodesis, leading to frequent failure and breakage.^{1,2,10}

Autogenous or allogenic cancellous bone graft material is inserted into the joints being fused to enhance bone formation and shorten healing time.² Cancellous bone grafts promote bone formation by three mechanisms^{29,30}:

- ▶ *Osteogenesis*, the direct introduction of osteoblasts and osteogenic precursor cells
- ▶ *Osteoinduction*, the release of growth factors that induce osteogenic differentiation in mesenchymal tissue to produce bone
- ▶ *Osteoconduction*, the physical presence of the cancellous bone trabeculae, which acts as a scaffold for blood vessels and osteogenic cells to produce bone

Osteogenesis occurs if an autogenous graft is used, whereas osteoconduction and osteoinduction



FIGURE 5
Photograph of the lateral aspect of the left forepaw in a greyhound with acute onset hyperextension injury after jumping down from a car.

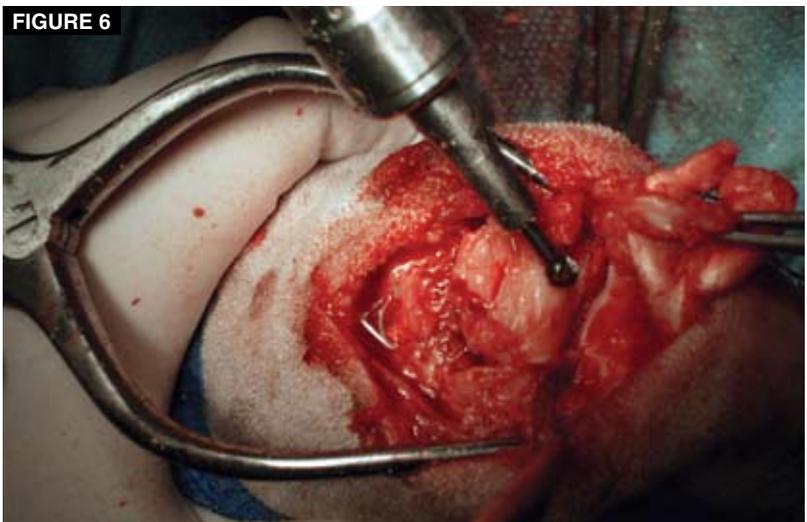


FIGURE 6
Photograph of pneumatic bur removing articular cartilage from the surface of the radial carpal bone.



FIGURE 7
Photograph after forage of the radial carpal bone created by a 1.5-mm drill bit.

duction occur with both autogenic and allogenic grafts.

Occasionally, a cortical bone onlay or inlay graft from a rib or the ilium or a commercial allograft can be used. Onlay or inlay cortical grafts are generally indicated only in patients with substantial loss of a portion of the carpal bones and are primarily useful for osteoconduction.

Preoperative Evaluation

Presurgical evaluation is very important for proper case selection. To determine which type of fixation (partial or pancarpal arthrodesis) is best for a patient, the desired postoperative activity level for both long-term use and dur-

ing the convalescent period must be identified. Owners must be made aware of the potential changes in gait and agility associated with the procedure. The type of injury also plays a major role in selecting the appropriate fixation type. For example, ESF is preferred over internal fixation for an open fracture, shearing wound, or septic joint because of the contamination associated with such conditions.

Another important consideration is the condition of the other limbs and joints. Ideally, the rest of the involved limb and adjacent joints should be functional and able to compensate for increased stress. Eward and colleagues¹¹ evaluated the effects of carpal range of motion restriction on gait analysis and found significant differences in the angle displacement of the ipsilateral shoulder and contralateral stifle, which suggests that the effect on surrounding joints may be an important consideration for arthrodesis candidates, especially those with concurrent diseases (e.g., arthritis, muscle atrophy).

Preoperative blood work to assess the overall health of the animal is always advisable before inducing anesthesia. Culture of synovial fluid from suspected septic joints or open wounds is critical, although initial cultures have a 50% false-negative rate.³¹ Cytology of joint fluid and tests for antinuclear antibody or rheumatoid factor should be conducted if immune-mediated disease is suspected.¹⁷

Because most flexion and extension occurs at the ABC joint, obtaining properly positioned stress radiographs before performing a partial carpal arthrodesis is very important (**BOX 1; FIGURES 8 AND 9**). In some patients, however, stress radiographs may not reveal damage involving the ABC joint, and hyperextension becomes apparent only after distal fusion has been performed.^{2,5}

Radiographs are also very helpful in planning the surgical procedure. Radiographs of the

BOX 1

Radiographic Findings Associated with Hyperextension Injuries¹⁰

Antebrachiocarpal joint

- ▶ An increased angle of extension is seen on a stressed lateral view.
- ▶ With chronic antebrachiocarpal injuries, radiographs show wearing of the palmar edge of the distal radius due to subluxation of the proximal carpal bones.

Middle carpal joint

- ▶ A gap can be seen between the palmar process of the ulnar carpal bone and the base of metacarpal 5; the caudal aspect of the accessory carpal bone appears tipped up (evidence of subluxation and proximal angulation).
- ▶ With chronic middle or intercarpal joint injuries, radiographs show radiocarpal and ulnar carpal bones pivoted in a distopalmar direction; the dorsodistal edges come to rest on the base of the metacarpals, creating a wide gap between the craniodorsal surface of the radius and the radiocarpal bone.
- ▶ Instability at the middle carpal joint with a loss of integrity of accessory carpal bone ligaments leads to a widening of the space between the palmar process of the ulnar carpal bone and the base of the fifth metacarpal, and the accessory carpal bone deviates dorsally.

Carpometacarpal joint

- ▶ The bases of the metacarpal bones appear to overlap the carpal bones.
- ▶ Instability at the carpometacarpal joint may lead to the proximal carpal bones overriding the distal row.

Accessory carpal joint

- ▶ Instability of this joint allows increased extension without altering the relationships of the carpal and middle or intercarpal bones. If ligaments from the accessory carpal bone to the fourth and fifth metacarpals are injured, radiographs show a movement of the caudal aspect of the accessory carpal bone proximally, approaching a parallel position with the ulna.
- ▶ Lateral subluxation of the accessory carpal bone with mild carpal hyperextension has been reported in one dog and was treated with one lag screw into the ulnar carpal bone.

BOX 2

Distribution Rates of Hyperextension Injuries¹⁰

- ▶ Antebrachiocarpal joint: 10%
- ▶ Middle carpal joint: 28%
- ▶ Carpometacarpal joint: 46%
- ▶ Middle carpal and carpometacarpal joints: 16%

affected limb, taken with the carpus stressed in hyperextension, are necessary to determine the location and extent of ligament damage (**FIGURE 9**). Standard orthogonal views and medial, lateral, and palmar stressed views are indicated. One source states that standing lateral radiographs are the most effective at highlighting the injury but might not be possible because of the size or demeanor of some patients.³ Radiographs of the normal limb, ideally in a standing position, are used to determine the desired position in which the affected joint is to be fused and can be referred to during surgery. The angle of fusion should be carefully considered in all three planes: the angle of extension or flexion, degree of varus or valgus, and proper rotational or axial alignment.⁵ Many techniques can be used to measure the proper joint angles, and ranges of normal joint angles have been published.^{2-5,10} Some surgeons bend a metal template into the proper angle by measuring it against the contralateral limb; the template is then sterilized and

used for comparison during surgery.^{5,10} Others take measurements with a goniometer, which is then sterilized.

Although radiography is the most common imaging modality for diagnosis of carpal instability, other modalities, such as computed tomography, magnetic resonance imaging, and nuclear scintigraphy, may help classify bony injuries to the carpus when radiographs or clinical signs are unclear. With nuclear scintigraphy, an obvious uptake of the radiolabeled material in the carpal bones indicates a non-specific positive result for injury or increased bone activity at the site from causes such as infection, arthritis, or neoplasia.¹⁷

Partial Carpal Versus Pancarpal Arthrodesis

The decision to perform a partial or pancarpal arthrodesis primarily depends on the joint(s) involved, the type of injury, and the owner's willingness to participate in postoperative care.

FIGURE 8



Lateral radiograph of a flexed view showing increased joint spaces at both the ABC and MC joints.

FIGURE 9



Stressed lateral radiograph of the left carpus. Note the osteoarthritis at the MC and CM joints as well as a small gap at the ABC joint. The syringe case used to hyperextend the distal forepaw is visible at the bottom of the radiograph.

Indications

Partial Carpal Arthrodesis

Partial carpal arthrodesis fuses the MC and CM joints. Because the ABC joint is responsible for 85% to 90% of the carpal range of motion, preserving the ABC joint is highly desirable if the joint is normal. Fortunately, approximately 90% of all hyperextension injuries involve the MC and/or CM joint (**BOX 2**).

Other indications for partial carpal arthrodesis include luxation or fracture of the MC or CM joints. Such injuries often cause damage to the ligamentous structures of the accessory carpal bone, which can be stabilized with wires and screws. Any injury to the accessory carpal bone or ligaments must be treated to reestablish stability; otherwise, the fusion may fail secondary to breakdown at the ABC joint. Stability will be preserved as long as the ligaments between the base of the accessory carpal, ulnar carpal, and fifth metacarpal bones are intact.

One study of partial carpal arthrodesis in dogs reported that 100% of owners were pleased with the function of the treated limb 32 months after surgery; some degree of hyperextension remained in 11% of the cases, and degenerative joint disease was identified on radiographs in 15.5% of the cases, but no dog required sub-

sequent pancarpal arthrodesis.³² A 1991 study reported that only 50% of partial arthrodesis cases regained full limb function with plate fixation. The major complication cited was residual lameness due to interference with motion in the ABC joint from straight dynamic compression plates.³³ A partial arthrodesis of just the ABC joint has been reported but is not recommended because the stresses placed on the MC and CM joints predisposes them to increased laxity and degenerative joint disease.³⁴

Pancarpal Arthrodesis

If ABC joint stability and function are concerns, a pancarpal arthrodesis may be performed to reduce the risk for future problems. Pancarpal arthrodesis essentially eliminates all movement in the carpus and, depending on the angle of fusion, may lead to a pronounced circumduction of the lower limb in the swing phase of the gait and during the walk or trot. The stride phase can be noticeably shortened.⁸ In one study of pancarpal arthrodesis, 97% of owners reported an improvement in gait and 74% reported normal use of the affected limb.³⁵

Complications associated with straight plates, such as metacarpal fractures or broken or loose implants, have led to the development of specialized plates (2.7-mm/3.5-mm hybrid dynamic compression plates; Jorgensen Laboratories, Loveland, Colorado) for pancarpal arthrodesis; the plates are designed for smaller screws to be used over the metacarpal bones and larger screws to be used proximally to decrease the risk for iatrogenic fracture^{2,36,37} (**FIGURE 10**). Current recommendations are to use a screw with a diameter no larger than 40% the width of the bone.² The screw holes of these plates are also located to conform to the canine carpus, with a central hole that can accommodate a screw of either size positioned over the radiocarpal bone. The plates are also bent at 5° to decrease the need for contouring and were shown in a recent study to attain an 8.1% increase in mean bending strength compared with a basic 3.5-mm dynamic compression plate.³⁸ Veterinary cuttable plates have also been used for pancarpal arthrodesis with a good clinical outcome.³⁹

Surgical Procedures

Craniocaudal bending is the most significant force leading to potential disruption of arthro-

QuickNotes

Stress radiographs are very important in deciding which method of arthrodesis (partial or pancarpal) is appropriate for the patient.

FIGURE 10

Orthogonal views of pancarpal arthrodesis done by plating. Note the specialized plate and the screw placement (four screws are placed in the radius, one in the radial carpal bone, and four in the third metacarpal bone).



Dorsopalmar view.

Lateral view.

desis. Ideally, plates should be placed on the tension (convex) side of the joint or bone to decrease the risk for plate failure.^{2,5,10} A plate applied to the compression (concave) side absorbs most of the bending load, and the bone absorbs almost none. As such, the plate must be stiffer than the bone and well secured to resist failure. During normal weight bearing, a tension surface plate produces interfragmentary compression and the plate is loaded in tension. Plates tolerate tensile loads very well and are relatively resistant to cyclic failure. Plates placed on the compression surface are subject to cyclic bending forces, which lead to fatigue failure because most weight bearing is on the plate, not the bone. Although placement on the tension side would be ideal, most plates are placed on the compression side because the surgical approach is much easier and iatrogenic damage to vital structures is less likely.

Partial Carpal Arthrodesis

A common technique for partial carpal arthrodesis uses a T plate extending from the radiocarpal bone onto the third metacarpal bone with the cross of the T positioned proximally (FIGURE 11), which provides stable fixation for distal fusions. Despite decreased range of motion in the ABC joint, the long-term results in one study were satisfactory.⁴⁰ T plates can be used for distal joint fusion, but care must be taken because they can impinge on the dorsal surface of the radius during extension, causing pain and lameness. Plate removal after fusion might reduce these problems.

Three other techniques are used:

- ▶ **Cross pins** are placed, starting in the second and fourth metacarpal bones and seated into the radiocarpal and ulnar carpal bones rather than the radius (FIGURE 12). Haburjak and associates³⁷ reported that this technique was easy to perform and allowed for latitude in pin placement. In their study, nine of 23 carpi had less-than-ideal positioning of the implants after surgery, but only one patient developed unsatisfactory results. Bandage-related complications and implant migration rates were approximately 30% but were not directly related to premature loss of stability.³³
- ▶ **Multiple small pins** are driven proximally from the second, third, and fourth metacarpal bones via the metacarpophalangeal joints

or slots in the metacarpals and across the MC joint into the carpal bones. The carpus is flexed to 90° when reducing the MC and CM joints as the pins are seated.

- ▶ **A circular or linear ESF** frame is secured by placing a pin and/or wire in the radiocarpal bone and base of the metacarpal bones. A ring at the distal radius is sometimes placed to give added security to the construct but does not fuse the ABC joint.

Pancarpal Arthrodesis

Although rigid fixation is recommended for all types of carpal fusion to provide stability and reduce complications, it is particularly necessary with pancarpal arthrodesis. The cranial or dorsal surface of the joint is most commonly plated because of the ease of the approach, even though this puts the plate on the compression side of the limb (FIGURE 10). Three to four screws are placed in the radius, one in the radiocarpal bone, and three to four in the third metacarpal bone. The disadvantages of this technique are its reliance on bone purchase in only one MC bone and the risk for metacarpal fracture. In large breeds, two cranial plates can be applied.^{2,5,10}

QuickNotes

Plates tolerate tensile loads very well and are relatively resistant to cyclic failure.

FIGURE 11

Orthogonal radiographs of a partial carpal arthrodesis done with a T-plate. The horizontal bar of the plate is positioned over the radiocarpal bone, and the vertical bar is secured to the third metacarpal bone.



Husle⁴¹ described a plate-rod technique in which a plate is applied and cross pins are placed from the metacarpals to the radius. The plate is bent to provide 10° to 15° of extension to mimic or achieve a normal standing angle. Leaving the plate straight causes excessive stress on the metacarpophalangeal joints.^{2,5} A dynamic compression plate has the advantage of providing compression between screw holes and between multiple joint surfaces. Radiographic evidence of healing is often noted as early as 4 to 5 weeks after surgery.⁴²

The use of a medial plate technique has also been reported.⁴³ The advantages include excellent purchase for distal screws through multiple metacarpal bones as well as greater biomechanical strength. Excision of the first phalanx may be necessary but is not difficult; however, contouring the plate to obtain the proper angle and alignment can be very challenging. To some extent, the degree of hyperextension is obtained by adjusting the position of the plate on the bones and the contour of the proximal aspect of the plate along the medial aspect of the distal radius.

From a biomechanical viewpoint, applying the plate on the palmar surface of the joint is the most desirable, but the extensive soft tissue dissection required makes this method

difficult. The technique was outlined in 1982 by Chambers and Bjorling,⁴⁴ who at the time did not believe the approach was too challenging. Deep dissection, including transection of the flexor retinaculum, tendons of the deep digital flexor tendon, and flexor carpi radialis, is performed. The plate needs to accommodate a gradual bend of approximately 15° to 20°, and the plate width and screw size are dictated by patient size. Although this technique does require a longer surgical time, the authors concluded that the advantage of a biomechanically stronger implant outweighed the disadvantages.⁴⁴ This technique has not gained wide acceptance even though the most common complications with arthrodesis are implant failure and nonunion.

Linear ESF has been used for arthrodesis for many years. Although linear ESF techniques are primarily recommended in cases of severe trauma with bone loss and open or infected joints, they can be used in patients without such injuries.^{20,45} Many types of frames (e.g., Kirschner–Ehmer, Securos, acrylic) are used for linear ESF. In one study, an acrylic frame was shown to be mechanically superior to a Kirschner–Ehmer frame for compression and shear loads and to be equally strong for torsion loads; acrylic frames have the added advantage of uncomplicated application for smaller patients.⁴⁶

A newer technique using circular ESF for arthrodesis has also been reported. In this technique, two wires per ring are placed in a closed fashion. Care must be taken to route the wires through a safe corridor, without passing them through large muscle bodies or neurovascular structures. Typical pin/ wire placement includes the mid and distal radius, across the proximal aspects of the metacarpals, and more distally in the bodies of the metacarpals (**FIGURE 13**). A noted disadvantage is difficulty in attaining the proper angle of extension. One study reports that the amount of stiffness and maximum load to failure did not differ significantly between ESF and a dynamic compression plate.³⁶ However, failure with plates was typically fracture of the third metacarpal bone, while failure with ESF was seen with deformation of the Kirschner wires.³⁶ Some authors believe that ESF is advantageous because of the less invasive approach, the avoidance of bandage or splint complications, and the



Dorsopalmar view of partial carpal arthrodesis done with cross pins. The cross pins start in the second and fifth metacarpal bones and emerge from the carpal bones.

absence of the need to remove implants at a much later date.⁴⁷ The most common complications of ESF are pin loosening and pin tract infections; however, fractures and sequestra have been reported, and owners need to be prepared for the postoperative home care.

One study cites 100% success in pancarpal fusion using circular ESF in 10 limbs.⁴⁷ As noted, achieving the proper angle of fusion can be challenging, and these dogs had a more acute angle of fusion. This is partly related to the principles of external fixation, which dictate that the desired position of the limb lie eccentrically within the ring. The average time to healing was 12 weeks, similar to that for plating techniques, and the morbidity associated with a limited approach to the carpus was much lower. An important part of ESF is the lack of external coaptation, which decreases not only the cost to the owner (i.e., frequent bandage changes) but also the possible complications (e.g., bandage sores, muscle atrophy).⁴⁷

Postoperative Management

Arthrodesis is an extensive, invasive surgery that causes more soft tissue trauma than typical internal fixation and results in more inflammation. As such, significant postoperative swelling and compromised circulatory drainage of the distal limb are possible. A coaptation bandage is typically applied to these patients immediately after surgery. The bandage is changed as swelling decreases; ultimately, a long-term splint is applied if plates or pins were used for stabilization. When using ESF, a large, soft, padded bandage with absorbent sponges packed between the skin and the construct is applied immediately after surgery. This bandage is changed in a few days if strikethrough is present and then left on for approximately 1 week. The bandage is then downsized to a “bumper bandage” (covering just the rings or bars) and changed weekly.

Radiographs are taken immediately after surgery to allow assessment of the angle and alignment of the joint and implant. Repeat radiographs are taken every 6 to 8 weeks to assess healing until bony fusion is complete. The pattern of osseous union within the joint spaces is influenced by the method of articular cartilage removal, width of the maintained surfaces, placement of bone graft, and presence of any remnants of dense subchondral bone plate. In the first 4 to 8 weeks after surgery, the

opacity of the joint spaces progressively and uniformly increases as the spaces are bridged by new bone trabeculae in response to the bone graft. Radiographic healing slows after 9 weeks, according to one source, because of stress protection by the plate, which is one indication for plate removal.⁴² During this time, the dense subchondral bone is resorbed and remodeled, but complete remodeling may take 6 to 12 months.

Over time, cancellous bone adjacent to the metaphysis becomes continuous with that bridging the arthrodesis. If healing is disturbed, delayed, or arrested, the joint space remains radiolucent. There will be widening of the joint space if any instability develops before complete healing because of resorption of the newly formed bridging bone. Most arthrodeses heal with minimal callus around the periphery of the joint (unless callus was present at the time of surgery or extensive bone grafts were used). This lack of callus seems related to the stable fixation methods used and the normal absence of periosteum at these joints. A study investigating healing after dorsal pancarpal arthrodesis revealed that neither sex, age, body weight, nor immediate versus delayed surgery had any influence on healing.⁴²

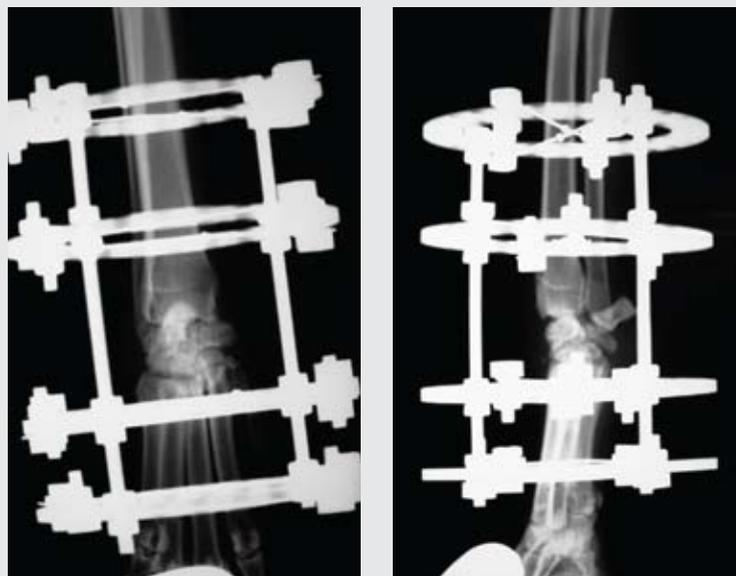
Owners can usually expect partial weight

QuickNotes

External skeletal fixation is an excellent technique to use in cases of shear or open wounds.

FIGURE 13

Orthogonal views of pancarpal arthrodesis done with circular ESF.



Dorsopalmar view.

Lateral view.

bearing after 1 to 2 weeks and full weight bearing by 2 to 4 months. At no time during the healing process should instability be detected. One recent study reported that as many as 83% of working dogs were able to return to most of their former duties after unilateral pancarpal arthrodesis fixation.⁴⁸ Exercise restriction is extremely important in the immediate postoperative period (6 to 8 weeks or until bony healing is confirmed) because any unregulated activity will subject the tissue to undue strain and could lead to early implant failure or loosening. ESF frames require more attention by owners. Daily pin tract cleaning and hydrotherapy are helpful to decrease morbidity associated with these implants.

Complications

When dealing with a low-motion joint like the carpus, limb function is usually excellent after surgery and dogs can be expected to resume such activities as running and jumping.^{1,5} Even some working dogs have been able to return to duty after the requisite healing period.

The principal features of a failed arthrodesis include continued lameness, continued instability at the joint, widening of the joint space(s) on radiographs, sclerosis of metaphyseal bone, and loose or broken implants. The most serious complication is a nonunion accompanied by failure of the implants with or without a septic joint.^{1,2,5,10} Two important causes of nonunion or malunion are incomplete removal of articular cartilage and the lack of an autogenous or allogenic bone graft.^{2,5,10} Failure to use bone grafts increases healing time, which makes the joint more vulnerable to instability⁸ and makes premature implant loosening and failure more likely.^{5,29} The insertion of a graft decreases the time to fusion by 4 to 8 weeks. Inadequate reduction of adjacent bones can lead to poor bone-to-bone contact, which slows healing. Failure to achieve a complete osseous union results in an unstable joint and painful ankylosis.

Another common complication is bandage or cast sores leading to abraded skin, possible infection, and pain. Owners must ensure that the bandage stays clean and dry. Bandages should be changed every 10 to 14 days (more often if the bandage becomes wet or soiled or slips), and frequent bandage changes can become costly. This complication is the primary

reason some surgeons prefer ESF techniques.

Diaphyseal fractures are another possible complication, especially with pancarpal arthrodesis. The ends of a plate can also act as stress risers—the abrupt change in material stiffness further increases the risk for fracture. Metacarpal bone fractures at the distal end of the plate are seen in a small percentage (9.4%) of patients with pancarpal arthrodesis, especially if the plate extends only a short distance onto the metacarpal bone. Recommendations currently are that the plate cover at least 50% of the length of the third metacarpal bone and that screw width not exceed 40% of the bone diameter.⁴⁹

Implant loosening or breakage can be the result of technical errors in implant placement or size, unrestricted activity, or insufficient external coaptation.⁵⁰ Late implant loosening, leading to pain, lameness, or intermittently discharging sinuses, usually happens approximately 6 months after surgery. Other complications include failure of arthrodesis due to infection and misalignment of joints and implants due to improper angle of fusion. Irritation of the extensor tendons or other overlying soft tissue by a plate can also lead to morbidity because of the minimal soft tissue covering available in these locations.⁵¹ All these complications are acceptable reasons to remove plates or other implants after healing is complete.

Conclusion

Carpal injuries, especially those caused by motor vehicle accidents and falls from heights, are common in companion animals. According to one source, both pancarpal and partial carpal arthrodesis provided excellent limb function in 80% of cases when used for hyperextension injuries, and the remaining 20% were substantially improved with varying degrees of limb dysfunction.³ Although some argue that pancarpal arthrodesis can be used for any indication, partial carpal fusion techniques have been proven reliable when the ABC joint is unaffected, which is in approximately 90% of cases.^{10,33} A study by Denny and Barr³³ documented return of full limb function in only 50% of cases treated by partial carpal arthrodesis. One study showed good results for partial arthrodesis 32 months after surgery, with 100% of owners pleased with their

QuickNotes

Most postoperative complications are associated with technical errors in implant size or placement, activity level, or insufficient coaptation.

pet's function. There was still some degree of hyperextension in 11% of cases, and degenerative joint disease was identified on radiographs in 15.5% of cases, but no further surgery was necessary.³² Partial carpal arthrodesis has the benefit of allowing almost normal motion in the carpus.

Pancarpal arthrodesis is used more often than partial carpal arthrodesis; even though motion in the carpus is eliminated, reasonable function of the limb remains. Many techniques have been discussed. In one study of pan-

carpal arthrodesis, 97% of owners reported improvement in gait and 74% reported normal use of the affected limb.³⁵ Another study found no presence of lameness during a 6- to 12-month follow-up period and reported that the complication rate was low.⁴⁷

Arthrodesis is an excellent surgical option for injuries involving the carpus and allows reasonable function of affected limbs with proper presurgical planning and postoperative management. **C**

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3 CE
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CE TEST 2

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1. Which statement regarding arthrodesis is true?

- Arthrodesis is the immobilization of a joint by a combination of osteophytosis, enthesiophytosis, intraarticular fibrosis, periarticular fibrosis, capsular adhesion, and musculotendinous contracture.
- Arthrodesis will not restore pain-free joint function.
- Arthrodesis is defined as the surgical stabilization and removal of joint motion by bony fusion of joint surfaces.
- Arthrodesis is recommended in select joints, such as the hip, elbow, or stifle.

2. Which anatomic structures are important in stabilizing the carpus?

- palmar fibrocartilage, short radial ligament, and extensor carpi radialis tendon
- short ulnar ligament, short radial ligament, flexor retinaculum, palmar fibrocartilage, and accessory ligaments
- short ulnar ligament, short radial ligament, flexor retinaculum, and abductor pollicis longus tendon
- palmar fibrocartilage, superficial digital flexor tendon, and short radial ligament

3. Most flexion occurs at which joint space?

- ABC
- MC
- CM
- the same amount of flexion occurs at ABC and MC

4. Which statement regarding the general principles of arthrodesis is true?

- The final angle of fusion does not need to be considered.
- Articular cartilage must be removed from all bones of the joint(s) to be fused.
- Bone grafts can be inserted into the joints being fused but do not enhance bone formation or shorten healing time.
- Rigid stabilization of the joints to be fused is unnecessary.

5. _____ is/are not a good indication for arthrodesis.

- Ligamentous injuries, carpal fractures, and luxations
- Congenital malformations leading to luxations
- Chronic osteoarthritis or immune-mediated disease leading to instability
- High radial nerve injury

6. Which statement regarding radiographic findings with carpal instabilities is false?

- Instability at the CM joint may lead to the proximal carpal bones overriding the distal row.
- With an instability of the MC joint, a gap between the palmar process of the ulnar carpal bone and the base of the fifth metacarpal is seen and the caudal aspect of the accessory carpal bone appears tipped proximally.
- With chronic ABC injuries, radiographs show wearing of the palmar edge of distal radius due to subluxation of the proximal carpal bones.
- Decreased angle of extension is seen at the ABC joint on a stressed lateral view.

7. When deciding between partial or pancarpal arthrodesis, which is the most important factor?

- which joint(s) is/are affected
- the increased cost (to the owner) of pancarpal arthrodesis
- the length of time in external coaptation
- the difference in weight bearing on the contralateral limb

8. The most common method of pancarpal arthrodesis is

- medial plating.
- ESF.
- dorsal plating.
- cross-pinning.

9. Which statement regarding the use of circular ESF for carpal arthrodesis is true?

- It is used only with open or infected wounds.
- It does not require any additional equipment compared with traditional linear ESF.
- It can be used with success in dogs without open wounds to avoid bandage or plate complications.
- Producing the proper angle of fusion is very easy with this technique.

10. Which of the following is the most serious complication of arthrodesis?

- nonunion
- diaphyseal fracture of the third metacarpal
- implant loosening or breaking
- osteomyelitis