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Fixation of Acute and Selected Nonunion Scaphoid Fractures

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Techniques in fracture treatment are evolving toward the use of indirect reduction and percutaneous fixation. Several studies have confirmed that scaphoid fractures can also be treated with percutaneous fixation, achieving high rates of union and promising functional outcomes.[1–3] Scaphoid fractures frequently have associated ligamentous injuries that can lead to long-term pain and dysfunction if undiagnosed or untreated. Arthroscopy provides a powerful tool to diagnose and treat these associated injuries. Additionally, it can assist in determining the adequacy of fracture reduction. Lastly, arthroscopy is useful in grading scaphoid fractures and nonunions. This chapter describes our technique treatment of scaphoid fracture and its associated injuries.

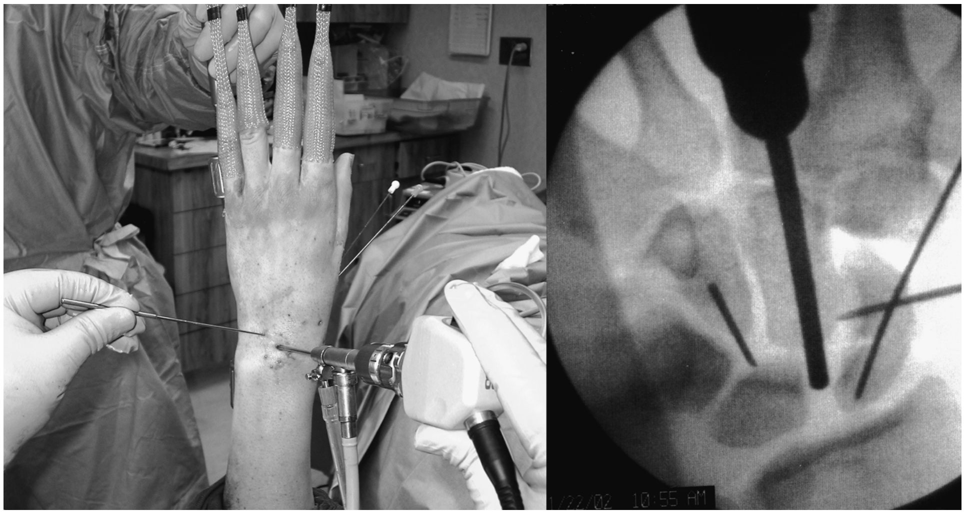
INDICATIONS

The indications for arthroscopically assisted repair of scaphoid fractures and nonunions are similar to the indications for open repair, as long as treatment goals can be accomplished. Small joint arthroscopy is used in tandem with mini-fluoroscopic imaging to evaluate and treat scaphoid fractures, ligament injuries, and fracture nonunions. These tools allow for traditionally open techniques to be adapted to minimally invasive procedures, sparing uninjured soft tissue such as stabilizing ligaments (i.e., scapholunate ligament) and the tenuous blood supply necessary for carpal and ligament healing (Figure 15.1A). Indications for treatment of scaphoid injuries have evolved since the successful adaptation of these minimally invasive procedures. These techniques have permitted effective treatment of scaphoid fractures and selected nonunions with a high union rate and minimal complications.[1–3] The indication for arthroscopically assisted treatment of scaphoid injuries can be divided into absolute and relative indications and contraindications (Table 15.1).

CLASSIFICATION AND PREOPERATIVE EVALUATION

The goal of a classification system is to permit accurate communication of an injury and evaluation of treatment methods. To this end there exist a variety of scaphoid fracture classifications, which do provide a reasonable description of the injury but have been less valuable as tools for evaluation of the efficacy of treatment. Fractures have been classified by anatomic location or direction of the fracture plane.[4] However, the most widely used classification is the Herbert classification, which attempts to classify fractures according to their stability.[5,6] This classification also attempts to classify scaphoid nonunions, but is not detailed enough to be a valuable tool in evaluating treatment results. The causes of treatment failure are multifactorial; among these are included the scaphoid's tenuous blood supply and fracture stability.[7] Unfortunately, standard radiographs are poor tools for effectively evaluating bone stability, displacement, viability, and healing potential.[8] Previous classification systems relied on standard radiographs and did not take into account the arsenal of diagnostic modalities presently available, including computerized tomography (CT); magnetic resonance imaging (MRI); and dynamic imaging with mini-fluoroscopy, arthroscopy, and bone biopsy to direct treatment. Proximal scaphoid fractures are at risk for avascular necrosis. Fracture location can suggest bone viability, but MRI and bone biopsy will provide more accurate assessment. Oblique fractures of the scaphoid have been reported to be unstable, and it is difficult to provide rigid fixation. Correct knowledge of the fracture plane can be important, but standard radiographs are limited. Computerized tomography of the scaphoid fracture will provide better information on fracture plane and displacement.

Utilizing the above tools, fractures are graded using location and a modification of the Herbert scaphoid fracture classification system.[5,6] Ligament injuries are graded using the Geissler classification system.[9] Slade and Geissler developed a classification scheme for management of scaphoid nonunions in Table 15.2. Failed scaphoid healing is defined as failed union by 3 months. Using CT, the gold standard for determining scaphoid union, some authors have determined average scaphoid healing to occur between 3 and 4 months.[8] If union has not occurred by this



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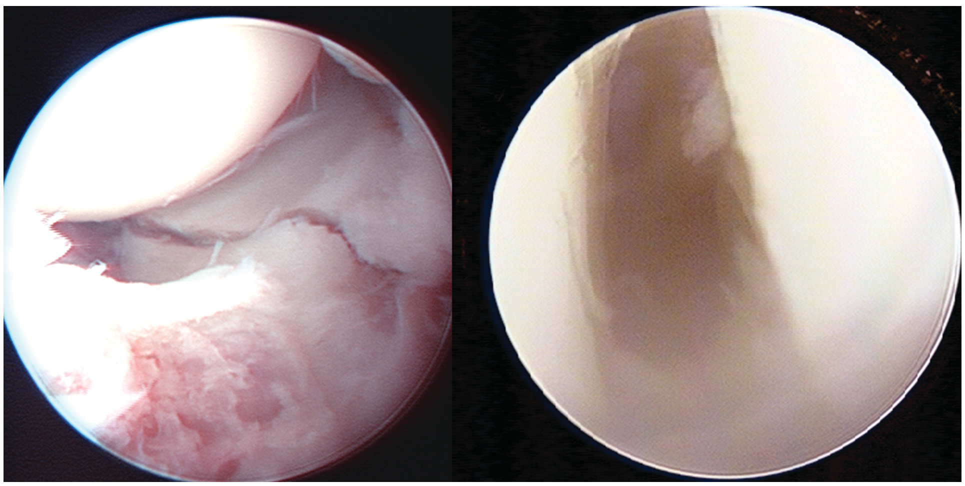

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FIGURE 15.1. **A.** Arthroscope able to be passed through a scapholunate tear. **B.** Evidence of bone bleeding from a proximal pole.

TABLE 15.1. Indications for Treatment.
Absolute indications
Displaced scaphoid fractures
Fractures of the proximal pole
Fractures with delayed presentation
Scaphoid fractures with fibrous unions without displacement
Nondisplaced scaphoid nonunions with minimal sclerosis
Combined injuries including scaphoid fractures
Distal radius
Other carpal bones (i.e., capitate fracture)
Ligament injuries (i.e., transscaphoid dorsal perilunate dislocation)
Polytrauma
Relative indications
Stable scaphoid fractures
Patients desiring early return to work or avocation
Contraindications
Scaphoid nonunions with severe cystic sclerotic changes and deformity
Pseudoarthrosis
Avascular necrosis
Nondisplaced pediatric injuries (distal pole)

time with conservative treatment, then surgical repair is recommended. If signs of failed union present earlier, intervention is warranted.

Scaphoid fractures presenting after one month for treatment have a poorer outcome with immobilization alone than those presenting earlier and should be treated with rigid fixation alone (Grade I).[10]

Fibrous unions appear solidly healed, but insufficient remodeling has occurred to resist the stresses of bending and torque (Grade II). Barton explored these fibrous unions, found solid union between the fracture fragments, and determined that healing had occurred. On follow-up, only half proceeded to union.[11] Shah, encountering a similar group of fibrous unions, stabilized them with a compression screw without a bone graft. These all went on to heal.[12] Fibrous scaphoid unions require only rigid fixation to prevent micromotion and to permit bone healing.

Correctly aligned scaphoid nonunions with minimal fracture sclerosis suggest micromotion and early

TABLE 15.2. Treatment Classification System for Scaphoid Nonunion.

I	Scaphoid fractures with delayed presentation for treatment: 4 weeks–12 weeks
II	Fibrous union: minimal fracture line at nonunion interface, no cyst or sclerosis
III	Minimal sclerosis: bone resorption at nonunion interface less than 1mm
IV	Cystic formation and sclerosis: bone resorption at nonunion interface greater than 1 mm but less than 5 mm, cyst, no deformity of lateral radiographs
V	Deformity and/or pseudoarthrosis: bone resorption at nonunion interface greater than 5 mm, cyst, fragment motion, deformity on lateral radiographs
VI	Wrist arthrosis: scaphoid nonunion with radiocarpal and/or midcarpal arthrosis

Special circumstances

PP Proximal pole nonunion. The proximal pole of the scaphoid has a tenuous blood supply and a mechanical disadvantage, which places it at greater risk of delayed or failed union. Because of these difficulties, this injury requires aggressive treatment to ensure successful healing.

AVN Scaphoid nonunion with necrosis is suggested by MRI demonstrating a decrease or absence of vascularity of one or both poles. Bone biopsy can confirm necrosis. Intraoperative inspection of the scaphoid for punctate bleeding is considered defintive.

LI Ligament injury is suggested by static and dynamic imaging of the carpal bones. Arthroscopy is the most sensitive tool for detecting carpal ligament injury.

resorption at the fracture site (Grade III). Small sections of bone may undergo reabsorption, making the fracture gap larger and reducing the overall strain. With gaps less than 1 mm in a stable fracture, healing can proceed across the gap. These nonunions require rigid fixation to achieve union. Wozasek and Ledoux separately reported on nonunions without necrosis or severe sclerosis that healed with rigid fixation without open bone grafting.[13,14] Cosio reported stabilizing nonunions with multiple Kirschner wires and achieved solid union in 80% of patients without open repair and bone graft.[15] A CT scan should confirm that the nonunion front represents only a minimal sclerotic line (less than 1 mm) and is in correct alignment.

Scaphoid nonunions with cystic changes at the fracture represent extensive resorption and nonviable tissue at the fracture site (Grade IV). These nonunions present with sclerotic zones between 1 and 5 mm. Fixation alone of these nonunions offers little success for healing. The large zones of devitalized tissue and the extent of fracture gap are too great a challenge for the local Haversion osteoclast-osteoblast repair system. Minimally, these nonunions require debridement, bone grafting, and rigid fixation. MR imaging should be considered if bone viability of these fracture fragments is of question. CT is required to define the extent of local destruction and confirm correct structural alignment. Both curettage and bone grafting can be accomplished through an arthroscopic portal.

Scaphoid nonunions with pseudoarthrosis and/or deformity require extensive debridement and structural bone grafting for mechanical support (Grade V). These nonunions have extensive bone resorption at the nonunion interface, which is usually greater than 5 mm with large cysts. A flexion deformity is seen on lateral radiographs. These nonunions will require correction of the deformity, interposition of a cortical-cancellous bone graft, and rigid fixation. Arthroscopy will provide valuable information of early signs of arthrosis.

Scaphoid nonunion with wrist arthrosis is a result of dysfunctional carpal motion (Grade VI). Early degenerative changes to the carpus permit the repair of the scaphoid nonunion and treatment of the local arthritis (i.e., radial styloidectomy). Extensive degenerative arthrosis with carpal collapse advances the treatment from fracture repair to wrist salvage procedures, depending on the extent of the arthritis.

Difficult Circumstances

The following circumstances increase the difficulty in achieving successful bone union. These include compromised vascularity and fracture instability due to ligament injuries or inadequate fixation of certain fractures and nonunions.

Proximal pole fractures are the most challenging of all scaphoid injuries, and treatment becomes greatly complicated when treatment results in nonunion. First, the blood supply becomes increasingly compromised the closer the fracture is to the proximal pole. Second, the smaller the fracture fragment the greater the bending forces from the distal scaphoid, which act at the fracture site to produce displacement. Proximal pole fractures should be aggressively fixed to avoid the difficulties of nonunion. Once the native bone of the proximal pole becomes replaced with osteopenic bone or reparative tissue, the challenge to achieve solid union greatly increases.

The presence of avascular necrosis of the scaphoid has been associated with a significant decrease in union rate.[7,12] Fracture necrosis can be difficult to define, but the gold standard remains the MRI.[16] Green evaluated avascular necrosis by direct, open inspection of the nonunion site for punctate bleeding at the time of surgery.[17] Slade has adapted this exam arthroscopically, limiting unnecessary vascular disruption. The proximal pole of the scaphoid is first reamed. The arthroscope is inserted into the base of the scaphoid in the previously drilled bone tract. The tourniquet is deflated, and the cancellous bone is inspected for punctate bleeding (Figure 15.1B). The presence or absence of bleeding bone is recorded, as is the time required for appearance.[18] Revascularization will often proceed with acute fractures if they are rigidly fixed. Nonunions with a large zone of devitalized bone are best treated with a vascular bone bridge. Vascularized bone grafts have increased the union rate and decreased the union time.[19] The introduction of a freshly harvested vascularized pedicle graft serves two purposes. First, the distance required for revascularization is greatly reduced, and second, the stiffness of this new bone as a cortical cancellous graft with the appropriate fixation may provide the stable mechanical construct required for bone healing and revascularization to proceed. This will salvage the wrist from arthrosis, but the trade-off will be limited wrist function.

Ligament injuries associated with scaphoid fractures and nonunion must be identified. Biomechanical studies suggest that torn ligaments result in carpal instability. Cooney reported that scaphoid union was much reduced in the presence of a collapsed scaphoid nonunion with dorsal carpal instability. He documented a 35% failure rate following bone grafting for unstable or displaced scaphoid nonunions.[20,21] Both injuries require evaluation and treatment. Arthroscopic examination of scaphoid fractures and nonunions aids us in staging for defining, identifying, and treating ligament injuries. During arthroscopy, carpal ligament injuries are graded using the Geissler grading system.[9] This system standardizes arthroscopic observation of injuries of the intracarpal ligaments. With a grade I lesion, attenuation of an interosseous ligament is seen with the arthroscope placed in the radiocarpal portal. There is no incongruency between the carpal bones with the arthroscope in the midcarpal portal. With a grade II lesion, there is attenuation of the interosseous ligament at the radiocarpal space and an incongruency between the carpal bones when viewed from the midcarpal portal. In grade III lesions, a separation between the carpal bones is evident from both the radiocarpal and the midcarpal portals. A small joint probe can be passed between the carpal bones, but a 2.7-mm arthroscope cannot be passed. With a grade IV lesion, gapping is sufficient to permit a 2.7-mm arthroscope to be passed between the carpal bones. The arthroscopic findings of increasing carpal gapping correlate with carpal separation as measured on the posteroanterior radiograph. Grade II lesions, which are partial tears, have a measured gapping between 2 and 3 mm. Grade III lesions, complete tears, measure between 3 and 4 mm, and Grade IV lesions are between 5 and 6 mm. Grade IV lesions also demonstrate lateral scapholunate angle greater than 75 degrees. Injuries graded II and III are debrided, reduced and pinned, and loose ligaments are treated with capsular shrinkage. Grade IV injuries are treated similarly, except a small dorsal incision is made and a repair with bone anchors of the dorsal scapholunate interrosseus ligament is performed. The decision to add a dorsal capsulardesis is determined by the degree of instability at the time of repair.

SURGICAL TECHNIQUE

This technique involves the placement of a 0.045-inch guidewire from dorsal to volar along the central axis of a reduced scaphoid fracture or nonunion. The placement of this guidewire and fracture reduction are both fluoroscopically and arthroscopically confirmed. A headless, cannulated compression screw provides rigid fixation and is introduced into the dorsal wrist through a percutaneous incision (Figure 15.2).

Imaging

The injured wrist is imaged with a mini-fluoroscope to identify fracture displacement and ligament injury. At the completion of this survey, the central scaphoid axis is identified. The central axis of the scaphoid is visualized using fluoroscopic imaging. Obtain a posteroanterior view of the wrist. Next, pronate the wrist until the scaphoid becomes a cylinder. This position aligns the proximal and distal poles of the scaphoid. Now flex the wrist 45 degrees, and the scaphoid will be flexed 90 degrees and parallel to the imaging beam. The scaphoid should appear as a circle, and the center of the circle is the central axis of the scaphoid and the exact position for placement of the guidewire. If the scaphoid axis is difficult to image, the central axis can be marked using a Kirschner wire. Using a posteroanterior view of the wrist, locate the distal

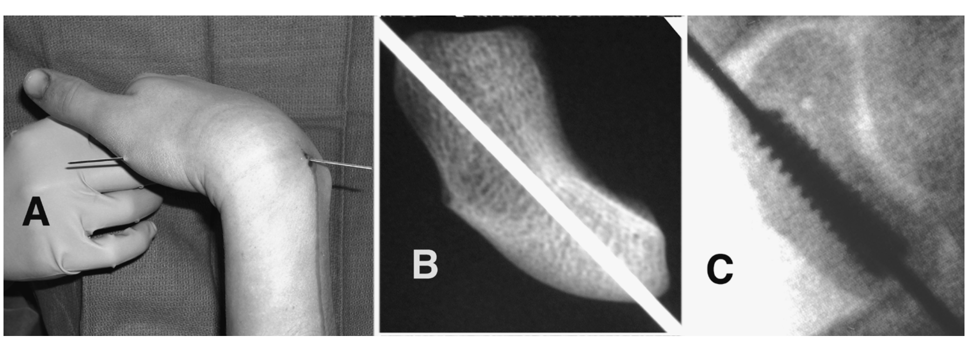
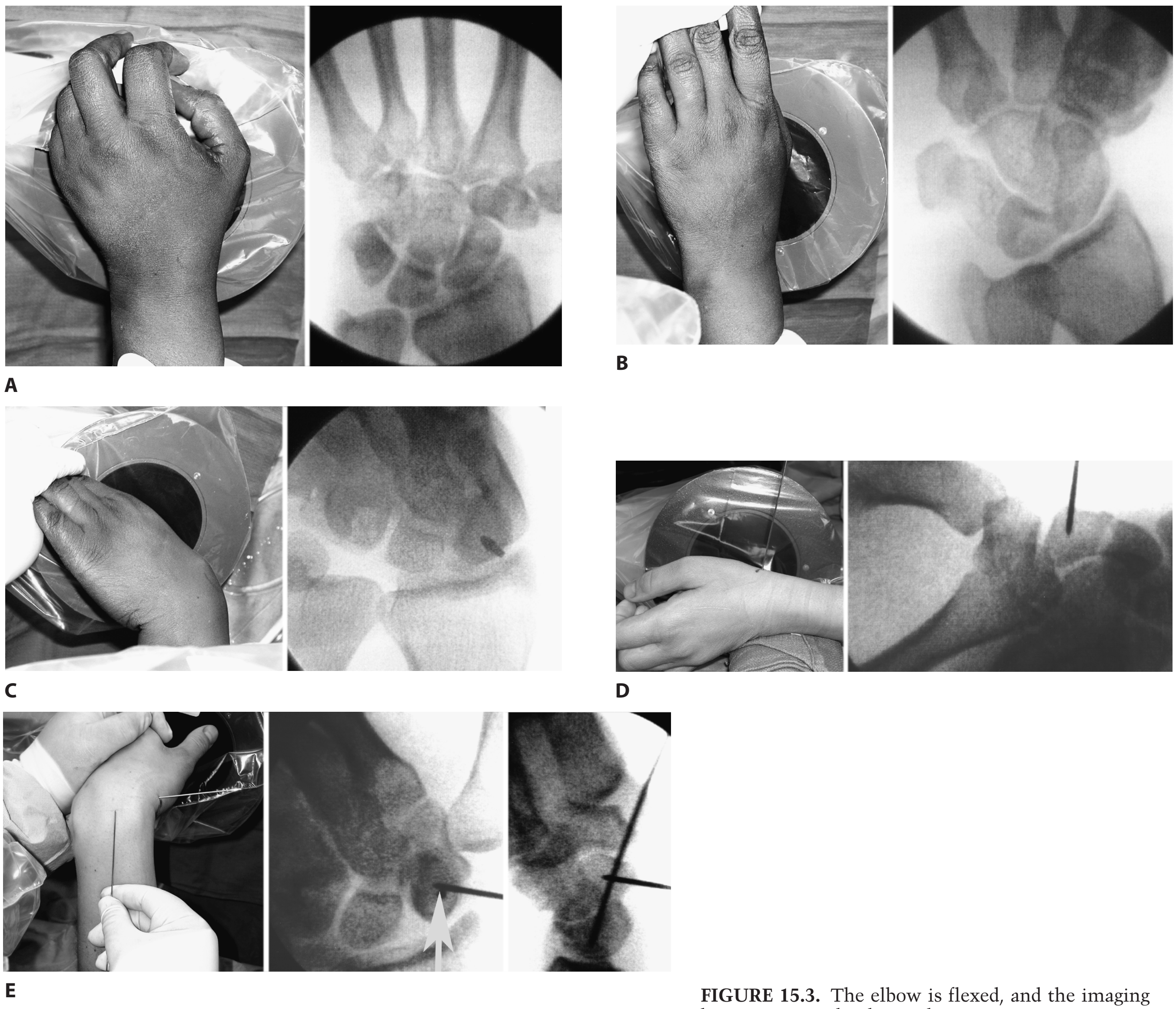


FIGURE 15.2. **A, B.** The key to the technique is the percutaneous placement of a guidewire along the central axis of a scaphoid. **C.** Scaphoid fracture is repaired via a dorsal percutaneous technique using a standard Acutrak screw. The fixation device is a headless cannulated compression screw implanted through the proximal pole.

scaphoid pole. Place a Kirschner wire into the distal scaphoid pole to the point of central axis. Pronating and flexing the wrist will place the tip of the wire in the center of the circle (Figure 15.3A–C). This will direct the placement of the central axis guidewire. If a mini-fluoroscope is not available, the same image can be obtained using a standard fluoroscope. In this case, the patient should be positioned in the supine position with the arm and elbow extended. The standard fluoroscopy unit is oriented vertically, with the re-



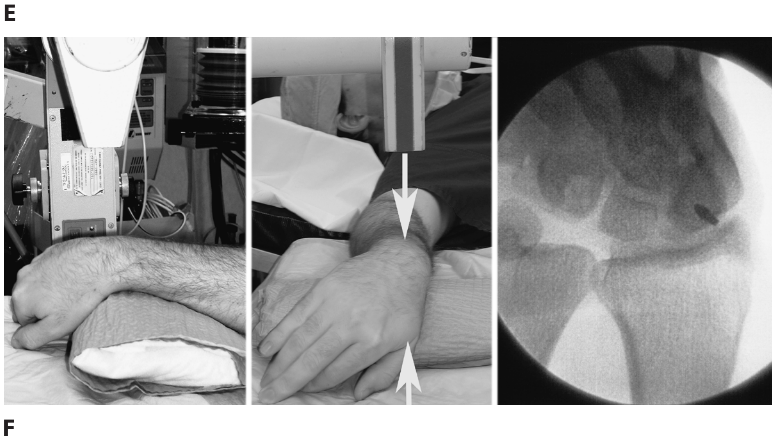


FIGURE 15.3. The elbow is flexed, and the imaging beam is perpendicular to the wrist. **A.** A posteroanterior view of the wrist radiograph and picture is demonstrated. **B.** Using fluoroscopy, pronate the wrist until the scaphoid poles are aligned and the scaphoid is viewed as a cylinder. **C.** Now, flex the wrist until the scaphoid cylinder appears as a circle. The central axis of the scaphoid is now in the imaging beam and is the center of the scaphoid circle. **D.** In an alternative technique, a pin is placed in the center of the distal pole of the scaphoid under fluoroscopic control. **E.** The guide pin for the cannulated screw is then placed in the proximal pole of the scaphoid and is aimed toward the distal pin. **F.** The guide pin may be placed in the horizontal position only if a large fluoroscopic unit is available. To obtain the cylinder, the wrist is flexed 45 degrees on a bump and pronated.

ceiving plate horizontal to the floor. A roll is placed under the wrist, flexing the wrist 45 degrees effectively flexes the scaphoid 90 degrees. Simply pronating the flexed wrist in the imaging beam will align the scaphoid pole and reveal the scaphoid central axis (Figure 15.3D–F).

Dorsal Wire Placement

The working distance between a mini-fluoroscopy unit's emission and receiving heads is approximately 14 inches. This limited distance can restrict the targeting of the scaphoid. A double-cut 0.045-inch guidewire is introduced percutaneously at the base of the proximal scaphoid pole using the drill guide improvised from a 14-gauge needle. With the central axis of the scaphoid imaged, the 14-gauge needle is inserted onto the scaphoid proximal pole (Figure 15.4A). The wrist can then be removed from the imaging field and the guidewire introduced through the needle and driven in approximately 1 cm. The position and direction of the wire can be checked and adjusted as needed. If multiple incorrect passes are made, establishing the correct path can be difficult using a 0.045 wire. A stouter 0.062 wire, with its increased stiffness, can be used to establish the correct track. Once the correct path is established, the 0.062 wire can be exchanged for the 0.045 guidewire. With the wrist flexed, the wire is driven in a dorsal to volar direction. The wire passes through the trapezium and exits the wrist from the radial thumb border. The central axis of the scaphoid passes through the trapezium. The radial thumb border is a safe zone devoid of neurovascular structures. The wire is then withdrawn until the wrist can be extended without bending the wire (Figure 15.4B). Once the wrist is fully extended, both the position of the wire and the alignment of the scaphoid can be carefully inspected with imaging. Unstable fractures and nonunions require a second parallel wire. Unstable fractures require the stiffness of the additional wire to prevent bending and rotational deformity during reaming and screw placement. Scaphoid nonunions require stabilization so the central axis can be reamed without loss of alignment.

Small Joint Arthroscopy

After positioning the guidewire and confirming fracture alignment by fluoroscopy, an arthroscopic survey is performed. The goal of arthroscopy here is to identify and treat ligament injuries, reduce and stabilize articular joint incongruities, and directly inspect the quality of the reduction in acute fractures. As in acute injuries, arthroscopy is used to identify and treat lig-

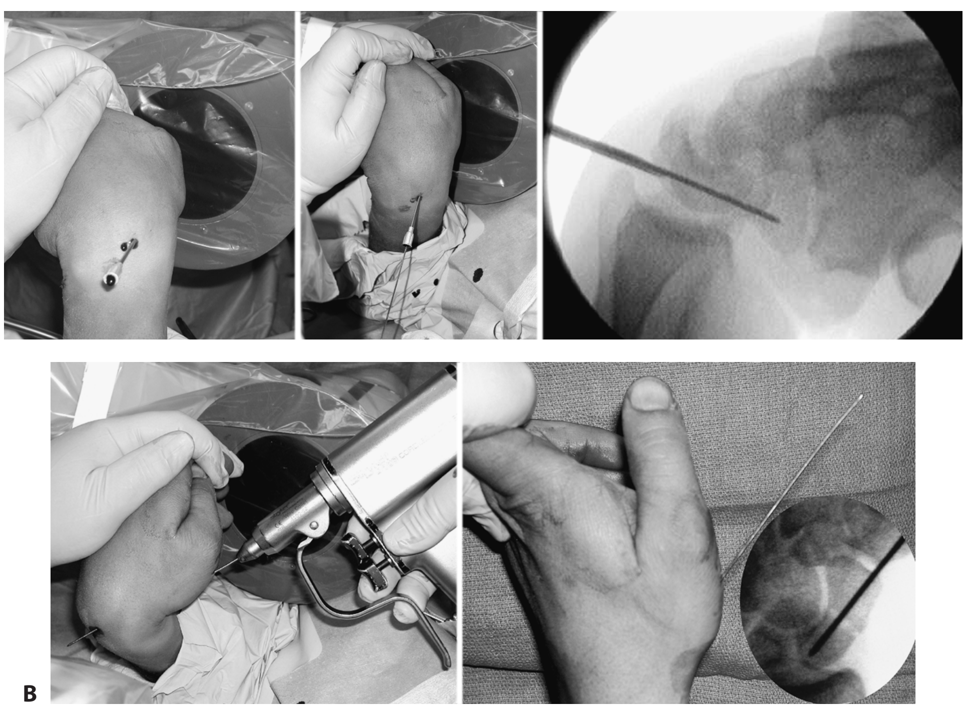


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FIGURE 15.4. A. 12- or 14-gauge needle can be used as an improvised drill guide for the 0.045-inch guidewire. After imaging identifies the central axis, the needle is inserted in the scaphoid proximal pole. The wrist can then be removed from the imaging field and the guidewire introduced through the needle and driven approximately 1 cm. Using fluoroscopy, the position and direction of the wire can be checked and adjusted as it is driven in a dorsal to volar direction. It is critical that the wrist be maintained in a flexed position until the distal end of the wire clears the radiocarpal joint to avoid bending the guidewire. **B.** The wire is withdrawn from the thumb base until the wrist can be extended and mini-fluoroscopy can be used to confirm the guidewire position along the central axis of scaphoid and fracture reduction.

ament and articular injury in scaphoid nonunions. In addition, the fracture site is inspected arthroscopically for evidence of healing, and the articular surface for evidence of degenerative changes.

With the patient in the supine position, the arm is exsanguinated, the elbow is flexed, and the wrist is positioned upright in a spring-scale-driven traction tower. Twelve pounds of traction is distributed via four finger traps to reduce the possibility of a traction injury. A fluoroscopy unit is placed horizontal to the floor and perpendicular to the wrist as the radiocarpal and midcarpal joint are identified with imaging (Figure 15.5A,B).

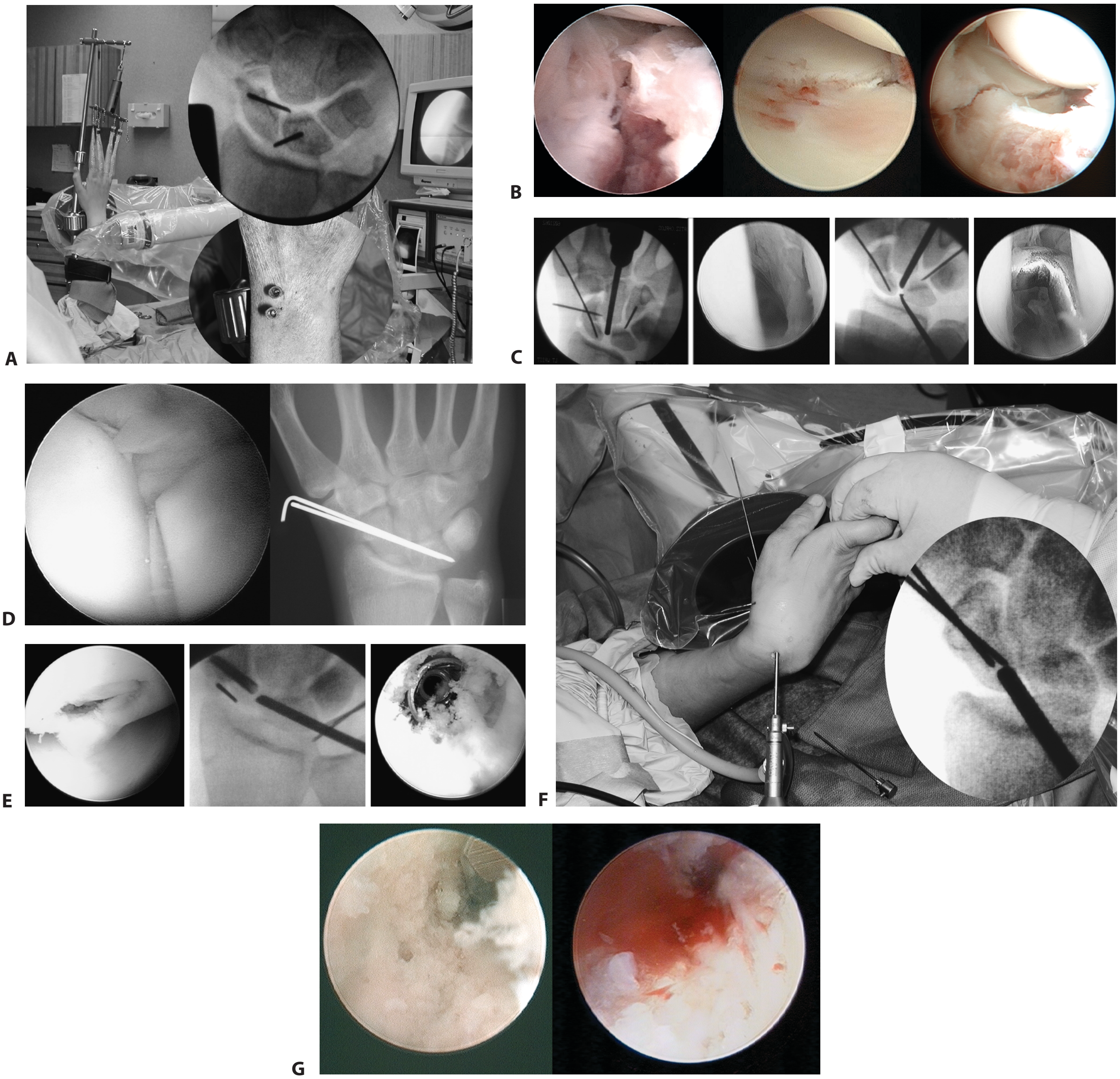

FIGURE 15.5. The goal of arthroscopy is to identify and treat ligament injuries, reduce and stabilize articular joint incongruities, and in acute fractures, to inspect the quality of the reduction directly. **A.** The arthroscope is placed in the radial midcarpal row. While large fracture displacements can be detected with fluoroscopy, smaller malalignments could easily be missed. **B.** An arthroscopic radial midcarpal view, from left to right: displaced scaphoid fracture, minimal displacement of scaphoid, and reduced proximal pole fracture with avulsion of the dorsal lunate. Ligament tears with carpal fractures are not uncommon. **C.** Another radial midcarpal view shows two tears of scapholunate interosseous ligament. On the left is a grade IV tear that will permit passage of a small-joint arthroscope. On the right is a grade III tear that permits the passage of a 2-mm probe. Small tears and flaps with stable joints are debrided back to a stable rim (I, II). **D.** Partial tears with instability are reduced and pinned (II, III). Complete unstable tears (IV) are open-repaired. **E.** Arthroscopy is used to confirm complete seating of headless screw. **F.** Small-joint arthroscopy permits the determination of the viability of the proximal scaphoid pole without risking further vascular injury from an open exploration. A small-joint angled arthroscope can be introduced into the reaming portal. Using fluoroscopy, its position is guided to the scaphoid base. **G.** With the arthroscope seated in the scaphoid proximal pole and the tourniquet deflated; punctate bleeding will soon appear if the bone is viable.

19-gauge needles are introduced into the wrist joint to identify the radiocarpal and midcarpal portals. This maneuver limits iatrogenic injury to the joint, which can result from multiple attempts to introduce a blunt trocar blindly. Once the portals have been successfully located and marked, the imaging unit is removed and the skin alone incised. A small, curved blunt hemostat is used to separate the soft tissue and enter the wrist joint. A blunt trocar is placed at the radial midcarpal portal, and a small-joint angled arthroscope is introduced. Additional 19-gauge needles are inserted to establish outflow. A probe is introduced at the ulnar midcarpal portal, and the competency of the carpal ligaments is evaluated by directly stressing their attachments to detect partial and complete tears. The probe is also placed in the 3-4 portal, immediately proximal to the radial midcarpal portal. With fluoroscopy, the sulcus, which defines the scapholunate ligament, can be identified and probed. With partial tears, the probe will be visualized by the arthroscope in the midcarpal portal as it passes from the radiocarpal joint into the midcarpal joint through a tear in the SLIO (scapholunate interosseous) ligament. Any carpal ligament injuries detected are graded using the Geissler grading system (Figure 15.5C). Grade I and II ligament injuries are treated with debridement and shrinkage alone. Grade III injuries are treated with debridement, and after fracture repair, carpal pinning for 6 weeks (Figure 15.5D,E). Grade IV ligament injuries require open repair of the dorsal SLIO ligament with bone anchors and carpal pinning. The need for the addition of a dorsal capsulardesis tether is determined by the quality of the acute repair after scaphoid fixation. Tears of the triangular fibrocartilage complex are classified using the Palmer classification, and treated.[22]

Green felt that scaphoid bone viability was best determined at surgery. The scaphoid was directly inspected for punctate bleeding from the proximal scaphoid pole. Avascular necrosis was suspected with the absence of punctate bleeding from the proximal pole.[17] Green's scaphoid bone viability test can be performed arthroscopically, limiting unnecessary vascular and soft tissue injury. Using the central axis guidewire only, the proximal pole of the scaphoid is reamed. The wire is withdrawn to the fracture site, and the small-joint arthroscope is inserted into the base of the scaphoid in the previously reamed bone tract. The tourniquet is deflated, and the cancellous bone is inspected for punctate bleeding (Figure 15.5F,G). Inflow irrigation is momentarily stopped, while the time of the first appearance of bone bleeding is recorded.

Correction of Scaphoid Malalignment

Fractures with displacement are reduced with joy sticks fashioned from percutaneously inserted 0.062-inch Kirschner wires placed dorsally in both fracture fragments. Prior to reduction, the previously placed central axis guidewire is withdrawn volarly across the fracture site, and traction is removed. Often the major deformity observed is a flexion deformity of the fracture fragments. When the dorsal joy sticks are brought together, the flexion deformity of the scaphoid is corrected (Figure 15.6A). These maneuvers can be monitored using either lateral fluoroscopy and/or arthroscopy. With acute injury, it is enough to

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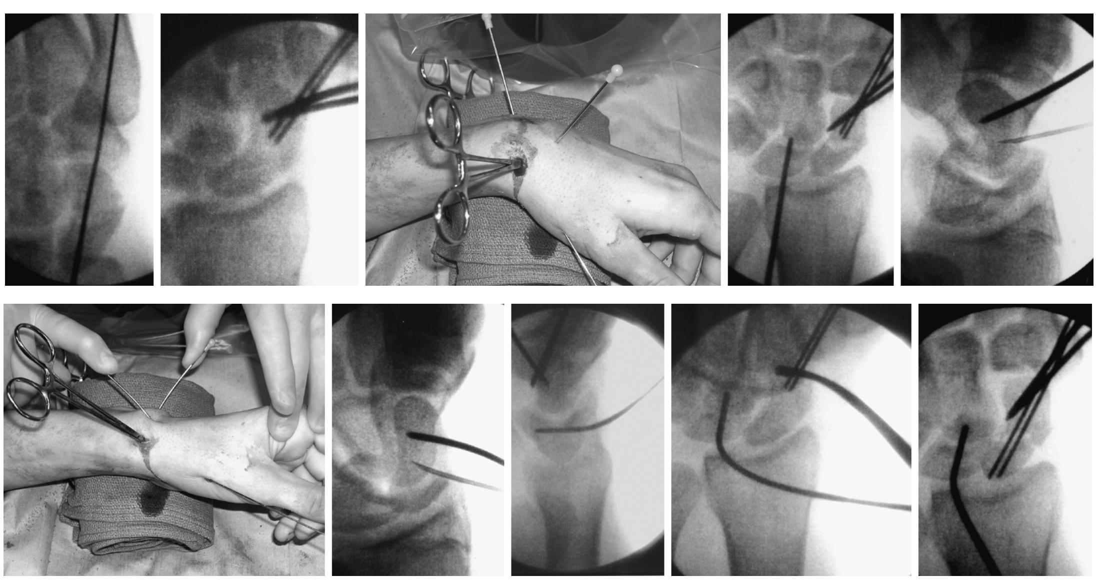

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FIGURE 15.6. The central axis wire is withdrawn volarly across the fracture site. **A.** Stout joy sticks, constructed from 0.062 guidewires, are placed percutaneously, dorsally, and perpendicularly into the fracture fragments. **B.** Reduction is achieved using the joy sticks, and fracture alignment is maintained while the volar guidewire is driven from the distal pole into the proximal scaphoid pole, capturing and securing reduction. A difficult fracture can be reduced with a small curved hemostat introduced percutaneously.

reduce the fracture to reestablish normal scaphoid length. This is because there is no loss of volar bone cortex because the volar scaphoid fails in tension with hyperextension injuries. Impacted or severely displaced fractures require the percutaneous insertion of a small, curved hemostat into the fracture site to guide fracture relocation (Figure 15.6B). The hemostat can be introduced through a midcarpal or accessory portal. While the joy sticks maintain reduction, the volar guidewire is driven back proximally and dorsally into the proximal pole to capture the reduction. These fractures are often very unstable and require the placement of a second parallel wire to resist the bending forces and maintain alignment during reaming and screw implantation. Fractures of the scaphoid waist are most likely to result in a humpback deformity from displacement due to forward flexion. Fractures of the proximal pole are more inclined to displace in a translational plane. These fractures are more inclined to displace with disruption of the radioscaphocapitate ligament that crosses and supports the scaphoid waist when uninjured. With fracture reduction secure, the central axis guidewire is adjusted to ensure it is still positioned along the central axis.

Scaphoid Length and Screw Size

At the completion of arthroscopy, with fracture reduction and guidewire position confirmed, the screw size must now be selected. To accomplish this, the scaphoid length must be determined. The wrist is flexed, and the guidewire at the base of the thumb is driven dorsally. The wire is adjusted until the trailing end is in the subchondral bone of the distal scaphoid pole. A second wire of equal length is placed percutaneously at the proximal scaphoid pole and parallel to the guidewire. The difference in length between the trailing end of each wire is the scaphoid length. The screw length selected should be 4 mm less than the scaphoid length. This permits 2 mm of clearance of the screw at each end of the scaphoid, thus ensuring complete implantation without screw exposure (Figure 15.7). The most common complication of percutaneous screw implantation is implantation of a screw that is too long. This complication can be avoided by selecting a screw length that provides for 2 mm of clearance between the screw's end and the proximal and distal scaphoid cortex. The screw length selected is 4 mm shorter than the scaphoid length. This permits the complete implantation of a headless compression screw in bone without exposure.

Now that the length of the screw has been determined, the width must be selected. The forces acting on a scaphoid waist fracture are bending forces. If untreated, this results in a flexed and foreshortened scaphoid. The scaphoid waist fracture can be imaged as two cylinder blocks for the purpose of biomechanical testing. To resist forward bending of these cylinders, the widest possible rod is needed at the fracture site. In selecting a screw type for scaphoid fracture fixation, the most important feature will be the width of the screw at the fracture site. A small increase in the radius leads to a significant increase in strength. In vitro cadaveric biomechanical studies have confirmed that the widest screws provide the strongest fixation. One concern about larger screws introduced dorsally is the consequences of the resulting cartilage defect, but these defects have been shown to heal over with cartilage in time, without degenerative changes.

Percutaneous Bone Grafting

If a scaphoid fracture or nonunion requires bone grafting, introduce a guidewire percutaneously into the scaphoid's proximal pole and drive the wire along the central axis of correctly aligned scaphoid using fluoroscopy. As described earlier, determine the scaphoid's length. Next, introduce a second wire parallel to the central axis wire to prevent scaphoid motion or translation at the fracture site. After introduction of this second wire, maintain the wrist in a flexed position and adjust the central axis wire so that its ends are equally exposed between the dorsal wrist and radial volar thumb. Incise the skin, and introduce the can-

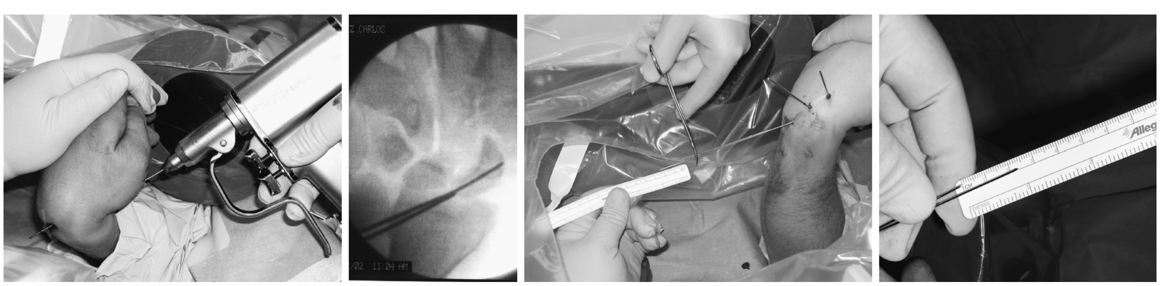

FIGURE 15.7. The wrist is flexed, and the guidewire is advanced dorsally until the trailing end of the volar wire is level with the distal scaphoid cortex. Scaphoid length is determined by placing a second guidewire at the base of the proximal scaphoid, next to the exposed dorsal guidewire. The difference between these wires is the scaphoid length. The screw length is determined by selecting a screw 4 mm shorter than the scaphoid length. This will permit 2 mm of clearance of the screw at each end of the scaphoid and complete implantation without screw exposure to cartilage.

nulated driver percutaneously into the proximal scaphoid along its central axis, using fluoroscopy to monitor the level of reaming. Next, remove the reamer and withdraw the central wire to the level of the fracture site, and curette the nonunion site by introducing the curette via the dorsal drill hole into the nonunion site. Using an 8-gauge bone biopsy needle, harvest bone as cores from either the iliac crest or the distal radius. Next, introduce the 8-gauge bone biopsy cannula over the central axis guidewire into the scaphoid proximal pole and again with the wire to the fracture site. Through this cannula, introduce previously harvested cancellous bone plug until the bone cavity on the radiolucent image has been replaced by a radiopaque image of similar texture to that of the surrounding bone (Figure 15.8).

Alternatively, Geissler devised a cannulated putty pusher system (Acumed, Hillsboro, OR) for injection of demineralized bone matrix or cancellous bone chips for scaphoid nonunions (Figure 15.9). In this system, a guidewire is placed down the center of the axis of the scaphoid, and the bone is drilled. The cannulated trocar is slid over the guidewire into the scaphoid nonunion. The guidewire is removed, the demineralized bone putty (Gens-Sci, Irving, CA) is injected into the cannula, and the trocar pushes the putty into the nonunion site. The guidewire is reinserted as the cannula is removed. The headless cannulated screw is then placed over the guidewire. This system may be used for percutaneous injuries of demineralized bone matrix in other fracture nonunions throughout the body.

After the introduction of bone graft into the scaphoid, advance the central axis guidewire and perform a second drilling prior to screw implantation. Inserting the screw and advancing it into an unprepared graft will force the graft toward the scaphoid cortex and risk exploding out the outer scaphoid cortex. This is avoided by reaming with a sharp drill prior to screw implantation. Implant the headless cannulated screw along the central scaphoid axis. If rigid fixation has not been achieved with screw fixation alone, additional fixation is required. This can be achieved with a 0.062-inch guidewire placed from the scaphoid into the capitate. This will be used to temporarily block midcarpal motion and reduce forces acting on the scaphoid fracture site.

Rigid Fixation with Headless Cannulated Screw

Once the scaphoid is correctly aligned and its length has been determined, the guidewire is adjusted so that its ends are equally exposed between the dorsal wrist and volar radial thumb. This prevents the wire from becoming dislodged during bone reaming and screw

FIGURE 15.8. A. Using a bone biopsy needle, cancellous bone is harvested from the iliac crest or the distal radius. Using fluoroscopy, the nonunion site can be debrided while maintaining the fibrous envelope around the scaphoid nonunion site. **B.** Percutaneously introduce a guidewire along the scaphoid central axis. Hand drill the scaphoid using a cannulated reamer along the scaphoid central axis. Withdraw the reamer and introduce the curette into the scaphoid to the level of the nonunion site. **C.** Introduce an 8-gauge bone biopsy cannula over the central axis guidewire into the scaphoid proximal pole. Through this cannula, introduce a previously harvested cancellous bone plug until the bone cavity has been completely filled.

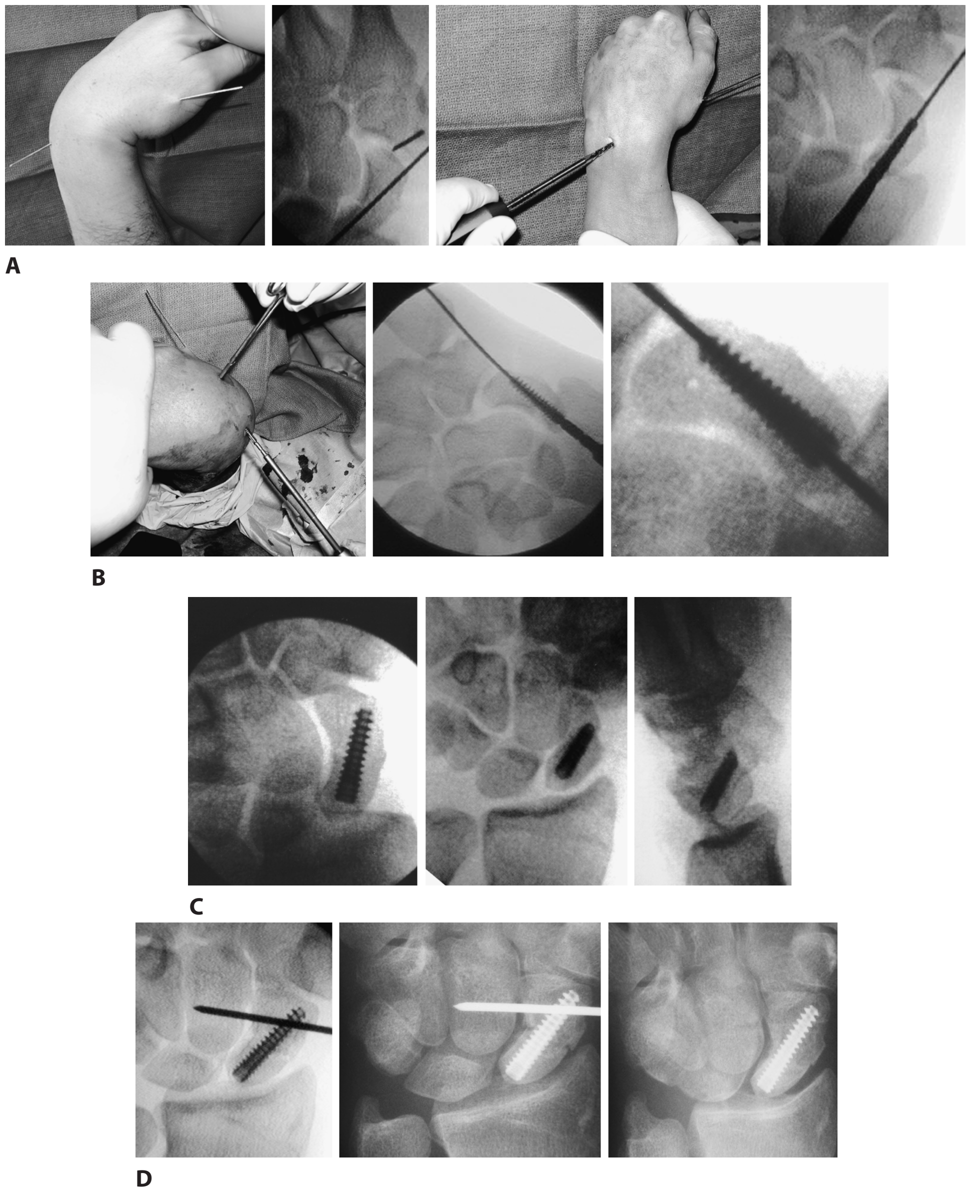

FIGURE 15.9. **A.** The scaphoid is prepared with a hand reamer. **B.** Fluoroscopy is used to check the position and depth of the drill. It is critical not to ream beyond 2 mm of the opposite cortex. **C.** Fluoroscopy is used to confirm the correct position of the fixation device. If rigid fixation has not been achieved with screw fixation alone, additional fixation is required. **D.** This can be achieved with a 0.062-inch guidewire placed from the scaphoid into the capitate. This will be used to temporaily block midcarpal motion and reduce forces acting on the scaphoid fracture site. In this panel the left picture is an intraoperative photo, the middle photo shows partial healing at one month, and at 2 months future healing has occurred and the midcarpal locking wire is removed to permit wrist rehabilitation.

implantation. It is critical that the wrist maintains a flexed position to prevent the wire from bending. Otherwise, drilling and screw placement will be difficult.

Dorsal implantation of a headless compression screw is recommended for scaphoid fractures of the proximal pole and volar implantation for distal pole fractures, as this permits maximum fracture compression. Fractures of the waist may be fixed from a dorsal or volar approach, as long as the screw is implanted along the central scaphoid axis. Blunt dissection along the guidewire exposes a tract to the dorsal wrist capsule and scaphoid base. The scaphoid is prepared by drilling a path 2 mm short of the opposite scaphoid cortex with a cannulated hand drill. This will permit the implantation of a headless compression screw completely within the scaphoid. It is critical to use fluoroscopy to check the position and depth of the drill. Overdrilling the scaphoid reduces fracture compression and increases the risk of motion at the fracture site. A standard Acutrak screw is advanced under fluoroscopic guidance along the central axis with the fracture surfaces firmly opposed to within 1 to 2 mm of the opposite cortex. This provides excellent compression. If the screw is advanced to the distal cortex, attempts to advance the screw further will force the fracture fragments to gap and

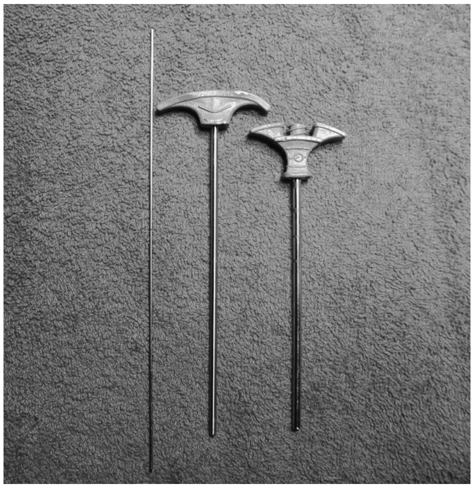

FIGURE 15.10. Cannulated putty pusher system designed by Geissler to inject demineralized bone matrix percutaneously.

separate. With unstable fractures, a joy stick is left in the distal scaphoid fragment for both reaming and screw implantation. As the screw is implanted, a counterforce is exerted through the joy stick, compressing both fracture fragments and ensuring rigid fixation (Figure 15.10).

With small proximal pole fractures or avulsions, there is increasing difficulty in obtaining rigid fixation with headless screw fixation. Having fewer than four screw threads crossing the fracture site leads to a rapid drop-off in pull-out strength.[24] There is also a possible risk of fragmentation with standard screw implantation; under these circumstances a smaller screw should be considered, and the wrist protected. With avulsion injuries, consideration should be given to fixation by temporarily sandwiching the avulsed fracture fragment between the distal scaphoid and lunate with a headless compression screw. This screw will be removed when CT scan confirms healing.

Unstable fractures may not achieve rigid fixation with screw implantation alone, and other temporary constructs may be required. Flexion forces act on the distal scaphoid and extension forces act on the proximal scaphoid through the proximal carpal row.[25] These forces can be balanced by the placement of a 0.062-inch wire from the scaphoid into the capitate. This temporarily blocks midcarpal motion and reduces forces acting on the scaphoid fracture site (Figure 15.9C,D).

Distal scaphoid fractures require the volar implantation of the screw for maximum compression. Guidewire placement and length determination are accomplished in a manner identical to the dorsal technique, except that the central axis carries the guidewire through the trapezium. To prepare the scaphoid for screw placement, both the trapezium and scaphoid are reamed with the cannulated hand drill; this ensures that the screw is implanted along the central scaphoid axis. This violation of the scaphotrapezial joint is minimal. The remainder of the technique is identical to the dorsal procedure, including screw selection, drilling, and implantation. This volar technique differs from other volar techniques that advocate eccentric screw placement. After screw placement, the guidewire is removed, and wrist fluoroscopy confirms screw position, fracture reduction, and rigid fixation. Arthroscopy at this time can also confirm reduction and complete seating of the screw.

Key Points on Arthroscopic Scaphoid Fixation via a Dorsal Percutaneous Approach

1. Scaphoid fractures and nonunions can be evaluated and graded using imaging (e.g., radiographs, CT, MRI), arthroscopy, and bone biopsy.
2. The central axis of the scaphoid is the key position for the placement of a guidewire in a reduced scaphoid.
3. To identify the central scaphoid axis, the wrist is pronated and flexed until the scaphoid is seen as a circle. The center of the circle is the target point for insertion of the guidewire into the proximal pole of the scaphoid.
4. The guidewire is driven in a dorsal to volar direction, so that the wire exits at the radial base of the thumb.
5. The reduction of the fracture and positioning of the guidewire in the scaphoid are accomplished using mini-fluoroscopy and arthroscopy.
6. Arthroscopy permits the detection, grading, and treatment of carpal bone and ligament injuries.
7. Screw length is determined using two identical parallel wires. The difference in length between these wires is the length of the scaphoid. The screw length is 4 mm shorter than this calculated scaphoid length.
8. Stop reaming 2 mm from the distal cortex of the scaphoid.
9. Implant the screw in the scaphoid at the level to which the scaphoid has been drilled.
10. Rigid fixation may require additional implants.

POSTOPERATIVE CARE

Immediate postoperative care includes a bulky compressive hand dressing and splint. Pain control is managed with narcotics, nonsteroidal antiinflammatory medications, and elevation. The use of thermal cooler pads appears to reduce the need for pain medications. Early finger exercises are encouraged to reduce swelling. The therapist fashions a removable volar splint that holds the wrist and hand in a functional position at the first postoperative visit. All patients are started on a strengthening program. Axially loading the fracture site now secured with an intramedullary screw stimulates healing. Postoperative radiographs are obtained at the first postoperative visit and at 6-week intervals. When fracture healing is suspected, usually at 4 to 6 weeks postoperatively, a CT scan of the scaphoid with 1-mm cuts (PA and lateral) is obtained to evaluate fracture healing. This is repeated every 6 weeks until final union is established. Bridging bone at the fracture site on CT or standard radiographs signifies fracture healing. It is important to understand that patients are often pain free prior to CT evidence of healing. Contact sports and heavy labor are restricted until fracture healing is confirmed by CT. Fractures of the wrist without complete ligament injuries are started on an immediate range of motion protocol, while proximal pole fractures are protected for one month prior to initiation of therapy. We do not routinely cast our scaphoid fractures postoperatively, but candidates for additional protection are evaluated on a case-by-case basis. The postoperative care of scaphoid nonunions is sometimes different from that of acute fractures. For nonunions of the scaphoid wrist, rigid fixation can often be achieved using a stout intramedullary device without additional immobilization. Proximal pole nonunions or wrist nonunions in osteoporetic bone are at a mechanical disadvantage, and rigid fixation can be difficult to achieve. These injuries are protected with a splint or short-arm cast for 4 to 6 weeks until bone union has been established. Only Grade III ligament injuries were protected for 6 weeks. An early strengthening program is also encouraged for early recovery of hand function.

CONCLUSION

At first, percutaneous techniques of scaphoid fracture reduction and fixation may appear daunting. However, with experience, they offer a powerful and versatile capability that is demonstrating promising results in the treatment of notoriously difficult fractures and nonunions. Development of small-joint arthroscopic skill is one of the essential steps in mastering this method of scaphoid fracture treatment.

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