# The Scaphoid

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**KEYWORDS**

• Scaphoid • Wrist function • Carpal fractures • Distal radius • Upper extremity trauma

**KEY POINTS**

- Almost completely covered with articular cartilage, this creates precise surface loading demands and intolerance to bony remodeling.
- Fracture location compounds risk of malunion and nonunion.
- Scaphoid fractures may significantly impair wrist function and activities of daily living, with both individual and economic consequences.

## INTRODUCTION

The scaphoid is vitally important for proper mechanics of wrist function. Its unique morphology from its boat-like shape to its retrograde blood supply can present with challenges in the presence of a fracture. Almost completely covered with articular cartilage, this creates precise surface loading demands and intolerance to bony remodeling. Fracture location compounds risk of malunion and nonunion. Scaphoid fractures may significantly impair wrist function and activities of daily living, with both individual and economic consequences.

### *Epidemiology*

The scaphoid is the most commonly fractured carpal bone, accounting for approximately 70% of carpal fractures, and the second most common fracture of the upper extremity after distal radius fractures. The majority occurs from a low-energy injury, such as a fall onto an outstretched wrist from standing height. High-energy mechanisms such as a fall from a height or motor vehicle injury account for the remainder.

The highest incidence of fractures occur in younger age groups; 1 study found the highest incidence in males between the ages of 20 and 29 years old.[1,2] Similarly, a Norwegian study found an average age of male individuals with scaphoid fractures to be 25 years old. Wolf recently studied the US military population and found an incidence of scaphoid fractures to be 121 per 100,000 person-years.[3] The higher incidence was in males in the 20- to 24-year age group is likely owing to the more active nature of the military population. Wolf's study using a public database of acute injuries with the US general population, found that there is a male predominance of 66.4%, and thus the remaining 33.6% female representing a higher incidence than the typically reported in the previous studies.[3] They postulated that the increased incidence in females over the years were likely owing to an increased participation in organized sports.

### *Anatomy*

The scaphoid has an unusual shape; the name is derived from the Greek word "skaphe" for 'boat.' The early 20th century nomenclature used 'navicular,' Latin for 'boat.' Given its odd and complex configuration, defining the exact fracture pattern or degree of displacement can be problematic. It appears concave in both ulnar and palmar axes. Its long axis is on an oblique plane. It is the largest bone in the proximal carpal row.

Four different regions of the scaphoid have been described. They are the tubercle, waist, distal

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pole, and proximal pole. The scaphoid is 75% articular, especially the ulnar side. Proximally, the scaphoid articulates with the distal radius at the scaphoid fossa, and distally with the trapezoid and trapezium. Ulnarly, it articulates with the lunate proximally and the capitate distally. The volar surface is partly nonarticular. The tubercle, which points radiovolarly, serves as an attachment for several ligaments and is also almost entirely covered by the crossing flexor carpi radialis (FCR) tendon. The scaphoid is oriented in the carpus with an intrascaphoid angle averaging approximately 40° in the coronal plane and 30° in the sagittal plane. Heinzelmann and colleagues[4] found that male scaphoids were significantly longer (by 4 mm) and wider in their proximal pole than female scaphoids. The implications for surgical screw sizing based on sex and habitus often leads to recommending smaller screw sizes for female patients when considering operative fixation.[5]

The majority of scaphoid fractures occur at the waist, and this higher incidence may also be related to the structural properties of the bone. Bindra[6] studied cadaveric scaphoid with computed tomography (CT) and found that the bone is most dense at the proximal pole, where the trabeculae are the thickest and are more tightly packed, whereas the trabeculae in the waist are thinnest and sparsely distributed.

The dorsoradial ridge separates the dorsal and proximal articular surfaces from the distal volar aspect. The ridge is a narrow and nonarticulating area with several vascular perforations allowing important perfusion of the scaphoid. About 70 to 80% of the intraosseous vascularity and the entire proximal pole are supplied from branches of the radial artery entering through this ridge. Having a singular dominant intraosseous vessel predisposes the scaphoid to avascular necrosis (AVN)[7–12] and nonunion if fractured. With the predominantly articular nature of the scaphoid, there are few potential sites for the entrance of perforating vessels; thus, it has a tenuous vascular supply. The major palmar blood vessels arise from either the radial artery directly or the superficial palmar arch and divide into several smaller branches before coursing obliquely and distally over the palmar aspect of the scaphoid to enter through the region of the tubercle. The anterior interosseus artery provides collateral circulation to the scaphoid. In addition, Herbert and Lanzetta have hypothesized that there must be some blood supply through the scapholunate ligament complex.[13] From their cases series, proximal pole fragments remained viable when their only remaining attachment was to the SLIL.

Given the predominantly articular surface of the scaphoid, its attached ligaments play a critical role in stability and mechanics of the wrist. The scaphoid links the proximal and distal carpal rows, and as such influences motion at each row depending its position and functional demand.[7,13–15] The scapholunate ligament is intra-articular and connects the scaphoid and lunate at the proximal aspect of their articulation with 3 main parts. The dorsal aspect of the ligament is the strongest and thickest, and composed of transverse collagen fibers. The dorsal portion is twice as strong as the palmar portion. The dorsal region resists palmar-dorsal translation and gap. The volar portion is not as strong as the dorsal portion, and the proximal or membranous portion is made of fibrocartilage and is not truly a ligament.

The radioscaphocapitate (RSC) ligament originates from the radial styloid and lies in the volar concavity of the scaphoid waist. It attaches the capitate ulnarly. The RSC acts as fulcrum to allow scaphoid rotation. It may also have a proprioceptive role, because it contains a high density of mechanoreceptors. The scaphocapitate ligament originates from the distal scaphoid. It inserts into the volar waist of the capitate distal to the RSC ligament. This ligament, along with the scaphotrapezial ligament, functions as a primary restraint of the distal pole.[13]

With displaced scaphoid fractures, the proximal pole extends because of its attachment to the lunate through the scapholunate ligament, whereas the distal fragment remains flexed because of its attachment to the trapezium and trapezoid via the scaphotrapezial ligament. These deforming forces lead to a humpback deformity. The anatomy of the scaphoid and its associated ligaments contribute greatly to the risk of malunion and nonunion. It is almost completely covered with articular cartilage, limiting the amount of surface area for bone contact and healing. Displacement of these articular fracture fragments can also allow synovial fluid to pass between them and delay or halt healing.

## KINEMATICS

Carpal kinematic studies provide several theories indicating a bone in a given carpal row (proximal or distal) will move in the same direction with varying magnitudes.[14,15] Wolfe and colleagues[15] challenged that wrist motion cannot be readily simplified into a 2-linkage system. In their study they used a 3-dimensional CT technique to study carpal kinematics. They found significant intercarpal motion between the scaphoid and lunate that negate a 2 linkage system explaining wrist kinematics. Wolfe and colleagues[15] further postulated that the scaphoid should be regarded as independent from the carpal rows and that its kinematics are determined by direction and magnitude of wrist motion and its neighboring bones. They studied uninjured wrists with a markerless bone registration technique using 3-dimensional CT and confirmed that the amount of rotation of each of these bones depends on the direction of the wrist motion. The scaphoid extends with ulnar deviation and flexes with radial deviation. There is a neutral position when the scaphoid flexion and extension occurs between 10° and 15° off of the sagittal plane along the dart thrower's path. In this plane of motion, there is a transition between the scaphoid and lunate flexion and extension whereby motions of the 2 bones were minimal.

## *Classification*

In general, scaphoid waist fractures are the most common at 70%, distal pole fractures compromise 10%–20%, proximal pole fractures are 5%, and tubercle fractures make up 5%. Herbert classified fractures in to stable acute, unstable acute, delayed union, and nonunion. Russe classified scaphoid fractures into horizontal oblique, transverse, or vertical oblique patterns (**Fig. 1**). The Herbert classification attempts to define stable and unstable fractures and therefore may be particularly helpful in determining treatment options. The type A Herbert classification fracture is a stable acute fracture and type B is an unstable acute fracture. Stable fractures include fractures of the tubercle (A1) and an incomplete fracture of the

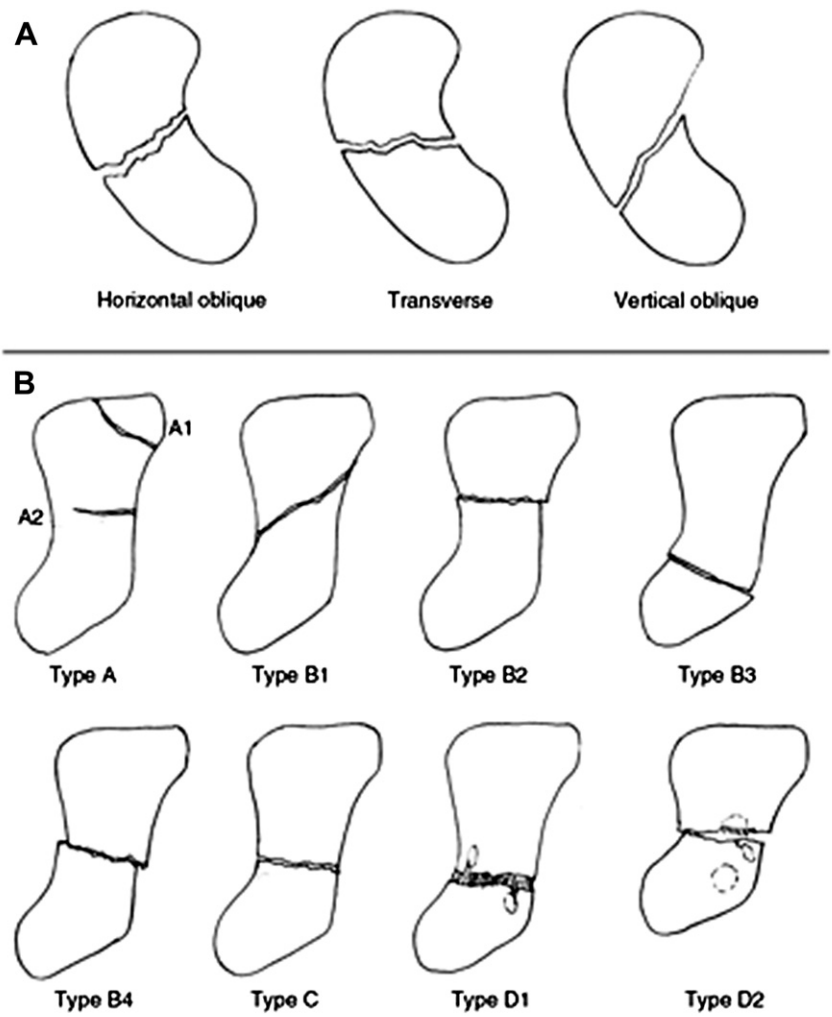


**Fig. 1.** (*A*) Russe classification. (*B*) Herbert classification. ([*A*] *Data from* Russe O. Fracture of the carpal navicular: diagnosis, non-operative treatment, and operative treatment. J Bone Joint Surg Am 1960;42:759–68; and [*B*] *Data from* Herbert TJ. The fractured scaphoid. St. Louis (MO): Quality Medical Publishing; 1990.)

waist (A2). These fractures can potentially be treated nonoperatively. The other types of fractures in the Herbert classification usually require operative treatment. Type B fractures (acute unstable fractures) include subtypes B1 (oblique fractures of the distal third), B2 (displaced or mobile fractures of the waist), B3 (proximal pole fractures), B4 (fracture dislocations), and B5 (comminuted fractures). Type C fractures show delayed union after more than 6 weeks of plaster immobilization, whereas type D fractures are established nonunions, either fibrous (D1) or sclerotic (D2).

## ACUTE SCAPHOID FRACTURE

### *Presentation*

The mechanism of injury is typically a fall onto an outstretched hand with the wrist in an extended position, placing the scaphoid vertical and making it vulnerable to injury. Patients may complain of vague or dorsal wrist pain, weakness, and limitation with range of motion, especially with flexion and radial deviation. On physical examination, tenderness may be present with palpation at the anatomic snuffbox, the distal scaphoid tubercle, and at the proximal pole dorsally. Longitudinal compression of the thumb may also elicit symptoms. Other findings may include crepitus, instability, swelling—including loss of the concavity of anatomic snuffbox—and ecchymosis.

Standard posterioanterior, lateral, and oblique radiographs (45°–60° of pronation) should be obtained (**Fig. 2**). Scaphoid views are particularly helpful to visualize the scaphoid architecture and look for fractures. Special views such as clenched fist views can be useful to rule out suspected scapholunate injury if no fracture is readily identified and clinical suspicion is high. The intra-scaphoid angle is the intersection of 2 lines drawn perpendicular to the diameters of the proximal and distal poles. Normal is less than 35°. An angle greater than 35° suggests a humpback deformity. The height/length ratio of the scaphoid is used to indicate collapse. Normal values are greater than 0.65.

If the radiographs are negative initially, patients may be treated with cast immobilization in a thumb spica splint for 2 weeks before re-imaging. These


**Fig. 2.** (*A–D*) Posterioanterior, lateral, oblique, and scaphoid views. The scaphoid view demonstrates a waist fracture.

follow-up x-rays may show bone resorption adjacent to the fracture site, thus making the nondisplaced fracture visible. If the initial x-rays readily identify a scaphoid fracture, this may represent displacement[16] and acute operative treatment is indicated.

Other radiographic modalities can make rapid diagnoses and prevent unnecessary immobilization in those patients with suspected, but not true fractures. Although no longer commonplace for identification of scaphoid fractures, bone scans show increased uptake in the area of the scaphoid within 24 hours (**Fig. 3**). A focal increased activity correlated with a clinical examination indicates an acute fracture. CT allows for an accurate analysis of the bony anatomy, allows fracture pattern characterization, and can be used for surgical planning.[16] The sagittal cuts, along the axis of the scaphoid, are best to define any collapse or humpback deformity at the fracture site (**Fig. 4**). The lateral intrascaphoid angle and height to length ratio can be measured. CT can also be used to follow healing, as a better assessment can be made of any cortical bridging.

The average sensitivity of CT for a nondisplaced fracture is 89% and specificity is 91%.[16] CT should be used with caution for triage of nondisplaced scaphoid fractures because false-positive results occur, perhaps from misinterpretation of vascular foraminae or other normal lines in the scaphoid. Given the relative infrequency of true fractures among patients with suspected scaphoid fractures, CT is better for ruling out a fracture than for ruling one in.

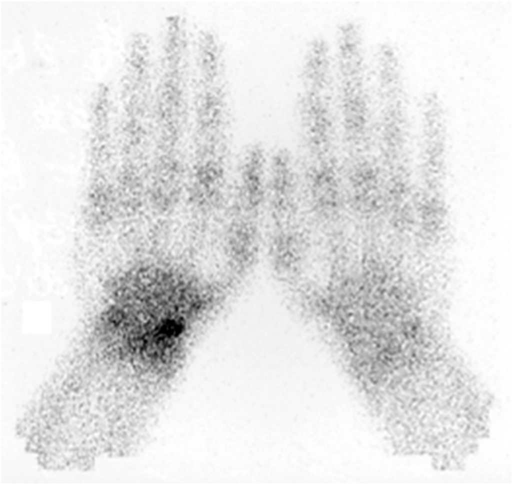

**Fig. 3.** Bone scan showing increased uptake. (*Data from* van Vugt RM, Bijlsma JW, van Vugt AC. Chronic wrist pain: diagnosis and management. Development and use of a new algorithm. Ann Rheum Dis 1999; 58:665–74. http://dx.doi.org/10.1136/ard.58.11.665.)

**Fig. 4.** CT and arrow demonstrating a humpback deformity. (*From* Yin YM, McEnery KW, Gilula LA. Computed tomography. In: Gilula LA, Yin YM, editors. Imaging of the wrist and hand. Philadelphia: Saunders; 1996. p. 425.)

Magnetic resonance imaging (MRI) is more sensitive and specific to detect an occult fracture.[16] One can also assess both the osseous blood supply and soft tissue integrity. Studies have been done to compare the cost of an initial MRI versus serial radiographic evaluation. Brooks and colleagues[17] performed a randomized, controlled trial investigated the cost-effectiveness of MRI for diagnosing suspected scaphoid fractures. There were 28 patients enrolled who had a suspected scaphoid fracture. Patients were randomized to undergo MRI scan or conservative treatment with immobilization and serial clinical and radiographic evaluation. Those who underwent MRI had a shorter duration of immobilization and decreased use of health care resources but increased cost to treat compared with patients randomized to the non-MRI group, who were immobilized and evaluated with serial clinical and radiographic examination. Cost per day of unnecessary immobilization between the groups was $44.37. The costs did not include work absence. Another study by Pillai and Jain[18] reported a rate of more than 80% of unnecessary immobilization for suspected scaphoid fractures and negative radiographs. They concluded that the cost of needless immobilization, with further clinical and radiographic studies, would have exceeded early alternative investigations, such as MRI or bone scan, which were frequently required anyway.[16] An MRI is also very useful in suspected cases of AVN with respect to diagnosis and surgical planning (**Fig. 5**).

## *Nonoperative Treatment*

Distal or tubercle fractures often heal adequately with cast immobilization. Nonoperative treatment

**Fig. 5.** MRI demonstrating AVN of the scaphoid. Outcome after vascularized bone grafting of scaphoid nonunions with avascular necrosis. (*From* Waitayawinyu T, McCallister WV, Katolik LI, et al. Outcome after vascularized bone grafting of scaphoid nonunions with avascular necrosis. J Hand Surg Am 2009;34(3):387–94; with permission.)

involves a long-arm or short-arm thumb spica cast, with the wrist in neutral position leaving the thumb interphalangeal joint free. This cast is maintained for 8 weeks and then CT can be done to assess healing. If the CT still suggests unhealed fracture, cast immobilization is maintained for another 4 to 6 weeks. For proximal pole fractures, operative reduction and fixation are indicated.[19]

## *Operative Repair*

Operative reduction and internal fixation are indicated for unstable fracture patterns. Some authors advocate, however, that nondisplaced waist fractures should be treated operatively.[17,20] Rigid internal fixation may allow early mobilization, decrease time to union, and improve range of motion. A more rapid functional recovery and the potential for earlier to return to sports and work after operative repair are both appealing to many patients with nondisplaced scaphoid fractures. Cast immobilization does not eliminate micromotion at the fracture site and does not favorably alter the biologic environment to promote healing. McQueen and colleagues[21] in a prospective, randomized trial randomly allocated 60 consecutive patients with scaphoid waist fractures to percutaneous fixation with a cannulated Acutrak screw or cast immobilization. Patients who underwent percutaneous fixation showed a faster time to union and a more rapid return of function and return to sports with a low complication rate and work compared with those managed nonoperatively. A randomized, controlled trial and a recent meta-analysis have been done to compare surgery versus conservative management of undisplaced waist fractures.[17,20] The rate of complications in the surgical treatment groups was significant with small comparative treatment effect. The complications include infection, complex regional pain syndrome (CPRS), prominent hardware, technical difficulties intraoperatively, scar-related complications, scaphotrapeziotrapezoid joint osteoarthritis in surgical treatment group, and radiocarpal osteoarthritis in the nonoperative group.

## *Fixation Methods*

A variety of implants have been examined to optimize the stabilization and healing of scaphoid fractures. Management and fixation constructs have to take into account the bone quality, fracture pattern, and reduction. The implant has to counter bending, shearing, and translational forces that act at the fracture site. Implants used for fixation include Kirschner (K)-wires, traditional screws placed in compression, headless compression screws, cannulated screws of both types, and bioabsorbable implants.

Studies have reported that cannulated screws have resulted in a higher rate of central placement in the scaphoid with better resistance and compressive forces. McCallister and colleagues[22] simulated scaphoid waist fractures and biomechanically compared screws placed in the central axis with screws placed eccentrically. Fixation with central placement of the screw demonstrated 43% greater stiffness, 113% greater load at 2 mm of displacement, and 39% greater load at failure. Trumble and colleagues,[23] found that screws should be placed centrally within the middle third of the proximal pole of the scaphoid on both the anterioposterior and lateral views in displaced scaphoid fractures.

Long, centrally placed screws (that end 2 to 3 mm under the chondral surface) offer superior biomechanical stability than short, eccentrically placed screws (**Fig. 6**). Longer screws reduce forces at the fracture site and spread bending forces along the screw. A screw placed centrally and deep in the cancellous bone of the scaphoid optimizes the stability conferred by scaphoid screw fixation.[5] However, one has to be careful with the length to avoid prominence at the chondral surface. In addition, it is critical to adequately ream the scaphoid central guide wire to obtain compression rather than distraction. Scaphoid screws should be no longer than 4 mm less than the measured scaphoid length (leaving $\geq$2 mm of bone coverage at both ends of the scaphoid). Screw prominence at the articular surface leads to unacceptable hardware impingement and subsequent chondral wear. When rigid fixation

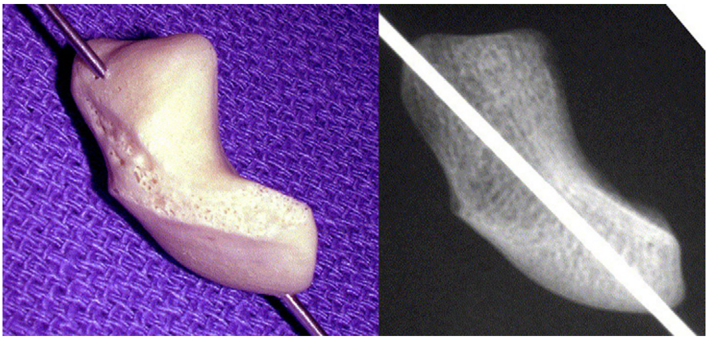

**Fig. 6.** Central pin placement. (*From* Slade JF, Merrell GA. Minimally invasive management of scaphoid fractures. Operat Tech Plast Reconstr Surg 2002;9(4):143–50; with permission.)

cannot be provided by a central screw placement alone (such as in proximal pole fractures and nonunions), augmentation may be necessary to prevent micromotion at the fracture site. Supplemental fixation is commonly applied from the distal scaphoid to the capitate using a 0.062-in K-wire or a mini-headless screw.[5]

Screw fixation, however, is not without its complications. Neighboring structures can be damaged. A cadaveric study found that the extensor digitorum communis, extensor indicis proprius, extensor pollicis longus, and the capsular insertion of the posterior interosseus nerve were at risk of injury.[22] Furthermore, the screw had protruded into the radioscaphoid joint in 2 cases. A retrospective review of 24 scaphoid fractures treated with dorsal percutaneous screw fixation included failure of a screw to capture the distal fragment and intraoperative breakage of a guide wire.[24]

## OPERATIVE TECHNIQUE

Both volar and dorsal approaches are described. Studies have shown that both the volar and the dorsal approaches offered reliable results. No differences have been identified between the 2 groups in terms of union time and functional outcome, which included pain, range of motion, return to work, and grip strength. The choice of approach is dictated by the fracture location. The dorsal, antegrade approach is the preferred approach for proximal pole fractures, whereas a volar, retrograde approach may provide better fracture stability for distal pole fractures. Waist fractures are amenable to either approach.

### *Volar Open Approach*

The open volar approach to the scaphoid requires a longitudinal incision, over the FCR tendon extended between the thenar muscles and the abductor pollicis longus tendon. This incision is carried proximally to 2 cm from the scaphoid tuberosity. The distal incision is in line with the thumb metacarpal. The ulnar border of the FCR is avoided to minimize trauma to the palmar cutaneous branch of the median nerve. The FCR tendon sheath is divided and the tendon is retracted ulnar-ward. The pericapsular fat is divided and this exposes the wrist capsule. The long radiolunate and RSC ligaments are sharply divided, which exposes the scaphoid waist. When closing, attention to proper repair of the volar carpal ligaments must be met to avoid problems with iatrogenic carpal instability.

### *Volar Percutaneous Technique*

A percutaneous technique may also be used to limit soft-tissue dissection and to protect the integrity of the volar carpal ligaments. In this technique, the STT joint is identified and marked on the volar side of the skin. A closed reduction is applied. A transverse stab incision is made at about 1 cm distal to the scaphotrapezial joint under image intensifier control. After blunt dissection to the distal end of the scaphoid, a 0.45-in K-wire is used for provisional reduction and stabilization along the long axis of the scaphoid and is directed (under fluoroscopic guidance) toward the center of the proximal pole. The length of the central guide wire within the scaphoid is determined. After hand reaming, a compression screw of appropriate length is advanced under fluoroscopy. The screw is buried to avoid intra-articular prominence (Fig. 7).

### *The Dorsal Open Approach*

The open dorsal approach to the scaphoid provides better access to the proximal scaphoid. This approach, however, can be a concern because of injury to the vascular supply of the scaphoid. The advantage is better targeting of the central axis of the scaphoid and allowing more precise placement of the screw within the scaphoid. Furthermore, one avoids injury to the volar carpal ligaments protecting stability.

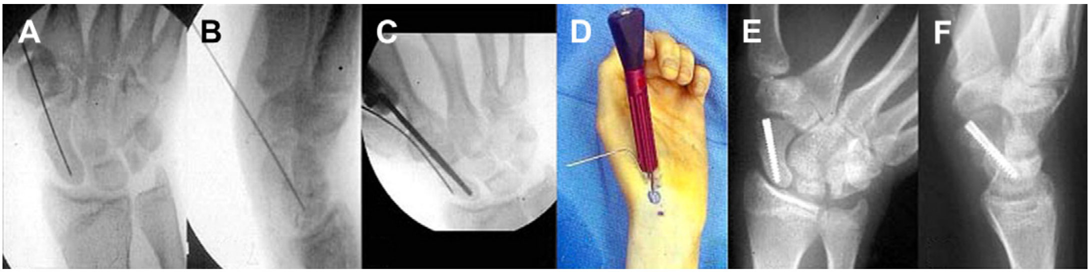


**Fig. 7.** Volar percutaneous technique. (*A, B*) Guidewire placement. (*C*) Drilling over guidewire. (*D*) Inserting screw. (*E, F*) Anterioposterior/lateral images of screw placement. (*From* Haisman JM, Rohde RS, Weiland AJ, et al. Acute fractures of the scaphoid. J Bone Joint Surg Am 2006;88:2750–58.)

A longitudinal incision is made over the scapholunate interval and radiocarpal joint (**Fig. 8**). The skin flaps are elevated and care is taken to protect the radial sensory nerve. The EPL is identified and retracted radially. The septum between the third and fourth compartments is opened and the extensor tendons are retracted ulnar-ward. The capsule is incised radial to the border of the dorsal radiocarpal ligament. With this approach, the entire proximal two thirds of the scaphoid, the radial styloid, and the scaphoid fossa in the distal radius can be exposed.

### *Dorsal Percutaneous Technique*

The open approach to fixation risk violating carpal ligaments with risk of carpal instability and potentially violating the blood supply; thus, there is an increasing trend to toward percutaneous fixation of scaphoid fractures, both displaced and undisplaced. Percutaneous technique allows for less soft-tissue dissection and subsequent faster healing.

The patient is placed supine and the hand is outstretched on a hand table. Landmarks are drawn on the pronated wrist. Under appropriate anesthesia with the patient in a supine position, the dorsal scapholunate interval is marked. Scaphoid reduction is assessed fluoroscopically. K-wires (usually 0.062") can be placed in the distal and proximal poles of the scaphoid and can be used as joysticks for manipulative reduction of a displaced fracture. The wrist is pronated and flexed until the scaphoid is seen as a circle on fluoroscopy. The center of the circle is chosen as the target point for the insertion of the guide wire into the proximal pole of the scaphoid. A small longitudinal skin incision is made over the center of the circle, soft tissues are dissected bluntly to the joint capsule, and a percutaneous arthrotomy is made with a small blunt tipped hemostat. The guide wire is driven dorsal to volar in an antegrade fashion so that it exits at the radial base of the thumb. The reduction and central placement of the guide wire is confirmed under fluoroscopy. A pilot hole is drilled along the guide K-wire. After tapping, a headless screw is inserted under fluoroscopy in a freehand manner (**Fig. 9**).

## ARTHROSCOPIC-ASSISTED PERCUTANEOUS SCAPHOID FRACTURE REPAIR

Arthroscopy can also be used to help with diagnosis of concurrent ligamentous injury such as the triangular fibrocartiligous complex and as a way to judge reduction of the fracture (**Fig. 10**). For example, midcarpal arthroscopy enables direct visualization of the articular reduction of a scaphoid waist fracture along the scaphocapitate articulation. An important tip is to place the central scaphoid osseus wire to prevent any displacement during the athroscopic assessment.[24]

### *Bone Loss Acute Fractures*

Bone defects can occur with scaphoid fractures and the amount of defect depends on the fracture location, as well as the degree of comminution. A highly comminuted fracture presents technical difficulty in that screw purchase may be challenging. One has to be ready to have options such as traditional K wire fixation or even nonoperative treatment. CT in these instances are very useful to determine the amount of bone loss and to help to delineate the fracture management and subsequent appropriate management.

### *Malunion, Delayed Union, and Nonunion*

Many variables influence treatment of a malunion, delayed union, or nounion: Previous treatment and duration, patient's activity and personal demands, as well as the surgeon's preference.

Oka and colleagues[25] looked at bone defects in scaphoid nonunion and found that the both the shape and amount of the defect differed with the fracture type. In distal fractures, a humpback deformity is seen and the bone defect is large

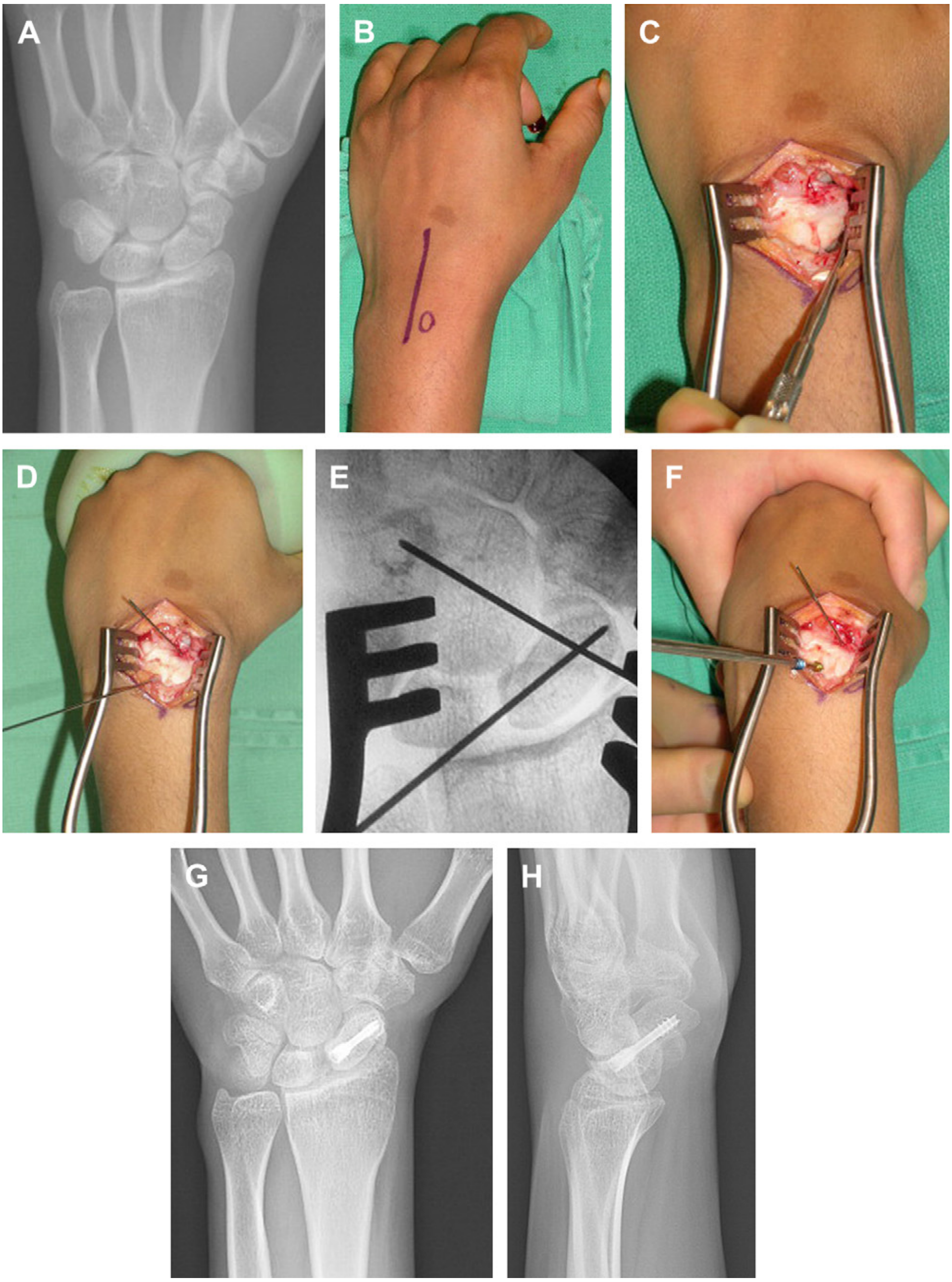


**Fig. 8.** Open dorsal approach. Dorsal incision is made exposing the radiocarpal joint. K-wires may be used for distal pole control as well as for provisional stabilization. (*From* Kawamura K, Chung KC. Treatment of scaphoid fractures and nonunions. J Hand Surg Am 2008;33(6):988–97; with permission.)

and triangular. Proximal fractures tend to have smaller defects with crescent-shaped patterns. The finding of this study suggested that both the pattern and amount of bone loss had to do with location of the fracture line relative to the dorsal apex of the scaphoid ridge. This is where the dorsal component of the scapholunate (SL) ligament and proximal part of the dorsal intercarpal ligament are located. They both provide stability to the dorsal scaphoid. In the distal fractures, the fracture line goes beyond these ligamentous attachments, which cause an inability of the fragment to resist flexion forces, resulting in the humpback deformity. In the proximal fractures, the ligaments remain attached on the distal fragment providing stability.

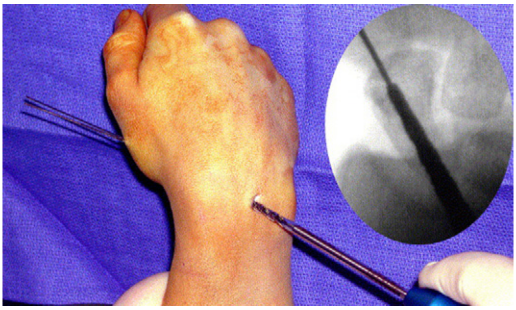

Fig. 9. Dorsal percutaneous technique. (*From* Slade JF, Merrell GA. Minimally invasive management of scaphoid fractures. Operat Tech Plast Reconstr Surg 2002;9(4):143–50; with permission.)

## *Type of Bone Graft*

The gold standard has typically been to use iliac crest bone in the treatment of scaphoid fracture. This was owing to the supposed superior biomechanical strength and osteogenic capacity. However, other sources such as the distal radius are viable sources of autogenous bone graft.

The studies that have compared these graft options have shown that the union rates were similar with both techniques. Tambe and colleagues[26] have documented 66% and 67% graft union in nonunited scaphoids treated by iliac crest bone graft and distal radius bone graft, respectively. There is also increased morbidity with the use of the iliac crest bone such has pain, infection, hematoma, and injury to the lateral femoral cutaneous nerve. This suggests the distal radius is an improved alternative given it only involves a minor increase in surgical exposure.[26]

The authors' preferred method is to use iliac crest bone graft. It has long been considered the gold standard for autogenous bone graft source with proven biomechanical strength and osteogenic capacity.

## *Nonunions*

Nonunion rates range from 5% to 25% (**Fig. 11**).[8,9,14,26,27] Factors that increase the risk are displacement of more than 1 mm, fracture of the proximal pole, history of osteonecrosis, vertical oblique fracture pattern, and nicotine use.[8,9,14,26,27] Nonunion can result in pain, altered carpal kinematics, and decreased range of motion, leading to disuse osteoporosis, weakness in grip, and degenerative arthritis. For an established symptomatic nonunion, whether it is fibrous or sclerotic, it should be treated with open repair and bone grafting. Proximal pole nonunion are best visualized through a dorsal approach and waist fractures should be managed by an approach that allows for a volarly placed bone graft. A humpback deformity requires an open approach with reduction of the scaphoid alignment and a corticocancellous wedge graft.

For conventional bone grafting of scaphoid nonunions, a recent study concluded that union rates were affected adversely by manual labor, nonunions of more than 5 years' duration, concomitant radial styloidectomy, and inadequate duration of postoperative immobilization.[28] Inoue and Kuwahata[28] reported that failure of conventional bone grafting with screw fixation of scaphoid nonunions was related to the existence of AVN of the proximal fragment, instability of the fracture fragment, prolonged delay in surgery, and fracture location.

Excision of the scaphoid distal pole can be used for nonunion of the scaphoid without advanced degenerative change. Ruch and colleagues[19,29–31] reported good results after arthroscopic excision of the distal pole for the treatment of AVN of the proximal pole. Malerich and colleagues[32] described this technique for the treatment of SNAC wrist. After removal of the scaphoid distal pole, carpal loads are transferred primarily to the radius through the radiolunate articulation (**Fig. 12**). There is a theoretic concern that degenerative changes

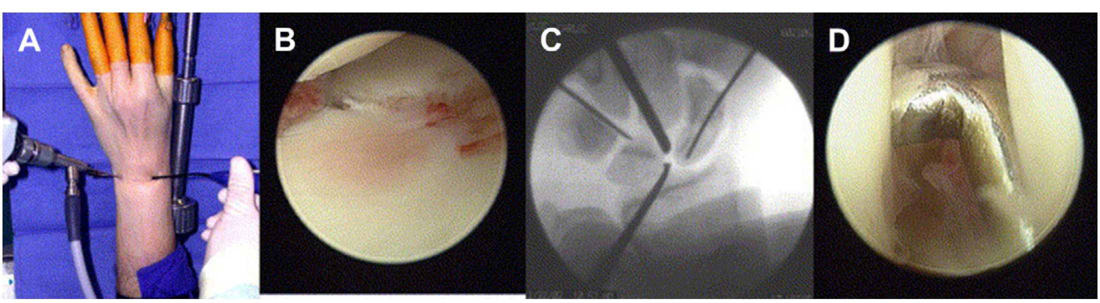


Fig. 10. The thumb is suspended from the traction tower, which allows switching from the AP to lateral projections when placing the guidewire. (*From* Slade JF, Merrell GA. Minimally invasive management of scaphoid fractures. Operat Tech Plast Reconstr Surg 2002;9(4):143–50; with permission.)

**Fig. 11.** Nonunion of scaphoid waist fracture.

in the radiolunate joint can occur; however, studies have not demonstrated this equivocally.

## *Nonvascularized Bone Grafting*

Nonvascularized bone grafting is probably sufficient for most waist fracture nonunions without AVN. Cases of proximal pole AVN, a failed previous surgery, or long duration of the nonunion should be considered for vascularized bone graft. Stark and colleagues reported successful union in 97% of 151 scaphoid nonunions, and recently Finsen and colleagues[33] demonstrated success in 90% of 39 nonunions with this technique. Notably, the results were also excellent for proximal pole nonunions in both studies. A corticocancellous wedge bone graft is inserted volarly at the nonunion site and the nonunion is repaired with either K-wires or screws. It can be difficult to shape the wedge graft accurately; hence, Stark offered an alternative technique to fix humpback deformities with nonunion, using temporary K-wire fixation and cancellous grafting.

**Fig. 12.** Excision of the distal pole. (*From* Malerich MM, Clifford J, Eaton B, et al. Distal scaphoid resection arthroplasty for the treatment of degenerative arthritis secondary to scaphoid nonunion. J Hand Surg Am 1999;24:1196–205; with permission.)

## *Vascularized Bone Grafting*

Vascularized bone grafting is used in many cases of nonunion, especially with cases of suspected or established AVN. Types of grafts include the pronator quadratus pedicled bone graft, or the palmar carpal artery, the radial styloid fasciosteal graft, and pedicled grafts from the index finger metacarpal and the thumb metacarpal. Zaidemberg described vascularized bone graft derived from the dorsal radial aspect of the distal radius, which is nourished by the 1,2 intercompartmental supraretinacular artery (1,2 ICSRA).[34] Free vascularized bone grafts from the iliac crest and the medial femoral supracondylar region have also been reported. Shin described a technique to harvest the medial femoral condyle bone graft based on the descending genicular artery or superomedial genicular artery.[35] Dissection and microvascular anastomosis of the vessel can be technically demanding and the need for pedicle rotation in some of those grafts may compromise the long-term patency. Sotereanos and colleagues[36] proposed the use of a vascularized bone graft that is capsular based. It is derived from the distal aspect of the distal radius and ulnar/distal to Listers tubercle. The advantage of this graft is its close proximity to the nonunion site without the need for excessive rotation. The vascular supply is derived from the strip of the dorsal capsule; a specific pedicle does not need to be dissected. One limitation of this technique includes the inability to correct a humpback deformity; in fact, an ideal indication for a dorsal capsular graft is a proximal pole nonunion. Another limitation is in patients who have had previous surgery or injury to the dorsal aspect of the wrist, because the vascularity of the capsule in those patients would not be predictable.

The principal advantage of vascularized bone grafting is a potentially more reliable union after grafting. A recent meta-analysis found that vascularized bone grafting achieved an 88% union rate compared with a 47% union rate with screw and intercalated wedge fixation in scaphoid nonunions with AVN.[37] Perlik and Guildford reported that increased density on the preoperative radiographs has only 40% accuracy for detecting proximal fragment avascularity, and thus many cases that were classified as AVN may actually have had satisfactory vascularity of the proximal pole.[38] Absence of punctuate bleeding from the proximal pole at surgery is a more accurate way of determining vascularity.

Boyer found a 60% healing rate in the study scaphoid nonunions treated by 1,2-ICSRA pedicled vascularized bone grafting.[39] All subjects in this study, however, had proximal pole AVN. Straw and colleagues[40] also reported only 2 of 16 nonunions with AVN united with the 1,2 ICSRA bone graft. Chang and colleagues[7] evaluated a large series of 1,2 ICSRA bone grafts that were performed for scaphoid nonunions and showed that 71% of 48 nonunions healed and the union rate was 91% in the absence of AVN and 63% in the presence of AVN. Successful outcome is not universal and depends on debridement of the nonunion site, reduction of scaphoid alignment, appropriate bone grafting, and rigid internal fixation, even when vascularized bone grafting is used for scaphoid nonunions.

### *Associated Instability*

The scaphoid functions as a complex link between the proximal and distal carpal rows of the wrist. A scaphoid fracture nonunion changes wrist mechanics, which can lead to carpal instability and secondary degenerative changes. A high incidence of SL ligament injuries found in scaphoid nonunions has raised the possibility of an association between the 2 injuries.[11] This association raises the indication for arthroscopy even in nondisplaced scaphoid fractures if surgical fixation and early mobilization is offered to avoid detrimental effects of an undiagnosed ligament tear. The advantage of arthroscopy is direct evaluation of associated ligament injuries not seen in standard imaging, and it helps to confirm both fracture reduction and the absence of screw protrusion after osteosynthesis.

### *Pediatric Scaphoid Fractures*

Scaphoid fractures are rare, as are most carpal fractures in children. The incidence is about 0.45% of all upper limb injuries in children and occurs typically in the teenage years.[41] In children, the ossification center is protected by a thick layer of cartilage, which accounts for the low incidence of fracture. As the ossification center changes with age, the pattern of injury also changes. Distal pole scaphoid fractures are more common in children as ossification progresses in a distal to proximal direction.[41] As the child approaches adolescence, the fracture pattern becomes similar to that in adults.

When examining the patient, it is important to have a high index of suspicion. Given the rarity of this fracture in children and difficulties with interpreting radiographs of a pediatric carpus, a scaphoid fracture can be missed. When interpreting radiographs, one should also be aware that the distance from the ossified lunate and scaphoid decreases as the child approaches adolescence. This is a normal radiographic finding, which changes with the age of the child. As the proximal pole matures and ossifies, the average scapholunate interval is 9 mm in a 7-year-old and 3 mm in a 15-year-old.

Management of most pediatric scaphoid fractures is with cast immobilization. Given that most are distal pole fractures (60%–85%), excellent healing is reported. Furthermore, most pediatric scaphoid fractures are nondisplaced or involve only 1 cortex. Proximal pole fractures are rare. For avulsion and incomplete fractures, a short thumb spica cast is recommended for 6 weeks. In the younger child, a long arm cast may be appropriate to prevent the cast from falling off. For waist and transverse fractures, 8 weeks of immobilization is recommended. It is reasonable to confirm healing with a CT scan before return to activity for a patient treated nonoperatively in a cast.

Nonunion of scaphoid fractures is a rare occurrence in children. Delayed presentation or failure of initial diagnosis contributes to nonunion. Most scaphoid nonunions in skeletally immature patients involve the scaphoid waist. Mintzer reported a series of 13 scaphoid nonunions in children ages 9 to 15 years. These fractures were treated with surgical stabilization and all healed.[42]

Fabre and De Boeck reviewed the literature and reported that of 371 children with acute scaphoid fracture treated with immobilization, only 3 (0.8%) developed a nonunion.[43] They found only 29 published cases of scaphoid nonunion in children. In their own series of 23 acute fractures of the scaphoid in children, all healed with cast immobilization. They also reported 2 cases of patients who had scaphoid nonunion that presented late after their injuries (referred from other institutions) at an average of 7 to 11 months after their injuries. Both were treated successfully with cast immobilization.

Another large series of scaphoid fractures (64 cases) reported 46 nonunions.[41] All the nonunion cases were waist fractures, except for 1 proximal and 1 distal pole fracture. The patients were between 11 and 15 years of age, and most injuries presented late. The reasons for delayed presentation were reluctance to forgo play on teams or report the injury, and symptoms that were not severe enough to warrant expedient evaluation.

## COST ANALYSIS

There continues to be cost analysis debate regarding both the role of surgery versus casting in the management of undisplaced or minimally displaced waist and distal pole scaphoid fractures. Both casting and surgery are reliable treatments and outcomes are comparable. Davis and colleagues[44] performed a cost-utility analysis of open reduction and internal fixation versus cast immobilization for acute nondisplaced midwaist scaphoid fractures. They concluded that open reduction and internal fixation offered more quality-adjusted life-years and is less costly than casting ($7940 vs $13,851 per patient) because of a longer period of lost productivity with casting.[13] When only considering direct costs incurred by Medicare reimbursement, casting was less costly than open reduction and internal fixation ($605 vs $1747). The authors did state, however, that the cost-utility analysis overestimates lost productivity with casting because people in casts can still work.

Vinnars[45–47] found that the total hospital costs were lower with cast treatment than surgery. They also found that manual laborers had a longer time off of work, especially if they received casting alone. They did not find the same difference with casting in nonmanual workers. The decision to operate versus casting depends on the individual's unique circumstances. Surgery is more expensive in the initial period; however, allowing an individual to get back to work faster may ultimately incur less costs with respect to workers compensation. Ultimately, if an individual's employment is hand and upper extremity intensive, surgery ultimately may be the more cost-effective management.

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