Scaphoid Nonunion

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Abstract

The natural history and treatment of scaphoid fractures and subsequent nonunions have occupied a substantial portion of the orthopaedic literature. The authors examine the role of modern diagnostic tools in making an earlier diagnosis of scaphoid nonunion, in more accurately determining the displacement and angulation of the fragments, and in identifying the presence of avascular necrosis. They also consider the various available treatment modalities, including immobilization, electrical stimulation, both conventional and vascularized bone grafting, and internal fixation. Finally, a brief review of salvage procedures and the authors' preferred treatment are presented.

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Among all wrist injuries, the incidence of fractures of the scaphoid is second only to that of fractures of the distal radius.[1] Scaphoid fractures constitute 60% to 70% of all carpal bone fractures. It has been estimated that there are 17,250 to 34,500 nonunions per year despite proper treatment.[2]

Nonunions have been attributed to delay in beginning treatment, inadequate immobilization, displacement of the fragments, instability due to ligamentous injury, and inadequate blood supply of the proximal fragment.[3] Biomechanical studies have demonstrated that the scaphoid plays a key role as the stabilizing link between the proximal and distal carpal rows.[4] Patients with scaphoid nonunions are likely to develop traumatic arthritis with increasing pain, decreased wrist mobility, and weakness.[5] However, the data concerning the natural history of scaphoid nonunions are largely anecdotal and difficult to interpret.[6]

Classification

Scaphoid fractures can be classified according to the time after injury as (1) acute fractures (less than 3 weeks old), (2) delayed unions (4 to 6 months old), and (3) nonunions (more than 6 months old). However, many clinicians diagnose these fractures as nonunions regardless of the time period if sclerosis, cyst formation, or bone resorption is present. Herbert devised an alphanumeric classification scheme that combines fracture anatomy, stability, and history; this system was designed to facilitate prognostic evaluation. Russe[7] classified fractures into three types according to the fracture line relative to the long axis of the scaphoid: horizontal oblique, transverse, and vertical oblique. Scaphoid fractures have also been classified as distal, waist, and proximal. Fractures of the middle third of the scaphoid are the most common type and have shown a high percentage of delayed unions and nonunions. Proximal-pole fractures have a slower rate of healing than more distal fractures.[3,7]

Diagnostic Imaging

Early Diagnosis

Because of the incidence of nonunions after occult scaphoid fractures, new methods have recently been investigated to further image the posttraumatic scaphoid. Traditionally, scaphoid fracture is assumed in the posttraumatic situation if there is tenderness in the anatomic snuffbox despite normal radiographs. Radiographs are then repeated at 10 to 14 days to determine whether a fracture is indeed present. A standard radiographic examination of the suspected scaphoid fracture includes neutral, ulnar deviation, posteroanterior, and lateral views, as well as oblique views obtained with the wrist in pronation.

In an effort to decrease the delay in diagnosis, King and Turnbull[8] recommended that a technetium bone

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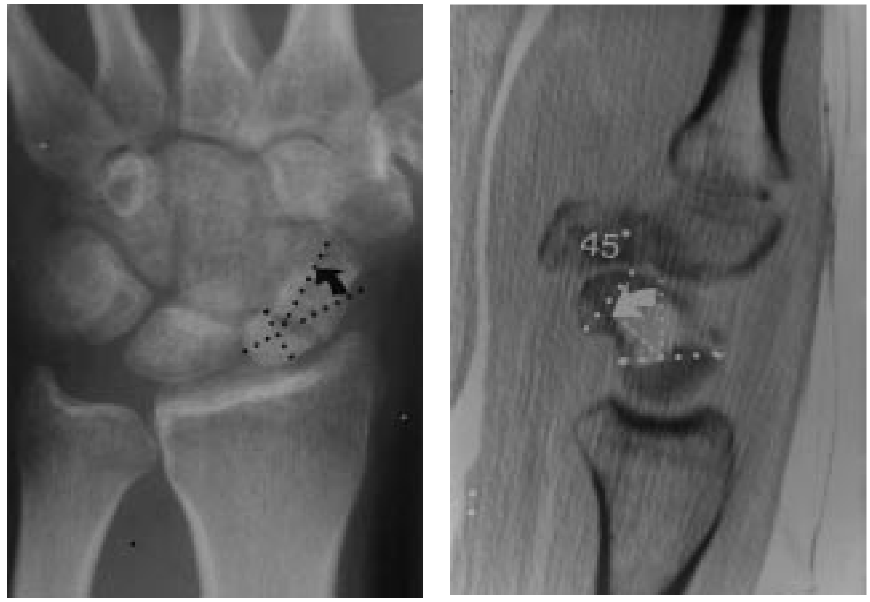
scan be obtained 24 hours after injury (Fig. 1). Because this technique is very sensitive (reported 100% sensitivity),[8] it can obviate unnecessary casting and allow early medical clearance for return to work. However, the procedure is relatively time-consuming and costly, and it exposes the patient to radiation. The low specificity (75%) of bone scans is improved with clinical correlation.

A vibratory instrument has recently been used as a means of screening for scaphoid fractures. It is reported to be reliable, inexpensive, noninvasive, and easy to use and involves no ionizing radiation.[9]



A B

Fig. 2 **A,** Anteroposterior radiograph reveals collapse and resultant angulation of the scaphoid. **B,** Lateral intrascaphoid angle on a sagittal CT scan of another patient indicates a significant (45-degree) displacement at the fracture secondary to collapse.

Displacement and Angulation

Precise imaging of the fracture fragments is difficult because of the complex shape of the scaphoid. Collapse of the fracture fragments is a concern and can be seen on plain radiographs (Fig. 2,A) and in more detail with computed tomography (CT) (Fig. 2,B). The scaphoid is visualized most completely when six to eight CT sections are obtained along the longitudinal axis of the scaphoid. Computed tomographic scans have been used to create three-dimensional images and models. The volume of bone loss as determined from computer models can vary from 6% to 15% and does not show a linear relationship with the duration of the nonunion. The missing-bone space is consistent in configuration, exhibiting a prismatic shape with a quadrilateral base, and is oriented palmarly. The proximal scaphoid fracture component is extended, radially deviated, and supinated in relation to the distal fracture component.[10]

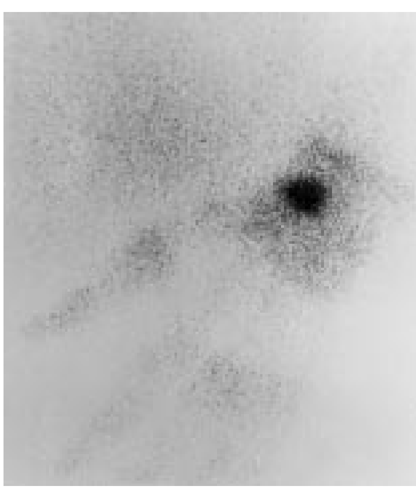


Fig. 1 Bone scan demonstrates scaphoid fracture not evident on plain radiographs in a patient with tenderness in the anatomic snuffbox.

Avascular Necrosis

Avascular necrosis of the proximal pole of the scaphoid is an important predictive factor in the success of surgery to correct scaphoid nonunion.[11] This is of particular importance in higher-risk elderly patients and in patients with longstanding nonunions. The correlation between gross examination of the osseous blood supply at surgery and success following bone grafting is controversial.

Magnetic resonance (MR) imaging studies can be used to detect avascular necrosis in carpal bones and to aid in patient selection[11] (Fig. 3). It is essential to use a label for bone formation in order to provide dynamic evidence of bone viability that can be correlated with the MR imaging appearance. Trumble[11] obtained histologic confirmation of the MR findings consistent with avascular necrosis by administering a tetracycline label preoperatively and then using a vital staining technique. This helped predict whether the scaphoid was unlikely to unite following bone grafting and internal fixation. In vivo labeling of bone samples is a reliable method for assessing the presence or absence of bone turnover.

Nonoperative Treatment

No Intervention

According to some reports, established nonunions, particularly if stable and without carpal collapse, may not require any operative treatment,

Fig. 3 Magnetic resonance image demonstrates avascular necrosis of the proximal scaphoid fragment.

for they can remain essentially symptom-free. Clearly, patients older than 40 years of age, patients with nonunions of more than 2 years' duration, and patients with evidence of avascular necrosis (without a decrease in carpal height or an increase in the scapholunate angle) may not require any treatment.

Casting

Cast immobilization has been shown to promote union of stable nondisplaced nonunions (i.e., those with no evidence of sclerosis, bone resorption, or carpal collapse and no prior history of casting). Casting can also be used in combination with other forms of treatment, including electrical stimulation. Immobilization for prolonged periods of time (longer than 6 months) can have a significant impact on a patient's wrist motion, as well as quality of life and productivity.

Electrical Stimulation

Electrical stimulation has been used as an alternative or adjunct to surgical treatment, but its use and effectiveness have been highly controversial. In some studies it has not been shown to be more useful than other nonoperative methods.[12] Furthermore, the efficacy of this type of treatment is difficult to evaluate objectively with double-blind studies because of the many variables associated with scaphoid fractures.

Although the current supporting evidence is not conclusive, pulsed electromagnetic fields have also been recommended as a treatment modality,[12] for example, for nondisplaced nonunions without carpal instability of less than 5 years' duration.[13] Pulsed electromagnetic field treatment is not inexpensive, however; the cost compares with that of surgical treatment and hospitalization. Frykman et al[13] treated 44 nonunions of at least 6 months' duration with a combination of electromagnetic field treatment and plaster immobilization and found that 35 (80%) healed after a mean of 4.3 months. According to this and other reports, this treatment is not as effective as bone-graft techniques, nor can it correct scaphoid collapse; however, the results seem satisfactory enough to justify its consideration as an alternative treatment.

More recently, Adams et al[14] reported that a successful outcome with pulsed electromagnetic field treatment and casting is less likely than they had previously believed.[13] They proposed that pulsed electromagnetic field treatment should be second choice to bone-grafting procedures until more controlled studies have been done.[14]

Operative Treatment

Indications and Options

There is now considerable evidence to suggest that the incidence of posttraumatic osteoarthritis increases in patients with scaphoid fractures treated with immobilization, because of the increased incidence of nonunion; however, the exact incidence is unknown.[5,15] The severity of osteoarthritis and the rapidity of its progression are increased for displaced fractures and for fractures with coexistent carpal instability. Several reports indicate that few nonunions remain stable or nondisplaced and free of arthritis after 10 years.[5,15] Accordingly, even asymptomatic patients with stable nondisplaced nonunions should be advised of the possibility of late degenerative changes. For these reasons, we believe that fragments that are grossly displaced or unstable because of ligamentous or osseous disruption should be treated with open reduction and internal fixation as soon as possible.[1,7] Because of the evidence linking scaphoid nonunions with osteoarthritis,[5] surgery is recommended for most young, healthy patients even if they are free of symptoms and have normal wrist mobility.

Operative techniques used to manage scaphoid nonunion at its various stages of presentation include bone grafting, vascularized bone grafting, internal fixation, and salvage procedures.

Surgical Approach

Studies of the arterial anatomy of the carpal scaphoid have provided relevant information on the various operative approaches that have been designed to preserve the critical intraosseous blood supply. They have generally confirmed that the palmar approach is least injurious to the vascular supply of the proximal pole.[3,16]

Gelberman and Menon[3] demonstrated that 70% to 80% of the intraosseous vascularity and the entire vascular supply of the proximal pole are from branches of the radial artery entering through the dorsal ridge. In the region of the distal tuberosity, 20% to 30% of the bone receives its blood supply from volar radial artery branches. There is excellent collateral circulation to the scaphoid by way of the dorsal and volar branches of the anterior interosseous artery.

More recently, Botte et al[16] reported the effects of the dorsal and the palmar operative approaches on the internal vascularity of the scaphoid. They found the palmar approach to be safer with respect to preserving the dorsal nutrient branches. The dorsal operative approach placed the vessels of the dorsal ridge at higher risk, particularly when the vascular leash was not visualized directly and protected.

Another important consideration is the location of the nonunion. Waist fractures should be approached through the volar incision to protect the vascular supply. However, proximal-pole fractures are best approached through a dorsal incision. This allows the small proximal fragment to be stabilized to the larger distal fragment with a screw or Kirschner wire. Because the blood supply has usually been completely divided in this fracture, the dorsal approach will not likely add additional injury to the bone vascularity.

Bone Grafting

Traditionally, bone grafting has been the most popular surgical treatment and remains the procedure of choice for scaphoid nonunion. It was recommended in 1928 by Adams and Leonard, who inserted a graft into the major cavity of the proximal fragment and laid the distal portion of the graft in a trough in the distal fragment. The technique was later refined by Murray, who used a cortical peg from the tibia and passed the graft through the intramedullary portion of both fragments in a proximal direction.

The concept of an inlay bone graft was introduced in 1937 by Matti. He described resection of sclerotic bone from the nonunion side approached dorsally. He then filled the defect with cancellous graft. In 1960 Russe[7] described a similar technique of inlay graft using a volar approach in which a corticocancellous graft was set in a cavity made in the proximal and distal fragments to serve as osteogenic material and stabilize the fracture. He believed that a palmar surgical approach was less likely to cause further damage to the bone circulation. Russe reported a 90% union rate, which has become the benchmark for the surgical management of scaphoid nonunions.

The high predictability of bone grafting in achieving bone union (80% to 90%) is well established.[1] The disadvantage of this technique is the prolonged period of postoperative immobilization, precluding an early return to work and potentially causing a loss of wrist motion. Green[17] has pointed out that the Matti-Russe technique has a lower success rate when the proximal pole is avascular, as documented intraoperatively by the absence of punctate bleeding sites in the bone. When dorsal intercalated segment instability is present, an anterior wedge graft after the method of Fisk and Fernandez[18] is the preferred option, as it allows restoration of scaphoid height.

If bone grafting has not been successful in treating a scaphoid nonunion, the procedure should be repeated if the criteria for the original surgery still exist (e.g., there are no secondary arthritic changes). Although the rate of healing after a second or third bone graft is lower than after a primary graft, it remains a viable option.[19]

Vascularized Bone Grafting

Vascularized bone grafting has been attempted to decrease the prolonged period of immobilization required after surgery, improve the rate of union, and provide an alternative if previous bone grafting has not been successful for a scaphoid nonunion. Zaidemberg et al[20] recently utilized a vascularized bone-graft source from the distal dorsoradial radius and had a 100% union rate in 11 cases, with an average time to union of 6.2 weeks. They consider this dorsal approach to be technically easier than implanting a vascularized bone graft from the volar approach. Furthermore, it does not require sacrifice of the radial or ulnar artery.

Internal Fixation

Internal fixation can decrease the duration of immobilization required to achieve union, thus allowing early range of motion, and can also correct collapsed deformities of the scaphoid. Many of the same devices recommended for use in the treatment of acute scaphoid fractures have been used in the treatment of scaphoid nonunions. In 1954 McLaughlin reported the use of a cobalt-chrome alloy screw, but its insertion was cumbersome and the union rate was unacceptable. Other devices that have been utilized include Kirschner wires,[21] pneumatically inserted staples, the Ender plate,[22] the ASIF screw,[23,24] and the Herbert screw.[25,26] A cannulated ASIF screw and a cannulated Herbert-Whipple screw have recently been introduced (Fig. 4).

The advantages of Kirschner wires include the ease of insertion and removal and the lack of a need for extended incisions or radial sty-

Fig. 4 Devices used for internal fixation. **A**, Cannulated ASIF screw with a derotational Kirschner wire in position. **B,** Cannulated Herbert-Whipple screw.

loidectomy. They can also be used in the presence of vascular changes in the proximal fragment. Kirschner wires have been utilized in conjunction with screws as derotational devices to provide torsional stability (Fig. 4, A). However, they do not provide compression of the fracture site.

Huene and Huene[22] demonstrated union in 19 of 20 cases of scaphoid nonunion treated with the Ender compression blade plate. They reported that this implant is helpful in the presence of complicating factors such as vascular necrosis, cystic degeneration, and bone-size disparity. The disadvantages of this implant include the necessity of late removal and the possibility of articular impingement. Also decreasing the popularity of this implant is the inability to achieve compression of the fracture fragments; a similar problem exists with use of pneumatic staples.

Leyshon et al[23] described a satisfactory experience treating delayed unions and nonunions of the scaphoid with the ASIF lag screw and use of an extended lateral and volar bayonet-shaped incision. A radial styloidectomy was not required, and they could directly visualize the reduction.

Using the ASIF screw, Sukul et al[24] achieved a greater than 90% union rate at an average of 26.9 weeks in 42 patients with established nonunions. A dorsolateral incision and a corticocancellous bone graft were used in these cases. The advantages of this implant include excellent compression without disruption of ligaments, which is often needed with other devices to achieve the same degree of compression. The disadvantages of the ASIF screw include the constraints due to the size of the fracture fragments and the possibility of intra-articular screw head placement. To help alleviate the possibility of intra-articular damage, Sukul developed a "dynamic compression screw for the scaphoid bone" that is totally contained within the bone, similar to the Herbert screw.

The Herbert screw was specifically designed for internal fixation of the scaphoid.[25] This provided the theoretical advantages of other forms of internal fixation. Its unique double-threaded design, relatively narrow diameter, and differential pitch allow complete subchondral containment, thereby decreasing the likelihood of hardware impingement. This usually eliminates the need for later removal and minimizes the host response to the implant. Most important, the Herbert screw allows early range of motion prior to the achievement of union. The Herbert screw can also be used from the dorsal side for small proximal-pole fractures. Potential disadvantages of the Herbert screw include the technical difficulty of its insertion,[26] the need to violate the scaphotrapezial ligament to allow screw insertion,[26] and its inferior ability to provide bone compression (when used without the jig) compared with the ASIF screw.[27]

We have recently compared the cannulated ASIF screw with the Herbert screw in scaphoid nonunions. The time to union averaged 3.8 months for the cannulated ASIF screw and 7.2 months for the Herbert screw. We believe that this difference in time to union between the implants is related to the increased accuracy of screw placement in the proximal fragment with the cannulated ASIF screw (Fig. 5).

Biomechanical studies have analyzed the strength of these internal fixation devices. The following implants designed for internal fixation of the scaphoid are listed in descending order of strength: the noncannulated ASIF screw, the cannulated ASIF screw, the Herbert-Whipple screw, two 0.045-mm Kirschner wires, and the Herbert screw.[28]

The ultimate goals of internal fixation are to provide immediate stability to correct deformity, to promote union, and to allow early return to function.

Salvage Procedures

There are a variety of operative salvage procedures, including excision of the proximal fragment or both fragments, proximal-row carpectomy, intercarpal fusion with scaphoid excision, arthrodesis of the wrist, replacement of the scaphoid with a metal or silicone prosthesis, radial styloidectomy, and interposition of soft tissue into the nonunion site or fascial arthroplasty. Some procedures, such as drilling of the bone, are of historic interest only and have little relevance to contemporary hand surgery.

Excising the proximal fragment is a useful procedure if the fragment is small (usually not exceeding one fourth of the length of the bone). A small fracture fragment can also be removed by using arthroscopic techniques. However, some of the modern implants are designed to incorporate small fragments of bone. Excising fragments larger than one third of the length of the scaphoid should be avoided because the surgery is likely to produce intercarpal instability. Excising the proximal carpal row as a salvage procedure should be considered with partial and total wrist arthrodesis if secondary arthritic changes have developed.

Fig. 5 Radiograph demonstrates the increased accuracy of screw placement in the proximal fragment of the scaphoid with a cannulated screw.

Replacing the scaphoid with a prosthesis is another option. Silicone carpal implants have been associated with numerous complications, including dislocation, breakage, and synovitis, and we do not recommend their use. Interposing a soft-tissue flap between the nonunited fragments was recommended by Bentzon in 1940 and is still used, mainly in the Scandinavian countries. It might be considered if postoperative immobilization is contraindicated.

Partial and total arthrodesis are also salvage options, depending on the degree and location of arthritis. For the common combination of radioscaphoid and midcarpal arthritis often seen in chronic nonunions, a combination of midcarpal arthrodesis and scaphoid excision can be considered. This has been called the scapholunate advanced collapse (SLAC) procedure.

Authors' Preferred Treatment

We define scaphoid nonunion as being present when radiographic signs consistent with inability of the fracture to heal (sclerosis, cyst formation, collapse, and bone resorption) are present or union has not occurred over a period of 6 months despite treatment.

If the patient is less than 40 years old or the fracture is of less than 2 years' duration, we recommend bone grafting with internal fixation. When the nonunion is proximal, a dorsal approach is used. When the nonunion is at the waist, a volar approach is used.

If the patient is more than 40 years old or if the fracture is of more than 2 years' duration, treatment depends on the symptoms. Asymptomatic patients are observed. If symptomatic and avascular necrosis is evident, either excision arthroplasty with intercarpal fusion or wrist fusion is performed, depending on the extent and location of osteoarthritis. When there is no radiolunate osteoarthritis, SLAC fusion is done. Addition of radioscaphoid and capitate-lunate joint osteoarthritis prompts consideration of a complete wrist fusion.

If there is uncertainty about the presence of avascular necrosis, MR imaging is performed. When avascular necrosis is not evident on MR imaging, bone grafting with internal fixation is undertaken. If the nonunion is proximal, a dorsal approach is used; if the nonunion is at the waist, a volar approach is used. When MR imaging is positive for avascular necrosis, SLAC fusion is recommended for active patients; a similar scaphoid excision is done in elderly patients.

We favor use of the Herbert-Whipple screw and a derotational Kirschner wire as the means of internal fixation.

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