Scaphoid nonunion: correction of deformity with bone graft and internal fixation

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The scaphoid is the most commonly fractured bone in the carpus. Although greater than 90% of scaphoid fractures unite with cast immobilization, failure to heal remains a clinical reality, particularly when the fracture is displaced or associated with intracarpal instability [1–3]. Dabezies [4] reported a 55% incidence of nonunion and a 50% rate of proximal pole avascular necrosis (AVN) in scaphoid fractures with greater than 1 mm of displacement. Cooney and colleagues [2] noted a nonunion rate of 46% for 13 displaced scaphoid fractures.

Scaphoid nonunion has been associated with progressive symptomatic radiocarpal and midcarpal arthrosis [5–7]. This arthrosis is the sequela of altered wrist kinematics [3,8,9]. The alteration of wrist kinematics reflects not only motion through the nonunion site, but also the apex-dorsal malalignment of the scaphoid (the so-called humpback deformity) with associated dorsal angulation of the lunate and alteration in carpal height [10,11].

Although scaphoid deformity and its adverse effects on kinematics were recognized early on by Fisk [12], for many years the standard treatment of symptomatic scaphoid nonunion was based on gaining union without an attempt to correct the deformity of the scaphoid. It has been recognized, however, that some patients with residual bony deformity of the healed scaphoid may continue to have pain and functional limitations [13–15]. As a result of a greater appreciation of carpal kinematics, many authors now believe that the approach to a scaphoid nonunion should consist of realigning the scaphoid anatomy and gaining union.

Scaphoid deformity

Posttraumatic scaphoid deformity is complex but predictable. Displaced scaphoid fragments lie in a so-called humpback configuration with flexion of the distal fragment. The dorsal intercalary pattern of carpal instability (DISI) follows [16]. With the use of three-dimensional reconstructions of computed tomography images, the three-dimensional orientation of a fractured scaphoid has been represented more clearly.

Belsole and coworkers [17] looked at a series of scaphoid nonunions and performed a detailed three-dimensional CT evaluation comparing the fractured and contralateral scaphoids. They found that the proximal scaphoid fracture component is extended, radially deviated, and supinated in relation to the distal fracture component. They also identified that the volume and configuration of missing bone is consistent. The amount of the scaphoid bone that was lost varied from 6% to 15% of bone volume. The bony defect is prismatic with a quadrilateral base facing palmarly.

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Nakamura and colleagues [18] also analyzed scaphoid deformity by three-dimensional CT. They identified two different positions for the distal fragment: volar type and dorsal type (Fig. 1). In the volar type, the distal fragment was flexed and overhung in the volar direction relative to the proximal fragment. This pattern was associated with fracture distal to the dorsal apex of the ridge of the scaphoid. In the dorsal type, the distal fragment moved dorsally on the proximal fragment and was associated with a more proximal and horizontal fracture line. Moritomo and colleagues [19] reproduced Nakamura’s findings. In their study, all of the distal or volar types of nonunions were associated with DISI deformity.

Several techniques to quantify scaphoid malalignment have been suggested. Amadio and colleagues [20] described measuring the intrascaphoid angle on anteroposterior and lateral tomograms. A perpendicular line is drawn to the proximal and distal articular surfaces, and the angle between these lines is measured (Fig. 2). The average values for the anteroposterior and lateral intrascaphoid angles are 40° (range 32° to 46°) and 24° (range 15° to 34°). Bain and colleagues [21] showed that the intraobserver and interobserver variability of the lateral intrascaphoid angle and dorsal cortical angle (Fig. 3A) are high. They recommended the scaphoid height-to-length ratio as a more reliable technique (Fig. 3B). A baseline is drawn along the volar aspect of the scaphoid. The length is measured along this baseline from the most proximal to the most distal aspect of the scaphoid, the maximum height of the scaphoid is measured on a line perpendicular to the baseline, and the ratio is calculated by dividing the height by the length. The normal ratio is less than 0.65.

Consequences of nonunion and deformity of the scaphoid

Studies by Mack and associates [5] and Ruby and Leslie [6] suggested an association between scaphoid nonunion and progressive radiocarpal and midcarpal arthrosis. Mack and associates [5] reviewed 47 patients with symptomatic scaphoid nonunions 5 to 53 years after injury. Of lesions, 23 had sclerosis, cyst formation, or resorptive changes confined to the scaphoid bone; 14 had radioscaphoid arthritis; and 10 had generalized arthritis of the wrist. They observed greater arthrosis with longer duration of nonunion. Fracture displacement and carpal instability also correlated with the severity of degenerative changes. Ruby and Leslie [6] reviewed 32 patients with scaphoid nonunion followed for at least 5 years after injury. Of the 32 patients, 31 developed arthrosis, and the extent of arthrosis increased with time in a predictable pattern.

Vender and coworkers [7] characterized this pattern of arthrosis in a retrospective radiographic analysis of 64 patients with symptomatic scaphoid nonunions. The pattern resembled that of scapholunate advanced collapse (SLAC). Successive degenerative changes

![Fig. 1. (A) In the volar type of scaphoid nonunion, the distal fragment is displaced volarly, and the proximal fragment is rotated dorsally. (B) In the dorsal type of scaphoid nonunion, the distal fragment translates dorsally. (From Fernandez DL, Eggli S. Scaphoid nonunion and malunion: how to correct deformity. Hand Clin 2001;17:631–46; with permission.)](image)
occurred in the radial styloid-scaphoid, capitate-scaphoid proximal fragment, and capitate-lunate articulations. The radius-proximal scaphoid fragment joint and the radiolunate joint consistently were spared from degenerative changes. This pattern has been termed the SNAC wrist for “scaphoid nonunion advanced collapse.”

The data derived from these studies have been advocated as evidence of the natural history of scaphoid nonunion; however, use of the term natural history is inaccurate because only symptomatic patients presenting for treatment were included in these investigations [22]. To know the true natural history of scaphoid nonunion, one would have to evaluate all patients with scaphoid nonunion, including patients who do not seek medical attention.

Results of treatment of scaphoid nonunions without deformity correction

For many years, the most common treatment for symptomatic scaphoid nonunion was the inlay technique of bone grafting [23]. Russe [23] described a volar approach to the scaphoid with
excavation of fragments and insertion of a corticocancellous bone graft from the iliac crest into
the nonunion site. No attempt was made to correct deformity. Analysis of the functional and
radiographic results of Russe bone grafting of the scaphoid provides some data regarding the
influence of malalignment on outcome.

Jiranek and colleagues [24] reported on the results of Russe bone grafting for 25 patients with
symptomatic scaphoid nonunion. Patients with severe carpal arthritis or significant ligamentous
injury were excluded. At an average of 11 years’ follow-up, there was an 81% union rate.
Malunion, defined as a 45° lateral intrascaphoid angle, was found in 50% of patients. There was
no significant difference between patients with malunion and patients with acceptable alignment
with regard to either subjective complaints or the extent of arthrosis. Malunion was associated
with a trend toward decreased motion and strength and a statistically significant increased
incidence of carpal collapse. The authors concluded that when pain was relieved, their patients
seemed to adapt to the potential functional deficits associated with malunion.

Stark and colleagues [25] also observed a high level of patient satisfaction after Russe bone
grafting. A total of 43 patients with symptomatic scaphoid nonunion were treated with the
Russe technique at an average of 40 months after injury. Of patients, 27 were evaluated at an
average of 12 years after the Russe grafting procedure; 22 (81%) had healed, 24 (89%) were
satisfied, and 17 (63%) were totally pain-free. Malalignment, defined as a persistent step-off
between fracture fragments of 2 mm or more, occurred in nine patients (33%). All patients with
malalignment had osteoarthrosis, and five of nine patients failed to heal. All cases of persistent
nonunion and severe osteoarthrosis were associated with scaphoid malalignment. Wrist pain
and functional limitations were twice as common in patients with persistent nonunion and
severe osteoarthrosis. Despite overall patient satisfaction, this study suggested the importance of
adequate reduction of scaphoid deformity for healing and improved functional and
radiographic results.

Burgess [10], in a cadaver study, found that scaphoid malalignment results in loss of
radiocarpal and midcarpal extension. Burgess simulated malunion in four specimens by
osteotomizing the middle third of the scaphoid and fixating the fragments in the humpback position. He progressively increased the angulation in 5° increments until all wrist extension was lost. With just 5° of malalignment, there was a 24% loss of extension. By 30° of intrascaphoid flexion, all radiocarpal and midcarpal motion was lost. This experiment was done with intact ligaments to show the effect of scaphoid malunion alone.

Amadio and colleagues [20] observed clinically that scaphoid malunion was associated with wrist dysfunction and arthrosis. They used trispiral tomographic and clinical evaluation to follow 46 patients with fractured scaphoids for an average of 3.5 years. After healing, 26 of the 46 scaphoids had malunion defined as a lateral intrascaphoid angle of more than 34°. Increasing lateral intrascaphoid angle was associated significantly with decreasing relative grip and with decreasing total functional score. The subset of the malunions with a lateral intrascaphoid angle of 45° or greater was more likely to have fair or poor results with posttraumatic arthritis and functional wrist impairment. The authors concluded that union alone is inadequate as a criterion for success in treating scaphoid fractures and that alignment is an important determinant of functional and radiographic results.

The justification for operative treatment of symptomatic scaphoid nonunions has been to relieve pain, improve function, and postpone or prevent progressive carpal arthrosis. The question remains with some as to whether or not the surgeon should attempt to correct deformity. The literature would suggest a trend toward greater pain, impaired function, and more severe arthrosis in cases of scaphoid nonunion that have healed but still have deformity. Additional outcome studies using precise and consistent methods to assess scaphoid anatomy and patient functional deficit would help answer this question.

Operative techniques to correct deformity

When planning operative treatment for a scaphoid nonunion, the surgeon must consider the site of the fracture, the vascular supply to the fragments, bony anatomy, prior treatment, and duration of nonunion. Most techniques to correct deformity have been described for the more commonly seen scaphoid waist nonunion, the Nakamura “distal or volar type,” in which there is a humpback deformity, a scaphoid bone defect, and a DISI pattern of carpal malalignment. For these cases, the palmar approach allows easier grafting of the prismatic bone defect and correction of the distal fragment malalignment. It also has been argued that the palmar approach is least injurious to the vascular supply of the proximal pole [26].

Before surgery, it is recommended that the surgeon evaluate for osteonecrosis using magnetic resonance (MR) imaging if necessary. The union rate of the scaphoid decreases as the vascularity decreases [27,28]. Conventional radiographic findings of AVN, including an increase in bone density, a loss of the normal trabecular appearance, collapse of subchondral bone, and cystic changes, may be unreliable. Green [27] and Perlik and Guilford [29] showed that intraoperative and histologic findings cannot be predicted accurately by the appearance of preoperative radiographs. Green [27] recommended that the proximal fragment vascularity be determined intraoperatively by punctate bleeding points in cancellous bone. The preoperative MR imaging finding of absent T1-weighted marrow signal may be more reliable [29]. According to Gunal and colleagues’ [30] study correlating intraoperative and MR imaging findings, the diagnosis of AVN should be made only when MR imaging and intraoperative findings indicate avascularity. In these cases, the surgeon should consider a vascularized bone graft [31] with or without an attempt to correct deformity.

The first operation to use a custom-shaped corticocancellous wedge graft for correction of deformity was the anterior interpositional wedge graft technique described by Fisk [32]. In cases of angulated or displaced nonunions of the waist or distal third, Fisk performed a radial approach, excising a wedge-shaped piece of the radial styloid and using it to fill the defect created by realignment. He claimed that by restoration of scaphoid length and correction of the flexion deformity, the pathologic rotation of the lunate and carpal collapse could be corrected. No internal fixation was used.

Fernandez [33–35] described a modification of Fisk’s original technique. His technique is based on careful preoperative planning using radiographs and tomograms of the contralateral
wrist to determine the exact bone graft shape needed to restore scaphoid anatomy (Fig. 4). The operative approach to the scaphoid is through a palmar incision and capsulotomy. A small bladed saw cleanly removes the sclerotic, avascular margin on either side of the nonunion. Reduction is achieved by wrist hyperextension, distraction of the fragments, and pushing the palmar pole of the lunate toward the radius. The bone graft is harvested from the iliac crest and carefully contoured based on the preoperative plan. The graft is inserted with the cortical part of the graft oriented palmarly, then secured to the scaphoid with a screw or Kirschner wires. After insertion of the graft, spontaneous derotation of the lunate usually takes place; however, in cases with long-standing DISI deformity, it may be useful to pin the lunate to the radius in anatomic position for 4 to 6 weeks after the operation. Postoperative immobilization depends on the degree of initial instability, associated carpal malalignment, and strength of the internal fixation. A plaster splint or a cast may be required until union is identified on sequential radiographs. This approach has been implemented by many surgeons, occasionally with minor modifications [36–39].

Herbert [40] prioritized preservation of a shelf of bone or soft tissue posteriorly over exact restoration of scaphoid anatomy. Although Fernandez may have cut the dorsal bone and soft tissues, Herbert left a dorsal hinge as a fulcrum around which the fragments may open. Herbert
suggested that this fulcrum enhances the stability of the graft. He recognized the potential for midcarpal arthrosis without exact restoration of the scaphoid anatomy.

Maruthainar and coworkers [41] and Leung and colleagues [42] described a “coring” technique as a way to maintain a good stable reduction without having to trim a well-fitting wedge. These authors perform a volar approach, core out the nonunion site, and reduce the humpback deformity. A cylindrical saw or serial trephine bone biopsy forceps are used to extract a cylindrical bone core from the iliac crest. The graft is placed and lies in compression within the nonunion bed. Maruthainar and coworkers [41] oversized the graft to avoid having to use internal fixation. Leung and colleagues [42] used a cannulated Acuratrak screw (Acumed, Beaverton, OR) inserted from the distal scaphoid. Postoperatively the patients are placed in a splint for at least 4 to 6 weeks. These authors claimed that the coring technique corrects scaphoid deformity, while being more mechanically stable than conventional wedge grafts to rotational and shear stress.

Other authors suggested that scaphoid reduction can be maintained without custom-shaped corticocancellous grafts. Watson and colleagues [43] described a dorsal approach with scaphoid reduction, cancellous bone grafting, and Kirschner wire fixation. Nagle [44] reported on a similar technique using a volar approach, packed morcellized cancellous bone graft, and Kirschner wire fixation. Reduction of the fracture is aided by wrist extension, then Kirschner wires are driven from distal to proximal across the nonunion site. Cancellous graft can be harvested easily from the distal palmar radius without the need for a separate incision as required for iliac crest grafts. Nagle [44] suggested that cancellous morcellized graft can be manipulated more easily and precisely to fit the scaphoid defect compared with cortico-cancellous graft. After surgery, the wrist is immobilized, and the Kirschner wires are left in place for 12 weeks.

In cases of persistent nonunion or AVN, vascularized bone grafts have been used in conjunction with internal fixation and correction of scaphoid deformity. The dorsoradial part of the distal radius is the most common donor site. Zaidemberg and coworkers [45] first described a pedicled corticocancellous bone harvest based on the branch of the radial artery running between the first and second dorsal compartments (1,2 ICSRA). Their original cases used a dorsoradial approach to harvest graft and to form a dorsal trough in the scaphoid for graft placement. Any correction of scaphoid deformity required a separate palmar incision. Steinmann and Bishop [46,47] subsequently described how to use the 1,2 ICSRA–based vascular graft as a wedge. Under direct visualization, the maximal dimensions of the palmar cortical defect, the dorsal-palmar width, radioulnar width, and internal defect are determined. A graft of appropriate dimension is raised and inserted, and vessels are placed palmarly to allow the cortical component of the graft to restore scaphoid length. Kirschner wires or a compression screw is used to add further stability. Trumble and Nyland [31] described a similar technique through a radiopalmar approach to the scaphoid.

Reported results and complications

It is difficult to interpret the reported results of volar wedge grafting for scaphoid nonunion and compare them with alternative techniques owing to the fact that among the more than 30 scaphoid nonunion outcome studies found in the English literature reliable and consistent criteria are lacking for assessing union [48,49] and alignment [21], there is intermixing of various fracture types, there are differences in the duration of the nonunion and the status of the carpal articulations at the time of treatment, various measures of patient outcome are used, and there is a lack of long-term follow-up. Most authors report their union rate but do not comment on the success in correcting scaphoid deformity.

The comparative benchmark remains the long-term follow-up of the Russe bone graft technique provided by Jiranek and colleagues [24] and Stark and coworkers [25]. Together these authors followed more than 50 patients for an average of greater than 10 years. In both studies, the average union rate was 81%, and at least 80% to 90% of patients were happy with their results. Postoperative radiographic malalignment was noted for 33% and 50% of patients in the Stark and Jiranek studies. Jiranek and colleagues [24] documented functional limitations and
carpal collapse in these cases. Stark and coworkers [25] did not report specific results for this subpopulation of patients but noted osteoarthrosis in all patients with persistent malalignment. In their patients with significant malalignment (lateral intrascaphoid angle of > 45°), Jiranek and colleagues [24] reported a flexion arc of 78% and a grip strength of 76% compared with the uninjured side. Overall, Stark and coworkers [25] reported postoperative extension and flexion arcs of 70% and 80%. The average postoperative grip strength was 82% of the uninjured side.

Eggl and colleagues [50] reported on the success of anterior wedge grafting at an average follow-up of 5.7 years. In 37 patients with nonunions treated with interpositional bone grafting and internal fixation, solid radiographic union was achieved in 35 cases (95%). Of patients, 26 (70%) had excellent or good results according to the Mayo Wrist Score. Of patients, 33 (89%) had restoration of scaphoid length to within 2 mm compared with the uninjured side, and all patients had correction of the DISI deformity. These results seem to represent an improvement in union rate and correction of scaphoid deformity compared with conventional Russe bone grafting. Similarly, restoration of the flexion arc (85%) and grip strength (88%) compares favorably with Jiranek and Stark’s studies. Most importantly, none of the patients in Eggl and colleagues’ [50] study developed severe degenerative changes after surgery. Although 81% of patients did have radiographic findings of mild or moderate degenerative changes, there was no significant progression of arthrosis after fracture union. Eggl and colleagues [50] postulated that anterior wedge grafting may delay or diminish the progression of arthrosis. Their complications included two persistent nonunions, three hypertrophic scars treated with scar revision, one patient who had a subsequent radial styloidectomy for impingement, and one patient treated with a subsequent radial shortening osteotomy and wrist denervation for pain.

Other authors also reported high rates of union and improved carpal alignment and wrist function after anterior wedge-shaped grafting [36,38,49,51,52]. The rates of union ranged from 94% to 100%. Nakamura [51], Tsuyuguchi [52], Takami [37], and Chen [38] specifically noted improvement in carpal instability and humpback deformity. In all studies, functional results and overall patient satisfaction were good.

Early results of the “coring” technique have been reported by Leung and colleagues [42] and Maruthainar and colleagues [41]. In the Leung study [42], all 11 patients with symptomatic scaphoid nonunion went on to heal after surgery. At the average follow-up of 30 months, all patients were satisfied, and 10 of 11 had resolution of pain. Four of the patients had a loss of 20% to 30% of wrist motion. The single complication was a case of screw impingement requiring reoperation and screw removal. Leung and colleagues [42] also found that if the bony gap is more than 9 mm after reduction, trephine graft may exceed the width of the scaphoid. In this scenario, a wedge graft may be needed. Maruthainar and colleagues [41] documented a union rate of 80% after their similar procedure. At a mean follow-up of 8.2 months, four patients had radiocarpal arthritis. Neither the Leung study nor the Maruthainar study specifically compared preoperative and postoperative scaphoid alignment or progression of arthrosis. Long-term results are needed to compare this technique further with that described by Eggl and colleagues [50].

Multiple factors have been identified that predict poor outcome despite custom-shaped bone grafting and correction of scaphoid deformity. Although there is some disparity among studies, these factors include the time between the initial fracture and the treatment of nonunion, the presence of AVN of the proximal fragment, and a history of prior surgery for nonunion. In studies reported by Nakamura [51], Schuind [53], Inoue [54], and Shah [28], time between injury and treatment of nonunion and AVN of the proximal fragment were recognized as poor prognostic factors. Daly and associates [36] and Shah and Jones [28] also identified a history of previous surgery in their patients with worse outcomes. In Eggl and colleagues’ [50] 5.7-year follow-up study, the two nonunions that failed to heal had intraoperative signs of avascularity. Each patient required at least one additional operation; one patient united with a revascularization procedure, and the other required a salvage SLAC wrist procedure. For these reasons, Fernandez and others suggested that patients with preoperative signs of AVN or failed prior surgery for nonunion should be treated with vascularized bone grafts.

In cases of prolonged nonunion or AVN, results with vascularized grafts have shown higher rates of healing compared with the Russe and wedge grafting techniques. Zaidemberg and associates [45] had a 100% union rate in 11 cases of long-standing nonunion of the scaphoid
using the 1,2 ICSRA. Steinmann and colleagues [46,55] also had a 100% union rate in 14 patients with established nonunions. These authors have not reported results for restoration of scaphoid anatomy at the time of vascularized graft insertion. As with the typical scaphoid nonunions, success in these difficult cases also may depend on correction of scaphoid deformity.

Patients with malunion may continue to have pain and functional limitations. For these cases, osteotomy and wedge grafting have been reported [13,15,40,56]. In the 18 patients found in the English literature, all osteotomies healed with improvement in patient function and carpal alignment. There have been no reports of iatrogenic AVN or other complications. Nevertheless, although most hand surgeons are willing to try to correct a deformed nonunion, the studies on scaphoid malalignment are not yet convincing enough that the average hand surgeon is comfortable performing an osteotomy on a well-healed scaphoid fracture.

References