A Capsular-Based Vascularized Distal Radius Graft for Proximal Pole Scaphoid Pseudarthrosis

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Purpose: To evaluate the clinical results of the application of a capsular-based dorsal distal radius vascularized bone graft in scaphoid proximal pole nonunions.

Methods: Thirteen patients with symptomatic nonunion at the proximal pole of the scaphoid (10 with avascular necrosis) were treated and reviewed retrospectively. The vascularized bone graft was harvested from the distal aspect of the dorsal radius and was attached to a wide distally based strip of the dorsal wrist capsule. It was inserted press-fit into a dorsal trough across the nonunion site after scaphoid fixation with a Herbert screw.

Results: After a mean follow-up period of 19 months 10 of the 13 nonunions (8 of the 10 with avascular necrosis) achieved solid bone union. No complications other than the 3 persistent nonunions occurred.

Conclusions: Results of the use of a capsular-based vascularized bone graft from the distal radius for proximal pole scaphoid nonunions compare favorably with the results of pedicled or free vascularized grafts. It is a simple technique that eliminates the need for dissection of small-caliber pedicle or microsurgical anastomoses. No donor site morbidity was observed.
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Type of study/level of evidence: Therapeutic, Level IV.

Key words: Dorsal wrist capsule, proximal pole, scaphoid nonunion, vascularized bone graft.

The vascularity of the proximal third of the scaphoid is tenuous and renders proximal pole fractures more prone to nonunion. Furthermore the proximal pole can undergo avascular necrosis, which further impairs healing. Nonunions involving the proximal pole and the presence of avascular necrosis adversely affect patients' chances of achieving bone union with conventional bone grafts.[1–5] Vascularized bone grafts (VBGs) provide an alternative to traditional bone grafting that may be beneficial for these patients.[6,7]

In an experimental setting VBGs were shown to heal faster and more reliably than nonvascularized grafts and in addition they facilitated revascularization and bone remodeling of the avascular segment.[8] Several VBGs have been described in the literature. These include the pronator quadratus pedicled bone graft,[9,10] pedicled grafts based on the ulnar artery[11] or the palmar carpal artery,[12,13] the radial styloid fasciosteal graft,[14] and pedicled grafts from the index finger metacarpal[15–17] and the thumb metacarpal.[18,19] Implantation of a vascular leash alone from the second dorsal intermetacarpal artery in combination with bone grafting also has been reported,[20] as has the use of a free VBG from the iliac crest[21,22] and the medial femoral supracondylar region.[23] The VBG derived from the dorsal radial aspect of the distal radius was described by Zaidemberg et al[24] and is nourished by the 1,2 intercompartmental supraretinacular artery as described by Sheetz et al[25] in their study of the arterial blood supply of the distal radius. This VBG has obtained considerable popularity in recent years.[26–31] Harvesting of VBGs can be demanding technically. It involves dissection of small vessels (the mean diameter of the 1,2 intercompartmental supraretinacular artery is 0.3 mm)[25] and, in free grafts, microsurgical anastomoses. Furthermore the need for pedicle rotation in some of those grafts may compromise their long-term patency. This led us to develop a new VBG from the distal aspect of the dorsal radius (just ulnar and distal to Lister's tubercle), which is attached to a wider distally based strip of the dorsal wrist capsule. This graft is close to the proximal pole nonunion site, thus permitting insertion with minimal rotation, and its vascular supply is derived from the strip of dorsal capsule without the need for dissection of a pedicle.

A latex-injection study of the vascular anatomy of periosteal wrist flaps[32] confirmed that the vascularization of the bone graft was not random but was based on the artery of the fourth extensor compartment (running under the dorsal retinaculum). The vessel was present in all specimens and extended between the anterior or posterior interosseous artery proximally and the dorsal carpal (radiocarpal or intercarpal) arch or the fifth extensor compartment artery distally (Fig. 1).[25,32,33] Thus the pedicle was included with the capsule attached to the bone graft. The pedicle diameter of the grafts were less than 1 mm in all specimens and their lengths ranged between 1 and 2 cm. After rotation of 10° to 30° the capsular pedicle of the graft easily reached the proximal third of the scaphoid. A previous study of the vascular anatomy of the distal radius[25] further confirmed these results.

The purpose of this article is to present the surgical technique and clinical results of the application of the capsular-based distal radius bone graft in scaphoid proximal pole nonunions.

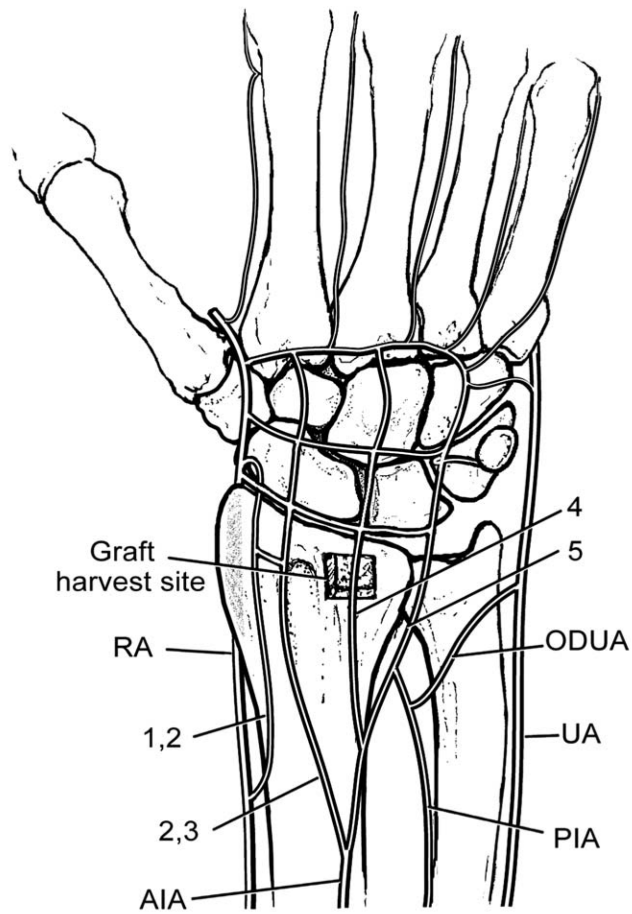

Figure 1. The dorsal vascular supply of the wrist. The donor site of the vascularized bone graft pedicled on the artery of the fourth extensor compartment is marked. RA, radial artery; UA, ulnar artery; AIA, anterior interosseous artery; PIA, posterior interosseous artery; ODUA, oblique dorsal ulnar artery; *1,2* indicates 1,2 intercompartmental supraretinacular artery; *2,3* indicates 2,3 intercompartmental supraretinacular artery; *4* indicates fourth extensor compartment artery; *5* indicates fifth extensor compartment artery.

Materials and Methods

A retrospective review of the senior author's (D.G.S.) records identified 16 patients treated for established proximal pole scaphoid nonunions with a capsular-based vascularized distal radius graft between 2000 and 2003. Among those patients 1 was lost to follow-up study and 2 had follow-up periods of fewer than 12 months. These 3 patients were excluded from this study, leaving 13 patients (11 men, 2 women) with a mean age of 26 years (range, 19–43 y) with symptomatic nonunion at the proximal pole of the scaphoid. Nine dominant and 4 nondominant upper extremities were treated. The mean time from injury to surgery was 25 months (range, 12–48 mo). Eight of the fractures failed to achieve bony union after an adequate period of immobilization; in 4 the diagnosis of a scaphoid fracture was missed originally or immobilization was inadequate and 1 patient was noncompliant with the initial treatment. None of the patients had had any previous surgical treatment. Six of the patients were smokers. The indication for surgery was established symptomatic proximal pole nonunion in patients who had had no previous surgeries to the dorsal wrist.

All of the nonunions involved the proximal third of the scaphoid. Four of them were displaced originally by more than 1 mm. Computed tomography (CT) scans had been performed in 4 of the patients. Of the 13 patients 10 were diagnosed with avascular necrosis of the proximal pole of the scaphoid; 3 did not have any evidence of avascular necrosis. These 10 patients presented with radiographic appearances indicative of avascular necrosis (sclerotic and cystic changes of the proximal pole of the scaphoid). Furthermore magnetic resonance imaging (MRI) was performed in 3 of the 10 patients with avascular necrosis of the proximal pole and confirmed the diagnosis (low-intensity signal in both T1- and T2-weighted sequences); the remaining 7 did not have an MRI. Avascularity was verified, however, in all 10 patients during surgery by the lack of punctate bleeding from the proximal pole.

Review of preoperative radiographs showed pointing of the radial styloid or joint-space narrowing between the radial styloid and the scaphoid (ie, scaphoid nonunion advanced collapse I wrist) in 4 patients. Two patients presented with mild dorsal intercalated segment instability deformity (scapholunate angles of 64° and 68°). None of the proximal poles had any fragmentation or collapse. The range of motion was restricted in most of the patients, with a mean flexion of 32° (range, 10°–60°), a mean extension of 44° (range, 20°–70°), a mean ulnar deviation of 12° (range, 0°–20°), and a mean radial deviation of 9° (range, 0°–20°). The mean preoperative grip strength was 64% (range, 32%–87%) of that of the contralateral healthy extremity.

Surgical Technique

The procedure is performed under general or regional anesthesia, tourniquet control, and loupe magnification. A 4-cm straight dorsal incision to the wrist centered just ulnar to Lister's tubercle is performed. Dissection is carried through the subcutaneous tissues and the extensor retinaculum of the fourth dorsal compartment is released partially to expose the wrist capsule and the distal radius. The extensor pollicis longus tendon is identified and retracted radially and the extensor digitorum communis tendons are retracted ulnarly.

Next the capsular-based vascularized distal radius graft is outlined with a skin marker on the dorsal wrist capsule (Fig. 2). The bone block for the graft measures approximately 1 × 1 cm and is harvested from the distal aspect of the dorsal radius just ulnar and distal to Lister's tubercle. The depth of the bone block is approximately 7 mm and includes the dorsal ridge of the distal radius, leaving 2 to 3 mm of distal radius cortex intact so as not to propagate into the cartilage of the radiocarpal joint. The bone block is attached to a distally based capsular flap. The flap's length is approximately 1.5 cm and it widens from 1 cm at the bone block to 1.5 cm at its base. The bone block is outlined on the distal radius cortex with multiple drill holes by using a 1.0-mm side-cutting drill bit. A thin osteotome then is used to elevate the bone block carefully. Care is taken not to propagate

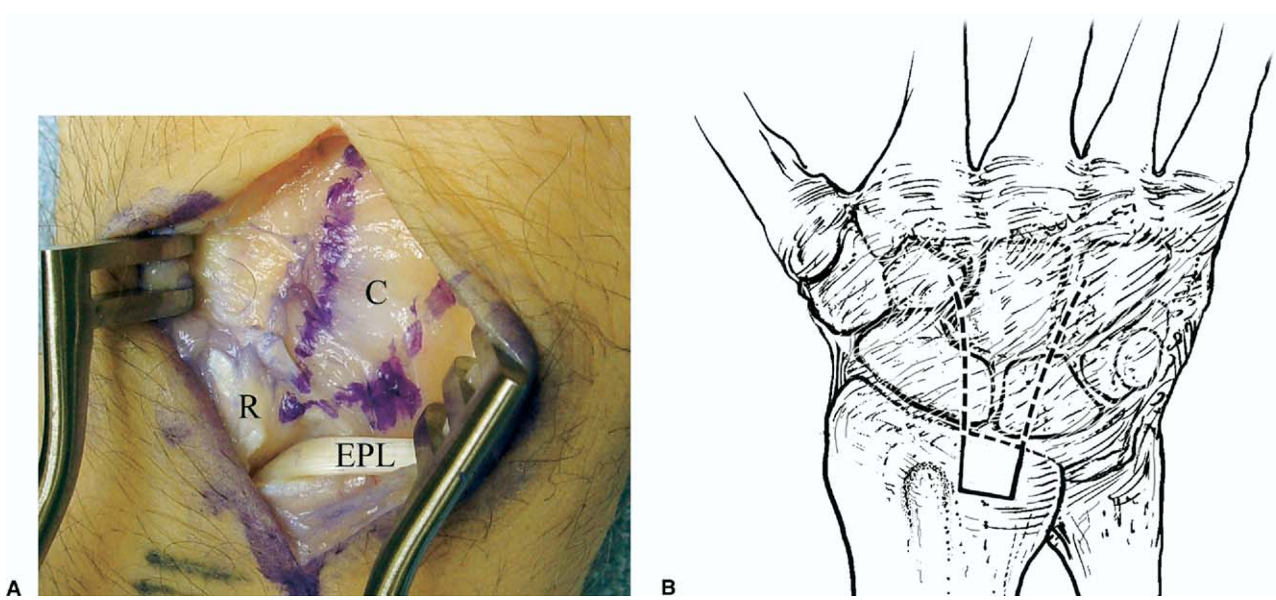

Figure 2. (A) The distal radius (R) and dorsal capsule (C) are accessed through a dorsal incision just ulnar to Lister's tubercle. The extensor pollicis longus (EPL) is retracted radially and the extensor digitorum communis is retracted ulnarly. The graft is outlined on the dorsal capsule and distal radius with a marking pen (B) The outline of the capsular-based VBG on the dorsal capsule and the distal radius.

the osteotomy lines into the joint. The capsular flap then is outlined sharply with the scalpel and the bone block with the capsular flap attached to it are detached carefully from the underlying tissues in a proximal-to-distal direction, with care taken not to injure the dorsal scapholunate ligament. At the completion of flap elevation the scapholunate ligament and the proximal pole of the scaphoid are exposed.

The scaphoid proximal pole nonunion site is identified next by flexing the wrist. If a pseudarthrosis with disruption of the cartilage shell is present, the nonunion is cleaned with a dental pick and small curettes. If the cartilage shell is not disrupted grossly then the nonunion site is not violated at this point. Next the tourniquet is released to verify the vascularity of the bone graft and to assess the vascular status of the proximal pole of the scaphoid (in cases of cartilage shell disruption). Usually the capsular flap shows abundant revascularization immediately, but punctate bleeding from the bone block itself lags behind for a few minutes.

Fixation of the nonunion under fluoroscopic control then follows. Two 1-mm smooth K-wires are inserted from the proximal pole of the scaphoid oriented toward the base of the thumb. One of them serves as a guidewire for a Herbert–Whipple bone screw (Zimmer, Warsaw, IN) and the other as an antirotation wire. Care should be taken to place the guidewire for the screw volarly in the scaphoid while maintaining sufficient purchase of the proximal and distal fragments because a trough will be created dorsally to accept the VBG. The length of the screw is determined next and after drilling the cannulated Herbert–Whipple screw is inserted and the antirotation wire is removed. The final implant should be countersunk from the articular surface. In cases of a very small avascular proximal pole, fixation with a Herbert Mini bone screw or even 2 K-wires may be chosen instead of the larger Herbert–Whipple cannulated screw. Fixation with 2 K-wires was performed in 2 patients and fixation with a Herbert mini screw was performed in 1 patient in this series. In patients with early arthritic changes of the radial styloid a styloidectomy can be performed through the same approach. A radial styloidectomy was performed in 3 patients.

After fixation of the nonunion site has been deemed sufficient a trough is created dorsally across the nonunion site with a side-cutting burr (Fig. 3). The trough is kept slightly smaller than the graft harvested (approximately 8 × 8 mm) to allow press-fit fixation. The vascularity of the proximal pole can be assessed at this point in patients with an undisrupted cartilage shell who did not have the nonunion taken down at the beginning of the procedure. In 10 of the 13 patients, punctate bleeding from the proximal pole of the scaphoid was not observed, thus verifying the diagnosis of avascular necrosis of the proximal pole. The nonunion fibrous tissue is cleaned with a small curette. The VBG with its capsular attachment then is inserted press-fit into the scaphoid trough (Fig. 4). Because of the convenient harvesting site for this graft only minimal rotation (10°–30°) of the flap is needed for the graft to be inserted into the trough.

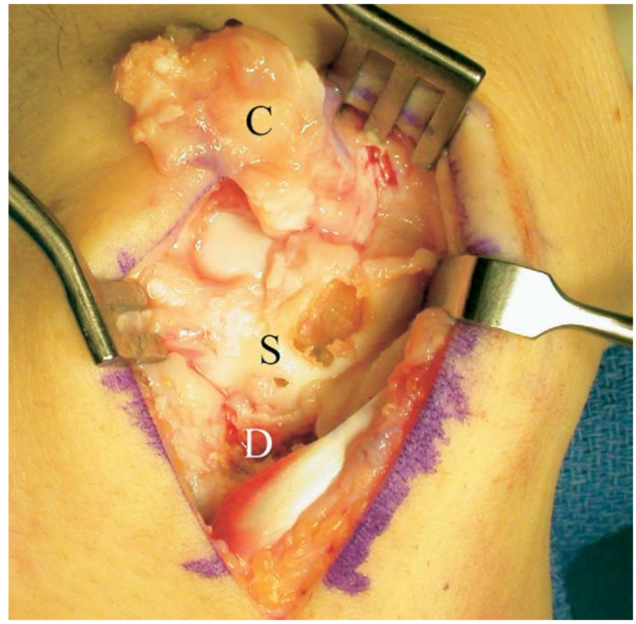

Figure 3. The capsular flap is elevated with the bone block attached to it; next the scaphoid nonunion site is fixed with a Herbert screw and a trough is created across the nonunion site. C, capsular-based bone graft; S, scaphoid; D, distal radius donor site.

The wound then is irrigated and closed in layers. A sugartong splint is applied for the first 2 weeks followed by a short-arm cast for another 4 weeks. Radiographs are obtained with the cast removed in 6 weeks and monthly thereafter to assess union progression. A removable orthoplast splint may be used for protection in patients who have delays in union and return to full activities is permitted only after solid union occurs.

The office notes and imaging studies of all patients were reviewed. At the final follow-up evaluations radiographs (posteroanterior, lateral, oblique) were obtained for all patients to assess bone healing (Fig. 5). Union was defined as bony trabeculae crossing the nonunion site and absence of sclerosis at the

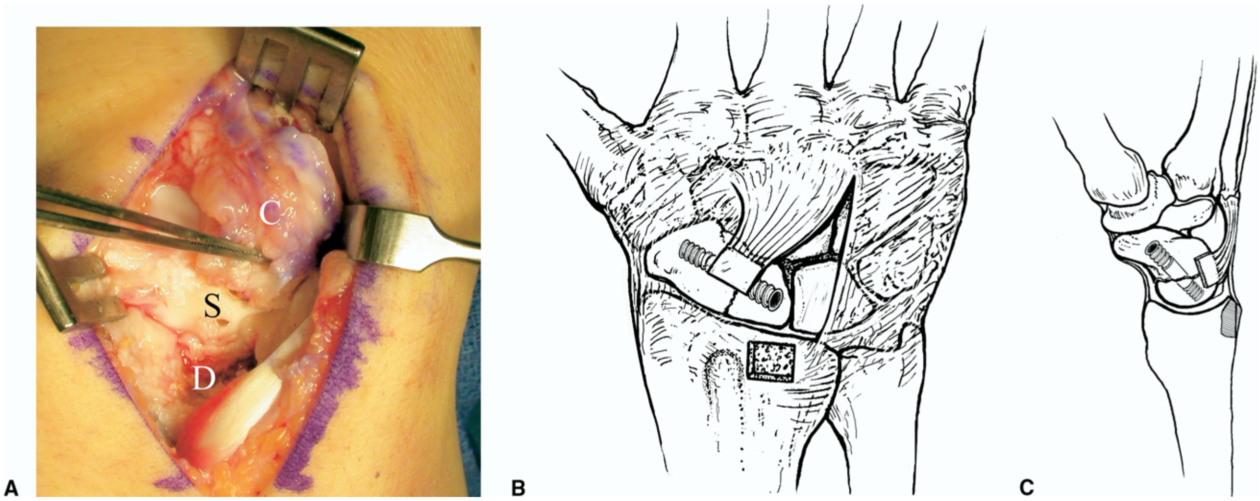

Figure 4. (A) The capsular-based bone graft (C) is inserted press-fit in the trough created across the nonunion site. S, scaphoid; D, distal radius donor site. (B) Dorsal schematic view of the completed procedure. (C) Lateral schematic view of the completed procedure. Note the volar placement of the Herbert-Whipple screw to accommodate the dorsal placement of the capsular-based bone graft. The shaded area is the donor site at the distal dorsal radius.

union site (Trojan's line). Furthermore radiographs also were evaluated for the presence of adverse features[34] such as persistence of radiographic gap, implant loosening, and fracture displacement. In 4 patients with doubtful healing based on x-rays (bony trabeculae crossing the nonunion site in only 1 view), additional CT scans at the longitudinal axis of the scaphoid[35] were obtained. The CT scans were evaluated by an experienced radiologist. All radiographic views were scrutinized for radiocarpal joint-space narrowing indicating arthritis. The scapholunate and lunocapitate angles were measured on the lateral projections.

Clinical examination included assessment of pain

Figure 5. (A) Preoperative and (B) postoperative posteroanterior radiographs of a nonunion of the proximal pole of the scaphoid treated with the capsular-based VBG.

with palpation (clinical union), assessment of pain during rest and activities, and range-of-motion measurements performed with a standardized technique. Grip strength was assessed using a dynamometer (Jamar Hydraulic Dynamometer; Sammons Preston, Bolingbrook, IL) and compared with the uninjured contralateral extremity. Statistical analysis was performed using the Student *t* test to compare preoperative and postoperative values; p values less than .05 were considered statistically significant.

Results

All patients were followed up for at least 1 year. The mean follow-up period was 19 months (range, 12–40 mo). Solid bony union was observed in 10 of the 13 patients. In 7 of these 10 patients bony union was determined by plain x-rays and clinical examination. No persistent gap, screw loosening, or fracture displacement was observed in any of these patients and trabeculae were seen crossing the nonunion site (in all 3 views in 5 patients and in 2 views in 2 patients). In 3 of the 10 patients a CT scan was used to show bone union. The mean time to union was 13 weeks (range, 6–23 wk). Eight of the patients with solid bone union were completely pain free and 2 complained of slight pain with strenuous activities. Solid union was observed in 8 of the 10 patients who were diagnosed with avascular necrosis of the proximal pole of the scaphoid.

Three scaphoids did not achieve union with the procedure; 2 had persistent nonunion (1 with constant pain, 1 with pain during activities). One patient with fibrous union as determined by CT scan had substantial pain improvement compared with the preoperative state, with complaints of pain only with strenuous activities.

The mean flexion was 45° (range, 30°–80°) compared with a mean of 32° before surgery. The mean extension was 68° (range, 30°–90°; preoperative mean, 44°). Ulnar deviation averaged 21° (range, 10°–35°; preoperative mean, 12°) and radial deviation averaged 15° (range, 10°–25°; preoperative mean, 9°). Pronation and supination were noted to be full in all patients. The mean grip strength was 81% (range, 65%–105%) compared with that of the contralateral healthy extremity, which had improved from a preoperative mean of 64%. Range of motion was improved significantly in the flexion ($p < .05$) and extension ($p < .01$) arcs compared with preoperative values. Improvement of grip strength also was statistically significant ($p < .01$).

No radiographic progression of arthritis was noted in any patient within the available follow-up time of 19 months. The dorsal intercalated segment instability malalignment pattern that was observed in 2 of the patients before surgery remained unchanged. No arthritic changes were noted at the dorsal ridge of the radius (where the graft had been harvested).

Seven of the 11 patients who were employed before their injuries returned to their occupations. Two more returned to lighter-duty work and 2 were unemployed. No complications other than the 3 persistent nonunions or donor site morbidity were observed.

Discussion

We present a capsular-based VBG for the treatment of scaphoid proximal pole nonunions. This is a reverse-flow graft that was shown in latex-injection studies to be nourished by the artery of the fourth extensor compartment. The vascularity of the graft was confirmed during surgery with tourniquet release. The graft is harvested without the need for a microvascular dissection of its pedicle. No donor site morbidity was observed from graft harvesting as shown by maintenance of wrist stability and improvement of the range of motion. No arthritic changes were observed at the harvest site at final follow-up evaluation; however, a longer follow-up period is needed to support this finding safely.

A VBG from the distal radius with a similar vascular supply (based on the fourth extensor compartment artery) has been described by Sheetz et al[25] as a pedicled graft for Kienböck's disease.[36–38] Results of the application of that graft for scaphoid nonunions have not been reported. The graft described in this article differs in that it is capsular based and its nutrient artery is not dissected.

With the exception of 2 studies[26,29] most of the published series of VBGs for all scaphoid nonunions have reported union rates of 80% to 100%.[11,12,16,18,19,21–24] In 2 studies the results were suboptimal. In the study by Boyer et al[26] 6 of 10 proximal pole nonunions healed. This study included only patients with avascular necrosis of the proximal pole and in all 4 unhealed nonunions previous grafting procedures had failed. The study by Straw et al[29] yielded a 27% rate of union. Of 22 patients in that study 16 had an avascular proximal pole and 5 had a history of previous surgery. Proximal pole avascularity and failed previous conventional bone grafting are well-recognized factors that can affect the outcome negatively. Other negative prognostic factures in-

Table 1. Union Rates of Scaphoid Pseudarthroses With an Avascular Proximal Pole Treated With Vascularized Bone Grafts

Study	VBG Source	Pseudarthroses with AVN United/Treated
Boyer et al[26]	Pedicled, 1,2 IC SRA	6/10
Uerpairojkit et al[27]	Pedicled, 1,2 IC SRA	5/5
Malizos et al[28]	Pedicled, 1,2 IC SRA	7/7
Straw et al[29]	Pedicled, 1,2 IC SRA	2/16
Doi et al[23]	Free, supracondylar femur	10/10
Gabl et al[21]	Free, iliac crest	12/15
Harpf et al[22]	Free, iliac crest	19/21

1,2 IC SRA, 1,2 intercompartmental supraretinacular artery.

clude preoperative humpback deformity, tobacco use, female gender, and K-wire fixation (Chang et al, presented at the 72nd Annual Meeting of the American Academy of Orthopaedic Surgeons, 2005). The rate of union in our study (10/13 proximal pole nonunions healed) compares favorably with the results reported with VBGs in general. Two out of 3 patients with persistent nonunion or fibrous union reported symptomatic improvement.

Results of treatment of scaphoid nonunions with an avascular proximal pole using VBGs have not been uniform (Table 1). Assessment of the vascularity of the proximal pole varies in these studies (radiographic appearance, MRI, surgical findings). Eight of 10 nonunions with an avascular proximal pole treated with the capsular-based VBG in this study achieved a solid union.

Monitoring of the maintenance of graft vascularity after insertion into the nonunion site is a common problem for all VBGs.[22,29] Even MRI studies showing revascularization of an avascular proximal pole cannot prove the origin of revascularization. Consequently only an indirect assessment of the efficacy of this approach can be made based on clinical results. The satisfactory union rate obtained in this series of difficult scaphoid nonunions (proximal poles), most of them with avascular necrosis, indicates that the capsular-based graft probably incorporates similarly to other VBGs reported in the literature.

Advantages of the capsular-based VBG for scaphoid nonunions include a simple and expedient harvesting technique without the need for dissection of small-caliber vessels (as in pedicled grafts) or microsurgical anastomoses (as in free grafts). Furthermore the short arc of rotation lessens the risk for vascular impairment caused by kinking of the nutrient vessel. Press-fit graft placement in the nonunion site in conjunction with relatively short immobilization time proved to be clinically successful with no graft extrusion and good clinical results in terms of both union and postoperative range of motion. No donor site morbidity was observed in this initial series.

A limitation of this technique includes the inability to correct a humpback deformity. 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.

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