Outcome After Vascularized Bone Grafting of Scaphoid Nonunions With Avascular Necrosis

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Purpose Vascularized bone grafting has been proposed as a treatment for scaphoid nonunions with avascular necrosis of the proximal pole. The purpose of this investigation is to report the results of vascularized bone graft and internal fixation for established scaphoid nonunions with proximal pole avascular necrosis as measured by validated outcome instruments.

Methods From 1996 to 2004, 30 consecutive patients with established scaphoid nonunion, proximal pole avascular necrosis, and no prior surgery were treated with open reduction and internal fixation in addition to a vascularized bone graft based on 1,2 intercompartmental supraretinacular artery. A total of 19 patients had nonunions of the scaphoid waist and 11 had nonunions of the proximal pole of the scaphoid. Preoperative and postoperative evaluation included measurement of clinical (grip strength and range of motion), radiographic (scapholunate angle, scaphoid height-to-length ratio, and radioscaphoid arthritis), function (Disabilities of the Arm, Shoulder, and Hand questionnaire) and satisfaction parameters. We recorded union and return to activity and analyzed data both in the aggregate and stratified by nonunion location.

Results Union rate was 28 of 30 (93%) and time to union was 5.1 months (±2.4). Significant improvements were found for grip strength, Disabilities of the Arm, Shoulder, and Hand score, satisfaction score, and scaphoid height-to-length ratio ($p < .01$). No significant difference was found for composite wrist range of motion. Two patients experienced complications and required a second procedure to achieve union. A total of 28 of 30 (93%) of patients returned to work or sports activity at their preinjury level.

Conclusions The results of this investigation support the use of a vascularized bone graft for the treatment of scaphoid nonunions with avascular necrosis of the proximal pole. *(J Hand Surg 2009;34A:387–394. © 2009 Published by Elsevier Inc. on behalf of the American Society for Surgery of the Hand.)*

Type of study/level of evidence Therapeutic IV.

Key words Vascularized bone graft, scaphoid nonunion, avascular necrosis, 1,2 ICSRA.

VASCULARIZED BONE GRAFTING may be considered a primary treatment for established scaphoid nonunion, proximal pole nonunions, or scaphoid nonunions that have not united after a nonvascularized bone graft.[1] In a recent systematic review of the literature regarding scaphoid nonunions published between 1928 and 2003, the authors found an average union rate of 78% for proximal pole scaphoid nonunions, including those with avascular necrosis (AVN), that were treated with nonvascularized bone graft tech-

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No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

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niques.[2] The use of a vascularized bone graft is an attempt to improve these union rates; however, reported union rates for vascularized bone grafts range from 27% to 100%.[1,3–10] A popular vascularized bone graft technique first described by Zaidemberg et al.[10] in 1991 is based on the ascending irrigating branch of radial artery, which was accurately defined by Sheetz et al.[11] as the 1,2 intercompartmental supraretinacular artery (1,2 ICSRA). Previous studies evaluating the treatment of scaphoid nonunions with avascular proximal pole using this vascularized bone graft are limited to small series (3 to 24 patients) that do not incorporate validated outcome instruments.[1,3–10]

The purpose of this investigation is to report the results of vascularized bone-grafting based on the 1,2 ICSRA and internal fixation for established scaphoid nonunions with proximal pole AVN as measured by validated outcome instruments.

MATERIALS AND METHODS

Between 1996 and 2004, a single surgeon treated 30 consecutive patients with scaphoid nonunion and proximal pole AVN using a 1,2 ICSRA pedicled vascularized bone graft and internal fixation. This study was performed according to the guidelines of the Institutional Review Board Human Subjects Division of the governing institution. We performed a retrospective review of charts and radiographs for each patient.

All patients with a scaphoid nonunion and magnetic resonance imaging (MRI)-documented proximal pole AVN were included in the study. Patients were excluded if they had previous ipsilateral surgery or contralateral wrist injury that prevented comparison for the purposes of clinical evaluation. We also excluded from this study patients with gross collapse of the proximal pole or with radiographic evidence of arthritis involving the entire radioscaphoid joint. Table 1 lists patients' characteristics. All patients initially presented to our center after failure of immobilization (23 patients) or after late presentation of an initially unrecognized fractures (7 patients). The shortest interval between injury and presentation was 5 months, a period which precluded reasonable hope for union with cast treatment alone.[12,13]

All patients were treated by a senior surgeon (T.E.T.). They were advised to stop smoking before surgery. Preoperative wrist range of motion (flexion, extension, and radial and ulnar deviation) of both the affected and unaffected extremities was measured. We measured grip strength of both the affected and unaffected extremities using a Jamar dynamometer (J.P. Marsh, Skokie, IL) and evaluated function with the

TABLE 1. Patient Characteristics (n = 30)

Mean age (y)	24 (range, 16–44)
Gender	
Male	25
Female	5
Fracture location:	
Proximal pole of scaphoid	11
Scaphoid waist	19
Dominant extremity involved	18
Mean time from injury to surgical treatment (mo)	13 (range, 5–47)
Mean duration of follow-up (mo)	21 (range, 13–34)

Disabilities of the Arm, Shoulder and Hand instrument (DASH score),[14] a 5-point satisfaction score (Question: "How satisfied are you with the use of your hand?" Answer: 1 = "Very unsatisfied, severely limited"; 2 = "Somewhat unsatisfied, moderately limited"; 3 = "Acceptable, minor constant limitations"; 4 = "Somewhat satisfied, occasionally limited"; and 5 = "Very satisfied, no significant or meaningful limitations").

Preoperative radiographic evaluation included plain radiographs, computed tomography (CT) scan, and noncontrast MRI. Plain radiographs were performed in a standard fashion (posteroanterior and lateral wrist views obtained in 90° shoulder abduction, 90° elbow flexion, neutral forearm rotation, and neutral wrist position) including scaphoid views in order to evaluate for radiographic evidence of scaphoid nonunion (a clear sclerotic line on both borders of the fracture fragments or cyst formation; Fig. 1), determine the scapholunate angle,[15] and examine the width of the radioscaphoid joint space. The scapholunate angle was the angle measured between longitudinal axes of scaphoid and lunate on the lateral wrist radiograph. Radioscaphoid joint-space narrowing was graded from 0 to 3 (grade 0 = no narrowing; grade 1 = mild beaking of the radius with involvement of the radioscaphoid joint; grade 2 = narrowing of radioscaphoid joint; and grade 3 = loss of radioscaphoid joint).[16] We used the CT scan to evaluate the scaphoid height-to-length ratio,[17] which was the ratio between the height of the scaphoid (measured by a line that was created perpendicular to the line passing the volar surface of scaphoid) and the length of the scaphoid (measured between the most proximal and the most distal aspect of the scaphoid) in sagittal images parallel to the long axis of the scaphoid. All patients had noncontrast MRI studies that showed AVN of the proximal pole of the scaphoid, determined by demonstrating low signal intensity of proximal pole fragments on T1

FIGURE 1: Preoperative plain radiograph shows scaphoid nonunion.

FIGURE 2: T1-weighted MRI demonstrates the avascular proximal pole of the scaphoid.

sequencing, and either heterogeneous or homogeneous low signal intensity on T2 sequencing[18–20] (Fig. 2). All proximal scaphoid fragments were also examined for intra-operative punctate bleeding.

Postoperative evaluation included measurement of wrist range of motion and grip strength. Plain radiographs were obtained at monthly intervals until there was evidence of bony bridging (Fig. 3). At this point,

FIGURE 3: Postoperative plain radiograph after vascularized bone graft and screw fixation.

we obtained a fine-cut (1-mm) CT scan with axial images reformatted to produce images in the coronal, sagittal, and scaphoid planes to confirm the presence of bridging trabeculae. Union was defined as bridging trabeculae on 2 consecutive sequences in either the sagittal or coronal plane.[21] DASH and satisfaction testing were repeated. The time to return to preoperative activities, including work and sports, and the level of activity achieved, were also recorded.

A certified hand therapist obtained the clinical measurements in a blinded fashion. Two fellowship-trained, board-certified hand surgeons and 2 fellowship-trained, board-certified musculoskeletal radiologists independently evaluated radiographs to determine when union occurred. All data were analyzed both in the aggregate and according to whether the scaphoid nonunion was located at the waist or the proximal pole of the scaphoid.

Surgical technique

The pedicle of the 1,2 ICSRA vascularized bone graft is a branch of the radial artery that courses between the first and second dorsal compartments of the wrist. This graft provides structural support and a blood supply to the nonunion site. The technical details are well described in previous publications.[1,3,6,10] When the tourniquet was deflated to assess the graft for punctate bleeding, the proximal pole of the scaphoid was similarly evaluated. In all cases, the absence of punctate bleeding of the proximal pole confirmed MRI evidence of avascularity.

TABLE 2. Clinical Evaluation

Parameter	Nonunion Location	Preoperative	Postoperative	Significant Difference
Grip strength (kg)*	Aggregate	37 (±10)	45 (±9)	Yes ($p < .001$)
	Proximal pole	41 (±13)	48 (±12)	Yes ($p < .001$)
	Waist	35 (±8)	44 (±7)	Yes ($p < .001$)
Composite wrist range of motion (degrees)				
Flexion–extension	Aggregate	119 (±11)	118 (±11)	No ($p = .26$)
	Proximal pole	124 (±8)	120 (±12)	No ($p = .28$)
	Waist	117 (±12)	116 (±11)	No ($p = .44$)
Radioulnar joint	Aggregate	46 (±5)	47 (±6)	No ($p = .23$)
	Proximal pole	47 (±4)	47 (±3)	No ($p = .63$)
	Waist	46 (±6)	46 (±7)	No ($p = .15$)

Data are presented as mean (standard deviation).
*Aggregate grip strength preoperatively was significantly different from the contralateral uninjured extremity ($p < .001$). Postoperatively, there was no significant difference in grip strength compared with the contralateral extremity.

We used internal fixation for the vascularized bone graft in all patients. In 9 cases we used a Herbert-Whipple cannulated screw (Zimmer, Warsaw, IN) and in 21 cases, an Acutrak cannulated screw (Acumed, Beaverton, OR). All patients had a concomitant radial styloidectomy to improve exposure, decrease tension on the vascular pedicle, and prevent radiocarpal impingement. In order to correct the humpback deformity of the scaphoid waist nonunions, the vascularized bone graft was maneuvered volarward.

Statistical analysis

We calculated the Wilcoxon signed ranks test to compare preoperative and postoperative values, and the Wilcoxon-Mann-Whitney test to compare the differences in values between patients with proximal pole and patients with waist nonunions, using statistical software (SPSS version 15.0; SPSS, Chicago, IL).

RESULTS

Union

Of 30 scaphoid nonunions with AVN, 28 united after the index procedure at an average of 5.1 ± 2.4 months. Two remaining nonunions healed after another surgery (nonvascularized bone grafting). There was a statistically significant difference in average time to union between the 2 nonunion locations: 4.1 months for nonunions of the waist, and 5.5 months for nonunions of the proximal pole ($p < .05$).

A total of 6 of 30 patients were smokers. Four of them stopped smoking 6 weeks before surgery and did not resume smoking during the follow-up portion of the study; their nonunions all healed with the first surgery. Both failures of vascularized bone grafting in this series were in smokers who did not quit preoperatively. These patients were advised to stop smoking and both did (as confirmed by a urine nicotine test before the second surgery). Both nonunions healed after the second surgery.

Clinical data

Table 2 shows preoperative and postoperative average grip strength and range of motion, presented in the aggregate and also stratified by nonunion location.

Radiographic data

All patients had preoperative MRI evidence of AVN. None of the patients had gross radiographic signs of proximal pole fragmentation. All the scaphoid waist nonunions had a humpback deformity. Table 3 shows the preoperative and postoperative average scapholunate angle and scaphoid height-to-length ratio. The average scapholunate angle improved in scaphoid waist nonunions, but not in proximal pole nonunions. The average scaphoid height-to-length ratio improved in both scaphoid waist and proximal pole nonunions. The 2 patients whose scaphoids failed to unite after the first surgery had the highest preoperative scapholunate angles (66° and 69°) and the highest scaphoid height-to-length ratios (0.85 and 0.87). Narrowing of the radioscaphoid joint space was identified in 3 of 11 patients with nonunions of the proximal pole, and 1 of 19 patients with nonunions of the scaphoid waist; all were grade 1.

TABLE 3. Radiographic Evaluation

Parameter	Nonunion Location	Preoperative	Postoperative	Significant Difference
Scapholunate angle (degree) (normal 46°, range, 30°–60°)	Aggregate	56 (±6)	50 (±2)	Yes ($p < .001$)
	Proximal pole	50 (±3)	50 (±2)	No ($p = .33$)
	Waist	60 (±4)	50 (±2)	Yes ($p < .001$)
Scaphoid height-to-length ratio (normal 0.59 ± 0.42)	Aggregate	0.75 (±0.08)	0.62 (±.04)	Yes ($p < .001$)
	Proximal pole	0.66 (±0.04)	0.62 (±0.02)	Yes ($p < .05$)
	Waist	0.81 (±0.04)	0.62 (±0.05)	Yes ($p < .001$)

Data are presented as mean (standard deviation).

TABLE 4. Outcome Analysis

Parameter	Nonunion Location	DASH Difference (Preoperative to Postoperative Score)		
DASH	Aggregate	17.0 (±8)		
	Proximal pole	19.0 (±8)		
	Waist	15.8 (±8)		
Satisfaction Score (range, 1–5)		Preoperative	Postoperative	Significant Difference
	Aggregate	3.0 (±0.8)	4.6 (±0.6)	Yes ($p < .001$)
	Proximal pole	3.2 (±0.8)	4.7 (±0.7)	Yes ($p = .001$)
	Waist	2.9 (±0.8)	4.6 (±0.6)	Yes ($p < .001$)

Data are presented as mean (standard deviation).

Outcomes

Table 4 shows the average DASH and satisfaction scores. There were no significant differences between preoperative and postoperative DASH scores, and average DASH scores for patients with proximal pole nonunions and scaphoid waist nonunions were not significantly different. The average improvement in DASH scores of 17.5 ± 7.9 for 26 patients without radiographic evidence of radioscaphoid arthritis was greater than the average improvement of 13.6 ± 6.1 for 4 patients with grade 1 radioscaphoid arthritis on preoperative plain radiographs. Nevertheless, this result was not significantly different. However, the satisfaction scores showed significant improvement between the preoperative and postoperative scores for the proximal pole and the distal pole as well as in aggregate.

Return to activity (work or sport)

A total of 28 of 30 patients returned to the job or sport at the time of injury. Both patients who did not return to their previous level of activity had nonunions of the scaphoid waist; one had failed to heal after vascularized bone graft, and the other had healed. The one who failed to heal was able to return to the same premorbid activity (work or sport), but not at the preinjury level.

Complications

Two patients with scaphoid waist nonunions required a second, nonvascularized bone grafting procedure for delayed union (at 7 and 6 months after the index procedure). They had demonstrable union at 11 and 13 months after the secondary procedure.

DISCUSSION

The management of scaphoid nonunions associated with AVN of the proximal pole is a challenging task for the hand surgeon. One treatment strategy that may improve the chances of achieving bony union is the use of a vascularized bone graft. The vascularized bone graft from the dorsoradial aspect of the distal radius described by Zaidemberg et al.[10] relies on the ascending irrigating branch of the radial artery that Sheetz et al.[11] defined as the 1,2 ICSRA. This vascularized bone-grafting technique is technically straightforward and facilitates treatment through a single incision. These advantages lead us to favor this technique over other

TABLE 5. Comparison of Clinical Outcomes

Parameter		Postoperative Results (% Preoperative)	Postoperative Result (% Contralateral)
Grip strength*	Current study	127	99
	Zaidemberg et al.[10]		95
	Boyer et al.[3]		77 (AVN)
	Uerpairojkit et al.[8]		72 (AVN)
	Malizos et al.[5]		85
Wrist range of motion			
Flexion–extension	Current study	99	91 (flexion-extension composite)
	Steinmann et al.[1]	98 (flexion), 107 (extension)	
	Zaidemberg[10]	200 (flexion), 175 (extension)	
	Boyer et al.[3]		61 (flexion), 54 (extension) (AVN)
	Uerpairojkit et al.[8]		82 (flexion), 90 (extension) (AVN)
	Malizos et al.[5]	138	
Radioulnar joint	Current study	102	96 (radioulnar composite)
	Steinmann et al.[1]	127 (radial), 93 (ulnar)	
	Zaidemberg et al.[10]	200 (radial), 300 (ulnar)	
	Boyer et al.[3]		51 (radial), 85 (ulnar) (AVN)
	Uerpairojkit et al.[8]		85 (radial), 79 (ulnar) (AVN)
	Malizos et al.[5]	171	

local vascularized pedicle bone graft techniques that have been described.

A recent systematic review by Merrel et al.[22] evaluating the surgical treatment of scaphoid nonunions identified 7 studies in which 64 patients with proximal pole AVN were treated. They reported an 88% union rate when vascularized graft with internal fixation was used, compared with a 47% union rate for treatment by nonvascularized graft with internal fixation. Another systematic review of literature published from 1928 to 2003 identified a variety of treatments using vascularized bone-grafting techniques with or without internal fixation, and reported a 91% union rate.[2] For proximal pole scaphoid nonunions, including cases with AVN, the union rate after treatment with a nonvascularized bone graft with internal fixation was 78%.[2] Furthermore, although authors acknowledge that bony union is the primary goal, there is little standardization among the outcomes data, which makes comparison challenging.

A variety of investigators have evaluated the utility of vascularized bone grafting to treat scaphoid nonunion. Six studies demonstrated 100% union rates of scaphoid nonunions treated with 1,2 ICSRA pedicled vascularized bone graft.[1,5,7–10] However, most studies included a mixed population of scaphoid nonunions, in contrast to the present study, which evaluated only scaphoid nonunions with AVN of the proximal pole regardless of whether the fracture occurred at the waist or the proximal pole. Two small series by Tsai et al.[7] and Waters et al.[9] (5 and 3 patients, respectively) achieved 100% union rates for scaphoid nonunions with proximal pole AVN using this vascularized graft. For the same grafting technique in patients with scaphoid nonunions and proximal pole AVN, Boyer et al.[3] reported a 60% union rate for 10 patients, and Chang et al.[4] observed a 50% union rate (12 of 24 patients). Straw et al.[6] reported a 13% union rate in 22 patients with this type of bone-grafting and K-wire fixation. Our study demonstrated a union rate of 93% after the index procedure in a large series of only scaphoid nonunion with proximal pole AVN.

The high success rate of our case series may be partially attributable to differences in scaphoid fracture location and the fact that our study did not include patients who had previous surgery for their scaphoid non-union. Our results are similar to those of Steinmann et al.[1] because the patients had evidence of avascular necrosis before considering the vascularized bone graft. Previous surgery was considered an adverse factor for successful outcome of surgical treatment for scaphoid nonunions by Boyer et al.[3] and Straw et al.[6] but a

history of prior conventional bone grafting had no significant effect on union rate with vascularized bone graft in the study by Chang et al.[4] Tobacco use may be another important factor for our union rates. All nonsmoking patients and patients who had stopped smoking achieved union, whereas the 2 patients who did not stop smoking required a second procedure to achieve union.

Scaphoid factors

Average time to union in our investigation was 4.1 months for nonunions of the scaphoid waist and 5.4 months for nonunions of the proximal pole. This difference was statistically significant and corresponds to reports in the literature[3,4,7] regarding avascular scaphoid nonunions.

Surgical factors

Iinternal fixation using a screw in all patients also may have contributed to the high union rate in our study. This confirms the findings of previous researchers who showed an improved healing rate of vascularized bone grafts for scaphoid nonunions with rigid internal fixation.[4]

Postoperative grip strength in this study was improved compared with the preoperative measurement and with the contralateral side (Tables 2 and 5). Our differences are greater than those reported by Boyer et al.[3] and Uerpairojkit et al.[8] (Table 5).

Our results demonstrated significantly improved scapholunate angle in scaphoid waist nonunion, but not in proximal pole nonunion. Our postoperative data revealed significant improvement of scaphoid collapse as measured by the scaphoid height-to-length ratio both in scaphoid waist and proximal pole nonunion. Scaphoid waist noinunion produced a greater height-to-length ratio compared with proximal pole nonunion, probably because the humpback deformity resulted in decreased length and may have increased the height or convexity of the scaphoid.

Although DASH scores did not improve significantly postoperatively, a total of 93% of patients in this investigation returned to their premorbid job or sport and the patients had a significant improvement in their satisfaction scores regardless of whether the fracture occurred at the waist or proximal pole. This corresponds to results by previous researchers. Uerpairojkit et al.[8] reported return to prior activity in 10 of 10 patients, and 100% of patients in the investigation by Malizos et al.[5] returned to their previous occupation within 4 to 6 months.

Similar to earlier reports in the literature, a limitation of this study was the lack of prospective, randomized, controlled trial that compares different local vascularized pedicle bone-grafting techniques for the treatment of similar scaphoid nonunions with AVN. Another limitation is the use of a nonenhanced magnetic resonance (MR) study to detect AVN of the proximal pole. Unenhanced MR has been reported to detect avascularity of the proximal fragment of scaphoid accurately in previous studies,[18,20] but Cerezal et al.[23] found it to be unreliable. The results of a study by Singh et al.[19] questioned the value of gadolinium-enhanced MR assessments of proximal fragment vascularity. Therefore, we had believed the value of enhanced MRI to be controversial. However, in this study, the unenhanced MR data corresponded to the reference standard of intraoperative punctate bleeding of scaphoid.

The results of this investigation support the use of the vascularized bone graft in the treatment of the scaphoid nonunions with associated AVN of the proximal pole when the outcome is measured by the union rate and validated patient-centered outcome instruments.

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