Bone Grafting for Scaphoid Nonunions: Is Free Vascularized Bone Grafting Superior for Scaphoid Nonunion?

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Abstract

Background: Nonvascularized bone grafting (NVBG) and vascularized bone grafts (VBGs) have been used to treat scaphoid nonunions. A comparison of a single institution's experience using structural iliac crest bone graft (ICBG), 1,2-intercompartmental suprapatellar artery (1,2-ICSRA), and medial femoral condyle (MFC) grafts to treat scaphoid nonunions was undertaken. **Methods:** Thirty-one patients underwent ICBG, 33 patients underwent 1,2-ICSRA, and 45 patients underwent MFC grafting. Mean time to follow-up was 16 months (range, 2–153). Twenty-three percent used tobacco products. Mean age was 24 years (range, 11–66), with 86% male patients. Outcomes included union rate, time to healing, range of motion, complications, and reoperations. **Results:** Union rates and mean time to union were 71% and 19 weeks for the ICBG group, 79% and 26 weeks for the 1,2-ICSRA group, and 89% and 16 weeks for the MFC group, respectively. Failure of union was associated with tobacco use but not with age, gender, time from injury to surgery, or type of fixation. There was no significant difference between the groups regarding range of motion or strength. **Conclusions:** These findings demonstrate the need for careful patient selection. In patients with the most complicated scaphoid nonunions (avascular necrosis, carpal collapse, and previous surgeries), the MFC group had the highest union rate and fastest time to union. Patients with risk factors for failure should be counseled on the outcomes and possible need for salvage fusion surgery.

Keywords: scaphoid nonunion, vascularized bone graft, carpal collapse, avascular necrosis, proximal pole

Introduction

Roughly 60% of all carpal bone fractures involve the scaphoid.¹⁰ Despite treatment, nonunion rates have been reported as high as 15%.¹⁴ Nonunions are often the result of failure of diagnosis with delayed treatment, displacement of the fracture, avascular necrosis (AVN), or proximal pole fractures.²⁵ Management of scaphoid nonunions is aimed at preventing the development of scaphoid nonunion advanced collapse (SNAC), which is the known natural history of this condition.^{16,21,27} Scaphoid nonunions present a challenging problem to surgeons, particularly as AVN develops.

Scaphoid nonunions result in a typical dorsal angulation with a dorsal intercalated segment instability (DISI) deformity as the lunate extends with the proximal pole.¹⁹ Traditionally, scaphoid nonunions with carpal collapse can be treated with structural allograft and screw fixation.^{3,6,23} Nonvascularized bone grafting (NVBG), however, is not

effective in the presence of AVN with a reported union rate of 47%, compared with vascularized bone grafts (VBGs).¹⁸

Pedicled VBG has been used to treat scaphoid nonunions and Kienbock's disease.²² Most studies demonstrated promising early results with the use of the 1,2-intercompartmental suprapatellar artery (1,2-ICSRA) pedicled graft with union rates of 100% and time to union between 6 and 12 weeks.^{17,24,26,28} However, Chang et al demonstrated only a 71% union rate with a high incidence of complications associated with the 1,2-ICSRA pedicled graft, particularly in older patients, those with proximal pole fragmentation, preoperative humpback deformity, Kirschner wire (K-wire)

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fixation, tobacco use, and female gender.⁴ Nine of the 14 failures in the study were noted to have a DISI deformity and were not corrected by the 1,2-ICSRA graft.

Free VBG from the medial femoral condyle (MFC) has also been reported in the treatment of scaphoid nonunions with carpal collapse and associated AVN.^{7,8,11-13,15} This graft utilizes both corticoperiosteal and corticocancellous components, which provide not only a structural graft to address the humpback deformity but also a vascular component to address the poor blood supply. Jones et al demonstrated a 100% union rate and correction of the scaphoid deformity with the use of a free vascularized MFC graft.¹¹ To date, few studies have compared the outcomes of the various grafting techniques owing to the different indications for each.

This study sought to assess a larger series of patients undergoing treatment for scaphoid nonunions with structural iliac crest bone graft (ICBG), 1,2-ICSRA, and MFC grafts with regard to union rate, time to union, and need for revision/reoperation.

Materials and Methods

Following institutional review board (IRB) approval, a retrospective review was conducted of all scaphoid nonunions treated operatively at our institution between January 1, 2000, and December 31, 2013. One hundred thirty-one treated scaphoid nonunions were identified. Twenty-two were lost to follow-up. The remaining 109 wrists were followed for a minimum of 6 months or until reoperation, with a mean follow-up of 16.5 months (range, 2-153 months). The mean age at the time of surgery was 24.7 years (range, 11-66 years). The cohort included 93 males and 16 females. The dominant extremity was involved in 66 (61%) cases. Twenty-five patients (23%) reported using tobacco products at the time of surgery. The time from injury to treatment averaged 15.6 months (range, 6-120 months).

Our study cohort was divided into 3 groups: those that underwent ICBG structural autograft or allograft ($n = 31$), 1,2-ICSRA pedicled grafting ($n = 33$), or MFC free vascularized grafting ($n = 45$). Forty-three (39%) patients had prior surgical treatment with 4 (13%) in the ICBG group, 10 (30%) in the 1,2-ICSRA group, and 29 (64%) in the MFC group. The senior authors performed 42% of the ICBG grafts, 42% of the 1,2-ICSRA grafts, and 95% of the MFC grafts. All other procedures were performed by hand fellowship trained surgeons with at least 5 years of attending experience.

All patients underwent a preoperative physical examination to assess range of motion and grip strength. Imaging studies included plain radiographs, computed tomography (CT) with reformats along the long axis of the scaphoid, and magnetic resonance imaging (MRI) in some instances.

Figure 1. Clinical intraoperative photograph of the scaphoid fracture demonstrating sclerosis and absent punctate bleeding following deflation of the tourniquet.

Eighty fractures involved the waist, while 38 fractures involved the proximal pole. Carpal collapse was determined based on the evidence of a revised carpal height ratio of ≤ 1.52 ,²⁰ a lateral intrascaphoid angle of $\geq 45^\circ$,¹ a radiolunate angle of $\geq 15^\circ$, or a height-to-length ratio of ≤ 0.59 .² Avascular necrosis of the proximal pole was suspected with proximal bone sclerosis, cyst formation, and indicative MRI findings; however, in all cases, it was confirmed based on intraoperative assessment with sclerotic bone and lack of punctate bleeding with deflation of the tourniquet⁹ (Figure 1). Table 1 summarizes the demographics in each group, as well as defines the indication for surgery.

Sixty-nine nonunions were treated with cannulated scaphoid screw fixation, 27 were treated with K-wire fixation, and 13 were treated with both. Fixation was determined by fragment size, stability of construct, and bone quality at the time of surgery with the goal of screw utilization.

Outcome measures included union rate, time to healing, range of motion, grip strength, change in radiographic parameters, complications, and reoperations.

Statistical Methods

Group comparisons were performed using Wilcoxon rank sum test for nonparametric outcomes. Means were compared using t tests. Statistical significance was considered at $P < .05$. Relative risk ratios were calculated.

Results

Union

Computed tomography scans were available in the postoperative course in all cases. Typical postoperative imaging surveillance included plain radiographs at roughly 2, 6, and 10 weeks, and a CT scan at approximately 12 weeks. Computed tomography scans were sometimes obtained sooner if

Table 1. Demographic Data.

Demographics	ICBG (31 scaphoids)	1,2-ICSRA (33 scaphoids)	MFC (45 scaphoids)
Gender			
Male	83.9%	81.8%	88.9%
Female	16.1%	18.2%	11.1%
Age at surgery (mean)	29.4 years	23.1 years	22.8 years
Dominant extremity	51.6%	57.5%	68.9%
Tobacco use	35.5%	30.3%	8.9%
Waist fracture	n = 30	n = 12	n = 38
Proximal pole fracture	n = 1	n = 21	n = 7
Avascular necrosis with tourniquet deflated	0%	81.8%	91.1%
Prior procedure	12.9%	30.3%	64.4%
Preoperative carpal collapse	87.1%	48.4%	100%
Follow-up duration, months, mean (range)	11.1 (3.4-96.5)	26.3 (3.5-153.3)	12.5 (2.4-53.9)

Note. ICBG = iliac crest bone graft; 1,2-ICSRA = 1,2-intercompartmental suprarretinacular artery; MFC = medial femoral condyle.

Table 2. Comparison of Union Rates, Time to Union, and Reoperation Rates by Treatment Group (Statistical Significance Defined as $P < .05$).

Variables	ICBG	1,2-ICSRA	MFC	P value
Union rate (%)	71.0%	78.8%	88.9%	.14
Time to union (weeks)	18.7	25.6	15.5	.005*
Overall reoperation rate	29.0%	15.1%	33.3%	.14
Reoperation rate for persistent nonunion and salvage procedures	22.6%	12.1%	15.6%	.52

Note. ICBG = iliac crest bone graft; 1,2-ICSRA = 1,2-intercompartmental suprarretinacular artery; MFC = medial femoral condyle.

*Significance set at $P < 0.05$.

radiographs demonstrated evidence of healing and patients desired return to activity. If no healing was noted, CT scans were repeated as indicated at longer follow-up times. The time frame for imaging studies varied slightly due to patient availability and scheduling parameter. Radiographic union as defined as bridging trabeculae across the majority of the proximal and distal interfaces was observed in 22 (71.0%) cases in the ICBG group, 26 (78.8%) cases in the 1,2-ICSRA group, and 40 (88.9%) cases in the MFC group. The mean time to union was 18.7, 25.6, and 15.5 weeks, respectively (see Table 2).

The nonunion characteristics were different for each group. With respect to intraoperative assessment of AVN, the ICBG group had 0%, the 1,2-ICSRA group had 82%, and the MFC group had 91% incidence of AVN. With respect to carpal collapse, the ICBG group had 87%, the 1,2-ICSRA group had 48%, and the MFC group had 100% incidence of carpal collapse. Previous surgery of the scaphoid nonunion occurred in 13% of the ICBG, 30% of the 1,2-ICSRA, and 64% of the MFC group. The MFC group had the greatest percentage of prior surgery, AVN, and carpal collapse in comparison with the ICBG group and 1,2-ICSRA group ($P < .05$). Active tobacco use was more

frequent in those cases where the scaphoid did not heal (risk ratio [RR], 3.1; 95% confidence interval [CI], 1.5-6.3). All 4 tobacco users in the MFC group went on to union, 3 of which had prior surgical intervention including structural iliac crest autograft in 1 and a pedicled distal radius vascularized graft in the other two.

Age, gender, time from injury to surgery, and type of fixation (screw, K-wire, or both) were not found to affect the rate of union.

Complications and Reoperations

There were a total of 9 (29%) reoperations in the ICBG group, 5 (15%) reoperations in the 1,2-ICSRA group, and 15 (33%) reoperations in the MFC group. In the MFC group, there were 8 planned buried K-wire removals; thus, the unplanned reoperation rate was 7 (15.6%). When evaluating reoperation for persistent nonunion or failure of surgery (not including planned or unplanned removal of hardware), there were 7 (22.6%) reoperations in the ICBG group, 4 (12.1%) reoperations in the 1,2-ICSRA group, and 7 (15.6%) reoperations in the vascularized MFC group. In the ICBG group, 1 ultimately underwent an MFC graft

Table 3. Final Assessment of Range of Motion by Treatment Group (Statistical Significance Defined as $P < .05$).

Wrist motion	ICBG (mean, range)	1,2-ICSRA (mean, range)	MFC (mean, range)	P value
Wrist extension	45.8° (20°-66°)	44.0° (15°-75°)	42.9° (10°-70°)	.45
Wrist flexion	51.0° (5°-82°)	48.2° (5°-80°)	50.8° (20°-81°)	.82
Radial deviation	16.5° (5°-31°)	16.3° (0°-43°)	16.7° (2°-60°)	.76
Ulnar deviation	26.9° (0°-49°)	28.3° (10°-45°)	30.3° (11°-46°)	.12

Note. ICBG = iliac crest bone graft; 1,2-ICSRA = 1,2-intercompartmental supratretinacular artery; MFC = medial femoral condyle.

Table 4. Preoperative and Postoperative Radiographic Parameters (Statistical Significance Defined as $P < .05$).

	Preoperative (mean, range)	Postoperative (mean, range)	P value
Medial femoral condyle			
Revised carpal height ratio	1.49 (1.32-1.71)	1.53 (1.29-1.80)	.11
Scapholunate angle	62.4° (28°-95°)	57.7° (34°-78°)	.15
Radiolunate angle	21.3° (2°-58°)	15.0° (1°-54°)	.002*
Lateral intrascaphoid angle	64.0° (8°-99°)	48.5° (18°-94°)	.002*
Height-to-length ratio	0.77 (0.5-1.1)	0.69 (0.5-1.0)	.0003*
1,2-ICSRA			
Revised carpal height ratio	1.59 (1.37-1.75)	1.60 (1.43-1.76)	.76
Scapholunate angle	52.9° (33°-81°)	52.0° (39°-90°)	.39
Radiolunate angle	13.5° (2°-46°)	14.5° (1°-39°)	.90
Lateral intrascaphoid angle	53.3° (33°-77°)	47.4° (30°-100°)	.13
Height-to-length ratio	0.67 (0.4-0.9)	0.68 (0.5-0.9)	.97
ICBG			
Revised carpal height ratio	1.55 (1.39-1.72)	1.55 (1.33-1.74)	.59
Scapholunate angle	61.8° (24°-91°)	61.1° (29°-116°)	.92
Radiolunate angle	20.4° (2°-45°)	19.1° (2°-77°)	.72
Lateral intrascaphoid angle	63.9° (38°-87°)	48.8° (15°-85°)	.0001*
Height-to-length ratio	0.74 (0.6-1.0)	0.69 (0.5-0.9)	.009*

Note. 1,2-ICSRA = 1,2-intercompartmental supratretinacular artery; ICBG = iliac crest bone graft.

*Significance set at $P < 0.05$.

with good outcomes, 5 underwent scaphoidectomy and 4 corner fusion for persistent nonunion and pain, 1 underwent local distal radius cancellous grafting, and 2 screw removals. In the 1,2-ICSRA group, 2 underwent salvage 4-corner fusion, 1 underwent a proximal row carpectomy, and 1 underwent a radial styloidectomy. This group had 1 implant removal. In the MFC group, 2 underwent a 1,2-ICSRA as an attempt to address inadequate healing, 3 underwent scaphoidectomy and 4-corner fusion, 1 underwent a radioscapulohumeral arthrodesis, 1 required an irrigation and debridement for deep infection of the donor site, and 8 underwent planned K-wire or screw removal. Given the higher incidence of small proximal pole with previous screw fixation and poor quality in the MFC group, there was a greater use of buried K-wires requiring planned removal in the operating room.

In addition, in the MFC group, there was no evidence of significant knee pain or loss of motion based on the available data in the medical record.

Clinical and Functional Outcomes

The mean final grip strength was 36.1 kg (range, 18-60) in the ICBG group, 40.2 kg (range, 13-85) in the 1,2-ICSRA group, and 38.9 kg (range, 10-62) in the MFC group which was 85%, 112%, and 87% of the contralateral side ($P = .65$).

Range of motion at final follow-up is summarized in Table 3. There was no statistically significant difference between groups in regard to range of motion.

Radiographic Outcomes

Radiographs and CT imaging were assessed preoperatively and postoperatively. The lateral intrascaphoid angle, scapholunate angle, radiolunate angle, height-to-length ratio, and revised carpal height ratio were assessed and are summarized in Table 4. There was improvement noted in the MFC and ICBG groups in regard to carpal deformity; however, this improvement was absent in the 1,2-ICSRA group. It

should be noted that only 48% of wrists in the 1,2-ICSRA group had preoperative carpal collapse, which may skew the data. When we included only those patients who presented with preoperative carpal collapse, there was a statistically significant improvement of the intrascaphoid angle and the height-to-length ratio for MFC ($P = .002$ and $.0003$, respectively) and ICBG ($P = .0003$ and $.006$, respectively) groups; however, these values did not show any significant improvement for the 1,2-ICSRA group ($P = .23$ and $.18$).

Discussion

Few studies have compared various operative techniques in the treatment of scaphoid nonunions.¹¹ Jones et al compared the use of a pedicled distal radius vascularized graft versus the use of the free vascularized MFC graft for nonunions of the scaphoid waist with a humpback deformity and AVN. Four of the 10 wrists treated with a distal radius graft went on to persistent nonunion, while all 12 scaphoids treated with the MFC graft demonstrated healing.

Recently, Elgammal and Lukas reported on 30 patients with a proximal pole necrosis, a humpback deformity, or that failed previous surgery who underwent free vascularized MFC graft.⁸ They reported an 80% union rate, with 4 of the 6 nonunions being active heavy smokers.

This study found that tobacco use was a relative risk factor for persistent nonunion following operative management. Interestingly, the 4 active smokers in the MFC group at our institution demonstrated union at 11, 11, 12, and 9 weeks. The effect of smoking on union was greatest in the 1,2-ICSRA with a relative risk of 13.8 (95% CI, 1.9-100.2). This is likely confounded by the greater distribution of fractures in this group involving the proximal pole. Nonetheless, the presence of a proximal pole fracture was not a risk factor for persistent nonunion in the 1,2-ICSRA group with a relative risk of 0.43 (95% CI, 0.11-1.6).

An earlier series noted a 100% union rate for MFC¹¹; however, this series had a 88.9% union rate in a group of patients with more complex nonunions compared with the ICBG group and 1,2-ICSRA group (AVN with carpal collapse). Elgammal and Lukas speculated that their nonunions repaired with vascularized MFC were due to tobacco use and poor fixation with K-wires.⁸ In our study, type of fixation did not appear to be a risk factor for persistent nonunion following an MFC graft. Upon review of the 5 nonunions treated with the vascularized MFC, it is unclear as to the etiology of each failure.

Chang et al previously reported on the outcomes of the 1,2-ICSRA for scaphoid nonunions and noted a high complication rate.⁴ The risk factors in their study included female gender, tobacco use, proximal pole AVN, older age, K-wire fixation, and a preoperative humpback deformity. Since this report, the indication for the 1,2-ICSRA graft has transitioned to treating those with proximal pole fractures

and nonunions with AVN without carpal collapse or deformity. The current series demonstrates a similar union rate of 79% compared with 71% reported by Chang et al, with similar risk factors for failure, namely, tobacco use.⁴

In contrast, scaphoid nonunions without a humpback deformity and no evidence of AVN may be reasonably treated with structural iliac crest bone grafting. This series demonstrates a 71% union rate with a structural graft where vascularity was deemed adequate with the tourniquet released and the proximal bleeding assessed. Recently, Cohen et al reported on 12 patients with a preoperative humpback deformity with an average lateral intrascaphoid angle of 49° without signs of AVN that underwent open reduction and internal fixation with a screw and cancellous autografting from the distal radius.⁵ The authors demonstrated a 100% union rate with good correction of the humpback deformity.

We recognize the limitations of retrospective studies. In addition the groups being compared in this study are not similar and the indications for each treatment are different. For example, the ICBG group was presumed to have proximal pole vascularity with only carpal collapse, the 1,2-ICSRA group was presumed to be nondisplaced proximal pole nonunions with AVN, and the MFC group was presumed to have carpal collapse with AVN. In addition, the number of prior surgeries was greatest in the MFC group, making this group the highest at risk for failure with AVN, carpal collapse, and prior surgery. Nonetheless, the findings in this study clearly demonstrated that the union rate was highest in the MFC group with a lower reoperation rate for nonunion than the ICBG group. The higher nonunion rate of the ICBG group as well as the higher incidence of reoperation for failed ICBG compared with the MFC group with presumably more complicated nonunions, makes the application of the vascularized MFC in these patients more attractive. The overall complication rate and reoperation rate were similar in the MFC group compared with the 1,2-ICSRA group when planned removal of hardware was accounted for. The findings in this study support the need for careful patient selection based on a thorough evaluation of the preoperative CT scan, patient history, and an intraoperative assessment of the vascularity of the proximal pole. Patients with risk factors for failure should be counseled on the outcomes and possible need for salvage fusion surgery. The data in this study highlight that the MFC graft provides the highest union rate with the shortest time to union in the most challenging cases. As such, it should be considered a useful tool in the armamentarium of surgeon's treating scaphoid nonunions. It remains the senior authors (A.T.B. and A.Y.S.) preferred method to treat patients with carpal collapse, a humpback deformity, and AVN with a free vascularized MFC graft. Additional controlled prospective comparative studies are needed to better assess the utility of this graft, as well as to assist with more careful patient selection.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

Procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

Statement of Informed Consent

Informed consent for research purposes was obtained per institutional protocol.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Alexander Y. Shin has royalties from Mayo Medical Ventures/TriMed Orthopedics.

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