A Critical Appraisal of Vascularized Bone Grafting for Scaphoid Nonunion

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J Wrist Surg 2017;6:251–257.

Abstract

Background Vascularized bone grafting (VBG) has the potential to yield reliable results in scaphoid nonunion; however, results across studies have been highly variable. This study critically evaluates surgical techniques, fracture location, and patient selection in relation to radiographic, clinical, and patient-centered outcomes after VBG for scaphoid nonunion.

Methods We conducted a systematic review of the literature for the use of VBG in scaphoid nonunion. Physical examination, radiographic, and patient-centered outcomes were assessed. Four substratifications were performed: the location of scaphoid nonunion, pedicled versus free technique, Kirschner wire (K-wire) versus screw fixation, and VBG done as a primary versus revision procedure.

Results A total of 41 publications were included in final analysis. VBG had an 84.7% union rate at 13 weeks after surgery. On an average, 89% of patients returned to preinjury activity levels by 18 weeks after surgery and 91% of patients reported satisfaction with the procedure. Proximal pole nonunions demonstrated similar union rates but lower functionality scores compared with nonunions across all regions of the scaphoid. Pedicled techniques demonstrated slightly improved range of motion compared with free technique. K-wire versus screw fixation demonstrated significantly higher union rates and faster union times. There were no differences in outcomes for VBG done as a primary versus revision procedure.

Conclusion VBG serves as a viable option for the treatment of scaphoid nonunion, with consistent union rates in addition to significantly improved postoperative patient functionality. The fixation of these vascularized bone grafts with K-wires versus screw fixation may result in superior radiologic outcomes.

Level of Evidence Therapeutic, Level III, systematic review.

Keywords

- bone graft
- microvascular
- nonunion
- scaphoid
- vascular

received
September 19, 2016
accepted
November 3, 2016
published online
December 8, 2016

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Tel: +1(212) 584-4662.

DOI <https://doi.org/10.1055/s-0036-1597575>.
ISSN 2163-3916.

Scaphoid fractures account for up to 70% of all carpal fractures, and although the majority of these fractures heal with nonoperative management, fractures of the proximal pole or with significant displacement have a higher chance of progression to nonunion.¹⁻³ The presence of nonunion presents a challenging situation to the treating physician as it can progress to scaphoid nonunion advanced collapse (SNAC), which can result in debilitating wrist symptoms and limitation of the overall hand function. Currently, several methods have been proposed for the management of scaphoid nonunion; however, there is no consensus with regard to which treatment modality yields the best outcomes.

Internal fixation of scaphoid nonunion allows for rigid fixation and compression of fracture fragments, thereby allowing bony healing. However, not all fractures may be amenable to isolated internal fixation, and numerous studies have reported on the need for augmentation of fixation with nonvascularized bone grafting (NVBG) to address the bony defect in scaphoid nonunion⁴⁻⁶; however, the results have been variable, with union rates ranging from 40 to 90%.⁷⁻¹⁰ This variability may be secondary to whether these nonvascularized bone grafts were executed in the setting of avascular necrosis (AVN), which can be difficult to diagnose preoperatively.¹¹

Vascularized bone grafting (VBG) has the potential to offer more reliable and consistent union rates by providing vascularized bone and viable osteocytes, as first reported by Roy-Camille et al in 1965.¹² This may offer a more amenable treatment for scaphoid nonunion in the presence of AVN, proximal pole involvement, previously failed surgery, or prolonged duration of nonunion. Several techniques of VBG that used both pedicled and free vascular supplies have been reported.^{13,14} As the techniques of VBG have been refined, some studies have demonstrated union rates as high as 90 to 100%; however, across all studies, union rates remain highly variable.¹⁵⁻¹⁷ The reason for this variation remains largely unknown and is likely due to a combination of surgical technique, location of nonunion, and previous surgical intervention.

The purpose of this systematic review of VBG for the treatment of scaphoid nonunion is to critically evaluate surgical techniques, fracture location, and patient selection in relation to radiographic, clinical, and patient-centered outcomes.

Materials and Methods

The study design included a review of MEDLINE and PubMed databases for human studies restricted to the English language published between January 1990 and January 2015; the search terms included “vascularized bone graft and scaphoid nonunion,” “vascularized bone graft in wrist injury,” and “vascularized bone graft and hand.” A set of inclusion and exclusion methodology was formed based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The title and abstract of each article from the MEDLINE and PubMed database queries was reviewed with the names, authors, and institutions of each manuscript blinded. We included studies that evaluated pedicled and free vascularized bone grafts from any donor site for the treatment of scaphoid nonunion with or without diagnosed AVN. The references cited in the articles that met inclusion criteria after screening were

reviewed to identify potential studies not captured by the initial database queries. We excluded studies with less than 10 patients, those with less than 6 months of follow-up, or those that did not report union time. We also excluded studies that included a combination of vascularized and NVBG techniques in the same patient, acute scaphoid fractures, patients with idiopathic scaphoid AVN, patients already reported in other publications, skeletally immature patients, and non-English language studies. The search protocol and article selection were completed by two reviewers (R.A., C.Y.) and reviewed by the senior author (K.P.).

Group and study characteristics recorded from each study included number of patients, mean age, gender (percent male), percent with previous surgery for scaphoid nonunion, mean duration of nonunion before vascularized bone graft, and duration of postoperative follow-up. Surgical technique variables recorded from each study included type of graft fixation (screw vs. Kirschner wire [K-wire]) and type of vascularized bone graft (free vs. pedicled). The location of the nonunion (proximal pole vs. all regions) and whether the surgery was done as a primary or revision surgery were also recorded. Physical examination outcomes included mean range of motion (ROM) and grip strength. Radiographic outcomes included percent union and mean time to union. Patient-centered outcomes included the mean Disabilities of the Arm, Shoulder and Hand (DASH) score, mean modified Mayo Wrist Score (MMWS), patient satisfaction, percent return to preinjury activity level without modification of sport or occupation, mean time to return to preinjury activity level, graft-site complications, and donor-site morbidity in free VBG.

Four clinical questions were analyzed with regard to their relation with postoperative physical examination, radiographic, and patient-centered outcomes: the location of the scaphoid nonunion comparing the proximal pole to any region of the scaphoid, pedicled versus free VBG technique, K-wire versus screw fixation of the vascularized bone graft, and VBG done as a primary versus revision procedure for scaphoid nonunion.

Student's *t*-test was used to assess for postoperative improvement from preoperative values in the overall outcomes data. In subgroup analysis, the same number of publications was not used for each analysis as the availability of data for each outcome varied. To account for variability in study sample size, these subgroup comparisons were done with weighted analysis of variance, with study sample size as the weighting factor. Outcomes were compared by surgical factors with adjustment for each study's reported mean age, percentage male patients, percentage prior surgeries, and mean duration of nonunion prior to VBG. Results are reported for each outcome as adjusted mean and standard error of mean (SEM). $P \leq 0.05$ was considered significant.

Results

Results from the initial electronic search yielded 489 potentially relevant citations. Of these citations, 145 abstracts were reviewed and subjected to further inclusion analysis. Fifty-seven articles ultimately described VBG for scaphoid nonunion of which 41 met inclusion criteria (—Fig. 1).

Fig. 1 Article selection.

A complete list of included studies can be found in the **►Supplementary Data** (available in the online version).

Overall study characteristics are demonstrated in **►Table 1**. There were two randomized, controlled trials; there was 1 prospective case series, and 38 case series or retrospective reviews. The average demographic and clinical variables across all 41 studies are also presented in **►Table 1**.

Across all studies, there were significant improvements in postoperative ROM and grip strength ($p < 0.05$). Patient functionality scores also demonstrated significant improvement relative to preoperative values ($p < 0.05$; **►Table 2**). On average, 84.7% (27–100%) of VBG resulted in radiographic union by 13 weeks (6.2–21.9 weeks) postoperatively. Approximately 89% (63.6–100%) of patients returned to previous activity level 4 months after VBG, and 91% (76–100%) of patients reported complete satisfaction with their postoperative outcome at final follow-up (**►Table 2**). Satisfaction was

Table 1 Overall study characteristics of vascularized bone grafting for scaphoid nonunion

Study demographics	
Number of studies	41
Number of subjects	1,009
Average number of subjects per study	24.61
Average age	28.69
% Male	89.6%
Duration of nonunion	29.87 mo
Length of follow-up	35.43 mo
Location of scaphoid nonunion	
Proximal pole	Twelve studies (207 subjects)
All regions	Twenty-six studies (746 subjects)
Vascularized bone graft technique ^a	
Free	Eight studies (157 subjects) Iliac crest: four studies Medial femoral condyle: three studies Supracondylar femur: one study
Pedicle	Thirty-four studies (852 subjects) 1,2 ICSRA: 20 studies Various dorsally based arterial pedicles: four studies Palmar carpal artery: three studies Pronator quadratus: two studies Fourth extensor compartment artery: one study 4,5 extensor compartmental artery: one study First dorsal metacarpal artery: one study Second metacarpal: one study Third metacarpal: one study
Vascularized bone graft fixation	
K-wire	Sixteen studies (296 subjects)
Screw	Five studies (141 subjects)
History of previous surgery ^b	
Primary	Thirteen studies (292 subjects)
Revision	Four studies (85 subjects)

^aOne study reported outcomes in both free and pedicle techniques.

^bOne study reported outcomes in both primary and revision patients.

most commonly assessed as a yes/no question to the patient either with respect to their functional outcome after surgery or if they would agree to the procedure again for the same condition.

Twelve studies described VBG to isolated proximal pole scaphoid nonunion, whereas 26 studies included patients with nonunion involving any region of the scaphoid. Patients with proximal pole nonunion had significantly lower postoperative MMWS values compared with nonunions across all regions of the scaphoid ($p < 0.05$). Physical examination

Table 2 Overall outcomes of vascularized bone grafting for scaphoid nonunion

Outcome	Mean postoperative score/value (range)	Number of studies	Mean % improvement from preoperative score/value (range)	Number of studies	p- Value
Disabilities of the Arm, Shoulder and Hand	14.78 (5–29)	5	80.75 (77.5–84)	2	<0.05
Modified Mayo Wrist Score	83.29 (75–88)	8	53.8 (32.8–70)	4	<0.05
Flexion (degrees)	51.20 (35–72)	22	24.2 (-21.7–100)	16	<0.05
Extension (degrees)	55.06 (34.4–86)	22	27.30 (0–88.9)	16	<0.05
Radial deviation (degrees)	13.67 (5–20)	18	55.42 (-20 to 241)	14	<0.05
Ulnar deviation (degrees)	26.73 (19–37.7)	17	47.64 (-14.5 to 200)	13	<0.05
Grip strength (kg)	36.82 (28.1–50)	14	46.52 (3.2–94.2)	9	<0.05
Time to union (wk)	13.03 (6.2–21.9)	31	n/a		n/a
% Union	84.70 (27–100)	41	n/a		n/a
Time to return to activity (wk)	17.73 (13.2–21.4)	6	n/a		n/a
% Return to activity	88.91 (63.6–100)	16	n/a		n/a
% Satisfaction	91.12 (76–100)	5	n/a		n/a

Note: Student's t-test was used to assess whether mean postoperative percentage improvement differed from zero.

(ROM and grip strength) and radiographic outcomes were similar between the two groups ($p > 0.05$; ►Table 3).

Eight studies used free VBG technique, 34 studies used pedicled VBG, and 1 study compared free versus pedicled VBG. Pedicled VBG demonstrated significantly greater postoperative percent improvement in flexion and absolute ROM in extension ($p < 0.05$). All other physical examination outcomes were similar ($p > 0.05$). Postoperative patient functionality, radiographic, and return to activity outcomes also did not differ between groups ($p > 0.05$; ►Table 3).

Five studies used isolated screw fixation of the VBG, whereas 16 studies used only K-wire fixation. Physical examination, functionality, and return to activity outcomes were similar across both groups ($p > 0.05$). However, K-wire fixation resulted in 25% higher union rates compared with screw fixation ($p < 0.05$) and demonstrated a trend toward shorter union times by 7 weeks ($p = 0.067$; ►Table 3).

Thirteen studies used VBG as a primary procedure for scaphoid nonunion, four studies used VBG as a revision procedure, and one study compared primary versus revision VBG. Patient functionality, physical examination, radiographic, and return to activity outcomes were similar between both groups ($p > 0.05$; ►Table 3).

Thirty-two studies assessed postoperative graft-site complications across 818 subjects. The overall complication rate was 5.9%. The most common complications were failure of fixation (1.7%), superficial infection (1.2%), and neuropathic pain (0.9%) (►Table 4). Five of eight studies using free VBG assessed donor-site complications in 70 patients, and the overall prevalence was 4.3%.

Discussion

In the United States, approximately 345,000 scaphoid fractures are diagnosed per year, of which 15% result in non-

union.³ For over two decades, VBG has been used in the treatment of scaphoid nonunion, particularly in settings of known AVN; however, the reported outcomes of VBG have varied widely, with particular regard to union rate.^{15,17,18} In this systematic review, 41 studies containing 1,009 subjects with scaphoid nonunion treated with VBG were analyzed with a focus on clinical, patient-centered, and radiographic outcomes.

Across all studies, there was significant improvement in postoperative ROM and grip strength relative to preoperative values, likely leading to the excellent functionality scores, return to preoperative activity levels and overall satisfaction rates demonstrated in our review. Approximately 84% of patients achieved scaphoid union by 13 weeks after VBG, a finding consistent with previous published reviews.^{10,19,20} At 4 months after VBG, nearly 90% of patients were completely satisfied with the procedure and able to return to preoperative activity levels.

The aforementioned results detail the outcomes of VBG for scaphoid nonunion in any region of the scaphoid. Currently, the indications for VBG in scaphoid nonunion are not clearly delineated, and some surgeons may limit VBG to patients with proximal pole nonunion. Merrell et al demonstrated a significantly lower union rate of 47% when stratified for NVBG to the proximal pole, whereas Munk and Larsen demonstrated an overall union rate of 84% in NVBG for nonunion in any region of the scaphoid.^{10,19} In our systematic review, similar union rates were seen with VBG regardless of nonunion location. Clinically, patients with isolated proximal pole nonunions had a significantly lower postoperative MMWS, whereas all other patient-centered outcomes were similar when compared with VBG in all regions of the scaphoid. The significantly lower MMWS should be interpreted with caution as the clinical significance is unclear and both groups had “good” postoperative scores.

Table 3 Clinical and radiographic outcomes of vascularized bone grafting: subgroup analysis

	Proximal	All regions	p-Value	Pedicated	Free	p-Value	K-wire	Screw	p-Value	Primary	Revision	p-Value
Mayo	76.43 (2.56)	87.62 (1.14)	0.02	85.67 (2.11)	82.13 (6.68)	0.64	-	-	-	-	-	-
Flexion	49.71 (3.37)	51.48 (2.69)	0.69	53.93 (2.33)	45.55 (3.30)	0.068	48.38 (3.06)	37.52 (13.04)	0.45	57.28 (3.37)	44.30 (6.97)	0.15
% Improvement	24.55 (11.53)	15.68 (7.38)	0.53	29.05 (6.55)	-17.22 (16.65)	0.03	-	-	-	23.62 (10.21)	14.87 (23.71)	0.75
Extension	51.75 (5.02)	53.66 (4)	0.77	59.87 (3.21)	42.37 (4.54)	0.009	46.30 (3.52)	47.86 (15)	0.92	60.54 (5.01)	53.82 (10.34)	0.59
% Improvement	32.02 (11.90)	18.33 (7.61)	0.75	29.44 (6.24)	-3.25 (15.85)	0.09	-	-	-	24.80 (11.02)	41.72 (25.60)	0.57
Grip strength (kg)	37.66 (5)	39.36 (1.59)	0.75	40.16 (1.53)	34.01 (3.96)	0.20	37.65 (1.84)	36.67 (9.24)	0.93	38.81 (3.04)	38.80 (6.01)	1
% Improvement	36.20 (30.76)	47.04 (10.72)	0.76	75.28 (29.26)	-26.56 (112.45)	0.43	21.64 (23.83)	97.08 (111.89)	0.67	37.82 (11.93)	63.83 (23.01)	0.44
% Contralateral	87.92 (6.06)	83.61 (2.55)	0.52	85.61 (2.50)	80.75 (6.24)	0.49	81.30 (2.40)	89.12 (7.15)	0.39	84.88 (4.08)	85.36 (9)	0.96
Time to union (wk)	14.18 (1.77)	12.60 (0.85)	0.43	12.43 (0.81)	14.28 (2.17)	0.44	11.08 (1.28)	17.83 (2.64)	0.067	12.93 (1.29)	17.45 (3.20)	0.23
% Union	85.84 (6.45)	83.44 (3.52)	0.75	82.23 (3.22)	93.33 (7.30)	0.18	95.83 (3.32)	70.60 (8.24)	0.024	91.95 (3.92)	80.30 (8.61)	0.25
% Return to function	73.43 (10.76)	90.18 (2.76)	0.17	87.38 (3.24)	96.08 (10.60)	0.46	91.59 (6.24)	76.10 (32.46)	0.69	92.13 (4.17)	78.73 (8.71)	0.25

Note: Numbers in table are adjusted mean and standard error of mean. Patient outcomes compared by study factors using weighted analysis of covariance, with number of subjects studied the weighting factor; analyses were adjusted for mean age, percentage male patients, and percent prior surgery (except for the comparison of primary versus revision, which was adjusted only for mean age and percentage male patients).

Table 4 Overall complications of vascularized bone grafting for scaphoid nonunion

Complication	Number of patients
Failure of fixation	14 (1.7%)
Superficial infection	10 (1.2%)
Nerve dysesthesia	7 (0.9%)
Failed anastomosis	5 (0.6%)
Complex regional pain syndrome	4 (0.5%)
Prominent hardware	4 (0.5%)
Pin tract infection	2 (0.2%)
Styloid protrusion	1 (0.1%)
Hematoma	1 (0.1%)
Total complications	48 (5.9%)

Across all 43 studies in our review, a wide variety of both pedicled and free VBGs were used to treat scaphoid nonunion. Pedicled VBG demonstrated improved ROM outcomes post-operatively, but the remaining clinical, radiographic, and patient-centered outcomes were similar across both the surgical techniques. The 93% union rate seen with free VBG in this study is consistent with previously published systematic reviews.²¹ Free VBG offers benefits over pedicled VBG, such as increased maneuverability and increased vascular supply, secondary to larger diameter arterial vessels; however, the clinical significance remains largely unknown. Our study demonstrated an 11% higher union rate with free VBG, but this was not of statistical significance. Jones et al demonstrated similar, but statistically significant, faster, and higher rates of union in free versus pedicled grafts.²² In settings where pedicle length or disruption of distal forearm osteocutaneous structures may limit ideal positioning or harvesting of the pedicled graft, a free graft, although technically more challenging, may be a more suitable graft choice and can be implemented with the expectation of similar postoperative outcomes when compared with pedicled VBG. Free VBG may also be used when osteocartilaginous grafts are needed to recreate the radioscaphoid joint.

In NVBG, the ideal technique to secure the graft has been debated with numerous studies demonstrating higher union rates and superior biomechanical outcomes with compression screws compared with K-wires.^{10,23} However, in VBG, superior interfragmentary compression seen with screw fixation may not be necessary. The larger diameter of these compression screws may disrupt the vascular inflow to the area of nonunion, thus prolonging time to union in comparison to narrower diameter K-wires. Our study lends evidence to this theory as K-wire fixation of VBG resulted in higher union rates by 25% and trended toward faster union times by 7 weeks. To our knowledge, this is the first study demonstrating improved results with K-wire fixation for VBG. Pinder et al assessed K-wire versus screw fixation in a systematic review of bone grafting for scaphoid nonunion and demonstrated a trend toward higher union rates with K-wire fixation in VBG.

Contrastingly, Chang et al demonstrated an 88% union rate with screw fixation and a 53% union rate with K-wire fixation after VBG for scaphoid nonunion; however, in the setting of AVN, there was no difference in union rate based on fixation choice.^{20,24} Ultimately, the location of the fracture, presence of AVN, surgical technique, time of K-wire removal, and time to mobilization are going to have significant influences on union rates aside from fixation choice and must be controlled for to truly assess superiority of fixation choice.

The progression of scaphoid nonunion to SNAC can have detrimental effects on patients' overall functionality. In our review, 68% of studies included patients with persistent nonunion who underwent VBG as a revision procedure in an attempt to prevent progression to SNAC or radiocarpal arthrosis. Previous studies have demonstrated mixed radiographic and clinical results when assessing revision procedures for scaphoid nonunion.^{25,26} This systematic review demonstrates that VBG as a revision procedure has similar outcomes across all metrics when compared with VBG done as a primary surgical intervention. This should lend confidence to providers who elect to pursue NVBG as a primary procedure because, if unsuccessful, VBG is a feasible revision procedure. However, VBG as a primary procedure for scaphoid nonunion may avoid the increased morbidity of a revision procedure after failed union following NVBG. Further prospective studies that control for patient characteristics are needed comparing the two techniques.

The overall complication rate demonstrated in this study was low, with most complications being minor, not necessitating further surgery. The complications seen in this study are some of the same complications that could be predicted in any surgical procedure, including NVBG such as infection, and pain, whether nerve-related or not.²⁰ It was not possible to statistically quantify the direct effect of complications on patients' outcomes as complications were largely qualitatively reported and anecdotal. Additionally, some studies reported multiple complications for a given patient from which we were unable to identify the true complication rate in these studies and therefore our overall complication rate may be slightly underestimated.

Although our study demonstrates favorable clinical, radiographic, and patient-centered outcomes following VBG for scaphoid nonunion, there are several limitations. First, the studies comprising our review were primarily retrospective, nonrandomized, and uncontrolled designs, thus prone to selection and publication bias. Second, it was difficult to control for confounding factors given most studies reported outcomes for their entire cohort. The ability to stratify the results by specific fracture characteristics, patient comorbidities, and postoperative protocols would have strengthened our results and possibly controlled for the high variation in union rates. Additionally, it was not possible to perform a true meta-analysis to calculate outcome effects for the individual treatment factors analyzed in our study because estimates of the variability of these outcomes were not available or derivable from the included studies. Our study would have been strengthened by controlling for AVN; however, this was not possible given that the definition of AVN varied widely by

study with some relying on preoperative imaging and others relying on the absence of punctate bleeding intraoperatively. The majority of studies in this review included patients both with and without AVN but did not perform a subgroup analysis comparing outcomes between these two patient groups. Lastly, the definition of union was inconsistent across studies, and some studies used computed tomography whereas others used plain radiography to confirm union.

VBG serves as a viable option for the treatment of scaphoid nonunion, with reliable and consistent union rates in addition to significantly improved postoperative patient functionality. Both pedicled and free VBG may be of particular utility in patients with proximal pole nonunion, regardless if done as a primary or revision procedure. Lastly, radiographic outcomes may be improved with K-wire fixation, potentially minimizing disruption to the vascular supply. Further prospective studies with patient-centered outcomes and well-defined parameters for AVN and radiographic union comparing NVBG to VBG and free versus pedicled VBG are still needed. These future studies should consider reporting preoperative patient and fracture characteristics, as well as postoperative outcomes on an individual patient basis to facilitate future systematic reviews or meta-analysis.

Funding

Research reported in this publication was partially supported by the National Center for Advancing Translational Sciences of the National Institutes of Health under Award Number UL1TR00013.

Conflict of Interest

None.

Acknowledgment

The authors acknowledge the support of Southern California Clinical and Translational Science Institute.

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