Treatment of Scaphoid Waist Nonunions with an Avascular Proximal Pole and Carpal Collapse. A Comparison of Two Vascularized Bone Grafts

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Treatment of Scaphoid Waist Nonunions with an Avascular Proximal Pole and Carpal Collapse
A Comparison of Two Vascularized Bone Grafts

By David B. Jones Jr., MD, Heinz Bürger, MD, Allen T. Bishop, MD, and Alexander Y. Shin, MD

Investigation performed at the Mayo Clinic, Rochester, Minnesota, and Landeskrankenhaus Klagenfurt, Klagenfurt, Austria

Background: Surgically, it is difficult to achieve union of a scaphoid nonunion that is associated with osteonecrosis of the proximal pole, and those with carpal collapse are especially difficult to treat. A variety of vascularized bone grafts can be used. The purpose of this study was to compare the effectiveness of two types of vascularized bone graft—a distal radial pedicle graft and a free vascularized medial femoral condyle graft—in the treatment of scaphoid waist nonunions associated with proximal pole osteonecrosis and carpal collapse.

Methods: A retrospective review was conducted at two institutions to identify all patients with a scaphoid waist nonunion associated with an avascular proximal pole and carpal collapse. Between January 1994 and June 2006, twenty-two such nonunions were identified in twenty-two patients. Ten were treated with a distal radial pedicle vascularized graft and twelve, with a free vascularized medial femoral condyle graft. Patient demographics were similar between the groups, and the duration of follow-up averaged twelve months. Union was determined with use of plain radiographs and computed tomography or trispiral tomograms. In addition, carpal angles, time to union, union rates, and complications were recorded.

Results: Four of the ten nonunions treated with the distal radial pedicle graft healed, at a median of nineteen weeks, and all twelve nonunions treated with the free medial femoral condyle graft healed, at a median of thirteen weeks. The rate of union was significantly higher (p = 0.005) and the median time to healing was significantly shorter (p < 0.001) for the nonunions treated with the medial femoral condyle graft.

Conclusions: A vascularized interposition graft from the medial femoral condyle is the recommended vascularized bone graft for the surgical treatment of scaphoid waist nonunion with avascularity of the proximal pole and carpal collapse.

Level of Evidence: Therapeutic Level III. See Instructions to Authors for a complete description of levels of evidence.

An estimated 34,000 acute scaphoid fractures go on to nonunion each year in the United States¹, and 5% to 15% of all acute scaphoid fractures fail to unite². While many of the nonunions are initially asymptomatic³, they frequently become painful over time. Natural history studies of symptomatic nonunions have demonstrated a uniform progression of degenerative carpal arthritis, the severity of which is proportional to the duration of the nonunion⁴⁻⁶. Risk factors for scaphoid nonunion include absent or delayed cast immobilization, fracture displacement, proximal location, osteonecrosis, and associated carpal instability⁷⁻⁹.

Various surgical techniques have been proposed to improve union rates¹⁰. A recent meta-analysis demonstrated a union rate of only 47% in the presence of avascularity of the proximal pole¹¹. Use of vascularized bone grafts has been associated with an 87% rate of union in similar circumstances¹². Thus, vascularized bone grafts have been recommended for the treatment of scaphoid nonunions associated with proximal pole osteonecrosis.

The use of a distal radial graft based on a 1,2 intercompartmental supratellar artery pedicle in the treatment of scaphoid nonunions associated with osteonecrosis has been reported to be successful in terms of achieving union and...
alleviating symptoms. While several studies have demonstrated high rates of union, we recently reported an overall union rate of 71% for scaphoid nonunions and a rate of 50% in the setting of osteonecrosis. Nine of the fourteen failures had evidence of dorsal intercalated segment instability and/or a humpback deformity. The high rate of failure in patients with carpal collapse was the result of a failure to restore normal scaphoid geometry, suggesting the need to modify the technique or use an alternative method. In nearly all other reports on pedicled vascularized bone grafts, the grafts were used only for nondisplaced or minimally displaced scaphoid nonunions or for nonunions with minimal structural collapse.

The use of a free vascularized medial femoral condyle bone graft was first described by Doi et al., who reported successful union in all of ten patients at an average of twelve weeks after the surgery. The technique that Doi et al. described involved use of the medial femoral condyle as a cortico-periosteal inlay graft with the descending genicular vessels anastomosed to the radial artery and venae comitantes. A modification of this technique that allows harvest of a corticocancellous structural graft in addition to maintaining the vascular supply for use in the treatment of scaphoid nonunions has been described.

The treatment of scaphoid waist nonunions combined with an avascular proximal pole and carpal collapse has not been thoroughly addressed in the literature. Typically, this subset of scaphoid nonunions has been included with other types of scaphoid nonunions, and it is therefore difficult to determine the results of their treatment from the literature. The purpose of the present study was to evaluate the outcomes in a series of scaphoid waist nonunions with an avascular proximal pole and carpal collapse to determine whether treatment with a distal radial graft based on a 1,2 intercompartmental supraretinacular artery pedicle or treatment with a free vascularized medial femoral condyle graft is more effective.

Materials and Methods

Following institutional review board approval, a retrospective review was conducted of the medical records of patients at two institutions (Mayo Clinic, Rochester, Minnesota, and Landeskrankenhaus Klagenfurt, Klagenfurt, Austria). A diagnosis of scaphoid waist nonunion with proximal pole osteonecrosis and carpal collapse (Figs. 1-A through 1-D) treated with either a distal radial bone graft based on a 1,2 intercompartmental supraretinacular artery pedicle or a free vascularized medial femoral condyle graft was necessary for inclusion in this study. The diagnosis of osteonecrosis was determined on the basis of preoperative radiographic findings, including loss of trabecular structure, collapse of subchondral bone, formation of bone cysts, and decreased uptake on gadolinium-enhanced magnetic resonance imaging. The diagnosis was ultimately confirmed at the time of surgery by a finding of white, sclerotic bone with absent punctate bleeding on tourniquet release. Carpal collapse, as evidenced by a scaphoid humpback deformity or dorsal intercalated segment instability deformity secondary to the nonunion, was defined as a revised carpal height ratio of ≤1.52 (normal, 1.57 ± 0.05), a lateral intrascaphoid angle of ≥45° (normal, ≤35°), or a radialunate angle of ≥15° (normal, ≤10°). Scaphoids without evidence of both osteonecrosis and carpal collapse or those treated with a different procedure were excluded. Between January 1994 and June 2006, twenty-two patients who met these criteria were identified. Medical records and radiographs were reviewed. Patient demographics, including age, sex, smoking status, and prior treatment, were recorded. Preoperative and postoperative radiographic measurements of carpal angles (lateral intrascaphoid, radiolunate, and scapholunate angles) and revised carpal height ratios were obtained. Operative details, including the type of graft, type of fixation, time to union, complications, and subsequent surgery, were also recorded.

Demographics

Three women and nineteen men with a total of twenty-two scaphoid waist nonunions associated with an avascular proximal pole and carpal collapse were followed until union or treatment failure. The minimum duration of follow-up was twelve months, and the maximum was fifty months. The average age of the patients was twenty-seven years (range, eighteen to sixty-six years). Treatment failure was defined as evidence of nonunion on computed tomography scans accompanied by persistent symptoms. Nine of the twenty-two patients reported smoking tobacco. Ten of the fractures occurred in the dominant hand. Ten of the patients had had prior surgical treatment, and eight of them still had a screw in place in the scaphoid when they presented for evaluation. The prior surgical treatment was open reduction with internal screw fixation in three patients, use of a nonvascularized iliac-crest wedge graft and screw fixation in four, use of a dorsal nonvascularized radial bone graft with screw fixation in one and with Kirschner wire fixation in one, and cancellous bone-grafting with Kirschner wire fixation in one. The duration of nonunion was known for twenty patients, for whom the median time to surgery was twenty-four months (range, six to sixty-six months).

Preoperative Assessment

Patients generally presented with a limited range of motion, pain at the extremes of motion or with exertion, and tenderness at the anatomic snuffbox. Preoperative evaluation included imaging (Figs. 1-A through 1-D) with plain radiographs as well as trispiral tomograms or computed tomography and/or magnetic resonance imaging with gadolinium (see Appendix). The range of motion and grip strength were measured preoperatively and postoperatively.

Surgical Procedures

Ten scaphoid nonunions were treated with a vascularized distal radial bone graft based on a 1,2 intercompartmental supraretinacular artery pedicle as described by two of us (A.T.B. and A.Y.S.) and colleagues (Figs. 2-A and 2-B). Four of these
Figs. 1-A through 1-D Images of a scaphoid waist nonunion with carpal collapse and osteonecrosis of the proximal pole. Figs. 1-A and 1-B Lateral (Fig. 1-A) and posteroanterior (Fig. 1-B) radiographs.

Lateral (Fig. 1-C) and coronal (Fig. 1-D) computed tomography scans.
patients had a radial styloidectomy in addition to the bone-grafting to treat early degenerative changes (i.e., beaking of the radial styloid process). The other six patients had no evidence of degenerative changes at the time of surgery.

Twelve scaphoid nonunions were treated with a free vascularized medial femoral condyle bone graft to achieve osseous union and simultaneously correct scaphoid length and vascularity as described by one of us (A.Y.S.) and by Larson et al. (Figs. 3-A, 3-B, and 3-C). The pedicle for this flap, which has been described, included the descending genicular artery or the superomedial genicular artery when the descending genicular artery was not present. The descending genicular artery and vein were used in ten patients, and the superomedial genicular artery was used in two.

A volar approach to the scaphoid was used for the medial femoral condyle graft procedures, and a dorsoradial exposure was used for the distal radial pedicle graft procedures. The scaphoid was inspected, and the nonunion was
identified and débrided. Carpal alignment was temporarily restored by flexion of the wrist and placement of a radio-lunate Kirschner wire when the lunate was collinear with the radius on a lateral fluoroscopic image. The wrist was then extended, which resulted in separation of the scaphoid nonunion gap. The proximal and distal edges of the nonunion were prepared with a sagittal saw or curets, and the dimensions of the defect were measured. The proximal pole was evaluated, and its vascularity was determined. White and sclerotic bone with the absence of punctate bleeding when the tourniquet was released was considered the final and ultimate evidence of osteonecrosis. The bone grafts were placed to span the nonunion site. The distal radial graft was placed dorsally as an inlay or wedge graft spanning the nonunion site, and the medial femoral condyle graft was placed volarly as a wedge graft.

**Type of Fixation**

Seven nonunions treated with the medial femoral condyle graft were stabilized with a cannulated scaphoid screw; four, with Kirschner wires; and one, with both a screw and Kirschner wires. Seven fractures treated with the distal radial pedicle graft were stabilized with Kirschner wires and three, with both a screw and Kirschner wires. Although the choice of
fixation was based on fragment size and stability at the time of the surgery, an attempt was made to achieve screw fixation in each case.

Radiographic Evaluation
All preoperative and postoperative radiographs, including computed tomography scans, trispiral tomograms, and magnetic resonance imaging scans, were reviewed. Union was defined as bridging trabeculae consolidating the majority of both the proximal and the distal interface as seen on plain radiographs and a computed tomography scan or trispiral tomogram accompanied by the absence of adverse features such as a gap at the graft interface or a shift of the graft. Preoperative and postoperative radiographic measures were analyzed with use of paired t tests. Since there were so few postoperative complications, these were summarized only descriptively; no formal comparisons were performed. All statistical tests were two-sided, and p ≤ 0.05 was considered significant.

Results
Distal Radial Pedicle Grafts
Ten nonunions in three women and seven men with an average age of thirty-one years (range, eighteen to sixty-six years) were treated with a distal radial graft on a 1,2 intercompartmental supraretinacular artery pedicle. Four of the patients were smokers at the time of surgery. The time from the injury to the surgery was known for eight of the patients and averaged twenty-six months (range, six to forty-eight months). Four of the patients had undergone prior surgery, and four still had a screw in place at the time of presentation. Of the ten nonunions that were treated, four united at a median of nineteen weeks (range, eleven to thirty weeks). Three of the seven grafts secured with Kirschner wire alone united, and one of three grafts secured with both a screw and Kirschner wire united. There were six failures. In one case, a deep postoperative infection developed and required incision and drainage and intravenous antibiotics. The screw backed out in another, requiring removal of the screw with simultaneous anterior and posterior interosseus neurectomy for pain control. The remaining four failures had no clear cause. Two of those failures were treated with subsequent salvage surgery, including a proximal row carpectomy in one and scaphoid excision combined with a four-corner arthrodesis in the other. The postoperative range of motion of the wrists in which the scaphoid failed to unite was 36° of flexion and 26° of extension. The grip strength of the affected hand of the patients who had a failure averaged 61% of that of the unaffected hand.

Fig. 3-C
The bone graft is inserted volarly and is placed as a wedge graft in the scaphoid nonunion site. Screw fixation is preferred, but occasionally Kirschner wires are used if the bone fragments are too small. An end-to-side anastomosis of the genicular artery to the radial artery and an end-to-end anastomosis of the vein to one of the venae comitantes are performed.

Comparison of preoperative and postoperative radiographs demonstrated no significant change in the revised carpal height ratio or the carpal angles (see Appendix). The postoperative range of motion of the wrists in which the scaphoid united averaged 38° of flexion and 47° of extension. The grip strength of the affected hand of the patients who had the change in carpal parameters, as the screw artificially held the nonunion in a partially corrected position.

Statistical Methods
The primary analysis outcome was the rate of successful fracture union among the twenty-two patients in the study. Because not all patients had union and the durations of follow-up differed, this end point was analyzed as a time-to-event outcome. Specifically, the cumulative probability of scaphoid union was estimated with use of the method of Kaplan and Meier, and fractures that remained ununited at the time of data collection were censored at the time of their most recent follow-up. As a secondary analysis, the subset of patients who had scaphoid union was analyzed with two-sample t tests to evaluate the strength of the association of prior surgery or screw fixation with the time to union. Preoperative and postoperative radiographic measures were analyzed with use of paired t tests. Since there were so few postoperative complications, these were summarized only descriptively; no formal comparisons were performed. All statistical tests were two-sided, and p ≤ 0.05 was considered significant.
union averaged 68% of that of the unaffected hand (40 and 59 kg, respectively).

**Free Vascularized Medial Femoral Condyle Graft**

Twelve men with an average age of twenty-three years (range, eighteen to thirty-two years) were treated with a medial femoral condyle graft (Figs. 4-A and 4-B). Five of the patients were smokers at the time of surgery. The time from the injury to the surgery was known for all of the patients, and it averaged thirty-one months (range, nine to sixty-six months). Six of the patients had undergone previous surgery, and four still had a screw in place at the time of presentation. All twelve nonunions united, at a median of thirteen weeks after the surgery (Figs. 5-A and 5-B). Seven grafts were secured with screw fixation alone; four, with Kirschner wire alone; and one, with both a screw and Kirschner wire.

Comparison of preoperative and postoperative radiographs demonstrated marked improvement, with an average decrease in the lateral intrascaphoid angle of 25° (from 57° preoperatively to 32° postoperatively; p < 0.001), an average decrease in the scapholunate angle of 13° (from 70° to 57°; p = 0.05), and an average decrease in the radiolunate angle of 5° (from 15° to 10°; p = 0.03). The average revised carpal height ratio increased from 1.49 preoperatively to 1.51 postoperatively; however, this change was not significant (p = 0.24). The postoperative range of motion averaged 42° of flexion and 40° of extension. The grip strength of the affected hand averaged 86% of that of the unaffected hand (44 and 51 kg, respectively).

All patients reported knee pain at the site of the medial femoral condyle. This resolved by an average of six weeks (range, four to seven weeks) postoperatively. There were no other donor-site-related complications.

**Comparative Analysis**

Kaplan-Meier analysis demonstrated that the median time to union after treatment with the medial femoral condyle graft (thirteen weeks) was significantly shorter than that after treatment with the distal radial pedicle graft (nineteen weeks) (p < 0.001). Analysis of the postoperative radiographic parameters demonstrated a significantly smaller average lateral intrascaphoid angle in the group treated with the medial femoral condyle graft compared with the group treated with the distal radial pedicle graft (32° and 48°, respectively; p = 0.003). Differences in postoperative revised carpal height indices, scapholunate angles, and radiolunate angles between the groups did not reach significance. A post hoc power analysis demonstrated an 80% power to detect differences in means between the groups of at least 0.07 for the carpal height ratio, 19.1° for the scapholunate angle, and 12.3° for the radiolunate angle. An analysis of potential risk factors for failure did not demonstrate a significant difference between nonunions treated with a screw and those treated with Kirschner wire (p = 0.62). However, only two of thirteen nonunions treated with a screw failed, whereas four of eleven treated with a Kirschner wire alone failed. There was also no significant difference in the risk of failure between patients with and those without previous surgery (p = 0.65). A post hoc power analysis demonstrated an 80% power to detect a hazard ratio of at least 3.76 for the comparison of screw and Kirschner wire fixation and 3.75 for the comparison of prior surgical treatment and no prior surgery.
Discussion

In a meta-analysis of the literature, vascularized bone-grafting of scaphoid nonunions with osteonecrosis was found to be associated with a union rate of 88% compared with 47% in association with conventional (nonvascularized) grafting. However, vascularized grafts do not uniformly yield the desired outcome. In 1998, Boyer et al. observed union in six of ten patients treated with a distal radial graft based on a 1,2 intercompartmental supraretinacular artery pedicle. In that series, the four persistent nonunions had all been previously treated with a nonvascularized graft, which had failed. It was suggested that previous surgery may be a predictor of a poor outcome. In 2002, Straw et al. reported a union rate of 27% after the use of vascularized distal radial grafts based on a 1,2 intercompartmental supraretinacular artery pedicle. In that series, sixteen of the twenty-two nonunions were associated with avascularity of the proximal pole and only two of those went on to union. Neither group of authors commented on the presence or absence of scaphoid deformity or carpal collapse.

Henry reported that use of a graft based on a 1,2 intercompartmental supraretinacular artery pedicle was successful in the treatment of scaphoid collapse and osteonecrosis. In that series, the graft was placed volarly as a wedge graft and all fifteen scaphoids united. We recently reported an overall union rate of 71% after treatment of scaphoid nonunions with a graft based on a 1,2 intercompartmental supraretinacular artery pedicle. A detailed analysis of the failures demonstrated the presence of dorsal intercalated segmental instability (or humpback) deformity in nine of fourteen cases with nonunion. It was hypothesized that the failure of the graft to correct humpback deformity may have contributed to the failure.

Several other pedicled vascularized grafts have been described for the treatment of persistent scaphoid nonunion. Use of a vascularized graft from the volar and ulnar aspect of the distal part of the radius supplied by the palmar carpal artery has been reported to result in excellent rates of union. This graft was initially described as an inlay graft for the treatment of nonunions without carpal collapse; its use for scaphoid waist nonunions with an avascular proximal pole and carpal collapse has not been reported, to our knowledge. Dailiana et al. modified this graft, shaping it into a trapezoidal wedge to provide structural support. However, carpal collapse was not present in association with any of the nine nonunions in this series, and only one nonunion was associated with osteonecrosis of the proximal pole. Bertelli et al. described a graft from the thumb that was pedicled on the first dorsal metacarpal artery. While they did not comment on the presence or absence of osteonecrosis in that series, six of the ten scaphoids had dorsal intercalated segment instability deformity and nine went on to union.

Other vascularized grafts that provide structural support in addition to a vascular supply to the scaphoid have been...
described. In a canine study, Hori et al. initially described the angiogenesis of autogenous bone when a bundle consisting of an artery, venae comitantes, and perivascular tissue was implanted into it. Fernandez and Eggli reported that ten of eleven nonunions associated with osteonecrosis of the proximal pole united at an average of ten weeks after treatment with an inlay corticocancellous wedge graft from the iliac crest accompanied by implantation of the second dorsal intermetacarpal arteriovenous pedicle. Eight of the nonunions were in the proximal one-third of the scaphoid, and three were at the waist. Only one of the wrists had dorsal intercalated segment instability deformity. The remaining wrists had normal carpal angles. Additionally, only three patients were treated with a structural iliac crest graft and screw fixation while the remainder were treated with an inlay graft and Kirschner wire.

Free vascularized iliac-crest wedge grafts have also been described. In 2001, Harpf et al. reported on sixty scaphoid nonunions (twenty-six with an avascular proximal pole) treated with this technique. The authors found an overall union rate of 91.7%. The union rate for the nonunions associated with an avascular proximal pole was 90%; however, it should be noted that none of these wrists had carpal collapse or humpback deformity and all grafts were used as an inlay graft. Donor site morbidity was high, with a 55% prevalence of hyperostosis of the iliac crest, an 8.3% prevalence of deformity of the iliac crest, and a 31.7% prevalence of nerve hypoesthesia.

In 2000, Doi et al. described the treatment of ten scaphoid nonunions with a free vascularized medial femoral condyle inlay graft. All ten united, at an average of twelve weeks after the surgery, and the scapholunate angle improved by an average of 6° (from 58° preoperatively to 52° postoperatively). The duration of follow-up averaged 3.5 years, and no patient had long-term morbidity at the donor site. In the present study, all twelve scaphoids treated with a free vascularized medial femoral condyle graft united, at a median of thirteen weeks after the surgery. The average correction of the scapholunate angle was 13° (from 70° preoperatively to 57° postoperatively). Donor site morbidity was minimal, with an average duration of knee discomfort of six weeks without loss of motion.

This study has several limitations; it was retrospective, and there were multiple surgeons and relatively small numbers of patients in each treatment group. The relative rarity of the combination of scaphoid waist nonunion with an avascular proximal pole and carpal collapse (humpback deformity) makes a comparison of multiple techniques challenging. These limitations notwithstanding, we demonstrated that the rate of union of scaphoid waist nonunions associated with osteonecrosis and carpal collapse is higher with the use of a medial femoral condyle graft, which provides both a vascular supply and correction of the scaphoid deformity, than it is with a distal radial graft based on a 1,2 intercompartmental supra-rotarincular artery pedicle. The vascularized pedicled distal radial bone graft was not sufficient to maintain carpal alignment and was associated with an unacceptably high failure rate when used to treat nonunions with both osteonecrosis and carpal collapse. The optimal vascularized bone graft is one that has structural integrity as well as a robust blood supply and can be harvested with minimal donor site morbidity. The vascularized medial femoral condyle bone graft has become the vascularized bone graft of choice for our patients with scaphoid waist nonunion associated with carpal collapse (humpback deformity) and osteonecrosis of the proximal pole.

Appendix

Tables showing demographics and detailed results for all patients are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on “Supplementary Material”) and on our quarterly CD/DVD (call our subscription department, at 781-449-9780, to order the CD or DVD).

References


