The Vascularity and Osteogenesis of a Vascularized Flap for the Treatment of Scaphoid Nonunion: The Pedicle Volar Distal Radial Periosteal Flap

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Abstract

Background: Vascularized periosteal flaps from the distal radius have been previously proposed. The purpose of this study was to investigate the vascularity and osteogenic potential of a vascularized volar distal radial periosteal flap for the treatment of scaphoid nonunion. **Methods:** In 5 fresh frozen cadavers, a rectangular periosteal flap was elevated from the distal radius with the pedicle just proximal to the watershed line. Latex dye was injected into the radial artery proximally and the vascularity of the flap characterized by microscopic evaluation. Patients with scaphoid nonunion were then treated with open reduction, internal fixation, and distal radius cancellous bone graft. Two groups of patients with midwaist nonunion scaphoid were then evaluated. The first group received the vascularized periosteal flap and the second group received a nonvascularized periosteal flap. A third group of proximal pole nonunions also received the vascularized flap. **Results:** Cadaveric dissections revealed that all of the injected flaps demonstrated vascularity to the distal edge of the flap. Vascularized flaps formed visible bone on imaging in 55% of cases. None of the nonvascularized flaps formed visible bone. In group 1, 12/12 midwaist nonunions united. In group 2, union was achieved in 6/6 of patients who completed the follow-up. In group 3, 6/7 proximal pole fractures united. **Conclusions:** Previously proposed vascularized periosteal flaps from the distal radius appear to possess notable osteogenic potential that may be of interest to surgeons treating scaphoid nonunion.

Keywords: scaphoid nonunion, vascular periosteal flap

Introduction

Duhamel, in 1745, was likely the first to propose that the periosteum is a powerful source of osteogenesis.¹⁹ Early in the 20th century, landmark animal studies demonstrated that the cambium layer of the periosteum could promote revascularization of necrotic bone segments.^{9,18} Finley et al found that nonvascular periosteal flaps applied to necrotic bone resorbed, whereas those periosteal flaps that were revascularized by microvascular means formed bone.¹³ Dailiana et al studied potential periosteal flaps about the distal radius but did not describe the details regarding vascular limitations of flap dimensions.⁷

A variety of vascularized bone grafts (VBGs) have been described that potentially can enhance the healing of ununited scaphoid fractures.^{8,12,15–17,20–24,27–29,31,33–35,42,43} The end point measured in these studies has been the presence or absence of scaphoid healing, which is the clinical goal. However, these studies do not definitively answer the

question of whether the vascularized flap itself actually generated bone. Other factors such as debriding the fracture surfaces, the internal fixation technique, cancellous or cortical bone graft, and the immobilization method also appear to play a role in achieving scaphoid union and make it difficult to isolate the true osteogenic effect of the VBG.

Interest in the volar periosteum of the radius was driven in part by the apparent robust osteogenic nature of the distal radius. Acute distal radius fractures rarely fail to unite with

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a reported 0.2% nonunion rate.¹ In addition, both dorsal and volar distal radial osteotomies for distal radial malunion have been shown to readily unite despite large gaps between the proximal and distal fragment, even without the addition of bone graft or bone graft substitutes.^{37,38} Thus, the metaphyseal bone of the distal radius and its periosteum appear to possess significant osteogenic potential.

Because of the known osteogenic nature of the cambium layer of the periosteum, the prior description of a potential volar distal radial vascularized periosteal flap,⁴ and the apparent excellent osteogenic nature of the distal radius, the vascularity and osteogenic potential of a volar distal radial periosteal flap was studied. The null hypothesis for this study was that a distally based, volar radius periosteal flap would have poor vascular supply and would exhibit no bone formation.

Materials and Methods

Cadaveric Study

An incision was made in line with the flexor carpi radialis (FCR) beginning 7 cm proximal to the distal wrist crease and extending to the distal wrist crease. The FCR and the flexor pollicis longus (FPL) were retracted ulnarly, and the pronator quadratus was lifted off the distal radius in an extraperiosteal manner.

The dimensions of the flap were 2 cm in width and 4 cm in length. The base of the flap was just proximal to the watershed line of the distal radius. The lengths of the flap were scored with a 15 blade creating 2 parallel lines 2 cm apart in the periosteum proximal to the watershed line. A third score in the periosteum was made connecting the parallel lines 4 cm proximal to the watershed line. The transverse radial artery was left undisturbed. The periosteal flap was elevated from proximal to distal off the distal radius and the flap was turned distally on its pedicle. Gauze sponges were placed around the periosteal flap so that it did not contact surrounding tissues during the injection of the dye. The radial artery was exposed in the proximal third of the forearm and cannulated. A 10-mL saline flush was performed followed by the introduction of 10 mL of colored latex. After a 10-minute exposure, interval each flap was harvested by dividing it at its base. Each flap was then placed into the subcutaneous tissue on the proximal ulna side of the forearm distant from any dye contamination to allow the dye to harden in the vessels. Each flap was evaluated 48 hours later under an operating microscopic and 4-power loupe magnification for the presence and distribution of vessels.

Surgical Technique

The same 7-cm incision as described above in line with the FCR was utilized and extended distally toward the thumb

carpometacarpal joint. The FCR and the FPL were retracted ulnarly, and the pronator quadratus was lifted off the distal radius in an extraperiosteal manner. The volar capsule of the wrist was divided in line with the axis of the scaphoid and the nonunion assessed.

In group 1 (n = 12) midwaist nonunions, a .062 Kirschner wire (K-wire) was inserted from the radial styloid into the lunate to keep the lunate in neutral flexion to correct any humpback deformity. The nonunion site was debrided to fresh cancellous bone, and a transtrapezial guide wire was placed from distal to proximal across the nonunion site. As the K-wire was advanced proximally and became visible in the nonunion site, a looped 3-0 wire suture was placed around the guide wire and the guide wire was further driven into the proximal fragment under fluoroscopic control. This wire suture was then used as a passing suture to shuttle a 3-0 Vicryl suture around the K-wire for later use in securing the periosteal flap to the nonunion site.

The periosteal flap was lifted off the distal radius as described above using a key elevator, and the flap was turned distally.

A 7-mm coring reamer was then used to drill a hole in the volar radius and a core of cancellous graft obtained. A rongeur was then used to harvest more cancellous graft from the distal radius and subsequently the distal radius donor site was filled with a bone graft substitute. The cancellous graft was packed into the nonunion site which pushed the Vicryl suture toward the dorsal margin of the nonunion site. This was followed by the placement of a variable pitch screw centrally in the scaphoid from distal to proximal.

The flap of periosteum was then rotated 180° on its long axis so that the cambium layer of the flap faced dorsally (Figures 1a-1c) allowing it to be applied to the nonunion site. The Vicryl suture was passed through the flap securing the cambium layer to the nonunion site in a manner so that there was no tension in the flap with wrist extension.

In group 2 (n = 7), the same procedure was done except a rectangle of periosteum was sewn to the nonunion without an attached pedicle (Supplemental Figures 1a and 1b).

In group 3 (n = 7), the proximal pole nonunions, the procedure was the same using the vascularized periosteal flap except the screw was driven from proximal-dorsal to distal-volar to capture the proximal pole.

Given the evidence for the improved efficacy of vascular grafts for proximal pole nonunions,^{3,15,20-22,28,33,34,42} there was no nonvascular control group for group 3. This did however add to the number of periosteal flaps that could be evaluated for bone formation.

Blood flow from the tip of the periosteal flap was not reliably seen after the tourniquet was released in most cases.

All patients were followed up with radiographs and computed tomographic (CT) scans as required to assess bone formation that could be attributed to the flap as well as to

Figure 1. (a) Illustration of a vascularized volar periosteal flap: Pedicle at watershed line. Dimensions shown. (b) Lateral projection demonstrating that the cambium layer of the periosteum is placed against the scaphoid by turning the flap 180° on its base. (c) Intraoperative photograph of the volar distal radial periosteal flap raised on its distal pedicle. The undersurface of the flap shows the appearance of the cambium layer of the periosteum.

assess the scaphoid for osseous union. Two hand fellowship trained orthopedic surgeons and 1 senior orthopedic resident reviewed the films. Consensus of all 3 was required to declare that there was evidence of bone formation within the flap as well as the presence or absence of scaphoid union. A retrospective analysis of a consecutive case series

was performed once institutional review board approval was received from University of California, San Francisco (#15-15943). All 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 2008.

Figure 2. Photomicrograph of the vascularity of the raised periosteal flap following latex dye injection into the radial artery. Cambium layer shown.

Figure 3. Twenty-year-old male, posterior-anterior radiograph 3 months postoperative.

Results

Cadaver Injection Results

All 5 periosteal flaps demonstrated 3 to 5 visible latex filled vessels at the distal free margin of the raised flap. Two of the 5 demonstrated a vessel measuring greater than 1 mm. In all of the flaps, the vascularity was greatest at the base near the watershed line of the distal radius (Figure 2).

Clinical Cases

Three independent reviewers, the primary surgeon and 2 senior orthopedic residents, evaluated the patient's imaging, either plain films, a CT scan, or both, for bony union.

Figure 4. Twenty-year-old male, lateral radiograph 3 months postoperative.

union was defined as absence of radiolucencies at the previous fracture site and bridging trabeculation on orthogonal views. Radiographic evidence for bone formation in the vascularized periosteal flaps was noted in 55% of cases. Group 1 patients with midwaist nonunions demonstrated visible bone formation in the flap in 40% of cases, and union was achieved in 100% of cases at an average of 15 weeks. At an average of 16 weeks, group 3 patients with proximal pole nonunions demonstrated bone formation in the flap in 83% of cases, and union was achieved in 83%. This includes 3 patients with documented avascular necrosis (AVN) of the proximal pole on preoperative magnetic resonance imaging.

In some cases where bone formation was radiographically noted, the periosteum appeared to form bone beginning as early as 4 weeks postoperatively, thereafter extended to the scaphoid by 3 months. The stability of this connection appeared to break down once range of motion was begun (Figures 3-6, Supplemental Figures 2-3). Some of the CT scans showed the periosteal bone connecting to the scaphoid at the nonunion site (Figure 7) by 6 months.

In group 2 patients, none of the nonvascular periosteal flaps formed visible bone in the region of the flap itself, and 100% union was achieved in the 6 patients who completed follow-up studies at an average of 18 weeks.

No patient lost a notable amount of range of motion, and no further surgery was required to enhance range of motion. One patient formed enough bone that it was palpable under the FCR and has expressed the desire to have the bone debrulked but that surgery has not yet been done.

Figure 5. Twenty-year-old male, posterior-anterior radiograph 11 months postoperative.

Figure 6. Twenty-year-old male, lateral radiograph 11 months postoperative.

Discussion

Previous authors have emphasized the importance of different steps in the treatment of scaphoid nonunion. These factors can be divided into fixation methods and grafting techniques. Fixation methods are thought to be important

Figure 7. Twenty-year-old male, computed tomographic scan 6 months postoperative.

because the scaphoid heals by primary bone healing. Fixation methods described include K-wires^{5,12,15,32,40,43} to maximize the cross-sectional bone area for healing and technical ease, centrally placed screws^{30,31} for maximal stability, 2 screws¹⁶ to decrease torsional instability, 1 screw and a derotation pin,³⁹ 1 screw and an external fixator to limit wrist motion to a greater degree than possible with a cast,²⁶ and a volar plate.¹¹ Graft methods that have been reported include cancellous bone chips,^{6,32,41} nonvascularized corticocancellous wedges,³⁶ vascular pedicle grafts such as the 1-2 intercompartmental graft,^{26,31,43} volar ulnar distal radial grafts,⁸ first and second metacarpal artery grafts,^{2,25,28,42} dorsal capsular grafts,³³ and free medial femoral^{12,40} and free iliac crest grafts.¹⁵

Given the wide variety of treatment options available, it is challenging to assign an incremental healing benefit to each of the possible steps in the treatment of scaphoid nonunion.

It is clear from the literature that there is a great deal of interest in vascular flaps for the treatment of scaphoid nonunion, particularly proximal pole nonunions with AVN.²⁴

To achieve the ideal combination of osteoconduction, osteoinduction, and osteogenesis, previous investigators have used either a vascularized graft with an associated wedge of cancellous bone, or a combination of nonvascular cancellous chips with a small vascular bone pedicle.¹⁷ The challenge is to demonstrate radiographically that such grafts possess osteogenic properties. Scaphoid healing has been the end point in determining success in prior studies of the

treatment of scaphoid nonunion, but this does not equate to specific radiographic evidence for osteogenesis in the vascularized pedicle graft itself.^{3,8,11,12,15,17,20,23,26,28,29,31,33,34,42,43}

Radiographic measures of bone formation have been studied in free vascular bone grafts. Periosteal driven hypertrophy in lower extremity VBGs has been variably reported,^{10,14} but does support its osteogenic nature. Osteogenesis may also be suggested by highly stressed vascularized cortical autografts that bridge nonunion fragments, when union occurs at both proximal and distal junctions and the graft does not suffer long-term collapse. These criteria are not especially helpful in scaphoid nonunions because nonvascular corticocancellous grafts have successfully bridged scaphoid nonunions without subsequent collapse.^{5,36}

Radiographic evidence of bone formation in a scaphoid nonunion may be less obvious in a typical pedicle VBG given the very small size of the bone segments that are placed in scaphoid nonunions. One measure of the osteogenic capacity of a vascularized graft for scaphoid nonunion might be radiographic evidence of bone formation isolated to the surface of the scaphoid in the region of its placement into the nonunion site. Bone formation might also be expected in the region of pedicle grafts known to have become partially or completely dislodged from the scaphoid noted on postoperative radiographs. To our knowledge, there are no reports in the literature of ectopic bone formation in either condition. In contrast, ectopic bone formation has been reported in free vascularized medial femoral flaps which restricted motion and required removal.⁴⁰ Ectopic bone was also demonstrated in 4 of 6 cases of scaphoid nonunion when bone morphogenetic protein-2 (BMP-2) was placed in the nonunion site.⁴ Thus, it seems clear that visible bone formation near a scaphoid nonunion can occur with adequate stimulation of osteogenesis.

The osteogenic capacity of the volar distal radial periosteal flap here described appears to be variable as 55% of the flaps in this study were associated with some degree of visible bone formation. Whether or not this is due to the variability with which the distal transverse carpal artery supplied the flap is not clear.

The ideal vascular flap would be one that would be simple to dissect, have sufficient pedicle length to easily reach the midwaist of the scaphoid, would be harvested from the same volar incision used to correct a humpback deformity if present, would be easily secured in the nonunion site, would allow access to the distal radius for cancellous grafting, would not require a microvascular anastomosis, would not restrict wrist motion, and could readily demonstrate actual bone formation.

The periosteal flap meets several of the ideal criteria defined above. It is easy to raise, requires no special equipment or training, and it has adequate pedicle length. The malleable periosteum is readily secured to the nonunion

site, and it is harvested through the same approach that used to correct a humpback deformity. However, despite the overall clinical success of union in this series, it seems inappropriate to attribute a majority of that success to the flap. As has been the case in many other studies of vascularized flaps, every attempt was also made to achieve adequate debridement, stable internal fixation, and good quality cancellous graft from the distal radius. In particular, this study agrees with the findings that midwaist nonunions appear to enjoy a high rate of union without vascular grafting.⁶ In this study, a reasonably high union rate was seen with proximal pole nonunions, and this is probably the best indication for this and other vascularized flaps.

The limitations of this study include the small number of patients involved. Further study of the details of the vascular supply to the flap might have the potential to improve the vascularity and the reliability of bone formation within the flap. In addition, more frequent CT scans would elucidate the details of the bone formation in the flap but are not practical given the radiation associated with the scan. And while no significant loss of wrist motion was noted, it is recognized that bone formation could restrict range of motion as has been experienced with the medial femoral graft. Close radiographic scrutiny for bone formation is recommended in future investigations into the utility of vascularized flaps for scaphoid nonunion.

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Ethical Approval

This study was approved by our institutional review board.

Statements of Human and Animal Rights

All 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 2008.

Statement of Informed Consent

Informed consent was not required from patients given that no identifying information was collected, and the study was retrospective in nature.

Declaration of Conflicting Interests

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