The use of pedicled vascularized bone graft from the dorsum of distal radius for the treatment of scaphoid nonunion

Rashed E. Rashed

Assistant Professor, Orthopaedic Surgery, Al-Azhar University, Cairo, Egypt

Correspondence to Rashed E. Rashed, MD, 6th October City, District 3, Neighborhood 4, St 30, Building 776, Cairo, Egypt
Tel: 00201001128160;
e-mail: rashedelsadek@hotmail.com

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Background
The use of vascularized bone grafts from the dorsum of the distal radius for the treatment of scaphoid nonunion. Poor reduction or neglect of an unstable carpal scaphoid fracture may lead to scaphoid nonunion with or without avascular necrosis. When preoperative suggestion of avascular necrosis of the proximal pole is confirmed with intraoperative evaluation, conventional bone graft is not enough and a vascularized bone graft is strongly recommended.

Patients and methods
From May 2011 to September 2014, 12 patients with nonunited fracture of the scaphoid were treated with pedicled vascularized bone graft from the dorsum of the distal radius using of the 1,2 intercompartmental supraretinacular artery. Presurgical and postsurgical clinical evaluation included pain, range of motion, and grip strength. Radiographic evaluation included plain radiographs and MRI. The average follow-up period was 26 months (range = 12–40 months).

Results
At a mean follow-up period of 26 months, all patients clinically improved. Nine patients (75%) reported the absence of any discomfort, two patients (16%) reported slight discomfort after hard work, and only one case (8%) reported pain with light work. The wrist range of motion improved significantly, and the hand grip strength also improved. According to the modified Mayo wrist scoring chart, clinical results were rated as excellent in eight cases, good in three cases, and fair in one case. Radiographically, in eight of the 12 patients, union was achieved within 12 weeks after surgery, and in the other four patients trabecular bridging of the scaphoid fracture was achieved 16 weeks after the procedure.

Conclusion
1,2 Intercompartmental supraretinacular artery is superficial to the extensor retinaculum and is a proper pedicle of vascularized bone graft due to the ease of visibility and dissection. The functional results and union rates were satisfactory in our study.

Keywords:
avascular necrosis, scaphoid nonunion, vascularized bone grafts

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Introduction

Scaphoid fractures constitute 60–70% of all carpal bone fractures. These fractures have a well-documented tendency to progress to nonunion [1]. The importance of a correct diagnosis and appropriate treatment of scaphoid fractures lies in the scaphoid's blood supply. The main blood supply to the scaphoid is from the radial artery. More than 80% of the scaphoid surface is covered with articular cartilage. The dorsal scaphoid branches from the radial artery enters the nonarticular portion of the scaphoid at the dorsal ridge at the level of the waist and supplies the proximal 70–80% of the scaphoid [2]. The volar scaphoid branches from either the radial artery or the superficial palmar branch enters at the distal tubercle and supplies the distal 20–30% of the scaphoid. Thus, the vascularity of the proximal pole depends entirely on intraosseous blood flow. This tenuous blood supply to the proximal pole of the scaphoid helps to explain the increased frequency of delayed union, nonunion, and avascular necrosis (AVN) of scaphoid fractures. AVN is reported to occur in 13–50% of scaphoid fractures, with an even higher incidence in those involving the proximal one-fifth of the scaphoid [3].

Both clinical and biological factors contribute to the development of nonunion. Biological factors include the degree of fracture displacement, the fragile vascular supply of the scaphoid, and its complex anatomy. Clinical factors include variable patient symptoms such as minimal pain and swelling, compliance with immobilization, lack of medical and radiological diagnosis, and delays in treatment [4]. Langhoff and Andersen [5] found that the nonunion rate was 40% when diagnosis and treatment was delayed by 4 weeks [5].

Most symptomatic scaphoid nonunions eventually develop a collapse, or 'humpback' deformity, followed by onset of wrist arthrosis. If left untreated, scaphoid nonunions are predisposed to premature carpal arthrosis and long-term disability [1]. The conventional Russe bone grafting procedure is a reliable method for the treatment of symptomatic nonunion of the scaphoid [6]. Interpositional wedge grafts or Maltese cross bone grafts have been suggested for patients with humpback deformities or significant gaps [7]. When preoperative suggestion of AVN of the proximal pole is confirmed by intraoperative evaluation, vascularized bone grafts are strongly recommended [8].

When a massive free bone graft has to be incorporated into a large bone defect in the presence of a poor vascular recipient bed, the risks of absorption and failure of the graft to revascularize are high. Studies have confirmed that a bone graft that is transferred to a recipient site with an intact pedicle of blood supply remains viable; in addition, it unites directly with the recipient bone without necessity of revascularization or replacement by creeping substitution. It also provides a live bone bridge for reconstruction of a massive bone defect and is a ready source of vascular osteogenic tissue, which sprouts new outgrowths to revascularize avascular recipient bone tissue [8].

The purpose of our study was to evaluate the long-term results of implantation of pedicled vascularized bone graft from the dorsum of the distal radius using 1,2 intercompartmental supraretinacular artery (1,2 ICSRA) in patients with nonunited fracture of the scaphoid with avascular proximal fragment.

Patients and methods

From May 2011 to September 2014, 12 patients with nonunited fracture of the scaphoid were treated with pedicled vascularized bone graft from the dorsum of the distal radius using the 1,2 ICSRA (Table 1). Five cases were treated in Sayed Galal University Hospital, four cases in El-Helal Hospital, and three cases in Naser Institute Hospital. Patient age ranged from 27 to 47 years, with an average of 35.7 years. There were nine male and three female patients. The dominant hand was affected in seven patients and the nondominant hand in five patients. Wrist pain and limitation of wrist movement was the presenting symptom in all patients and was present for an average of 20.3 months (range = 12–40 months) preoperatively. Nine patients had previously undergone conservative treatment for the acute fracture in the form of below elbow thumb spica cast; only one patient had previously undergone matti Russe onlay graft trial to the nonunion 8 months before the procedure, and two patients had no previous treatment and neglected any form of immobilization to the acute fracture. All patients were available for follow-up at an average of 26 months (range = 12–40 months) after the procedure. The study protocol was approved by the ethics committee of faculty of medicine, Al-Azhar university. An informed consent was obtained from all study patients prior to their inclusion in the study.

Preoperative and postoperative clinical and radiographic evaluation was carried out. Clinical evaluation involves assessment of pain, range of motion of the wrist, and grip strength. The range of motion was measured with a goniometer, including flexion, extension, and radial and ulnar deviation. The grip strength was measured with a dynamometer. Postoperatively, clinical and functional results were reported according to the modified Mayo wrist scoring system (Table 2).

The radiographic evaluation involves plain radiograph posteroanterior, scaphoid view and lateral views preoperatively and postoperatively. The scapholunate angle was measured. The presence of AVN was diagnosed using MRI. Areas of low signal intensity on T1-weighted images and high signal or isosignal intensity on T2-weighted images were the criteria for the diagnosis of AVN. The final confirmation of AVN was the absence of punctate bleeding in the proximal pole intraoperatively.

Table 1 Details of the 12 patients with nonunited fracture of the scaphoid

Cases	Sex	Age	Side	Fracture site	Duration of nonunion (months)	Previous treatment	Follow-up period (months)
1	M	34	RT	Waist	18	Conservative	40
2	F	27	LT	P. pole	12	Neglected	39
3	M	36	LT	Waist	24	Conservative	36
4	M	40	RT	Waist	24	Conservative	36
5	M	35	RT	Waist	36	Russe onlay graft	30
6	M	43	LT	P. pole	12	Neglected	26
7	F	38	RT	Waist	12	Conservative	26
8	M	33	RT	Waist	12	Conservative	24
9	M	29	RT	P. pole	18	Conservative	20
10	M	37	LT	Waist	12	Conservative	18
11	F	30	RT	Waist	24	Conservative	12
12	M	47	LT	Waist	40	Conservative	12

Operative procedure

All patients were placed supine on the operating table with their arm pronated on the hand table. A tourniquet was used, but inflated only to 250 mmHg. The Esmarch was not used to exsanguinate the extremity before tourniquet inflation. This allowed for better visualization of the donor vessels during operation. The operative field was approached through a curvilinear dorsoradial incision (Fig. 1). Once the subcutaneous tissues were gently raised from the extensor retinaculum, the 1,2 ICSRA was visualized on the surface of the extensor retinaculum between the first and second extensor compartments (Fig. 2). An interval was developed between the first and second dorsal compartments that were opened at the graft elevation site.

The tendons of the first compartment were retracted radially and the tendons of the second compartment were retracted ulnarly (Fig. 3). The pedicle was dissected gently to its distal radial artery anastomosis and proximally to the level of the harvest site (Fig. 4). The center of the graft was 1.5 cm proximal to the radiocarpal joint to include the nutrition vessels (Fig. 5). Before the graft was elevated, the scaphoid nonunion site was prepared. A small osteotome and a small curette were used to remove fibrous tissue from the nonunion site and to remove sclerotic bone from the proximal and distal fragments (Fig. 6). The absence of punctate bleeding in the proximal pole confirmed the diagnosis of AVN. A dorsal trough was made in the dorsal cortex of the scaphoid bridging the nonunion site to fit the graft (Fig. 7).

A graft sufficiently large to fill the scaphoid defect was raised containing the vessels and cuff of the retinaculum between the first and second compartments (Fig. 5). Before implantation of the graft, multiple cancellous bone chips were taken from the graft site bed to help in filling the defect in the fracture site. The graft was implanted in the prepared site and the scaphoid was fixed with one or two smooth Kirschner wires depending on the size of the proximal fragment. The tourniquet was deflated to ensure hemostasis. The capsule was closed without strangulating the pedicle and the skin was closed.

Table 2 Mayo wrist scoring system

Categories	Score	Findings
Pain (25 points)	25	No pain
	20	Mild pain with vigorous activities
	20	Pain only with weather changes
	15	Moderate pain with vigorous activities
	10	Mild pain with daily activities
	5	Moderate pain with daily activities
	0	Pain at rest
Satisfaction (25 points)	25	Very satisfied
	20	Moderately satisfied
	10	No satisfied, but working
	0	No satisfied, unable to work
Range of motion (25 points)	25	100% percentage of normal
	15	75–99% percentage of normal
	10	50–74% percentage of normal
	5	25–49% percentage of normal
	0	0–24% percentage of normal
Grip strength (25 points)	15	75–99% percentage of normal
	10	50–74% percentage of normal
	5	25–49% percentage of normal
	0	0–24% percentage of normal
Final result (total points)	90–100	Excellent
	80–89	Good
	65–79	Fair
	<65	Poor

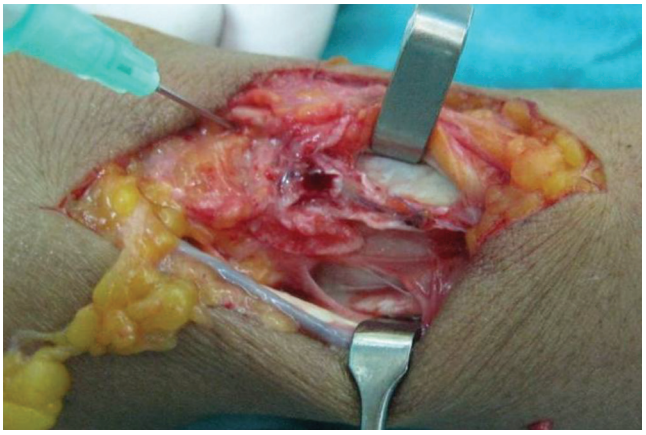
Figure 1

Approach to 1,2 ICSRA through a cuvilinear dorsoradial approach.

Figure 2

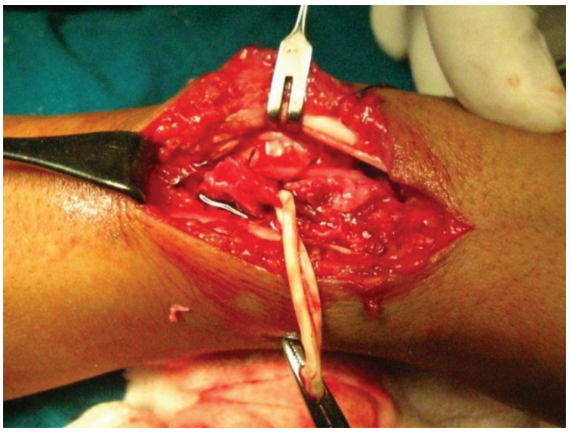
The 1,2 ICSRA appears on the surface of the extensor retinaculum between he 1st and 2nd extensor compartments.

Figure 3



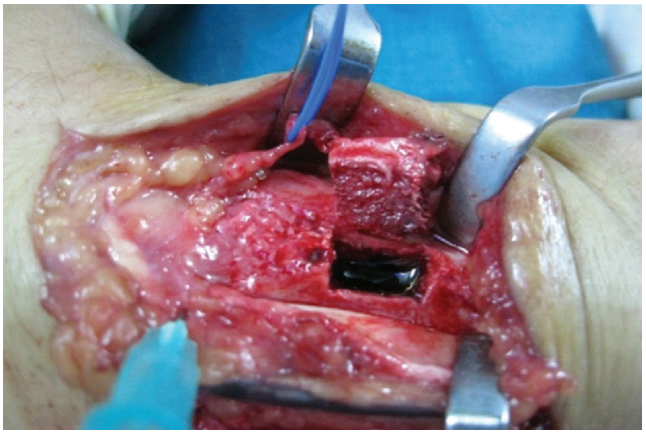
The tendons of the first compartment are retracted radically and the tendons of the second compartment are retracted ulnarly and the1,2 ICSRA appears in the septum between the compartments.

Figure 4



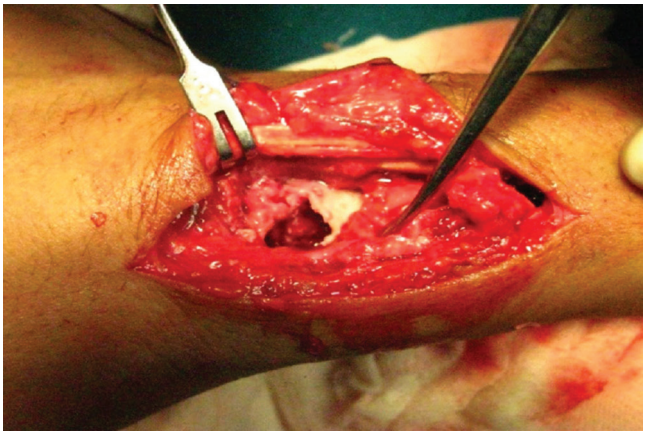
The pedicle of the graft is dissected and marked with a rubber piece.

Figure 5



The center of the graft at 1.5 cm proximal to the radiocarpal joint to include the nutrition vessels.

Figure 6



Preparation of the nonunion site with a small osteotome and a small curette to remove fibrous tissue from the nonunion site and to remove sclerotic bone from the proximal and distal fragments.

Postoperative care

A below elbow volar slab was applied for 6–8 weeks and replaced with removable splint. The K-wires were removed after complete bone healing under local anesthesia.

Results

Clinical and functional results

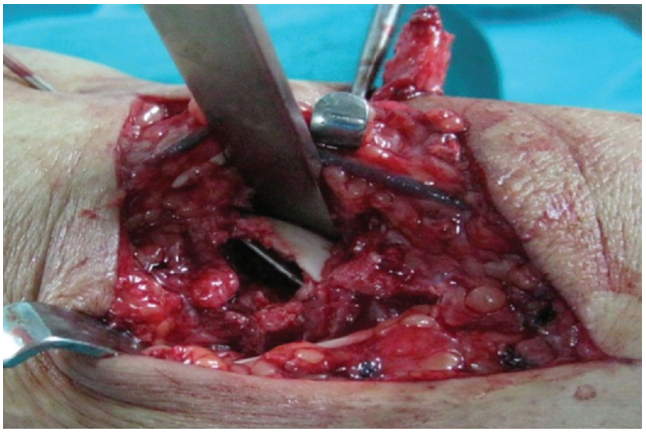
The average follow-up period was 26 months (range = 12–40 months). The clinical and functional results are summarized in Table 3. All patients complained of pain before surgery. All patients clinically improved: nine patients (75%) reported the absence of any discomfort, two patients (16%) reported slight discomfort after hard work, and only one case (8%) reported pain with light work and required radial styloidectomy 10 months after the grafting procedure for arthritic radioscaphoid joint.

The wrist range of motion improved significantly. The mean preoperative wrist extension was 57° (range = 45–65°) and improved to 73.3° postoperatively (range = 65–80°). The mean preoperative flexion was 59.1° (range = 50–65°) and improved to 75.4° postoperatively (range = 60–80°). The hand grip strength also improved, with the average preoperative grip strength being 17.4 kg (range = 14–20 kg) and the average postoperative grip strength being 25.2 kg (range = 20–30 kg). According to the modified Mayo wrist scoring chart, clinical results were rated as excellent in eight cases, good in three cases, and fair in one case.

Radiographic results

In the early postoperative period, all patients were subjected to plain radiography (posteroanterior, scaphoid and lateral) every 4 weeks. In eight of the

Figure 7



A dorsal trough made in the dorsal cortex of the scaphoid bridging the nonunion site to fit the graft and the scaphoid fixed with one or two K-wires.

12 patients, the bones united and the trabeculae appeared bridged within 3 months after surgery (Figs 8–11), whereas in the other four patients trabecular bridging of the scaphoid fracture was achieved within 4 months after surgery. The mean union time was 11.6 weeks (range = 8–16 weeks). The preoperative severity of the collapse and postoperative correction of the deformities were measured and comparatively reviewed, and the results are summarized in Table 4. The mean preoperative scapholunate angle angles were 61.25° (range = 50–70°) and postoperatively it improved to 43.75° (range = 40–50°). All patients underwent preoperative MRI for assessment of vascularity of the proximal fragment, but only six patients underwent postoperative MRI and all showed improvement in T1 and T2 signal as a sign of bone revascularization (Figs 8 and 9).

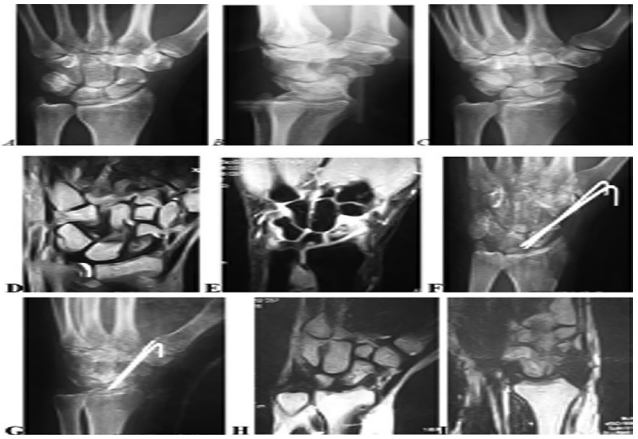
Discussion

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 [9]. Green [10] reported a prospective study of patients with nonunion of the scaphoid treated using the Russe bone grafting method. A total of 24 of 26 patients (92%) with good vascularity in the proximal pole achieved solid union, but none of the five patients in whom the proximal pole was totally avascular achieved successful union. He concluded that the absence of intraoperative punctate bleeding points on the cancellous surface indicated avascularity of the proximal pole and may explain the failure of bone grafting procedures. When preoperation suggestions of severe AVN of the proximal pole are confirmed

Table 3 Results of the 12 patients with nonunion of fracture of the scaphoid

Case	Fracture site	Pain		Range of motion		Grip strength		Preoperative	Postoperative	Time to union (weeks)	Clinical results (Mayo wrist scoring system)
		Preoperative	Postoperative	Flexion		Extension					
				Preoperative	Postoperative	Preoperative	Postoperative				
1	Waist	+	–	60	80	55	75	18	25	10	Excellent
2	P. pole	+	–	60	80	60	75	20	26	14	Excellent
3	Waist	+	–	55	75	60	80	16	25	10	Excellent
4	Waist	+	+/–	60	75	55	70	15	23	12	Good
5	Waist	++	+	50	60	45	65	14	20	12	Fair
6	P. pole	+	–	65	75	65	75	18	28	16	Excellent
7	Waist	+	–	60	75	60	70	17	26	14	Excellent
8	Waist	+	–	60	80	65	80	18	27	8	Excellent
9	P. pole	+	+/–	60	70	55	65	16	22	16	Good
10	Waist	+	–	65	80	60	75	20	30	10	Excellent
11	Waist	+	–	60	80	55	75	19	26	8	Excellent
12	Waist	+	–	55	75	50	75	18	25	10	Good

Figure 8



A 47-year-old male patient with nonunited fracture scaphoid of 40-month duration: (a–c) preoperative radiograph, (d, e) preoperative MRI revealing avascular necrosis (AVN) of the proximal fragment, (f, g) radiograph at 10 weeks postoperatively revealing united fracture, (h, i) MRI at 10 months postoperatively revealing union and revascularization of the proximal fragment.

Table 4 Preoperative and postoperative assessment of the scapholunate angle

Case number	Preoperative SL angle (in deg.)	Postoperative SL angle (in deg.)
1	65	45
2	60	40
3	70	50
4	65	40
5	65	45
6	55	40
7	60	45
8	55	40
9	50	40
10	60	45
11	65	45
12	65	50

SL, scapholunate angle.

intraoperatively, a vascularized pedicle bone graft should be strongly considered [10]. Living bone heals faster compared with nonvascularized autografts and does so without creeping substitution of necrotic bone. This offers a shorter period of immobilization and a higher union rate. A grafted bone with adequate blood supply may aid the revascularization of an avascular segment of the bone [8].

Many different methods have been reported for obtaining vascularized grafts. One of the earliest reports of a vascularized pedicled bone graft applied to carpal pathology was by Roy-Camille in 1965 [11]. Using the scaphoid tubercle on an abductor pollicis brevis muscle pedicle, Roy-Camille performed a vascularized bone graft to assist successfully in the healing of a scaphoid waist delayed union [11]. In

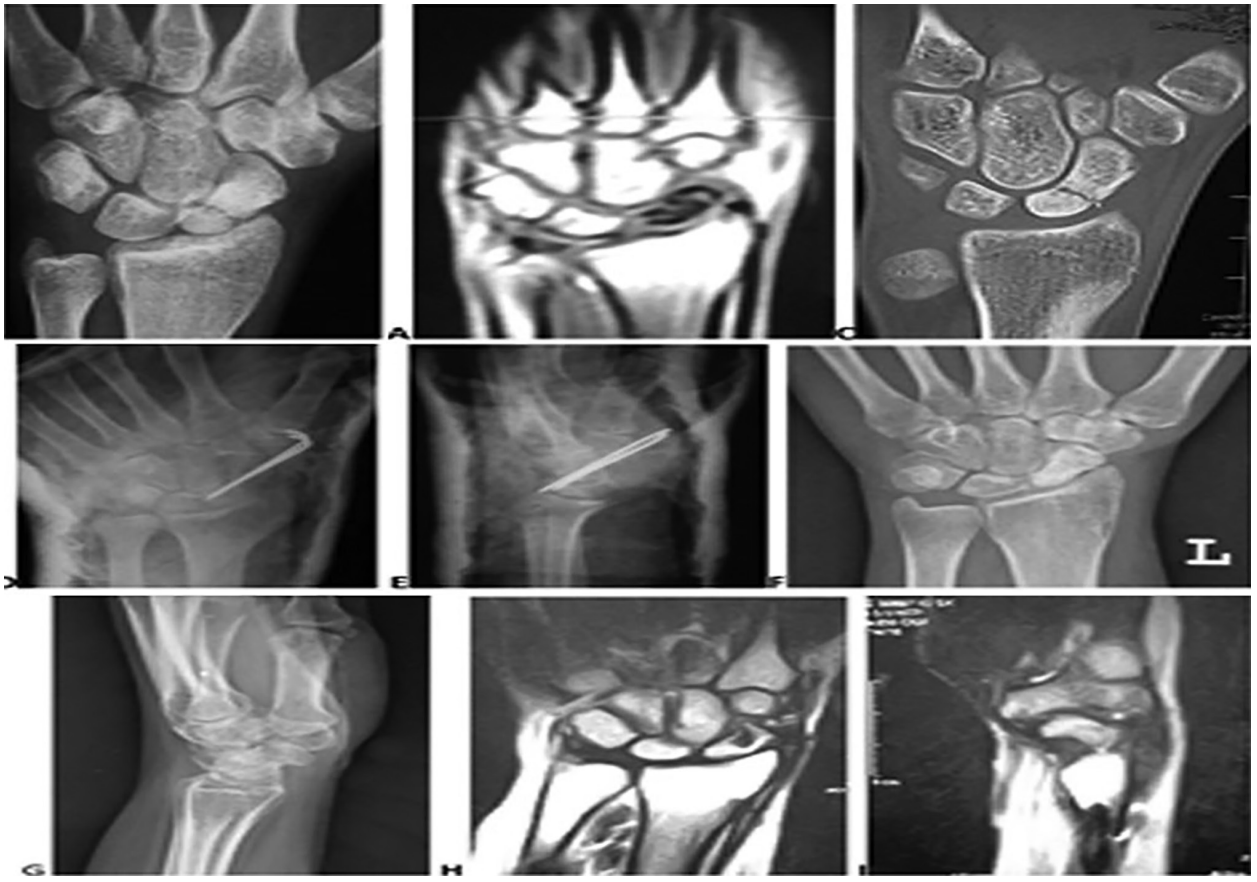
Figure 9

A 27-year-old male patient with nonunited fracture of the scaphoid: (a) preoperative posteroanterior (PA) radiograph, (b, c) preoperative MRI revealing diminished signal intensity over the proximal fragment of the scaphoid denoting avascular necrosis (AVN) of the proximal fragment, (d) early postoperative radiography after VBG procedure, (e, f) PA and lateral radiography 4 months after the procedure revealing united fracture, (g) computed tomography (CT) scan 6 months after the procedure revealing completely united fracture.

1983, Braun [12] described a volar distal radius bone graft based on a pronator quadratus muscle/anterior interosseous artery pedicle and successfully treated five scaphoid nonunions [12]. Similarly, Kuhlmann [13] described a palmar distal radius graft based on a branch of the palmar radiocarpal arch used successfully in three scaphoid nonunions after failed conventional grafts [13]. However, the volar distal radius grafts have significant limitations, including variable nutrient vessel position and diameter, a short arc of rotation, and potential for ligamentous injury and carpal instability resulting from carpal exposure from a palmar approach [14]. Guimberteau and Panconi [15] described a distal ulna pedicled graft based on a reverse-flow ulnar artery pedicle and successfully treated eight established scaphoid nonunions that failed conservative bone grafting. These authors reported the technique as demanding and recommended an ulnar arterial reconstruction with a vein graft [15].

In 1991, a pedicled vascularized distal radius bone graft was described by Zaidemberg *et al.* [16], based on the ascending irrigating branch of the radial artery

Figure 10



A 29-year-old female patient with nonunited fracture of the proximal pole of the scaphoid: (a) preoperative posteroanterior (PA) radiograph, (b) preoperative computed tomography (CT) scanning with coronal reconstruction revealing fracture with increased radiodensity of the proximal fragment, (c) preoperative MRI revealing decreased signal intensity in T1 over the scaphoid due to avascular necrosis (AVN) of the proximal fragment, (d, e) PA and lateral radiograph 12 weeks after the procedure, (f, g) postoperative MRI 8 months after the procedure revealing united fracture with revascularization of the proximal fragment.

Figure 11

A 29-year-old male patient with scaphoid waist nonunion, with failed previous matti Russe graft fixed with Herbert screw. (a, b) Posteroanterior (PA) and oblique radiograph showing the nonunion site and the graft fragment, and erosion of the trapezium by the screw head. It was treated with 1,2 intercompartmental supraretinacular artery (1,2 ICSRA) pedicled bone graft. (c) PA radiograph 4 weeks postoperatively. (c) Radiographs at 6 months after the procedure show trabecular bridging of the nonunion site.

and reported 100% union of 11 established scaphoid nonunions. The dorsal radial location of this graft allowed a single surgical incision for graft harvest, carpal exposure, and placement in scaphoid nonunions [16]. Because of its location, the vessel was named the 1,2 ICSRA. It is easily visible after retraction of the skin and subcutaneous tissues. The arc of rotation was sufficient to reach the scaphoid bone area [8].

Tu *et al.* [17,18] reported an animal study and demonstrated that the pedicle vascularized bone grafts maintained enhanced bone circulation for longer term, and the data supported the clinical use for scaphoid AVN [17,18]. Boyer *et al.* [19] reported scaphoid nonunion with AVN of the proximal pole that was managed with a vascularized dorsal interposition graft from the distal radius [19]. The procedure resulted in the union of six of 10 fractures. Uerpairojkit *et al.* [20] also reported a vascularized bone graft from the dorsoradial aspect of the distal radius used with internal fixation to treat nonunion of the scaphoid in 10 patients who had not received any previous surgical treatment [20].

Associated AVN was observed in five patients. Postoperatively, pain was relieved and union was achieved in all cases. Range of motion, grip strength, and pinch strength were also satisfactorily restored. The 1,2 ICSRA is superficial to the retinaculum and runs directly into the bony tubercle. It is a proper pedicle of vascularized bone graft due to the ease of visibility and dissection.

In this series, good results were obtained, as a single small incision was used for graft harvest and approaching the scaphoid. The short healing time of the vascularized bone graft (VBG) allowed the patients to start range of motion exercises early. Good results were obtained in case of failed previous grafting procedure. All patients in our series returned to their work with good functional results.

Conclusion

Vascularized bone graft with 1,2 ICSRA pedicle is useful to repair a nonunion of the scaphoid with or without AVN of the proximal fragment.

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Conflicts of interest

There are no conflicts of interest.

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