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The management of proximal pole scaphoid nonunion with avascular necrosis using 1, 2 intercompartmental supraretinacular arterial bone graft and radial styloidectomy: A midterm outcome study

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Abstract
Background: The management of proximal pole nonunions of scaphoid with avascular necrosis remains the most controversial of all scaphoid fracture nonunions. Various types of vascularised bone grafts have been used to hasten union. We studied the union rate, clinical and functional outcome of 1, 2 intercompartmental supraretinacular arterial bone graft (1, 2 ICSRA) and radial styloidectomy for proximal pole scaphoid nonunion with avascular necrosis.
Methods: We retrospectively analysed the four year outcome of vascularised distal radius bone graft (1, 2 ICSRA) and radial styloidectomy in 20 patients treated at our institution for proximal pole scaphoid nonunion with avascular necrosis between 2010 and 2014. Majority of cases (10) presented as failure of adequate immobilization. The average time to surgery from trauma was 14 months and mean duration of follow up was 30 months. Twelve (12) cases had features of early radioscaphoid arthritis. Nonunion and avascular necrosis were confirmed in all cases with radiographs and MRI scan. We followed the technique described by Zaidemberg *et al* for harvesting the vascualrised bone grafting from the distal radius.
Results: Majority of the cases (80%) united by 20 weeks. There was significant improvement in the grip strength and pain postoperatively. Wrist flexion-extension and radial-ulnar deviation arcs improved but was not statistically significant. The Mayo Wrist Score showed 75 percent of patients had an excellent or good outcome. The scapholunate angle also improved from 62.5 deg to 46.5 deg postoperatively. Radiographic union was achieved in sixteen cases (80%) by 20 weeks. Three cases (15%) went for delayed union and achieved bony healing by thirty weeks. One case (5%) developed pintract infecton and progressed to radioscaphoid arthritis.
Conclusions: Our study highlights the efficacy of 1,2 ICSRA vascualrised distal radius bone grafting in proximal pole scaphoid nonunions with avascualr necrosis in achieving good union rate with acceptable clinical and functional outcome in this difficult problem. This procedure can be done under regional block without the need for microsurgical set up and costly implants. Vascularised distal radius grafts with radial styloidectiomy is a promising solution for scaphoid proximal nonunions with avascular and early radioscaphoid arthritic changes.

Keywords: scaphoid nonunion, proximal pole, vascualrised bone grafts

1. Introduction
Scaphoid is the most commonly fractured carpal bone occurring in the young healthy individuals [1]. These fractures may escape early detection in many cases as the initial symptoms are minimal. Missed scaphoid fractures pose a high risk of nonunion, avascular necrosis or malunion due to its precarious blood supply [2]. The major 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 branch of the radial artery enters the non-articular portion of the scaphoid at the level of dorsal ridge at the waist and supplies the proximal 70% to 80% of the scaphoid [2]. Thus, the proximal pole depends entirely on intraosseous blood flow for its vascularity. This explains the increased frequency of delayed union, nonunion and avascular necrosis (AVN) of the proximal pole of the scaphoid fractures. AVN is reported to occur in 13% to 50% of scaphoid fractures, with an even higher incidence in those involving

the proximal one-fifth of the scaphoid[3,4].Scaphoid nonunions especially those in the proximal pole are challenging to treat successfully and can progress to carpal collapse and degenerative arthritis if left untreated. The arthritic changes begin in the radioscaphoid joints progressing to pancarpal arthritis. There are high chances of failure of conventional bone grafting in proximal pole scaphoid nonunions due to its compromised vascularity [5]. In this situation, vascularised bone grafting appears to be an appealing option as it provides a source of angiogenesis and osteogenesis [6]. Vascularized bone grafts heals faster than nonvascularized autografts without undergoing creeping substitution of necrotic bone [7]. This predicts a higher success rate of union with a shorter period of immobilization. For past 15 years, vascularised pedicle based bone grafts (VBGs) have been successfully used in the treatment of scaphoid nonunions. Zaidemberg *et al*. reported successful use of 1, 2-intercompartmental supraretinacular artery (ICSRA) pedicled VBGs from the distal radius in the dorsum of the wrist, for the first time [6]. They reported a 100% union rate in 11 scaphoid nonunions at an average of 6 weeks, with significant improvements in rest pain and grip strength in all patients. Radial styloidectomy has been long used as a treatment modality to reduce the radiocarpal impingement pain.

We retrospectively analysed four years clinical and functional outcome of twenty patients, who presented with scaphoid nonunion and avascular necrosis of the proximal pole with early radioscaphoid arthritis, treated with 1, 2 intercompartmental supraretinacular arterial (1, 2 ICSRA) bone grafts and radial styloidectomy.

2. Material and Methods

In this retrospective study, a total of 20 patients (age 20-40yrs) with non-union of proximal pole of scaphoid with AVN were included. All cases had clinical symptoms of pain and decreased grip strength. The diagnosis was confirmed with radiographs and non-contrast MRI. Around 8 cases were having features of early radioscaphoid arthritis (preserved radioscaphoid joint space). All cases with nonunion of scaphoid waist, post-surgical non-union of scaphoid, failed bone grafting procedure, Preiser's disease, advanced radioscaphoid arthritis, pan carpal arthritis, scaphoid nonunion advanced collapse (SNAC), associated fractures of carpal and radioulnar bones were excluded. Of the 20 patients, 10 cases presented as failure of adequate immobilization, 8 cases presented after local massage treatment and 2 cases presented as initially unrecognized injury. The shortest interval between injury and presentation was 6 months which precluded any treatment option with cast treatment [8]. Preoperative wrist range of motion (flexion, extension, and radial and ulnar deviation) of both the affected and unaffected joint was documented. Grip strength of both the affected and unaffected wrist was measured using a Jamar dynamometer.

Plain radiographs (posteroanterior, lateral and scaphoid views) of the wrist were performed in a standard fashion. We evaluated the radiographs for evidence of scaphoid nonunion (a well-defined sclerotic line on both borders of the fracture fragments or cyst formation (Fig. 1), determining the scapholunate angle [9]. And examined the width of the radioscaphoid joint space. The scapholunate angle was the angle measured between longitudinal axes of scaphoid and lunate on the lateral wrist radiograph. Radioscaphoid joint space narrowing was graded from 0 to 3 (grade 0 - no narrowing; grade 1 - mild beaking of the radius with involvement of the radioscaphoid joint; grade 2 - narrowing of radioscaphoid joint; and grade 3 - loss of radioscaphoid joint) [10]. Only grade 0-2 cases were involved in this study. All patients were advised to stop smoking.

The datas of all patients treated with vascularised bone grafting based on 1, 2 ICSRA pedicle grafting and styloidectomy with K-wire fixation at our institution, from June 2010 to May 2014, were collected retrospectively for the study. The study was approved by institutional ethics committee.

Table 1: Patient characteristics (n= 20)

Mean age (yr)	24 (20- 40yrs)
Male /female	20 /0
Side involved	14 (right) / 6(left)
Mean time to surgery from trauma	14 months (6-30 months)
Mode of injury presentation	10 (failure of immobilization) 8(local massage treatment) 2 (initially unrecognized injury)
Mean duration of follow up	30 months (26 – 48 months)
Radioscaphoid arthritis (grade 1/2)	12 cases

2.1 Surgical technique

All the procedures were performed by under regional anaesthesia (ultrasound-guided axillary block). Brachial tourniquet was applied but not inflated initially.

A 5 to 6cm longitudinal incision was made on the dorso-radial aspect of the wrist centred over the radial scaphoid and radio-carpal joint line (Fig.2).

Fig 1: The surgical incision centered over the radial styloid (pointed with scalpel tip) and between first and second extensor compartment. Superficial radial nerve marked with dotted lines

Fig 2: Superficial radial nerve dissected to avoid peroperative damage.

Fig 3: The hemostat pointing at the 1, 2 ICSRA branch. Better visualized without tourniquet.

Fig 4: First and second extensor compartment incised to expose the intermediate bone bridge.

Fig 5: 1, 2 ICSRA graft harvested with bone graft. The vascular pedicle is taken along with capsuloperiosteal sleeve

Fig. 6: The scaphoid nonunion exposed and prepared after radial styloidectomy.The bone graft is interposed into the nonunion site

Fig 7: The graft fixed with two 1.2mm K-wires under fluoroscopic guidance and postoperative radiographs in cast

Fig 8: United scaphoid after K wire removal with good wrist function.

Special attention was given to protect the radial nerve and its branches (Fig. 3). The first and second extensor compartments were dissected achieving good hemostasis. This exposes the 1, 2-ICSRA seen ascending between the first two extensor compartments in a tortuous trajectory over the extensor retinaculum (Fig 4). The first and second extensor compartments are opened with a longitudinal incision keeping intact a narrow strip from the extensor retinaculum on either side of the artery's trajectory (Fig.5). The wrist joint is opened by performing a longitudinal arthrotomy over the length of the second compartment. This provides a capsular-periosteal flap that is used to protect the graft pedicle (Fig.6).It is better to inflate the tourniquet at this stage as arthrotomy is accompanied with synovial bleeding. This also makes identification of the nonunion site easier. Arthrotomy exposes the proximal half of the scaphoid bone (Fig.7). A radial styloidectomy is routinely performed to improve the exposure of the scaphoid nonunion site. This also provides pain relief in early radioscaphoid arthritis. Ligaments attached to the radial styloid are protected by subperiosteally elevating them before osteotomy. A small saw is used to perform radial styloidectomy with adequate care given to protect the graft pedicle. Nonunion site is freshened using small osteotomes and curettes. Care is given to remove mainly the fibrous tissue in the nonunion site and retaining the proximal pole bone. The intraoperative assessment of proximal pole with absence of punctuate bleeding confirms the avascular nature. Osteophytes, if any, are resected. The pedicled bone graft is harvested by osteotomy using a small saw or narrow osteotomes centred over the 1, 2-ICSRA (Fig.6). The depth and thickness of the graft depends on the nonunion site morphology. The bone graft is then harvested on the vascular pedicle, which is protected by the capsular-periosteal flap. The graft is positioned as a cross-wise inlay over the non-union site by spreading the two scaphoid fragments with small hooks or K wires. We curette out little cancellous graft from the harvested bed over the distal radial styloid. These cancellous grafts are also placed in the scaphoid nonunion site. Special care is taken to avoid traction on the vascular pedicle while mobilizing it to the nonunion site by carefully dissecting it from the nearby tissues. Bony malalignment was corrected by forcefully extending the wrist dorsally before the fragments are transfixed with the K wires passed from distal to proximal pole. Deformity correction demanded reshapening of the graft and packing with the cancellous chip grafts. The graft is fixed using two 1.2mm K wires inserted at the waist of the scaphoid and directed through the graft into the proximal pole under visual and C Arm control (Fig.8). The ends of the K wires are bent and cut. A two-layer closure is performed without a drain burying the K wires under the skin. We usually immobilize the wrist in below elbow thumb-

spica cast for eight to ten weeks based on the radiological union. Thereafter a removal wrist brace is worn for next four to six weeks. Patient was followed up every 4 weeks. By end of 16 weeks, majority of patients regained good range of movements and radiological union (Fig. 9).

2.2 Postoperative evaluation

Posterior-anterior (PA) and lateral radiographs were taken for all patients after surgery and every 4 weeks postoperatively out of plaster to better visualize the union. Bony union was confirmed when trabecular bridging of the scaphoid fragments had occurred. The Kirschner wires were removed after complete bone healing, both clinically and radiologically, as a outpatient procedure under local anesthesia. Full weight-bearing activity was not permitted until 6 months after the operation. Functional evaluation was performed using the modified Mayo wrist scoring system. Range of motion, grip strength, pain and satisfaction score were measured allowing for a total count of 100 points in four categories. Final results was graded as 90-100(total points)-Excellent; 80-89 - Good; 65-79- Fair and < 65- poor. The severity of collapse were measured based on assessment of scapholunate (SL) angle pre and postoperatively.

2.3 Statistical analysis

We calculated the Wilcoxon signed ranks test to compare preoperative and postoperative values using statistical software (SPSS version 15.0; SPSS, Chicago, IL).

3. Results

The average follow up period was 30 months (24-48 months). The results are sumarised in Table 1. Of the 20 cases, 16 cases united after the index procedure at 16 weeks (12 – 20 weeks). Four cases showed persistent fracture line at the end of five months but were symptomatically better. Three of them showed union by the end of thirty weeks (Table 3). One of these cases showed extrusion of the graft radiologically at the end of eight weeks (Table 4). He was immobilized for further eight weeks and went on to unite uneventfully. None of these patients were willing for a repeat procedure as there initial symptoms disappeared. Higher incidence of delay in union was noted in smokers but no statistical significance could be elicited. One of the cases developed pintract infection and required early removal of K wires at six weeks. Scaphoid cast was continued for sixteen weeks but showed fracture line till end of eight months. At the end of 36 months, this patient showed features of progressive radioscaphoid arthritis. He was not willing for salvage procedures. Grip strength showed a significant improvement ($P < 0.01$) postoperatively on followup. The composite arc of wrist movements remained without much difference. The wrist extension remained restricted for upto 10 to 14 months postoperatively. The wrist radial deviation showed improvement in cases with early radioscaphoid arthritis. Regarding the intercarpal instability, the mean preoperative SL angles improved from 62.5 degrees (range, 45-70 degrees) preoperatively to 46.5 degrees (range, 40-50 degrees) postoperatively but found to be statistically insignificant. The average Mayo wrist score improved to 85 (Table 2).

Table 2

Parameter	Preoperative	Postoperative	Significance
Grip strength (kg)	38	46	Yes ($p < 0.01$)
Wrist flexion extension ROM (deg)	110	118	No ($p = 0.20$)
Wrist Radial ulnar deviation ROM (deg)	36	40	No ($p= 0.26$)
Pain	10	20	($p= 0.14$)
Satisfaction	10	20	($p=0.14$)
Scapholunate angle (SL angle)	62.5 deg	46.5 deg	No ($p= 0.16$)

Table 3

		No of patients
Time of union	<12 weeks	4
	12-20 weeks	12
	>20 weeks	4
Mayo's scoring	Poor	1
	Fair	4
	Good	14
	Excellent	1

Table 4

Complications	No of patients
Graft extrusion	1
Infection	1

4. Discussion

The management of proximal pole scaphoid nonunions with avascular necrosis is a challenging task. Though many treatment strategies have been in use, the chances of achieving bony union using vascularized bone graft is appealing. In a prospective study of patients with scaphoid nonunion treated using the Russe bone grafting method, Green reported 92% of patients with good vascularity in the proximal pole achieved solid union, but none of the patients in whom the proximal pole was totally avascular achieved successful union [11]. He concluded that the absence of intraoperative punctate bleeding points on the fracture bony surface indicated avascularity of the proximal pole and could explain the failure of non vascularised bone-grafting procedures. Vascularized pedicle bone graft should be strongly considered in cases of proximal pole scaphoid nonunion with suspicious AVN changes [12]. Living bone heals faster than non-vascularized auto grafts as this happens without creeping substitution of necrotic bone. This provides a shorter immobilization and a higher union rate of the nonunion site following surgery. A grafted bone with adequate blood supply may aid the revascularization of an avascular segment of bone.

Various techniques have been reported for obtaining vascularized grafts. Roy-Camille reported the use of vascularized pedicled bone graft applied to carpal pathology in 1965. They used the scaphoid tubercle on an abductor pollicis brevis muscle pedicle vascularized bone graft to successfully treat delayed union of scaphoid waist [13]. In 1983, Braun described a volar distal radius bone graft based on a pronator quadratus muscle/anterior interosseous artery pedicle and successfully treated five scaphoid non-unions [14]. Similarly, Kuhlmann *et al* described a palmar distal radius graft based on a branch of the palmar radiocarpal arch used successfully in three scaphoid non-unions after failed

conventional grafts [15]. The volar distal radius grafts have significant limitations, however, 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. Guimberteau and Panconi described a distal ulna pedicled graft based on a reverse-flow ulnar artery pedicle and successfully treated 8 established scaphoid nonunions that failed conservative bone grafting [16]. Munk *et al.* in a systematic review concluded that vascularized bone grafts has better union rates than nonvascularised bone grafts in treating scaphoid nonunions [17]. Pedicled vascularized bone grafts from the dorsoradial aspect of the distal radius were first described by Zaidemberg (6). It is based on the ascending irrigating branch of the radial artery, specifically the 1, 2 intercompartmental supraretinacular artery (ICSRA) as described by Sheetz *et al* [18]. They studied 11 patients with scaphoid nonunion, with and without avascular necrosis, who healed in an average duration of 6 weeks. Rest pain and average grip strength improved in all. Similar outcomes were found in other studies [19, 20]. Malizos *et al* studied 30 patients with a minimum 2-year follow-up. Twenty patients were treated with dorsal bone grafting, and all of them went for union at an average of 12 weeks [20]. The authors suggested that patients with degenerative changes fared worse with the procedure. Steinmann *et al* reviewed eight cases of proximal pole nonunions which went on to heal at an average of 11 weeks [21]. They also reiterated that early arthritic changes were a poor prognostic sign. Another option for scaphoid proximal pole non-unions with avascular necrosis is free vascularized bone grafts from the medial femoral condyle [22]. They provide both structural support and blood supply to promote union in the difficult subset of scaphoid non-unions complicated proximal pole avascular necrosis but are technically demanding as compared to the vascularised distal radius grafts.

The distal radius vascularized bone grafting technique is relatively simple and straightforward surgical procedure. It utilizes the same incision for scaphoid exposure and can be done under upper limb blocks. These advantages lead us to favor this technique over other. It is less technically demanding procedure. There is no graft site additional morbidity. The radial styloidectomy improves visualization of the scaphoid nonunion site and therapeutically reduces the radioscaphoid arthritic pain. There is no need of microsurgical setup as needed in free vascularised grafts transfer. The use of K wires is bone preserving as compared to screws. These k wires can be removed under local anesthesia. One of the problems of dorsal approach is difficulty in correction of the humpback deformity. This issue can be tackled by harvesting a slightly bigger graft and reshaping it to the desired size and shape. It is advisable to insert the bone graft 1-2mm deeper at the nonunion site so that the bony ridge doesn't remain prominent. The bone graft was interposed in full width between the proximal and distal segments of the scaphoid so that greater surface area of the bleeding graft is available for union with the avascular proximal bony segment. Majority of our patients had improvement of grip strength and pain which is one of the major complaints preoperatively for majority of cases. There is improvement in the wrist range of movements though not statistically significant. Patients needed 8-12 weeks immobilization of the wrist in short arm plaster cast which may not be acceptable to all. Given the poor prognosis with available treatment modalities, patients must be made to understand the importance of immobilization. The union time of 12-20 weeks is comparable to the previous studies [23].

Our study had few limitations. Firstly, we didn't took postoperative MRI scans to assess the vascularity due to the financial constraints. We had only limited number of patients due to the rarity of the injury. Another limitation of our study is that it does not compare the 1, 2 ICSRA bone grafting procedure with established techniques, such as the Herbert screw fixation and non-vascularized bone grafting.

The current study shows that 1, 2 ICSRA vascularized distal radius bone grafting, although technically demanding, results in high union rates, even in chronic nonunions and early radioscaphoid arthritis cases. Although union was achieved in majority of cases (accept one), the functional outcome was good to fair in majority as delineated with Mayo's scoring. This should be discussed with the patient preoperatively.

A prospective, randomized, multicenter controlled study is advised to compare the current technique with the standard techniques of non-vascularised bone grafts and Herbert screw fixation to define the indications and advantages of each one.

5. Conclusion

Management of scaphoid proximal pole nonunions with avascular necrosis and radioscaphoid arthritis with 1, 2 ICSRA pedicled vascularized distal radius bone grafts and radial styloidectomy results in a high union rate with resolution of pain and improvement of grip strength and wrist function.

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