Management of Scaphoid Nonunion with Avascular Necrosis Using 1, 2 Intercompartmental Supraretinacular Arterial Bone Grafts

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Background: Poor reduction or neglect of an unstable carpal scaphoid fracture may lead to scaphoid nonunion or avascular necrosis. When pre-operative suggestion of avascular necrosis of the proximal pole is confirmed by intra-operative evaluation, conventional bone graft is not enough and a vascularized bone graft is strongly recommended.

Methods: Five patients with nonunion of scaphoid fractures associated with avascular necrosis based on results of radiography and further confirmed by magnetic resonance images and intra-operative findings were operatively managed with 1, 2 intercompartmental supraretinacular arterial (1, 2 ICSRA) vascularized bone graft combined with supplemental cancellous bone grafts from the radius. Follow-up periods were at least 18 months. The functional outcomes and radiographs were analyzed.

Results: In four of the five patients, the nonunion sites united within 4 months after surgery. The other patient had a superficial pin tract infection and bone healing was complete 6 months after the operation. The functional results were good in all five patients.

Conclusion: 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. The functional results and union rates were satisfactory in our study.

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Key words: **scaphoid nonunion, avascular necrosis, vascularized bone graft.**

Poor reduction or neglect of an unstable scaphoid fracture may lead to nonunion or avascular necrosis.[1-6] The conventional Russe bone grafting procedure is a reliable method for the treatment of symptomatic nonunion of the scaphoid.[4,5,7-9] Interpositional wedge grafts or Maltese cross bone grafts have been suggested for patients with humpback deformities or significant gaps were present.[9] When preoperative suggestion of avascular necrosis (AVN) of the proximal pole and confirmed by intraoperative evaluation, vascularized bone grafts are strongly recommended.[10]

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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. There are two rationales for use of vascularized bone grafts.[11,12] First, living bone tissue heals faster than nonvascularized autografts and does so without creeping substitution of necrotic bone. This offers the potential advantages of a shorter period of immobilization and a higher success rate of union. Second, a grafted bone with adequate blood supply may aid in the revascularization of an avascular segments of bone.

We present the surgical results of five patients with scaphoid nonunion and avascular necrosis of the proximal pole treated with 1, 2 intercompartmental supraretinacular arterial (1, 2 ICSRA) bone grafts from the dorsoradial aspect of the distal radius.

METHODS

From May 1999 through January 2000, five patients with scaphoid nonunion secondary to AVN were treated with 1, 2 ICSRA vascularized pedicle bone grafts and interposed cancellous bone grafts from the radius. There were three men and two women; the average age was 42.2 years (range, 24-55 years). The presence of AVN was diagnosed using magnetic resonance imaging (MRI). Areas of low signal intensity on T1-weighted images and high signal or iso-signal intensity on T2-weighted images were the criteria for the diagnosis of avascular necrosis.[13,14] The final confirmation of avascular necrosis was the absence of punctate bleeding in the proximal pole intraoperatively.

Operative procedure

With the patient under general anesthesia, the extremity was elevated and a tourniquet was inflated. Operative field was approached through a curvilinear dorsoradial incision (Fig. 1).[15] Once the subcuta-

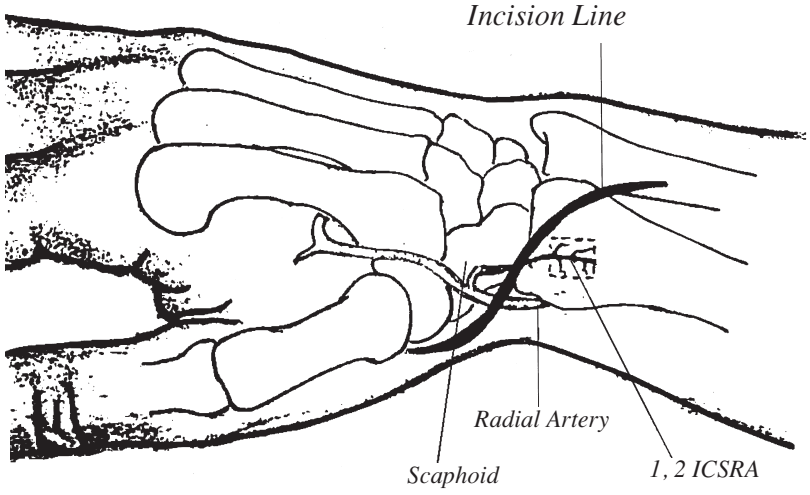

Fig. 1 Treatment of a scaphoid nonunion with a 1, 2 ICSRA pedicle bone graft. A curvilinear dorsoradial incision is used for exposure of the scaphoid and the 1, 2 ICSRA.

neous tissues were gently raised from the retinaculum, the 1, 2 ICSRA was visualized on the surface of the extensor retinaculum. This artery was easily inspected using loupe magnification. The artery and venae comitantes were dissected gently toward their distal anastomosis. After identification and protection of the sensory branches of the radial nerve, an interval was developed between the first and second dorsal compartments that were opened at the graft elevation site. Before the graft was elevated, the scaphoid nonunion site was prepared. Curetting and osteotomies were used to remove fibrous tissue from the nonunion site. The absence of punctate bleeding in the proximal pole confirmed the diagnosis of avascular necrosis. A trough for a dorsal inlay graft was prepared, snapping the nonunion. 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. The center of the graft was 1.5 cm proximal to the radiocarpal joint to include the nutrition vessels. The pedicle was dissected gently to its distal radial artery anastomosis. The tourniquet was briefly released to check bleeding on the surface of the vascularized bone graft. After re-inflation of the tourniquet, the graft was transposed to reach the nonunion site where it was gently impacted into position and placed as a dorsal inlay. Supplemental cancellous bone grafts were taken from the radius to fill the ducking site of the vascularized graft. Depending on the size of the proximal fragment, one or two smooth Kirschner wires were used to stabilize the nonunion.

Postoperative evaluation

Postoperatively, the extremity was placed in a below-the-elbow thumb-spica cast for 6 weeks, then shifted to a removable short thumb-spica splint for another 4 weeks. Full weight-bearing activity was not permitted until 6 months after the operation.

Posterior-anterior (PA) and lateral radiographs were taken for all 5 patients every 4 weeks postoperatively. Bone healing was evaluated and unions were confirmed when trabecular bridging of the scaphoid fragments had occurred. The Kirschner wires were removed after complete bone healing under local anesthesia.

Measurements of both preoperative and postoperative radiographic studies were comparatively reviewed. The assessments were made on PA views of neutral and deviation position and lateral views with the forearm in neutral rotation. The severity of collapse were measured based on intrascaphoid (IS) angle and scapholunate (SL) angle.

Functional evaluation was performed using the modified Mayo wrist scoring system (Table 1). Range of motion, grip strength, and pain were measured. Range of motion was reported as both the absolute measurement and that compared with the contralateral side. Maximal grip strength on the injured side was measured and was reported as a percentage of maximal strength on the contralateral side. The pain scale was self-reported and graded with the use of a questionnaire. With the addition of the satisfaction score, a modification of the Mayo Wrist Scoring Chart was used for functional assessment, allowing for a total count of 100 points in four categories.[16]

Table. 1 Mayo Wrist Scoring System

Category	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 activities of daily living
	5	Moderate pain with activities of daily living
	0	Pain at rest
Satisfaction	25	Very satisfied
(25 points)	20	Moderately satisfied
	10	No satisfied, but working
	0	No satisfied, unable to work
Range of	25	100% percentage of normal
motion	15	75%-99% percentage of normal
(25 Points)	10	50%-74% percentage of normal
	5	25%-49% percentage of normal
	0	0%-24% percentage of normal
Grip strength	25	100% percentage of normal
(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	90-100	Excellent
(total points)	80-89	Good
	65-79	Fair
	<65	Poor

RESULTS

The average follow-up was 1.8 years (range, 1.5 to 2.1 years). In four of the five patients, the bones united and trabeculars bridged within 4 months after surgery. The other patient had superficial pin tract infection, therefore, the Kirschner wires were removed. Trabecular bridging of the scaphoid fracture was achieved 6 months after surgery. The mean union time was 4.2 months (range, 3-6 months). The functional results, according to the modified Mayo Wrist Scoring Chart, were rated as good in all five of the patients (Fig. 2 and Table 2).

The preoperative severity of collapse and postoperative correction of deformities were measured and comparatively reviewed with the following results (Table 3). The preoperative IS angle averaged 52 degrees (range, 45-65 degrees); postopera-

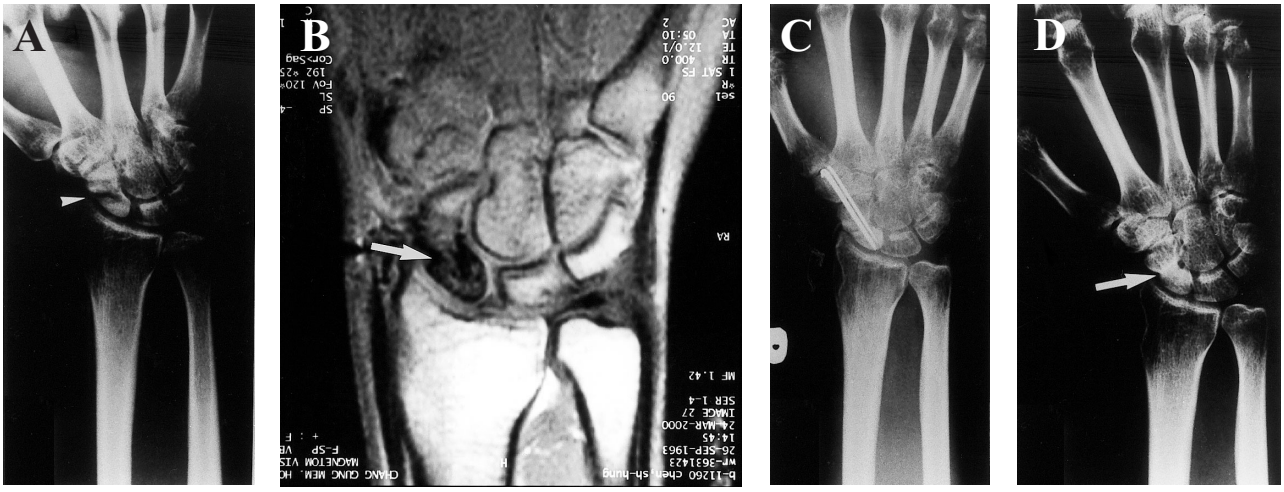

Fig. 2 A 38-year-old male patient with scaphoid nonunion. (A) Radiographs show scaphoid nonunion. (B) MRI shows low signal intensity on T1-weighted images which reveals avascular necrosis of the proximal pole of the scaphoid. (C) Treated with 1, 2 ICSRA and Kirschner wires fixation. (D) Radiographs at 18 months after operation show trabecular bridging of the nonunion site.

Table. 2 Patients List and the Results of Mayo Wrist Score

Age (years)	Side	Gender	Delay (month)	Previous Treatment	Mayo wrist score	Complications
42	Right	M	120	Neglected	80	-
52	Left	F	24	Conservative Treatment	80	Pin tract infection
38	Right	M	4	Conservative Treatment	85	-
55	Right	F	24	Conservative Treatment	80	-
24	Left	M	6	Russe inlay bone graft	85	-

Table. 3 Intrascaphoid (IS) and Scapholunate (SL) Angles (in degrees)

Case No.	Preop IS	Postop IS	Final IS	Preop SL	Postop SL	Final SL
1	45	35	35	75	65	55
2	55	40	35	70	60	60
3	65	50	50	65	55	50
4	45	40	40	50	50	50
5	50	40	40	55	50	50

tive, 41 degrees (range, 35-50 degrees). The mean IS angle of radiographs taken at the final follow-up examination was 40 degrees (range, 35-50 degrees). The differences in the IS angle between preoperative and postoperative radiographs represented the correction of scaphoid malalignment and averaged 11 degrees (range, 5-15 degrees). No significant loss of reduction was noted at the latest follow-up examination (paired *t* test, $p=0.18$). Regarding the intercarpal instability, the mean preoperative and postoperative SL angles were 63 degrees (range, 50-75 degrees) and 56 degrees (range, 50-65 degrees), respectively. The angle of correction averaged 7 degrees (range, 5-10 degrees). There were no statistically significant losses of reduction noted at the final follow-up examinations (paired *t* test, $p=0.10$).

DISCUSSION

The conventional Russe inlay bone graft is considered as the treatment of choice for the patients with scaphoid nonunion.[4,5,7-9] Chen et al. retrospectively review 39 patients with scaphoid nonunion treated using the "sandwich" method that consisted of a wedge corticocancellous strut graft and numerous cancellous bone chips. Divergent Kirschner wires were used for fixation of reduction.[17] All 26 patients had follow-up periods of 3 to 6 years and the nonunion scaphoids of all patients had united within 4 months of their operations. The functional results were either good or excellent.

However, the "sandwich" method is relatively contra-indicated for patients in whom the proximal pole of the scaphoid is totally avascular.[4] Green reported a prospective study of patients with nonunion of the scaphoid treated using the Russe bone grafting method.[7] Twenty-four 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 pre-operation suggestions of severe AVN of the proximal pole are confirmed intra-operatively, a vascularized pedicle bone graft should be strongly considered.[10]

If there is a clinical history of previously failed bone grafting with plain radiographic and MRI evidence of AVN and intraoperative positive findings of the marrow changes in the proximal and distal scaphoid indicating a resolution of AVN, revascularization may be accelerated by the use of a vascularized bone graft. Living bone heals faster than 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 bone. Studies have confirmed that a vascularized bone graft unites directly with the recipient bone without need of revascularization and 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.

Many different methods have been reported for obtaining vascularized grafts. Chacha reported a bone graft with a vascular pedicle from the pronator quadratus.[18] The disadvantages of the pedicle were that the arc was too short and the muscle bulk limited adequate visualization of the reduction. Contraction of the muscular pedicle sometimes caused loss of reduction.

Guimberteau and Panconi reported a vascularized cortical and cancellous bone graft from the ulna.[19] The vascular pedicle was obtained from the ulnar artery. The disadvantages of this procedure included a long operating time and the need to reconstruct the ulnar artery with a venous graft. In addition, the procedure was associated with a risk of fracture of the ulna.

Brunelli et al. described a bone graft that was obtained from the distal part of the second metacarpal.[20] The vascularity of the graft was derived from the deep artery of the first web space on the lateral aspect of the metacarpal. Mathoulin and Brunelli reported that it was difficult to obtain the graft and to position it within the scaphoid.[21]

Gabl et al. described free vascular bone grafts from the iliac crest.[22] Kazuteru et al. described free vascular bone grafts harvested from the femoral supracondyle.[23] The results of their studies were all good but the procedures needed microscopic vessel

anastomosis and required long operative times.

Zaidemberg et al. presented a vascularized bone graft from the radial aspect of the distal part of the radius.[24] The vascular pedicle was based on the recurrent branch of the radial artery. Rather than directly lying on periosteum as originally described, the vessel was lying superficially on the dorsal surface of the extensor retinaculum between the first and second compartments. Because of its location, the vessel was named the 1, 2 intercompartmental supraretinacular arteries (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. Tu et al. reported an animal study and demonstrated that the pedicle vascularized bone grafts maintained enhanced bone circulation long-term, and the data supported the clinical use for scaphoid avascular necrosis.[11,12] Boyer et al. reported scaphoid nonunion with AVN of the proximal pole that was managed with a vascularized dorsal interposition graft from the distal radius.[25] The procedure resulted in the union of 6 of 10 fractures. Uerpairojkit et al. 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.[26] 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. We concluded that vascularized bone graft with 1, 2 ICSRA is useful to repair a nonunion with AVN of a scaphoid fracture.

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以第一、二腔室間支持帶上附血管骨移植治療舟狀骨癒合不良併近端缺血性壞死

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背 景： 舟狀骨骨折復位不良或延誤治療常導致舟狀骨癒合不良及缺血性壞死 (avascular necrosis)。當手術前懷疑及術中證實舟狀骨缺血性壞死時，傳統骨移植常無法治癒，建議必須使用附血管之活骨移植 (vascularized bone graft)。

方 法： 我們提出五例舟狀骨骨折癒合不良，經手術前評估及術中證實併有缺血性壞死，治療以第一、二腔室間支持帶上附血管活骨移植 (1, 2 ICSRA vascularized bone graft)。追蹤時間至少一年半以上，分析其功能性評估 (functional outcome) 及影像學結果 (radiographs)。

結 果： 五例其中的四例，其舟狀骨骨折癒合不良處在四個月內完全癒合。另一例併發骨釘感染 (pin tract infection)，在移除骨釘後半年亦完全癒合。功能性評估皆爲良好。

結 論： 第一、二腔室間支持帶上附血管活骨移植 (1, 2 ICSRA vascularized bone graft) 血管位於支持帶表層，且直接滋養骨骼內。其優點爲在解剖學上易於找到，易於分離出，且術後骨癒合率高，功能性評估結果良好，因此很適合做爲治療舟狀骨骨折併缺血性壞死的附血管活骨移植。

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關鍵字：舟狀骨癒合不良，缺血性壞死，附血管骨移植。

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