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Original Research

Carpal Collapse After Scaphoid Nonunion: A Novel Combined Approach to the 1,2 Intercompartmental Supraretinacular Artery Radial Flap



Konstantinos A. Vakalopoulos, MD, PhD, * Nicolas Balagué, MD, * † Philippe Vostrel, MD, * Sana Boudabbous, MD, † Jean-Yves Beaulieu, MD *

* Department of Trauma and Orthopedic Surgery, Hand and Peripheral Nerve Surgery Unit, Geneva University Hospitals, Geneva, Switzerland

† Department of Radiology, Geneva University Hospitals, Geneva, Switzerland

‡ Department of Plastic and Reconstructive Surgery, Centre Hospitalier du Valais Romand, Sierre, Switzerland

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Purpose: Scaphoid nonunion remains a major problem in hand surgery. The 1,2 intercompartmental supraretinacular artery flap (1,2 ICSRA), as first described by Zaidenberg et al, is widely used with reported union rates of approximately 80%. However, its use is limited in the case of associated carpal collapse as in dorsal intercalated segmental instability (DISI) and humpback deformity. In this study, we present a novel approach to this flap enabling the correction of associated carpal collapse.

Methods: Between 2006 and 2015, 9 patients with scaphoid nonunion or delayed union with carpal collapse were treated with a vascularized bone flap based on the 1,2 ICSRA using a combined volar and dorsal approach. Immobilization in a short-arm cast was applied for 8 weeks. Union rates, correction of DISI and humpback deformity, as well as clinical end points were noted. In addition, scapholunate (SL) angles were measured using 2 accepted radiological techniques, employing either the scaphoid midline axis or its proximal radiological landmarks as a reference.

Results: All cases united and a median time to bone consolidation of 4 months (range, 2–5 months) was observed. Preoperative DISI deformities (n = 4) were corrected in all patients. Humpback deformities (n = 5) were also corrected. Two patients had repeat surgery: one for K-wire removal after bony consolidation and the other for neuropathic pain.

Conclusions: The 1,2 ICSRA bone flap is a reliable treatment for scaphoid nonunion associated with carpal collapse. This combined volar and dorsal approach permits the correction of DISI and humpback deformity without compromising the scaphoid vascular supply, which eliminates the need to use free bone flaps from other sites. In this series, we observed a 100% union rate. Two patients required reoperation for symptomatic hardware and dorsal wrist pain linked to superficial neuritis.

Type of study/level of evidence: Therapeutic IV.

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Fractures of the scaphoid bone represent 60% of all carpal fractures, which makes them one of the most common pathologies dealt with

K.A.V. and N.B. contributed equally to this manuscript.

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Corresponding author: Konstantinos A. Vakalopoulos, MD, PhD, Department of Trauma and Orthopedic Surgery, Hand and Peripheral Nerve Surgery Unit, Geneva University Hospitals, Rue Gabrielle-Perret-Gentil 4, 1205 Geneva, Switzerland.

E-mail address: k.a.vakalopoulos@gmail.com (K.A. Vakalopoulos).

by hand surgeons around the world.¹ Considering that these fractures occur mostly in adults of working age and that median leave of absence from professional activities is 105 days, this remains a major source of medical expenditure with a large societal impact.^{2,3}

One of the most important complications of scaphoid fractures remains scaphoid nonunion. Correctly diagnosed and treated scaphoid fractures are associated with a 5% to 15% nonunion rate, which may lead to serious complications including severe arthritic changes of the wrist and dorsal intercalated segmental instability (DISI) with subsequent diminution of range of motion and chronic

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pain.^{4–7} Treatment of scaphoid nonunion is surgical and is traditionally achieved using nonvascularized bone flaps (NVBF) or vascularized bone flaps (VBF), usually from the distal radius or iliac crest. Currently, there is no consensus on the optimal surgical treatment of scaphoid nonunion. Evidence shows that NVBF and VBF are equal in terms of union rate, postoperative mobility, and grip strength, with screw fixation leading to earlier mobilization than in the case of K-wire (KW) fixation.^{7,8}

Various techniques of VBF have been described, the most popular of which is harvesting the flap from the distal radius or iliac crest. Conceptually, a pedicled bone flap is harvested from the distal radius and redirected into the scaphoid defect without interrupting its vascular pedicle; or, in the case of a VBF from the iliac crest, it is transferred to the nonunion site and perfused by microvascular anastomosis of the pedicle. In both cases, the rationale for VBF repair is to increase perfusion in the scaphoid, an anatomical area notorious for its fragile perfusion.⁹ Because union rates are similar at about 80%, the main difference between them arises from secondary outcomes such as the addition of a second operative site in the case iliac crest VBF and the potential for donor site complications such as infection and postoperative pain.^{8,10} Furthermore, the need for general anesthesia, longer operative times, and microsurgery should be considered for free VBF. Recent studies reported promising results using a VBF from the medial femoral condyle with a low incidence of donor site complications and high union rates¹¹; however, large studies with long-term results are lacking.

Of the VBF, the 1,2 intercompartmental supraretinacular artery (1,2 ICSRA) flap, described by Zaidenberg et al¹² in 1991, remains the most commonly used. This flap uses a vascularized bone wedge from the distal radius, which is then lifted and placed into the nonunion defect, conserving the artery and eliminating the need for a second operative site and microsurgical vessel anastomosis. This technique is associated with a high union rate, even in the presence of avascular bone necrosis (AVN).⁵ The limitation of this flap, according to recent studies, appears to be difficulty in correcting the geometric misalignment of the scaphoid in the sagittal plane.¹ Specifically, this is the case in humpback deformity, when the distal scaphoid fragment is volarly angulated, resulting in augmentation of the scapholunate angle and dorsal tilt of the lunate bone.¹

In our center, we have introduced a novel combined dorso-palmar approach to the 1,2 ICSRA flap that may overcome these limitations by enabling the transfer of a distal radius bone flap into the anterior aspect of the scaphoid nonunion, treating preexisting humpback deformities. Here, we describe the initial results of this technique.

Patients and Methods

In this single-center, retrospective analysis of a prospective series, we included patients who presented with a scaphoid nonunion or delayed union with humpback deformity or DISI between 2006 and 2015 and who were treated by a single surgeon. In these patients, surgical treatment was implemented by means of a novel combined 1,2 ICSRA flap repair combining a palmar and dorsal approach. We obtained approval from our institutional review board (Swissethics Case Number 2018-00178).

Surgical technique

First, a palmar incision is made, passing radially to the flexor carpi radialis tendon and through the radioscapocapitate ligament, directly over the scaphoid tubercle. The nonunion site is located and decorticated and drill holes are made on its proximal and distal borders to fenestrate the bone. Next, the humpback

deformity is corrected with the Linscheid maneuver: the wrist is placed in hyperflexion and the lunate is temporarily fixed with a 1.4-mm (0.045-in) radiolunate KW under fluoroscopic guidance, passing through Lister tubercle. Afterward, the wrist is dorsiflexed, correcting the humpback deformity and enabling direct visualization of the nonunion defect to assess the size of the bone flap. A trapezoidal zone is then created in the palmar aspect of the scaphoid to receive the VBF as an inlay flap, as inspired by Fernandez.¹³

A longitudinal dorsoradial skin incision is then centered on the radiocarpal joint and the 1,2 ICSRA is located between the first and second extensor compartments (Fig. 1). The articular capsule is opened along the axis of the flap, creating access to the radiocarpal joint and the nonunion site. Care must be taken to visualize and protect the radial artery. Next, a radial styloidectomy is performed and the bone flap is harvested in the radial metaphysis, based on the measured bone loss. The bone flap is raised using an osteotome and care is taken to leave a maximum amount of cancellous bone attached to the cortical bone. The periosteoretinacular pedicle should be long enough to permit volar translocation of the bone flap in a tension-free manner (Fig. 2). To ensure this, the bone is harvested about 1 cm proximal to the radial styloid.

A passage is created by blunt dissection between the scaphoid and lateral capsule, ulnar to the first extensor compartment, through which the bone flap is passed anteriorly, making sure not to twist the vascular pedicle. The VBF is then inserted in the prepared nonunion site, and the humpback deformity is corrected macroscopically (Fig. 3). Permanent fixation of the VBF is performed with 2 1.25-mm (0.043 inches) KWs placed in a retrograde

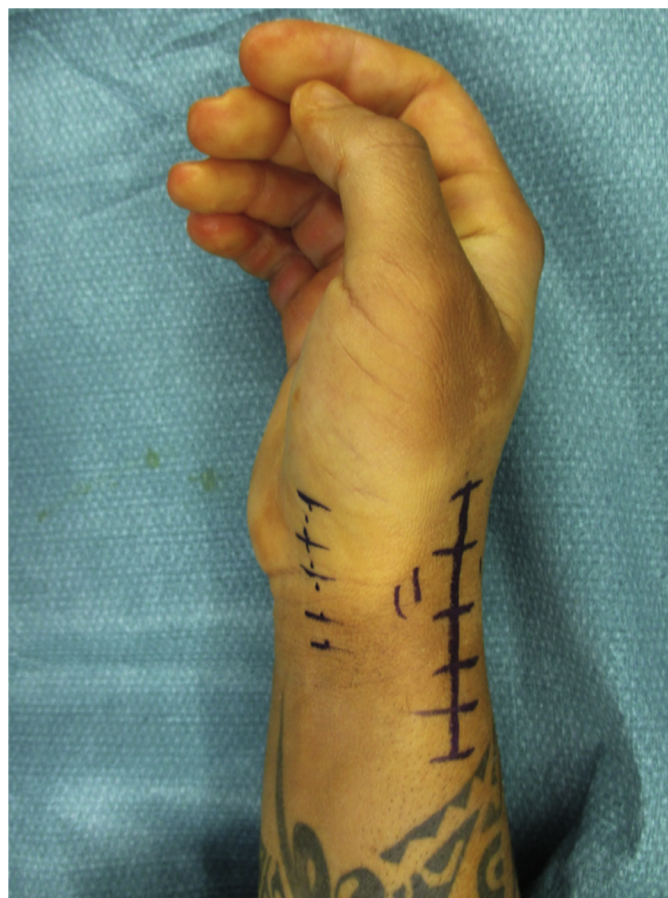


Figure 1. Preoperative incision placement.

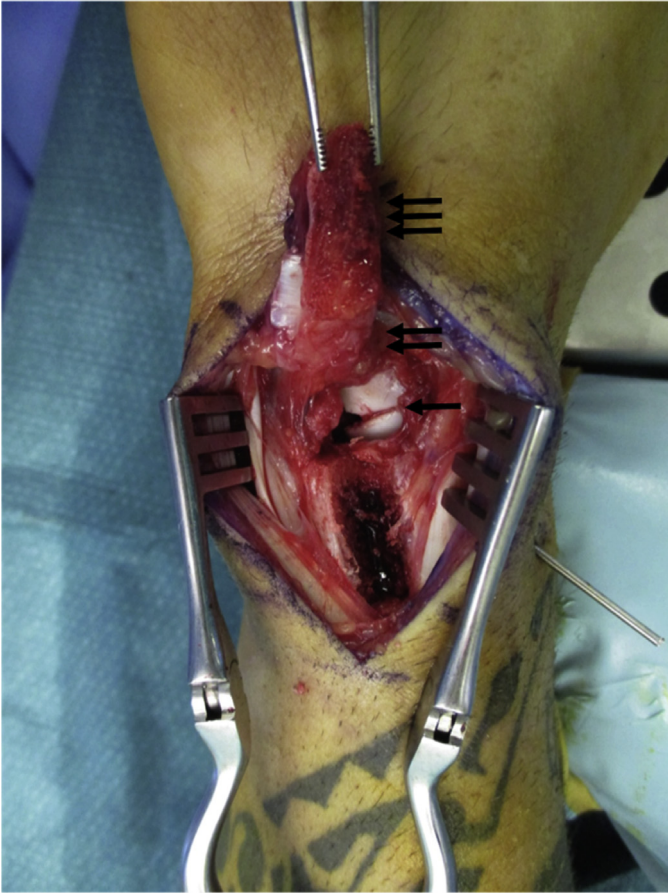


Figure 2. Dorsal view of the nonunion site (single arrow), raised VBF (triple arrow), and pedicle (double arrow).

manner from the distal tubercle to the proximal rim under fluoroscopic control. Both the palmar capsule and the radio-scaphocapitate ligament are repaired. Dorsally, only the skin is closed. No drains are left in place.

Postoperative period

The patient is placed in a postoperative short-arm cast for 8 weeks. At this time, computed tomography (CT) is performed to evaluate bony union. Physical therapy is initiated between the 8th and 12th weeks, depending on the acquired union. A short orthosis is used nocturnally for an additional month after the start of physical therapy.

Study outcomes

The main study outcome was correction of the SL angle on conventional x-rays, performed at 3 time points (ie, before surgery, directly after surgery, and at long-term follow-up). The SL angle was measured by 2 different techniques: (1) the angle between the midplane axis of the scaphoid and the axis joining the distal palmar and dorsal borders of the lunate (MASL); and (2) the angle between the most proximal ventral and dorsal points of the scaphoid and the axis joining the distal palmar and dorsal borders of the lunate (PSB).

All angles were measured by an independent consultant musculoskeletal radiologist (S.B.) who was blinded to study outcomes. Secondary outcomes were the correction of humpback deformity, bone consolidation as measured by CT at 8 weeks, wrist range of motion measurements at 6 months, and the presence of dorsal or ventral intercalated segmental instability (DISI or VISI, respectively), assessed on conventional x-rays. An SL angle of greater than 70° was considered a DISI deformity, and an SL angle of less than 30° was assessed as VISI. Furthermore, we assessed the differences in the 2 most common types of SL angle measurement.

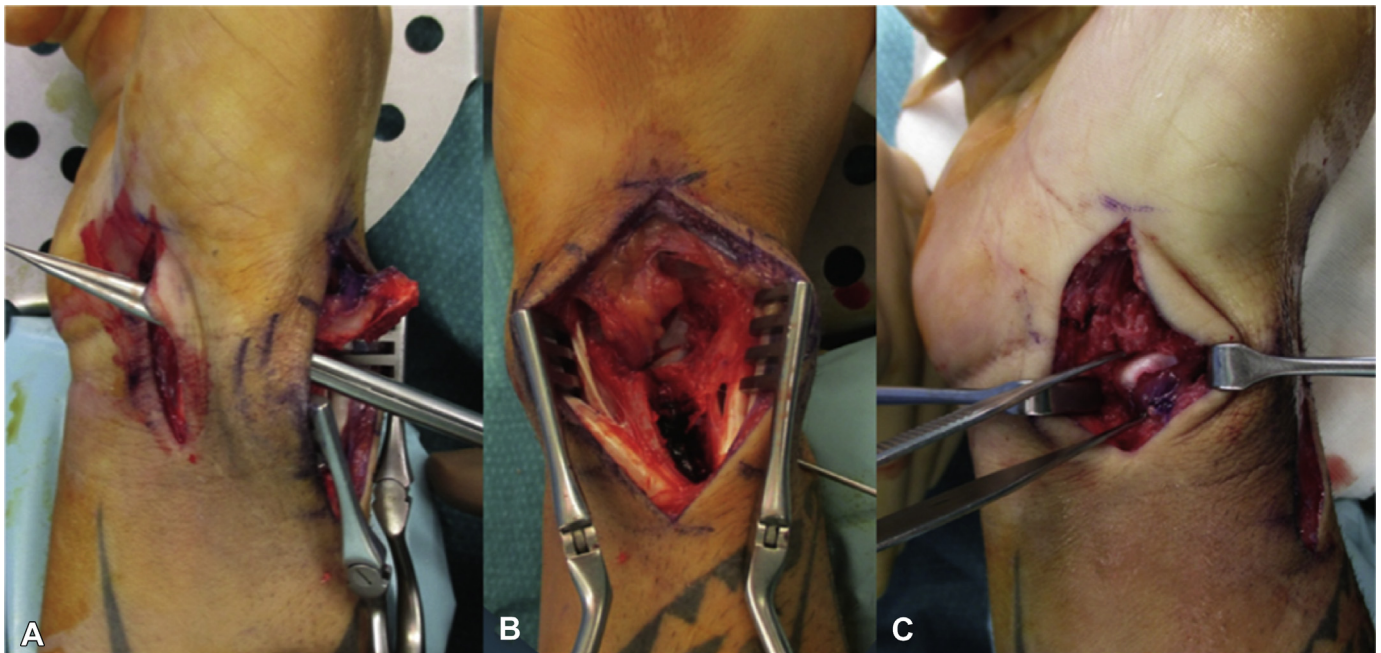


Figure 3. A Palmar passage of VBF created by scissors. B View of transposed pedicle. C Palmar positioning of flap shown between forceps.

Table 1
Demographic and Preoperative Data

Patient	Sex	Age, y	Side	Schernberg Zone	Previous Operation	Delay Operation, mo
1	Male	17	Right	3		5
2	Female	37	Right	4		24
3	Male	18	Right	4	Screw	8
4	Male	30	Right	3	Screw	3
5	Male	25	Left	4		5
6	Male	36	Right	4		7
7	Male	20	Right	4		12
8	Male	19	Left	4		3
9	Male	22	Right	3		10
Median		22				7

The classification of Schernberg et al¹⁴ was used to describe scaphoid nonunion sites.

Statistics

Statistical analysis was performed using SPSS software (version 20.0, SPSS, Chicago, IL). Differences in SL angle measurement technique were considered to be observer dependent; therefore paired *t* tests were used. $P \leq .05$ was chosen to define statistical significance.

Results

Table 1 lists patient demographics. Nine patients were included in this study. Median age was 22.5 years (range, 18–53 years) and most patients (8) were male. Median follow-up was 9 months (range, 3–33 months). Seven patients were initially treated with casting and 2 had previous scaphoid fracture repairs with compression screws. Four patients presented with delayed union, and 5 with nonunion. Median time from injury to nonunion treatment was 6 months (range, 3–24 months). In 3 patients, scaphoid nonunion was discovered incidentally at 10, 12, and 24 months after the initial injury, respectively, after new wrist trauma. Scaphoid nonunion sites were in Schernberg zone 3 or 4 in all patients except one, who had a proximal pole nonunion in Schernberg zone 2 associated with AVN. In this series, VBF fixation was performed with 2 KWs except in the patient with a Schernberg zone 2 nonunion, in whom 3 KWs were used. Median time to KW removal was 5 months (range, 2–10 months). Bone consolidation, as assessed by CT imaging, was acquired in 100% of patients. Median time to obtaining complete bone consolidation was 4 months (range, 2–5 months), as described in Table 2. Mean wrist flexion

Table 2
Operative Data

Patient	Graft Size, mm	Consolidation Time, mo	Follow-Up, mo	Complication
1	10 × 10	5	33	Dorsal wrist pain
2	8.4 × 9.4	4	24	K-wire migration
3	9 × 11.5	5	3	Radial neuralgia
4	9.2 × 10.1	2	12	
5	10 × 10.5	5	9	
6	6.4 × 11.7	4	8	
7	7.2 × 10.5	3	7	
8	9.2 × 9	2	9	
9	10.2 × 9.6	3	6	
Median	9.2 × 10.1	4	9	

and extension at 6 months were 38° (range, 30° to 40°) and 40° (range, 20° to 60°), respectively.

Before surgery, 4 patients had a DISI deformity when measured with the MASL measurement. When using the PSB technique, a total of 8 patients had a DISI deformity (Fig. 4). After surgery, DISI deformity was corrected in all cases; in one case, it was overcorrected into a VISI deformity with an SL angle of 29°. Table 3 lists SL measurements. Mean postoperative correction of SL angle was 18.2° (range, 1.32° to 29.66°) in the case of MASL and 20.6° (range, 9.21° to 32.70°) for PSB. No significant difference was found between the 2 measurements ($P = 0.3$; degrees of freedom = 8). There was no correlation between MASL and PSB measurements ($r = .69$; $P = .041$) (Table 2). Preoperative humpback deformity was corrected in all cases.

Median size of the VBF was 9.2 × 10.1 mm, varying between 6.4 and 10.2 mm of transversal length and 9 and 11.7 mm of longitudinal length. Two patients had a complication requiring reoperation: dorsal wrist pain in one patient was due to inflammation of the posterior interosseous nerve (PIN), linked to a positive Tinel sign on the dorsum of the wrist and confirmed by echography. This was successfully treated by resection of this nerve. A second patient had KW migration presenting after bone consolidation and resolving after pin removal. One additional patient had a minor complication consisting of radial nerve irritation that resolved spontaneously.

Discussion

Treatment of scaphoid nonunion remains challenging in hand surgery. Traditionally, VBF and NVBF are used and provide similar results in terms of bone consolidation. Nevertheless, nonunion persists in approximately 8% and 12%, respectively.^{6,8,15} The presence of proximal pole AVN or humpback deformity may further decrease union rates. A recent meta-analysis of VBF union rates reported a general union rate of 83.3% for the 1,2 ICSRA flap, decreasing to 79.2% in the presence of AVN.¹⁶ Moreover, the 1,2 ICSRA flap was associated with a union rate of 64% when used for nonunion in the presence of carpal collapse and humpback deformity.^{17,18} However, Henry¹⁹ reported a 100% union rate in 15 patients with collapsed scaphoid nonunion with DISI treated with palmar translocation of the 1,2 ICSRA flap without the previously described volar skin approach. In this series, we found a 100% union rate as confirmed clinically and radiologically.

Recent studies on the use of the free medial femoral condyle flap²⁰ showed promising results for the treatment of scaphoid nonunions, with reported union rates of 94% to 100%.^{16,17} This flap gave particularly good results in patients with proximal pole AVN and those with scaphoid collapse with humpback deformity or DISI deformations.¹⁷ This may be a promising technique for scaphoid nonunion treatment; however, level I evidence as well as long-term results are still lacking. Moreover, this technique implies operating on an asymptomatic, healthy knee and demands the use of general anesthesia, access to microsurgery, and possible donor site complications.¹¹ A study by Windhofer et al²¹ on knee donor site morbidity after the use of a medial femoral condyle flap for carpal reconstruction showed satisfactory long-term results but noted a period of approximately 3 months before pain and discomfort subsided. Furthermore, femoral osteonecrosis after medial condyle bone graft harvest has been reported.²²

The main limitation of the 1,2 ICSRA flap is the treatment of associated scaphoid collapse with humpback deformity. As the scaphoid collapses volarly, a pure dorsal approach to the scaphoid will not allow visualization of the palmar defect and may prevent anatomical correction of the defect, potentially leading to lower union rates.^{1,21} As Amadio et al^{23,24} demonstrated, the correction of humpback deformity is pertinent for preventing degenerative

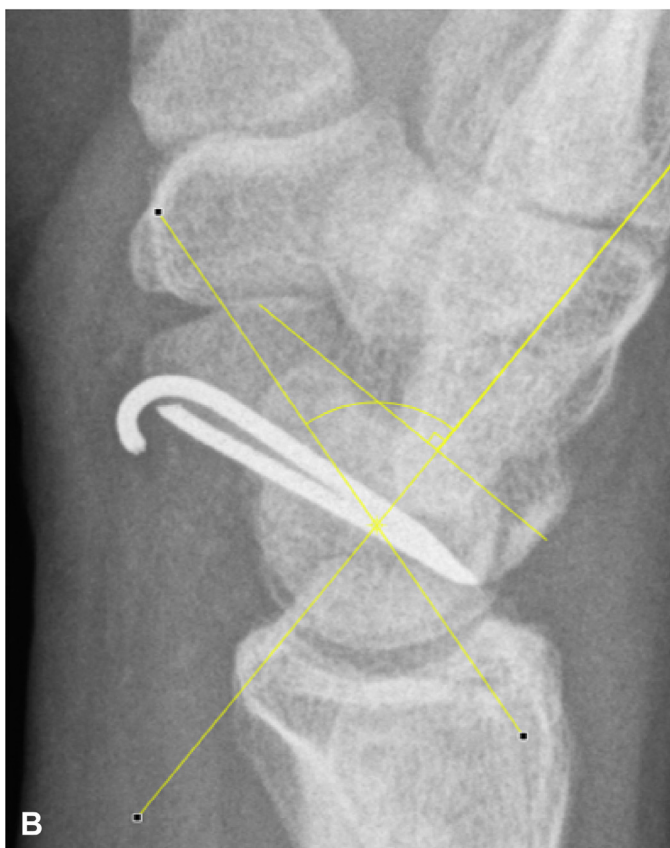


Figure 4. Scapholunate angle measurement. **A** Scapholunate angle measurement using the PSB technique (SL angle = 74.6°). **B** Scapholunate angle measurement using MASL technique (SL angle = 74.2°).

Table 3
Scapholunate Angles*

Patient	Preoperative SL Angle	Postoperative SL Angle	Long-Term SL Angle	SL Angle Correction
1	76.4°/74.8°	65.1°/65.6°	44.2°/57.89°	11.3°/ 9.2°
2	50.0°/50.9°	31.6°/29.6°	28.0°/28.83°	18.4°/21.2°
3	66.7°/ 70.3°	47.1°/49.8°	55.0°/58.7°	19.6°/20.5°
4	67.4°/ 73.5°	37.8°/40.8°	45.9°/64.5°	29.7°/32.7°
5	82.3°/80.1°	64.6°/65.8°	69.3°/69.3°	17.7°/14.3°
6	86.8°/84.5°	62.1°/67.2°	72.8°/73.7°	24.7°/17.3°
7	76.9°/85.8°	51.0°/55.8°	78.0°/73.1°	25.9°/30.0°
8	58.9°/ 73.4°	57.6°/58.8°	63.4°/59.7°	1.3°/14.6°
9	65.4°/ 72.4°	49.8°/46.7°	66.0°/53.4°	15.7°/25.7°
Mean				18.24/20.60

SL angle on right is PSB technique.

* Pathological (DISI) angles are in bold. Scapholunate angle on left is MASL technique;

changes. They concluded that scaphoid fractures with more than 35° of lateral intrascaphoid angle should be corrected to prevent posttraumatic arthritis. According to a study by Patayakes et al,¹⁸ scaphoid waist nonunions, especially with a humpback deformity, should not be treated by dorsal 1,2 ICSRA flaps because they are not shaped to fit volarly and cannot restore the scaphoid anatomy.

In this series, a combined volar and dorsal technique enabled treatment of the humpback deformity by placing the VBF volarly, directly into the scaphoid defect (Fig. 5). All cases of preoperative humpback deformity were corrected.²⁵ In the current series, the largest flap was 1 × 1.5 cm. The flap was harvested in the metaphyseal zone of the radius, ensuring optimal quality and quantity of cancellous bone. We recommend performing the palmar approach first, correcting the humpback deformity and enabling precise measurements of the receiver site under direct visualization.

Several authors reported that when placed volarly, a dorsal flap may induce kinking of the pedicle.^{18,26,27} In our series, we did not observe kinking of the pedicle. This may be because of a long proximal dissection of the vascular pedicle and meticulous verification of the absence of kinking, essential steps in the surgical procedure. Another potential reason may be that a radial styloidectomy was performed in all patients. It is possible that radial styloid impingement may lead to kinking of the vascular pedicle²⁸ and that a styloidectomy avoided this potential complication. Finally, we observed no bone devascularization or proximal pole necrosis in this study. One patient required reoperation for dorsal wrist pain linked to the PIN. Our surgical approach passes between the first and second extensor compartment, radial to the PIN. However, if the PIN is visualized, we believe it should be resected and thermocoagulated to prevent neuroma formation.

We decided to include SL angle measurements based on 2 classic measurement techniques, because clinically we found that there was large interobserver variance between SL angles. In fact, there is no consensus on how to measure an SL angle correctly, and textbooks propose using either the midaxis of the scaphoid or the proximal border of the scaphoid, in relation to the lunate.²⁹ In this study, the proximal border technique systematically provided larger SL angles than the midaxis technique, leading to a higher number of preoperative DISI when that technique was used. This finding is interesting because the exaggerated SL angles provided by the proximal border technique led to a higher incidence of DISI deformity, which may change the therapeutic approach in these patients. We believe there is a need for a more systematic approach to SL angle measurement, which may increase interobserver correlation and aid in diagnosing carpal collapse. Further research on this



Figure 5. Conventional x-ray images of **A, B** preoperative nonunion with associated humpback deformity and DISI and **C, D** postoperative VBF with correction of humpback deformity and DISI.

subject may shed light on the actual interobserver variability of various (radio)carpal angles.

The combined volar and dorsal approach to the classic 1,2 ICSRA radial flap as presented in this small series may enable surgeons to repair scaphoid nonunions with subsequent carpal collapse and humpback deformity. This technique avoids the

need for a second operative site or microsurgery and can be performed under regional anesthesia. In this study, all patients acquired complete scaphoid union and all humpback deformities were corrected. This novel technique should be further examined in a larger prospective series with a long-term follow-up. Furthermore, we found that large differences existed between

the standard measurement techniques for the SL angle, which may have clinical implications in terms of the presence of DISI carpal misalignment; this may be an interesting subject for further research.

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