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Original article

Volar rerouting of the 1,2 intercompartmental supraretinacular artery vascularized bone graft for middle and distal scaphoid nonunions

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Abstract

Background The bone graft vascularized by the 1,2 intercompartmental supraretinacular artery (1,2 ICSRA) placed on the scaphoid by a dorsal approach is a technique used to treat scaphoid nonunions with avascular necrosis of the proximal pole and without significant bone loss or carpus collapse. We present the results of patients treated with a volar rerouting of the 1,2 ICSRA graft under the tendons of the first extensor compartment to treat more distal scaphoid nonunions than the proximal pole. The aim of this study was to assess the clinical and radiological outcomes of patients operated with this technique with the hypothesis that it would allow to treat more distal nonunions than those of the proximal pole.

Patients and methods This retrospective study involved patients treated by a volar rerouting of the 1,2 ICSRA graft for nonunions of the middle and distal thirds of the scaphoid. Assessments included clinical outcomes and radiological bone consolidation. QuickDASH and Mayo Wrist scores were computed. Range of motion and grip strength were evaluated for both the operated and the contralateral sides.

Results Nineteen patients were followed-up for 33 months (range: 6-75). Mean postoperative QuickDASH score was 10 (range: 0-45), and mean Mayo wrist score was 85 (range: 50-100). Flexion and extension, ulnar and radial deviations were statistically different between the affected and healthy sides ($p<0,05$). Consolidation was achieved in 17 patients (89%).

Discussion This technical modification allowed good functional outcomes and scaphoid consolidation. It expands the classic indications of the vascularized 1,2 ICSRA bone graft to more distal nonunions than the proximal pole.

Level of evidence IV

Keywords Wrist; scaphoid nonunion; 1,2 ICSRA; vascularized bone graft; Zaidemberg.

INTRODUCTION

Several surgical techniques have been described to treat scaphoid nonunions depending on the location of the nonunion, the vascularity of the proximal pole, the volume of bone loss and the severity of carpal collapse. The choice between the different techniques remains controversial [1–3].

Zaidemberg et al. described a dorsally-based radial bone graft vascularized by the 1,2 intercompartmental supraretinacular artery (1,2 ICSRA) [4]. This popular technique is classically indicated to treat avascular necrosis of the proximal pole without significant bone loss or carpal collapse [4–6]. Its indications are limited given the dorsal location of the pedicle between the first and second extensors compartment that requires a dorsal approach and gives access to the proximal scaphoid pole with ease whilst more distal nonunion sites are difficult to reach and important humpback deformities or anterior bone resorptions difficult to correct [1,7].

Our hypothesis was that a volar rerouting of the graft, access and volar grafting would offer good functional results and consolidation rates on patients presenting distal nonunions to the proximal pole. This volar rerouting of the graft has been suggested previously and the measurement of the pedicle length have been assessed by anatomical studies [4,6,8–13]. However, there is no precise description of the technique nor standardized clinical evaluations of patients treated with it.

Our aim was to describe the clinical results of patients presenting more distal nonunions than the proximal pole treated with a volar rerouting of the 1,2 ICSRA vascularized bone graft.

This study aimed to answer three questions:

- What are the QuickDASH and Mayo Wrist Score of patients treated with this technique?

- Is there an improvement on range of motion and grip strength of patients treated with this technique?
- Is it possible to achieve bone consolidation and correction of the carpal deformity with this technique?

METHODS

This single-center, single surgeon, retrospective study took place between June 2017 and July 2018 and respected the STROBE guidelines.

Patients presenting nonunion of the middle or distal third of the scaphoid who underwent this surgical procedure between January 2011 and January 2018 were included. All patients presented an anterior bone resorption. Fifteen patients had a dorsal intercalated segment instability (DISI) on preoperative radiographs. No patient had radiographical signs of avascular necrosis. The minimum last follow-up was 6 months. Patients were evaluated by an independent evaluator. Data collection took place between November 2017 and June 2018. Epidemiological characteristics were described as well as the etiology of the injury and the date of return-to-work.

The simplified "Disabilities of the Arm, Shoulder and Hand Questionnaire" (QuickDASH) score and Mayo wrist score were calculated [14,15]. Assessment of range of motion (ROM) included goniometric measurements of pronation/supination, ulnar/radial deviation, and flexion/extension of the wrist. Grip strength was measured in kilograms-force (kgf) with a Jamar® hydraulic dynamometer (Performance Health, France) and data were compared to the contralateral side. Bone consolidation was assessed at the last follow-up based on cortical continuity and no evidence of nonunion on standard X-rays which included: anteroposterior, lateral, and anteroposterior with ulnar deviation views [16]. The radiolunate angle was compared pre-and postoperatively to assess correction of the proximal row deformity. Images were obtained via a digital camera.

Surgical technique

A specialized consultant in hand surgery performed all surgeries. This technical modification has been exposed by Falcone et al, in a previous anatomical article [8]. Patients underwent surgery under brachial block, in supine position with an arm tourniquet. The approach was dorso-radial sinusoidal crossing the radial styloid and extending towards the volar aspect of the hand at the cutaneous dorsal/palmar skin junction of the thumb (Fig. 1).

Subcutaneous dissection allowed identification and protection of the dorsal radial sensitive branches. Through the volar approach, the radial artery was identified and protected before opening the radio-scapho-capitate ligament and the volar capsule to access the nonunion site. A temporary radio-lunate 0.062" Kirschner-wire was introduced with the wrist in flexion, then the wrist was extended to correct the DISI deformity ("Linscheid maneuver") and to assess the loss of scaphoid height [17–19]. Nonunion was exposed and its edges were resected until healthy bone was found.

Through the dorsal approach, the 1,2 ICSRA was identified and the first and second extensor compartments were incised lengthwise to release the pedicle. A rectangular cortico-cancellous bone graft was harvested from the dorsal radius according to the size of the scaphoid bone loss. The pedicle was elevated from the radius subperiosteally. It is important to keep the distance between the radial styloid and the proximal end of the graft less than 37 mm to guarantee its vascularization. It is recommended to include a bone segment between 8-18 mm from the articular surface as the number of perforators is maximal at this point [8,20]. A second lateral arthrotomy was made beneath the tendon extensors from the joint to the anatomical snuffbox with Halstead forceps to protect the pedicle. The graft was hold with forceps without catching the pedicle and it was diverted under the tendons of the first extensor compartment, trough the lateral arthrotomy and around the scaphoid to place it at the volar opening of the articular capsule (Fig. 2). We recommend to keep the dorsal side of the graft parallel to the articular surface of the radius to avoid kinking of the pedicle during the volar rotation of the graft which can be up to 155° [8]. In case of tension of the pedicled a radial styloidectomy could be considered [20]. The graft was then placed on the volar scaphoid with the dorsal side facing volarly and with its length at the site of greatest bone loss. The scaphoid was fixed with a retrograde, self-tapping, self-drilling 2.5 mm screw (AutoFIX, Stryker, United States). The temporary radiolunate Kirschner-wire was removed at this point.

Fluoroscopy was used to control anatomical reduction and material placement. Skin was closed and the tourniquet was released at the end of the procedure. Wrist was immobilized in neutral position with a short thumb-free spica splint for 6 weeks and patients were allowed to move unrestricted after splint removal.

Three patients required radial styloidectomy: two because of symptomatic radioscaphoid conflict due to scaphoid nonunion advanced collapse stage 1 (SNAC 1), and one to secure the pedicle by decreasing its tautness.

Informed consent was obtained from patients. The study protocol respected the ethical guidelines of the 1975 Declaration of Helsinki which and it was approved by the local Institutional Review Board.

Statistical methods

Quantitative data are expressed as means and standard deviation (SD), median and range (min-max). Qualitative data are expressed as numbers and percentages. Due to the sample size, comparisons of functional scores between healthy and affected sides were performed using the non-parametric Wilcoxon rank test. Threshold of significance was set at 5% ($\alpha = 0.05$) and all tests were bilateral.

RESULTS

Nineteen patients underwent surgery between January 2011 and January 2018. All patients were included for analysis: 17 men (89%) and two women (11%). Mean age was 24.9 years (SD 9.1; range: 14-45). The sample consisted of 12 active workers (63%), four school students (21%) and three university students (16%). Five patients were active smokers (26%).

The dominant hand was treated in nine patients (47%). The accident was work-related in four cases (21%). The initial fracture mechanism was a fall in 16 cases (84%), a shock against a wall with the wrist flexed in one patient (5%) and reception of a ball with the wrist extended in two patients (11%). Eighteen patients had scaphoid nonunion at the waist (Schernberg zones 2-4) (95%) and one had a nonunion of the distal scaphoid (Schernberg zone 5)(5%) [21,22]. All patients had an anterior bone resorption and fifteen had a DISI deformation (79%). No patient presented avascular necrosis of the scaphoid. The mean time between the initial trauma and the surgery was 31.9 months (SD 49.5) (range: 3-180). All patients returned to work. The average sick leave was 12 weeks after surgery (SD 14.5) (range: 1-52).

Mean follow-up was 33.4 months (SD 21.6) (range: 6-75). No patient was lost to follow-up. One patient was previously treated with a bone graft from the distal volar radius vascularized by the volar carpal artery. Six patients had an onset of radiocarpal osteoarthritis (SNAC 1). Epidemiological data is summarized in Table 1.

Mean postoperative QuickDASH score was 10.4 (SD 12.3) (range: 0-45) and mean Mayo score was 84.5 (SD 13.4) (range: 50-100). Ulnar deviation, radial deviation, flexion, and extension were statistically different between the operated and the healthy hand ($p<0.05$). Mean difference in grip strength between the two hands was -2.7 kgf (SD 6.9) (range: -18-12) ($p=0.130$) (Table 2).

Mean postoperative immobilization length was 5.9 weeks (SD 0.7) (range: 4-8). No secondary displacement of material occurred. One patient developed a complex regional pain syndrome (CRPS) type 1. One patient presented flexor carpi radialis tenosynovitis by ectopic bone formation and required revision surgery for resection. One patient developed a volar and irritative osteophyte of the scaphoid that required surgical excision. Three patients had dorsal dysesthesia of the wrist surrounding the scar that resolved secondarily. One patient developed a deep infection requiring surgical drainage and antibiotics without consequences on bone consolidation.

Radiologically, 17 scaphoids were consolidated at the last follow-up (89%). The radiolunate angle decreased from 21.4° (SD 13.9°) (range: 2-50) preoperatively to 4.2° (SD 8.1°) (range: -15°-12°) postoperatively ($p<0.001$) (Fig. 3).

DISCUSSION

We report clinical and radiological outcomes of a modified 1,2 ICSRA bone graft technique to treat middle or distal-third scaphoid nonunions.

Our clinical functional results were good based on the early return to activities of patients, the mean QuickDASH score, the mean Mayo wrist score, and the grip strength (Table 2). The mean QuickDASH score was 10.4 which corresponds to the upper limit of the normative value proposed by Aasheim et al. for the same group age and it is similar to other publications that studied Zaidemberg's graft [23–25].

Conversely, consolidation rates are more heterogeneous in the literature and range from 27% for the worst results to 100% for the best results using the 1,2 ICSRA bone graft [1,4]. With 17 out of 19 patients (89%) showing bone consolidation our results are rather satisfactory but its relevance is arguable as its rate is not 100%. We analyzed retrospectively the two cases (11%) that failed to consolidate to look for confounders. We found that one patient was an active smoker with a long-lasting intoxication (520 pack years) suffering from *polycythemia vera* which is associated with thrombotic complications [26,27]. The second patient did not have any comorbidity and our hypothesis is that failure might have been influenced by a too short screw whom thread did not completely penetrate the proximal fragment and therefore offered less compression and bone stability [28]. Both patients had a nonunion of the waist of the scaphoid.

Regarding the correction of carpal collapse, we achieved to correct the proximal row deformation (DISI) from a mean preoperative radiolunate angle of 21.4° to 4.2° which is inside the range of the normal values of the general population [29]. In our study, the graft size was enough to fill the bone gap after resection of the fibrous tissue and correction of the DISI deformity based on preoperative fluoroscopy without compromising its vascular pedicle. The short pedicle length of the 1,2 ICSRA, the arduous access to distal nonunion sites and poor correction possibilities are the main reasons of its classical limited indications to the proximal scaphoid nonunions. Similarly, some authors argue that the size of the graft is insufficient to correct humpback deformities and to fill important bone losses [1,3,4,7,30,31].

The length of the 1,2 ICSRA pedicle and the volar placement of the graft have been assessed on cadaveric studies and similar techniques have been studied clinically by three authors [4,6,9–13]. One specific anatomical study has demonstrated that the pedicle was long enough to reach distal nonunion sites by rerouting the graft below the tendons of the first compartment [8]. The three clinical publications exposing a similar technique confirmed its feasibility and efficacity by achieving consolidation rates of 97-100% on patients with nonunion of the proximal-third or waist [9–11]. Those authors agree with us to affirm that a combined dorsal and volar approach offers good exposure of more distal nonunions than the proximal-third and allow better assessment and correction of the scaphoid deformity compared to the classic dorsal approach [4].

Those publications have however some discrepancies with our study. First, they treated scaphoids presenting avascular necrosis confirmed whether by magnetic resonance imaging and/or perioperative visualization of proximal pole viability. In our study, no patient had vascular necrosis on preoperative radiographs. The controversy about the reliability of diagnostic tools to assess scaphoid vascularity and their value in the treatment of nonunion is beyond the scope of this study [32,33]. We decided of a vascularized graft based on the higher consolidation rates of vascularized bone grafts compared to non-vascularized bone grafts, the low donor site morbidity and the better clinical and radiological results on patients that received a vascularized bone grafting as a primary procedure [1,34,35]. Secondly, unlike our study, those articles used Kirschner-wires for fixation. This explain the complications they encountered due to this material: pin infection, painful prominence of the material which required removal, and extrusion from the graft probably due to insufficient rigidity. Finally, Henry proposed to access the volar scaphoid while working through a dorsal and radial skin incision. We believe his modification preserves the skin innervation and avoid the dysesthesias observed by Ingari et al. and by us [9]. However, it requires a wide opening of the first and second compartments to achieve a volar retraction of the tendons and might offer poorer visibility of the volar scaphoid compared to our technique as we reroute the graft around the scaphoid, under the extensor tendon and access the volar capsule of the scaphoid volarly. Yajima et al. described a similar technique but only four patients were included, and few information is given regarding clinical and radiological results to allow analysis [11].

In our study, three patients required radial styloidectomy, two because of symptomatic radioscaphoid conflict due to scaphoid nonunion advanced collapse stage 1 (SNAC 1), and one to secure the pedicle by decreasing its tautness at the beginning of surgeon's experience [36]. Given the neurovascular and ligamentous complications reported after radial styloidectomy (injury of the dorsal branches of the radial sensory and lateral antebrachial cutaneous nerves, injury to the dorsal branch of the radial artery, wrist instability) we avoided it as it was not required to allow visualisation and grafting of the scaphoid in the remaining cases. However, one should keep in mind that styloidectomy might be required in cases of pedicle tautness or poor surgical exposure [1,6,20].

The indication of vascularized bone grafts for cases without avascular necrosis is questionable. A metanalysis of 147 publications analyzed consolidation rates of vascularized and non-vascularized bone graft and found higher rates for the former with values above 91% [34]. More interestingly, one study compared consolidation rates and clinical results of vascularized bone grafts as a primary procedure versus vascularized grafted used after failure of a non-vascularized bone graft in patients without avascular necrosis. Their results encourage the use of local vascularized bone graft as a primary procedure as secondary vascularized bone grafts have worst outcomes after non-vascularized bone grafts even in cases without avascular necrosis of the proximal pole [35]. Given these results, and relative easy technique, we decided to use the 1,2 ICSRA graft despite the lack of avascular necrosis [1,30]. For us, the 1,2 ICSRA bone graft is a reliable technique that does not require difficult dissection as the vessel are superficial on the extensor retinaculum, the donor site morbidity is low, and the procedure can be carried out under regional anesthesia as an outpatient surgery [1].

The main limitation of our study is its retrospective design which did not allow to collect data necessary for a detailed analysis. A comparison of pre- and post-operative data would have provided information the clinical evolution after surgery. Similarly, we analyzed bone consolidation at last follow-up (≥ 6 months) and we could not give the precise time of bone healing. Such analysis would have required another study schema with closer radiological follow-up. The correction of anterior bone loss and scaphoid height loss were assessed intraoperatively after resection of the fibrous tissue, correction of DISI deformity and measurement of the radiolunate angle. Other more direct measurements such as the preoperative intrascaphoid angle would help to measure the deformity directly [37]. However, as Henry described, we be believe that intraoperative visualization after nonunion resection, correction of the bone loss and of the proximal row deformity offers a more precise evaluation than preoperative imaging as the graft should be tailormade to the intraoperative bone loss [10].

Our results also suffer from selection bias as five patients were smokers, one patient had been previously treated with another vascularized graft, one patient suffered *from polycythemia vera* and six patients presented radioscaphoid osteoarthritis (SNAC 1) which are risk factors of thrombosis or nonunion treatment failure [38,39].

Another limitation of our study is the evaluation of consolidation with standard X-rays instead of using more sophisticated tools. We believe that bone consolidation can be assessed easily on radiographs based on cortical continuity between the graft and the bone, absence of gap at the graft interface, latency around the graft, movement of the implant, or displacement of the graft which are signs of nonunion [16]. Even if CT-scanning is easily available and its irradiation has been reduced, it is arguable to prescribe it to patients that do not complain post-operatively and have stable X-rays without signs of nonunion nor degenerative changes [33]. Moreover, CT scans and MRI can be difficult to interpret as the dichotomy between union and nonunion is sometimes challenging due to the radiological noise from the fixation hardware [33]. Those tools remain less accurate to assess bone consolidation than bone scintigraphy which is the most precise diagnostic tool but it is not a routine technique [33,37,40–44].

The current concerns regarding treatment of scaphoid nonunions are to define whether vascularized grafts are necessary and whether nonunions of the proximal pole require vascularized grafts. These concerns were presented recently but the treatment and etiopathology of scaphoid injuries are still debatable [45]. From a vascular point of view, Xiao et al. demonstrated that vascularization of the scaphoid was not as precarious as reported by Gelbermann and Menon in 1980 [46–48]. For the former authors, there are two to three constant arterial trunks that enter the bone through the dorsal crest of its isthmus, no artery penetrates the proximal 40% of the scaphoid and the major trunk enters the bone only distally to the proximal half of the bone. Thus, the high incidence of proximal pole nonunions could be explained not only by the poor vascularization of the bone but also by the pressure exerted medially by the capitate on the proximal pole which causes bone stresses translated by a major radiologically density classically interpreted as necrosis [46].

As these concerns about vascularization remain, there is no consensus regarding the best bone graft [2,3]. Some authors argue that vascularized grafts are not mandatory while others consider that reduction of the DISI deformity is the critical parameter to be addressed [17,32,49,50]. Pinder et al. reviewed 48 articles and compared the effectiveness of vascularized versus non-vascularized techniques and showed that none of the techniques were better than any other [2]. Only the study of Jones et al. offers a good level of evidence comparing two techniques [51]. They demonstrated superiority of free vascularized grafts from the medial femoral condyle compared to 1,2 ICSRA grafts in terms of consolidation rates. Although the study was well conducted, we believe that free grafts remain poorly reproducible, require specific technical platforms and highly experienced teams. This technique exposes to greater donor site morbidity compared to pedicled bone grafts and would be more suitable after failure of pedicled bone grafts and in the hands of experienced microsurgical teams [31,52–54].

In conclusion, treating mid to distal scaphoid nonunions by volarly rerouting the 1,2 ICSR bone graft offers good functional results. Patients should be informed of the consolidation rates and potential complications rates. This technique widens the indications of the classical graft to more distal nonunions than the proximal pole.

Conflicts of interest: none

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Authors' contribution:

Camilo Chaves: writing and data analysis

Ghada Asmar: data recovery and analysis

Fanny Billac: analysis and review

Marc-Olivier Falcone: supervisor

REFERENCES

[1] Henry M. Scaphoid nonunion: What is the role of the zaidemberg 1,2 intercompartmental supraretinacular arterial flap? J Hand Surg Eur Vol 2018;43:41–7. doi:10.1177/1753193417739510.

[2] Pinder RM, Brkljac M, Rix L, Muir L, Brewster M. Treatment of Scaphoid Nonunion: A Systematic Review of the Existing Evidence. J Hand Surg Am 2015;40:1797-1805.e3. doi:10.1016/j.jhsa.2015.05.003.

[3] Shin EH, Shin AY. Vascularized Bone Grafts in Orthopaedic Surgery. JBJS Rev 2017;5:e1. doi:10.2106/JBJS.RVW.16.00125.

[4] Zaidemberg C, Siebert JW, Angrigiani C. A new vascularized bone graft for scaphoid nonunion. J Hand Surg Am 1991;16:474–8. doi:10.1016/0363-5023(91)90017-6.

[5] Alluri R, Yin C, Iorio M, Leland H, Mack W, Patel K. A Critical Appraisal of Vascularized Bone Grafting for Scaphoid Nonunion. J Wrist Surg 2017;06:251–7. doi:10.1055/s-0036-1597575.

[6] Saint Cast Y, Césari B, Dagregorio G, Le Bourg M, Gazarian A, Raimbeau G, et al. Simplified scaphoid reconstruction technique with Zaidemberg's vascularized radial graft. Orthop Traumatol Surg Res 2012;98:S66-72. doi:10.1016/j.otsr.2012.04.007.

[7] Jones DB, Bürger H, Bishop AT, Shin AY. Treatment of scaphoid waist nonunions with an avascular proximal pole and carpal collapse. A comparison of two vascularized bone grafts. J Bone Joint Surg Am 2008;90:2616–25. doi:10.2106/JBJS.G.01503.

[8] Chaves C, Asmar G, Falcone M-O. Anterior rerouting of the 1,2 intercompartmental supraretinacular artery-based bone graft for scaphoid non-union: an anatomical study. J Hand Surg (European Vol 2020;45:193–5. doi:10.1177/1753193419876900.

[9] Ingari J V., Nayar SK, Taylor KF. Volar Vascularized Strut Graft for Avascular Scaphoid Nonunion Using the 1,2 Intercompartmental Supraretinacular Artery. Tech

Hand Up Extrem Surg 2019;23:14–21. doi:10.1097/BTH.0000000000000215.

[10] Henry M. Collapsed scaphoid non-union with dorsal intercalated segment instability and avascular necrosis treated by vascularised wedge-shaped bone graft and fixation. J Hand Surg Am 2007;32:148–54. doi:10.1016/j.jhsb.2006.11.018.

[11] Yajima H, Ono H, Kizaki K, Yamauchi T TS. Vascularized bone graft for scaphoid necrosis and nonunion. J Japanese Soc Surg Hand 1998;15:56–61.

[12] Saint-Cast Y. [Zaidemberg's vascularized radial graft]. Chir Main 2010;29 Suppl 1:S77-82. doi:10.1016/j.main.2010.10.005.

[13] Mouilhade F, Auquit-Auckbur I, Duparc F, Beccari R, Biga N, Milliez P-Y. Anatomical comparative study of two vascularized bone grafts for the wrist. Surg Radiol Anat 2007;29:15–20. doi:10.1007/s00276-006-0164-2.

[14] Beaton DE, Wright JG, Katz JN, Amadio P, Bombardier C, Cole D, et al. Development of the QuickDASH: COmparison of three item-reduction approaches. J Bone Jt Surg - Ser A 2005;87:1038–46. doi:10.2106/JBJS.D.02060.

[15] Cooney WP, Bussey R, Dobyns JH, Linscheid RL. Difficult wrist fractures. Perilunate fracture-dislocations of the wrist. Clin Orthop Relat Res 1987:136–47.

[16] Dias JJ. Definition of union after acute fracture and surgery for fracture nonunion of the scaphoid. J Hand Surg Am 2001;26 B:321–5. doi:10.1054/jhsb.2001.0596.

[17] Ho P-C, Wong CW-Y, Tse W-L. Arthroscopic-Assisted Combined Dorsal and Volar Scapholunate Ligament Reconstruction with Tendon Graft for Chronic SL Instability. J Wrist Surg 2015;4:252–63. doi:10.1055/s-0035-1565927.

[18] Linscheid RL. Scapholunate ligamentous instabilities (dissociations, subdislocations, dislocations). Ann Chir La Main 1984;3:323–30. doi:10.1016/S0753-9053(84)80008-3.

[19] Lynch NM, Linscheid RL. Corrective osteotomy for scaphoid malunion: Technique and long-term follow-up evaluation. J Hand Surg Am 1997;22:35–43.

doi:10.1016/S0363-5023(05)80177-7.

[20] Waitayawinyu T, Robertson C, Chin SH, Schlenker JD, Pettrone S, Trumble TE. The detailed anatomy of the 1,2 intercompartmental supraretinacular artery for vascularized bone grafting of scaphoid nonunions. J Hand Surg Am 2008;33:168–74. doi:10.1016/j.jhsa.2007.08.021.

[21] Schernberg F, Elzein F, Gérard Y. [Anatomo-radiological study of fractures of the carpal scaphoid bone. Problems of abnormal callus]. Rev Chir Orthop Reparatrice Appar Mot 1984;70 Suppl 2:55–63.

[22] Ten Berg P, Drijkoningen T, Strackee S, Buijze G. Classifications of Acute Scaphoid Fractures: A Systematic Literature Review. J Wrist Surg 2016;05:152–9. doi:10.1055/s-0036-1571280.

[23] Aasheim T, Finsen V. The DASH and the QuickDASH instruments. Normative values in the general population in Norway. J Hand Surg (European Vol 2014;39:140–4. doi:10.1177/1753193413481302.

[24] Hirche C, Heffinger C, Xiong L, Lehnhardt M, Kneser U, Bickert B, et al. The 1,2-intercompartmental supraretinacular artery vascularized bone graft for scaphoid nonunion: management and clinical outcome. J Hand Surg Am 2014;39:423–9. doi:10.1016/j.jhsa.2013.10.028.

[25] Ong HS, Tan G, Chew WYC. Treatment of scaphoid non-union with 1,2 intercompartmental supraretinacular artery (1,2 ICSRA) vascularised graft. Singapore Med J 2011;52:658–61.

[26] Griesshammer M, Kiladjian JJ, Besses C. Thromboembolic events in polycythemia vera. Ann Hematol 2019;98:1071. doi:10.1007/s00277-019-03625-x.

[27] Little CP, Burston BJ, Hopkinson-Woolley J, Burge P. Failure of surgery for scaphoid non-union is associated with smoking. J Hand Surg Br 2006;31:252–5.

doi:10.1016/j.jhsb.2005.12.010.

[28] Patel S, Giugale JM, Debski RE, Fowler JR. Effect of Screw Length and Geometry on Interfragmentary Compression in a Simulated Proximal Pole Scaphoid Fracture Model. HAND 2018:155894471879528. doi:10.1177/1558944718795281.

[29] Falck Larsen C, Mathiesen FK, Lindequist S. Measurements of carpal bone angles on lateral wrist radiographs. J Hand Surg Am 1991;16:888–93. doi:10.1016/S0363-5023(10)80156-X.

[30] Chang MA, Bishop AT, Moran SL, Shin AY. The outcomes and complications of 1,2-intercompartmental supraretinacular artery pedicled vascularized bChang, Michael A. et al. "The Outcomes and Complications of 1,2-Intercompartmental Supraretinacular Artery Pedicled Vascularized Bone Grafting of Scaph. J Hand Surg Am 2006;31:387–96. doi:10.1016/j.jhsa.2005.10.019.

[31] Sauerbier M, Bishop AT, Ofer N. [Pedicled vascularized bone grafts from the dorsum of the distal radius for treatment of scaphoid nonunions]. Oper Orthop Traumatol 2009;21:373–85. doi:10.1007/s00064-009-1908-z.

[32] Rancy SK, Swanstrom MM, Dicarlo EF, Sneag DB, Lee SK, Wolfe SW, et al. Success of scaphoid nonunion surgery is independent of proximal pole vascularity. J Hand Surg Eur Vol 2018;43:32–40. doi:10.1177/1753193417732003.

[33] Giddins G, Leblebicioğlu G. Evidence Based Data In Hand Surgery And Therapy. Federation of European Societies for Surgery of the Hand; 2017.

[34] Munk B, Larsen CF. Bone grafting the scaphoid nonunion: a systematic review of 147 publications including 5,246 cases of scaphoid nonunion. Acta Orthop Scand 2004;75:618–29. doi:10.1080/00016470410001529.

[35] Gras M, Mathoulin C. Vascularized bone graft pedicled on the volar carpal artery from the volar distal radius as primary procedure for scaphoid non-union. Orthop Traumatol

Surg Res 2011;97:800–6. doi:10.1016/j.otsr.2011.08.008.

[36] Vutescu ES, Jethanandani R, Sneag DB, Wolfe SW, Lee SK. Radial styloidectomy for scaphoid nonunion advanced collapse – relevance of nonunion location. J Hand Surg (European Vol 2018;43:80–3. doi:10.1177/1753193417739519.

[37] Bain GI, Bennett JD, MacDermid JC, Slethaug GP, Richards RS, Roth JH. Measurement of the scaphoid humpback deformity using longitudinal computed tomography: Intra- and interobserver variability using various measurement techniques. J Hand Surg Am 1998;23:76–81. doi:10.1016/S0363-5023(98)80093-2.

[38] Boyer MI, von Schroeder HP, Axelrod TS. Scaphoid nonunion with avascular necrosis of the proximal pole. Treatment with a vascularized bone graft from the dorsum of the distal radius. J Hand Surg Br 1998;23:686–90. doi:10.1016/S0266-7681(98)80029-6.

[39] Straw RG, Davis TRC, Dias JJ. Scaphoid Nonunion: Treatment with a Pedicled Vascularized Bone Graft Based on the 1,2 Intercompartmental Supraretinacular Branch of the Radial Artery. J Hand Surg J Br Soc Surg Hand 2002;27:413–6. doi:10.1054/jhsb.2002.0808.

[40] Buijze GA, Wijffels MME, Guitton TG, Grewal R, van Dijk CN, Ring D, et al. Interobserver reliability of computed tomography to diagnose scaphoid waist fracture union. J Hand Surg Am 2012;37:250–4. doi:10.1016/j.jhsa.2011.10.051.

[41] Buijze GA, Jørgsholm P, Thomsen NOB, Björkman A, Besjakov J, Ring D. Diagnostic Performance of Radiographs and Computed Tomography for Displacement and Instability of Acute Scaphoid Waist Fractures. J Bone Jt Surg 2012;94:1967–74. doi:10.2106/JBJS.K.00993.

[42] Mallee WH, Wang J, Poolman RW, Kloen P, Maas M, de Vet HC, et al. Computed tomography versus magnetic resonance imaging versus bone scintigraphy for clinically suspected scaphoid fractures in patients with negative plain radiographs. Cochrane

Database Syst Rev 2015. doi:10.1002/14651858.CD010023.pub2.

[43] Ten Berg P, de Roo M, Maas M, Strackee SD. Is there a trend in CT scanning scaphoid nonunions for deformity assessment?—A systematic review. Eur J Radiol 2017;91:124–9. doi:10.1016/j.ejrad.2017.03.023.

[44] Rhemrev SJ, Ootes D, Beeres FJ, Meylaerts SA, Schipper IB. Current methods of diagnosis and treatment of scaphoid fractures. Int J Emerg Med 2011;4:4. doi:10.1186/1865-1380-4-4.

[45] Lee SK, Wolfe SW. Treatment of scaphoid and carpal injuries. J Hand Surg (European Vol 2018;43:3–3. doi:10.1177/1753193417744710.

[46] Xiao Z, Xiong G, Zhang W. New findings about the intrascaphoid arterial system. J Hand Surg (European Vol 2018:175319341875889. doi:10.1177/1753193418758890.

[47] Gelberman RH, Menon J. The vascularity of the scaphoid bone. J Hand Surg Am 1980;5:508–13.

[48] Morsy M, Sabbagh MD, van Alphen NA, Laungani AT, Kadar A, Moran SL. The Vascular Anatomy of the Scaphoid: New Discoveries Using Micro–Computed Tomography Imaging. J Hand Surg Am 2019;44:928–38. doi:10.1016/j.jhsa.2019.08.001.

[49] Kim J, Park JW, Chung J, Bae KJ, Gong HS, Baek GH. Non-vascularized iliac bone grafting for scaphoid nonunion with avascular necrosis. J Hand Surg Eur Vol 2018;43:24–31. doi:10.1177/1753193417730657.

[50] Luchetti TJ, Rao AJ, Fernandez JJ, Cohen MS, Wysocki RW. Fixation of proximal pole scaphoid nonunion with non-vascularized cancellous autograft. J Hand Surg Eur Vol 2018;43:66–72. doi:10.1177/1753193417743438.

[51] Jones DB, Bürger H, Bishop AT, Shin AY. Treatment of scaphoid waist nonunions with an avascular proximal pole and carpal collapse. Surgical technique. J Bone Joint

Surg Am 2009;91 Suppl 2:169–83. doi:10.2106/JBJS.I.00444.

[52] Ditsios K, Konstantinidis I, Agas K, Christodoulou A. Comparative meta-analysis on the various vascularized bone flaps used for the treatment of scaphoid nonunion. J Orthop Res 2017:1076–85. doi:10.1002/jor.23242.

[53] Higgins JP, Bürger HK. The use of osteochondral flaps in the treatment of carpal disorders. J Hand Surg Eur Vol 2018;43:48–56. doi:10.1177/1753193417739545.

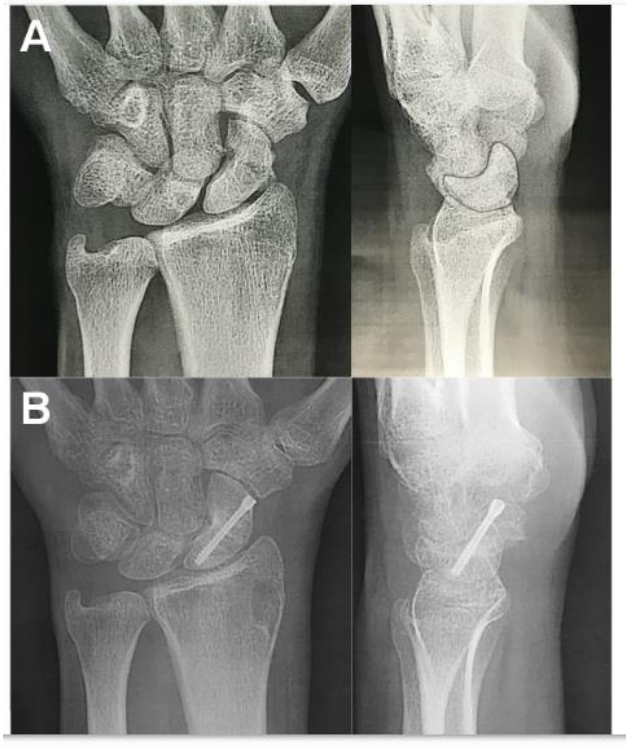
[54] Malizos KN, Dailiana Z, Varitimidis S, Koutalos A. Management of scaphoid nonunions with vascularized bone grafts from the distal radius: mid- to long-term follow-up. Eur J Orthop Surg Traumatol 2017;27:33–9. doi:10.1007/s00590-016-1867-7.

FIGURE LEGENDS

Figure 1. Surgical approach.

Figure 2. Rerouting of the bone graft below the tendons of the first extensors compartment and around the radial styloid. (A) Initial dorsal placement of the harvested graft. (B) Volar rerouting of the graft below the first extensors compartment around the radial styloid. The scaphoid is approached volarly to access its waist or more distal nonunions.

Figure 3. Clinical results. (A) Preoperative anteroposterior and lateral X-rays. (B) Post-operative anteroposterior and lateral X-rays.



TABLES

Table 1. Epidemiological data (n=19).

Variable	Mean	SD	Range (min-max)
Follow-up (months)	33.4	21.6	(6-75)
Treatment delay (months)	31.9	49.5	(3-180)
Age (years)	24.9	9.1	(14-45)
Sex (male), n	17		
Dominant hand affected, n	9		
Work-related injury, n	4		
Smoker, n	5		
Radial styloid osteoarthritis (SNAC 1), n	6		

SD: standard deviation, SNAC: scaphoid nonunion advanced collapse

Table 2. Clinical results (n=19).

Measure	Operated side Mean (SD)	Healthy side Mean (SD)	Difference (SD)	p
UD (°)	42.2(8.5)	46.0(7.5)	-3.8(6.1)	0.016
RD (°)	23.6(6.9)	27.5(6.6)	-3.6 (4.4)	0.001
Pronation (°)	90.0 (0.0)	90.0 (0.0)	0.0 (0.0)	-
Supination (°)	90.0 (0.0)	90.0 (0.0)	0.0 (0.0)	-
Flexion (°)	56.1 (14.0)	62.7(9.8)	-6.6(7.6)	0.004
Extension (°)	61.2(12.2)	66.5(10.5)	-5.3(5.2)	0.001
Strength (kgf)	33.4(13.0)	36.2(13.9)	-2.7 (6.9)	0.130

RD: radial deviation; UD: ulnar deviation; SD: standard deviation; kgf: kilogram-force.