Clinical and functional outcomes of vascularized bone graft in the treatment of scaphoid non-union

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Abstract

Introduction
Scaphoid non-union is a challenging and complex problem. Various methods have been proposed for the management of patients with scaphoid non-union and to reduce the risk of complications. In this study, our aim was to evaluate the clinical and functional outcomes of using a vascularized bone graft in the treatment of scaphoid non-union.

Methods
Patients with scaphoid non-union who underwent 1,2 intercompartmental supraretinacular artery pedicled vascularized bone graft between January 2005 and January 2011 were enrolled. The parameters assessed included clinical and functional outcomes, radiological measures, and potential risk factors.

Results
Forty-one patients were finally included. Thirty patients achieved union (73%) and 11 did not. Smoking was a significant risk factor for non-union after the surgery. In patients who achieved union, grip strength and radioulnar abduction were greater in comparison to that in patients who did not achieve union. Functional measures, including the Disabilities of Arm and Shoulder score and the Modified Mayo Wrist Score, improved in patients with scaphoid union. The scaphoid length also improved significantly postoperatively in these patients.

Conclusion
Surgical treatment of scaphoid non-union using vascularized bone graft led to a high union rate with good clinical and functional outcomes. Smoking is a risk factor for non-union, even with the use of a vascularized bone graft. Avascular necrosis was not associated with an increased risk for non-union.
Introduction

Scaphoid fractures account for 50–80% of all carpal fractures [1, 2], with the highest incidence in young and active men [3]. According to epidemiological studies, the incidence of scaphoid fractures varies between 0.08–1.21 per 1000 person-years in different populations. These fractures usually are treated with conservative measures, resulting in union rates between 55–100% [4, 5]. Approximately 10% of scaphoid fractures progress to non-union [6], which often is the consequence of different risk factors (Table 1). Complications of neglected scaphoid non-union (SN) are summarized in Table 1 [7–13].

Numerous bone grafting techniques have been proposed for the treatment of SN. The differences between these techniques include the bone graft harvest site, fixation method and using vascularized bone graft (VBG) or non-vascularized bone graft (NVBG) [14–18].

VBG is a reasonable treatment option because it maintains cell viability and drives a bone healing process similar to primary fracture healing [19]. Quicker stabilization and lesser immobilization period are other advantages of VBGs [20].

Various vascularized grafts have been used previously [21–26] and the main donor sites were the palmar and dorsal parts of the radius. The method of 1,2 intercompartmental supraretinacular artery pedicled vascularized bone graft (1,2-ICSRA-VBG) was used by Zaidenberg [26] for the first time in 1991 and is the most commonly used method because of the proximity to scaphoid bone [19]. However, its outcomes were controversial because various studies demonstrated union rates between 27–100% [24, 26–30]. Therefore, it is difficult to consider a specific surgery technique as superior to others [31, 32].

The main purpose of this study was to present the clinical outcomes of scaphoid non-union (SN) treated using 1,2-ICSRA-VBG.

Patients and methods

Patient data

A retrospective study was designed to evaluate the records of patients with SN between January 2005 and January 2011. Patients with SN diagnosed by X-ray or computed tomography (CT) who were treated with 1,2-ICSRA-VBG and had postoperative follow-up with X-ray or CT were included. Ethics approval was obtained from the Baqiyatallah hospital ethics committee. All patients signed an informed consent allowing us to use their medical records in the study. The surgery technique used has been previously reported [24, 26]. Avascular necrosis (AVN) was diagnosed intraoperatively by the absence of punctate bleeding at the non-union site.

Radiographic examinations were performed at 6, 12, and 16 weeks after the surgery and during the latest visit. Different X-ray views (posterior-anterior, lateral, and scaphoid) were obtained and CT was used if X-ray was unclear for diagnosing union.

Table 1. Risk factors leading to nonunion scaphoid fractures and nonunion complications.

| Risk factors for nonunion | Results of scaphoid malunion or non-union |
|--------------------------|------------------------------------------|
| Displacement of more than 1 mm | Pain                                     |
| Fracture of the proximal pole | Altered carpal kinematics                |
| History of osteonecrosis   | Diminished range of motion                |
| Vertical oblique fracture pattern | Disuse osteopenia                        |
| Nicotine use               | Decreased grip strength                   |
| Delay in diagnosis         | Dorsal intercalary segmental instability  |
| Inadequate immobilization  | Degenerative changes                      |

(scaphoid nonunion advanced collapse)
Immobilization using a cast was performed for all patients at least for 6 weeks. Subsequently, the cast was removed if union was achieved. After 16 weeks, the cast was discontinued regardless of achievement of union.

Demographic characteristics and baseline data of patients were obtained from their medical records. Postoperative data were collected at the end of the follow-up period.

We assessed the scaphoid length (mm), scapho-lunate angle (degree), Nattrass Carpal Height Index, active range of motion (degree), Jamar grip strength (kg), key pinch strength (kg), and tripod pinch strength (kg) for clinical assessment. For evaluating clinical outcomes, we used the Disabilities of Arm and Shoulder (DASH) questionnaire (0: no limitation, 100: maximum limitation) and the Modified Mayo Wrist Score (MMWS; 91–100: excellent; 80–90: good; 65–79: fair; and < 65: poor).

**Statistical analysis**

Student’s t test or Wilcoxon rank sum test was used to analyze normally distributed continuous variables. We compared categorical variables using chi-square or Fisher’s exact test. To identify the risk factors affecting DASH score more than 50 and MMWS less than 65, binary logistic regression analysis was performed. \( P < 0.05 \) was considered significant and all calculations were performed using SPSS software, version 22 (IBM Corp., Armonk, NY, USA).

**Results**

Fifty-four patients underwent 1,2-ICSRA-VBG. Thirteen patients were lost to follow-up, and forty-one patients satisfied the inclusion criteria. The demographic data and characteristics are summarized in Table 2. The total number of subjects included 35 males and 6 females with a mean age of 26.7 ± 7 years (mean ± standard deviation, SD). The mean body mass index (BMI) was 22 kg/m² and 19 patients were current smokers. Thirty-three patients had proximal pole fractures and none of the patients underwent bone grafting before vascular bone grafting. The mean delay between scaphoid fracture and vascular surgery for the treatment of non-union fractures was 16 ± 7 months.

| Measure, n (%) | Total (n = 41) | Non-union (n = 11) | Union (n = 30) | \( P \) value |
|---------------|---------------|--------------------|---------------|-------------|
| Age, years    |               |                    |               |             |
| \( > 25 \) y  | 19 (46%)      | 7 (64%)            | 12 (40%)      | 0.30        |
| \( \leq 25 \) y| 22 (54%)      | 4 (36%)            | 18 (60%)      |             |
| Sex           |               |                    |               |             |
| Female        | 4 (10%)       | 3 (27%)            | 1 (3%)        | 0.25        |
| Male          | 37 (90%)      | 8 (73%)            | 29 (97%)      |             |
| Smoking       |               |                    |               |             |
| Yes           | 19 (46%)      | 9 (82%)            | 10 (33%)      | 0.02        |
| No            | 22 (54%)      | 2 (18%)            | 20 (67%)      |             |
| BMI, kg/m²    |               |                    |               |             |
| \( > 22 \)    | 18 (44%)      | 6 (55%)            | 12 (40%)      | 0.45        |
| \( \leq 22 \) | 23 (56%)      | 5 (45%)            | 18 (60%)      |             |
| Time to surgery, months | | | | |
| \( > 47 \)    | 16 (39%)      | 6 (55%)            | 10 (33%)      | 0.33        |
| \( \leq 47 \) | 25 (61%)      | 5 (45%)            | 20 (67%)      |             |
| PIN neurcetomy|               |                    |               |             |
| Yes           | 15 (37%)      | 3 (27%)            | 12 (40%)      | 0.80        |
| No            | 26 (63%)      | 8 (73%)            | 18 (60%)      |             |
| K-wire fixation|              |                    |               |             |
| Yes           | 10 (24%)      | 2 (18%)            | 8 (27%)       | 0.59        |
| No            | 31 (76%)      | 9 (82%)            | 22 (73%)      |             |
| Avascular necrosis|           |                    |               |             |
| Yes           | 26 (63%)      | 6 (55%)            | 20 (67%)      | 0.73        |
| No            | 15 (37%)      | 5 (45%)            | 10 (33%)      |             |
| Follow-up     |               |                    |               |             |
| \( > 49 \)    | 23 (56%)      | 8 (73%)            | 15 (50%)      | 0.66        |
| \( \leq 49 \)| 18 (44%)      | 3 (27%)            | 15 (50%)      |             |

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was 47 (±11) months and the mean duration of the surgery was 100±22 minutes. Twenty-six patients were diagnosed with AVN intra-operatively.

The follow-up period was 49±21 months. Thirty patients achieved union and eleven did not. The diagnosis of non-union was based on X-ray taken at 4 and 6 weeks intervals; therefore, we were unable to recognize the exact time of union.

The overall mean DASH score and mean MMWS score were 26 and 78, respectively, at mean follow-up of 49 months postoperatively. All patients with successful union returned to their previous jobs without any limitation. Of the patients who did not achieve union after the surgery, four kept their previous jobs, four lost their jobs, and three changed their occupation.

Outcomes of patients who achieved union at the end of follow-up are summarized in Table 3. The MMWS score improved from 60 preoperatively to 83 at the last follow-up. Excellent results were achieved in 14 patients (46.6%), good results in 10 (33.3%), fair results in 5 (16.6%), and poor results in only 1 (3.5%). The DASH score decreased from 54 to 21, and grip strength decreased to 73% of the contralateral hand strength.

Radio-ulnar deviation pre- and post-operatively improved significantly but extension-flexion did not show significant differences. With comparison to the contralateral wrist, there was significant limitation of both radio-ulnar deviation and extension-flexion movements. During radiological evaluation, scapho-lunate angle and Nattrass carpal height index did not present any significant difference. Scaphoid length increased significantly after the operation.

Differences of outcomes between patients who achieved union and who did not are presented in Table 4. Of the reported outcomes, radio-ulnar deviation and grip strengths had significantly improved in patients with scaphoid union. After exploration for risk factors affecting postoperative non-union, only smoking was identified as a risk factor (Table 2). After performing logistic regression analysis, we did not find any risk factors for MMWS score less than 65 and DASH score more than 50.

**Discussion**

Scaphoid nonunion is a challenging and complex problem which results owing to multiple factors. Review of literature demonstrates union rates of 74–84% using non-vascularized bone graft and 74–83% with vascularized bone graft.
Vascularized bone graft in the scaphoid nonunion treatment

Fracture healing is a multi-step process that is facilitated by the interaction of different cellular elements to achieve union. Theoretically, the use of VBGs in non-union fractures provides essential components such as cytokines and cellular mediators by maintaining cell viability, which drives the healing process similar to the primary process of fracture healing [19].

Vascularized bone grafts were introduced more than two decades ago and became popular in the treatment of SN [24, 26, 29, 30, 32, 33, 35–40]. Different studies have reported different union rates from 27–100% [29, 30].

Reviewing previous studies that have compared VBG and NVBG in the treatment of SN has revealed heterogeneous outcomes. Two prospective studies by Ribak et al. [41] and Caporrino et al. [42] demonstrated better healing rates and quicker bone healing, respectively, with VBG in comparison with NVBG. A recent systematic review and meta-analysis of 1602 patients reported 92% union rate with the use of VBG compared with 88% union rate with NVBG [32]. Patient selection appears to be an important factor influencing the union rates [43].

In our study, 41 patients treated with 1,2-ICSRA-VBG were included. Similar to most studies in this regard, none of the patients had undergone previous NVBG transplantation. However, Hirch et al. [43] and Werdin [44] reported that previous iliac crest bone graft was not a risk factor for non-union after VBG transplantation surgery.

Previous studies reported AVN as a risk factor for non-union [33, 45] and Chang et al. [46] reported better union rates without AVN. Our study included 26 patients with AVN; 20 went on to achieve scaphoid union and 6 did not. However, AVN was not found to have a significant impact on union rates, in concordance with the findings of Malizos et al. [29] and Tsai et al. [24]. A meta-analysis of 1827 scaphoid non-union repairs also reported superiority of VBG in patients with AVN [33].

We found smoking to be a significant risk factor for non-union in agreement with the results of previous studies [46, 47]. Smoking appears to be the main negative prognostic factor affecting the achievement of union in patients. Smoking impairs angiogenesis [48] and has a negative effect on fracture union [49]. Al-Hadithy et al. [49] also concluded that smoking has more negative effect on the union of fractures that require bone grafts and increases the chance of devascularization after the grafting is performed.

Previous studies have reported varying results regarding grip strength after the achievement of union [26, 29, 35, 36, 47, 50]. In our study, the grip strength of the injured hand was 73% that of the contralateral hand, which was significantly lower. Therefore, our results are in agreement with those of Malizos et al [29] and Hirche et al [43]. We observed significant improvements in grip strength of patients who achieved union than in those who did not. Therefore, we can conclude that the achievement of union restores grip strength.
Our study demonstrated that active radioulnar deviation was significantly increased in hands with scaphoid union, and compared to that of hands with non-union, it was significantly higher. Our results are contradictory to those of Malizos et al. [51].

In our study, of the patients with scaphoid union, the scapho-lunate angle and Nattrass carpal height ratio did not change significantly after the surgery, which is in accordance with the results of Malizos et al. [29], Steinmann et al. [40], and Hirche et al. [43]. However, Malizos et al. [51] reported in a long-term study of SN treated with VBG that both scapho-lunate angle and Nattrass carpal height ratio returned to normal after five years. According to our results, the length of scaphoid improved significantly after the surgery. Normalization of scaphoid length retains the tension of the tendons crossing the wrist and thus improves grip strength.

The DASH score was significantly decreased and the MMWS score was significantly increased, thus reflecting overall improvement of clinical and functional outcomes after the surgery. A long-term study of scaphoid surgeries for non-union demonstrated positive effects in terms of MMWS, DASH, and VAS with early surgery before the progression to arthritic changes [52]. Deformity correction and achievement of anatomical union are critical to achieving stable and long-lasting wrist function. However, our study was limited in determining the correlation between the achievement of anatomical union and better clinical outcomes.

The limitations of our study are as follows. First, we lost 13 patients to follow-up, and considering the relatively small sample size of our study, our results may be biased because of the missed patients and may not be representative of the entire population. Second, we were unable to exactly determine the time of union. Finally, we could not evaluate the revascularization of scaphoid bone after the surgery.

In conclusion, we found that surgical treatment of scaphoid non-union using vascularized bone graft led to a high union rate with good clinical and functional outcomes; smoking is a risk factor for non-union, even with the use of a vascularized bone graft; and that avascular necrosis was not associated with an increased risk for non-union.

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References
1. Alshryda S, Shah A, Odak S, Al-Shryda J, Ilango B, Murali SR. Acute fractures of the scaphoid bone: Systematic review and meta-analysis. The surgeon: journal of the Royal Colleges of Surgeons of Edinburgh and Ireland. 2012; 10(4):218–29. https://doi.org/10.1016/j.surge.2012.03.004 PMID: 22995773
2. Sendher R, Ladd AL. The scaphoid. The Orthopedic clinics of North America. 2013; 44(1):107–20. https://doi.org/10.1016/j.ocl.2012.09.003 PMID: 23174339
3. Van Tassel DC, Owens BD, Wolf JM. Incidence estimates and demographics of scaphoid fracture in the U.S. population. The Journal of hand surgery. 2010; 35(8):1242–5. https://doi.org/10.1016/j.jhsa.2010.05.017 PMID: 20684922
4. Dias JJ, Brenkel IJ, Finlay DB. Patterns of union in fractures of the waist of the scaphoid. The Journal of bone and joint surgery British volume. 1989; 71(2):307–10. PMID: 2925752
5. Bhat M, McCarthy M, Davis TR, Oni JA, Dawson S. MRI and plain radiography in the assessment of displaced fractures of the waist of the carpal scaphoid. The Journal of bone and joint surgery British volume. 2004; 86(5):705–13. PMID: 15274268
6. Kawamura K, Chung KC. Treatment of scaphoid fractures and nonunions. The Journal of hand surgery. 2008; 33(6):988–97. https://doi.org/10.1016/j.jhsa.2008.04.026 PMID: 18656779
7. Dinah AF, Vickers RH. Smoking increases failure rate of operation for established non-union of the scaphoid bone. International orthopaedics. 2007; 31(4):503–5. https://doi.org/10.1007/s00264-006-0231-7 PMID: 16947049
8. Bedi A, Jebson PJ, Hayden RJ, Jacobsen JA, Martus JE. Internal fixation of acute, nondisplaced scaphoid waist fractures via a limited dorsal approach: an assessment of radiographic and functional outcomes. The Journal of hand surgery. 2007; 32(3):326–33. https://doi.org/10.1016/j.jhsa.2007.01.002 PMID: 17336838
9. Belsky MR, Leibman MI, Ruchelsman DE. Scaphoid fracture in the elite athlete. Hand clinics. 2009; 25(3):359–69. https://doi.org/10.1016/j.hcl.2009.05.004 PMID: 19643336
10. Geissler WB. Arthroscopic management of scaphoid fractures in athletes. Hand clinics. 2009; 25(3):359–69. https://doi.org/10.1016/j.hcl.2009.05.004 PMID: 19643336
11. Inoue G, Shibuya K, Kuwahata Y. Herbert screw fixation for scaphoid nonunions. An analysis of factors influencing outcome. Clinical orthopaedics and related research. 1997(343):99–106. PMID: 9345214
12. Langhoff O, Andersen JL. Consequences of late immobilization of scaphoid fractures. Journal of hand surgery. 1988; 13(1):77–9.
13. Ozalp T, Oz C, Kale G, Erkan S. Scaphoid nonunion treated with vascularised bone graft from dorsal radius. Injury. 2015; 46 Suppl 2:S47–52.
14. Sunagawa T, Bishop AT, Muramatsu K. Role of conventional and vascularized bone grafts in scaphoid nonunion with avascular necrosis: A canine experimental study. The Journal of hand surgery. 2000; 25(5):849–59. https://doi.org/10.1053/jhso.2000.8639 PMID: 11040300
15. Brunelli GA, Brunelli GR. A personal technique for treatment of scaphoid non-union. Journal of hand surgery. 1991; 16(2):148–52.
16. Judet R, Roy-Camille R, Guillamon JL. [Treatment of pseudarthrosis of the carpal scaphoid by pediculated graft]. Revue de chirurgie orthopedique et reparatrice de l’appareil moteur. 1972; 58(7):699–705. PMID: 4267867
17. Kuhlmann JN, Guerin-Surville H, Mimoun M, Kirsch JM, Baux S. [Pediculated bone grafts as vascularization aids. At the wrist level]. Acta orthopaedica Belgica. 1986; 52(6):753–70. PMID: 3551479
18. Tsai TT, Chao EK, Tu YK, Chen AC, Lee MS, Ueng SW. Management of scaphoid nonunion with avascular necrosis using 1, 2 intercompartmental supraretinacular arterial bone grafts. Chang Gung medical journal. 2002; 25(3):321–8. PMID: 12141705
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25. Yuceturk A, Isiklar ZU, Tuncay C, Tandogan R. Treatment of scaphoid nonunions with a vascularized bone graft based on the first dorsal metacarpal artery. Journal of hand surgery. 1997; 22(3):425–7.

26. Zaidenberg C, Siebert JW, Angrigiani C. A new vascularized bone graft for scaphoid nonunion. The Journal of hand surgery. 1991; 16(3):474–8. PMID: 1861030

27. Hankins CL, Budoff JE. Analysis of wrist motion following vascularized bone graft to the proximal scaphoid. The Journal of hand surgery. 2011; 36(4):583–6. https://doi.org/10.1016/j.jhsa.2010.12.035 PMID: 21414729

28. Malizos KN, Dailiana ZH, Innocenti M, Mathoulin CL, Mattar R Jr., Sauberbier M. Vascularized bone grafts for upper limb reconstruction: defects at the distal radius, wrist, and hand. The Journal of hand surgery. 2010; 35(10):1710–8. https://doi.org/10.1016/j.jhsa.2010.08.006 PMID: 20888511

29. Malizos KN, Zachos V, Dailiana ZH, Zalavras C, Varitimidis S, Hantes M, et al. Scaphoid nonunions: management with vascularized bone grafts from the distal radius: a clinical and functional outcome study. Plastic and reconstructive surgery. 2007; 119(5):1513–25. https://doi.org/10.1097/01.pr.s.0000256144.52654.da PMID: 17415246

30. Straw RG, Davis TR, Dias JJ. Scaphoid nonunion: treatment with a pedicled vascularized bone graft based on the 1,2 intercompartmental supraretinacular branch of the radial artery. Journal of hand surgery. 2002; 27(5):413.

31. Ferguson DO, Shanbhag V, Hedley H, Reichert I, Lipscombe S, Davis TR. Scaphoid fracture nonunion: a systematic review of surgical treatment using bone graft. The Journal of hand surgery, European volume. 2016; 41(5):492–500. https://doi.org/10.1177/1753193416647788 PMID: 26423614

32. Pinder RM, Brikjac M, Rix L, Muir L, Brewster M. Treatment of Scaphoid Nonunion: A Systematic Review of the Existing Evidence. The Journal of hand surgery. 2015; 40(9):1797–805 e3. https://doi.org/10.1016/j.jhsa.2015.05.003 PMID: 26116095

33. Merrell GA, Wolfe SW, Slade JF 3rd. Treatment of scaphoid nonunions: quantitative metaanalysis of the literature. The Journal of hand surgery. 2002; 27(4):685–91. PMID: 12132096

34. Meisel E, Seal A, Yao CA, Ghiassi A, Stevanovic M. Management of scaphoid nonunion with iliac crest bone graft and K-wire fixation. Eur J Orthop Traumatol. 2017; 27(1):23–31. https://doi.org/10.1007/s00590-016-1876-6 PMID: 27830329

35. 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. Journal of hand surgery. 1998; 23(5):686–90.

36. Dailiana ZH, Malizos KN, Zachos V, Varitimidis SE, Hantes M, Karantanas A. Vascularized bone grafts from the palmar radius for the treatment of waist nonunions of the scaphoid. The Journal of Bone and Joint surgery American volume. 1999; 81(10):1414–28. PMID: 10535591

37. Gabl M, Reinhart C, Lutz M, Bodner G, Rudisch A, Hussl H, et al. Vascularized bone graft from the iliac crest for the treatment of nonunion of the proximal part of the scaphoid with an avascular fragment. The Journal of Bone and Joint surgery American volume. 1999; 81(10):1414–28. PMID: 16516733

38. Malizos KN, Dailiana ZH, Kirou M, Vragalas V, Xenakis TA, Soucacos PN. Longstanding nonunions of scaphoid fractures with bone loss: successful reconstruction with vascularized bone grafts. Journal of hand surgery. 2001; 26(4):330–4.

39. Malizos KN, Dailiana ZH, Varitimidis SE, Papatheodorou L. Scaphoid reconstruction with vascularized bone grafts from the distal radius. Journal of hand and microsurgery. 2009; 11(1):50–3. https://doi.org/10.1007/s12593-009-0003-x PMID: 23129932

40. Steinmann SP, Bishop AT, Berger RA. Use of the 1,2 intercompartmental supraretinacular artery as a vascularized pedicle bone graft for difficult scaphoid nonunion. The Journal of hand surgery. 2002; 27(3):391–401. PMID: 12015712

41. Ribak S, Medina CE, Mattar R Jr., Ulson HJ, Ulson HJ, Etchebehere M. Treatment of scaphoid nonunion with vascularised and nonvascularised dorsal bone grafting from the distal radius. International orthopaedics. 2010; 34(5):683–8. https://doi.org/10.1007/s00264-009-0862-6 PMID: 19730861

42. Caporizzo FA, Dos Santos JB, Penteado FT, de Moraes VY, Belloti JC, Faloppa F. Dorsal vascularized grafting for scaphoid nonunion: a comparison of two surgical techniques. J Orthop Trauma. 2014; 28(3):e4–8. PMID: 24566538

43. 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. The Journal of hand surgery. 2014; 39(3):423–9. https://doi.org/10.1016/j.jhsa.2013.10.028 PMID: 24444804

44. Werdin F, Jaminet P, Naegle B, Pfau M, Schaller HE. Reconstruction of scaphoid nonunion fractures of the proximal one third with a vascularized bone graft from the distal radius. Plasty. 2014; 14:e24. PMID: 25165493
45. Schuind F, Moungono F, El Kazzi W. Prognostic factors in the treatment of carpal scaphoid nonunions. Eur J Orthop Surg Traumatol. 2017; 27(1):3–9. https://doi.org/10.1007/s00590-016-1886-4 PMID: 27896458

46. Chang MA, Bishop AT, Moran SL, Shin AY. The outcomes and complications of 1,2- intercompartmental supraretinacular artery pedicled vascularized bone grafting of scaphoid nonunions. The Journal of hand surgery. 2006; 31(3):387–96. https://doi.org/10.1016/j.jhsa.2005.10.019 PMID: 16516732

47. Waitayawinyu T, McCallister WV, Katolik LI, Schlenker JD, Trumble TE. Outcome after vascularized bone grafting of scaphoid nonunions with avascular necrosis. The Journal of hand surgery. 2009; 34(3):387–94. https://doi.org/10.1016/j.jhsa.2008.11.023 PMID: 19258134

48. Konishi H, Wu J, Cooke JP. Chronic exposure to nicotine impairs cholinergic angiogenesis. Vascular medicine. 2010; 15(1):47–54. https://doi.org/10.1177/1358863X09106326 PMID: 19778953

49. Al-Hadithy N, Sewell MD, Bhavikatti M, Gikas PD. The effect of smoking on fracture healing and on various orthopaedic procedures. Acta orthopaedica Belgica. 2012; 78(3):285–90. PMID: 22822565

50. Uerpairojkit C, Leechavengvongs S, Witoonchart K. Primary vascularized distal radius bone graft for nonunion of the scaphoid. Journal of hand surgery. 2000; 25(3):266–70.

51. 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(1):33–9. https://doi.org/10.1007/s00590-016-1867-7 PMID: 27785580

52. Reigstad O, Grimsgaard C, Thorkildsen R, Reigstad A, Rokkum M. Long-term results of scaphoid nonunion surgery: 50 patients reviewed after 8 to 18 years. J Orthop Trauma. 2012; 26(4):241–5. PMID: 21918482