Scaphoid fractures: anatomy, diagnosis and treatment

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Chapter 13

Management of scaphoid nonunion: current concepts

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Abstract

The primary risk factor for nonunion of the scaphoid is displacement/instability, but delayed or missed diagnosis, inadequate treatment, fracture location, and blood supply are also considered. It seems that untreated nonunion will lead to degenerative wrist arthritis—the so-called SNAC wrist (scaphoid nonunion advanced collapse). However, the correlation of symptoms and disease is poor; the true "natural history" is debatable because we only evaluate symptomatic patients presenting for treatment. It's not clear that surgery can change the natural history even if union is obtained. The diagnosis of nonunion is made on radiographs but CT or MRI scans may be useful to assess deformity and blood supply. Treatment options vary from percutaneous fixation to ORIF with vascularized or non-vascularized bone grafting, to salvage procedures involving excision and/or arthrodesis of carpal bones.

Introduction

Although the majority of scaphoid fractures heal with nonoperative treatment, the focus is usually on the approximate 10% nonunion rate in most case series.[1] More recent data confirm that when displacement is accurately diagnosed and adequate protection provided the union rate approaches 100%.[2,3] Fracture displacement (usually defined as a gap or translation between the fracture fragments) has been associated with a risk of nonunion up to 55%.[4-6]

It is tempting to speculate that the nonunions in older series were primarily displaced fractures. Most published series and clinical trials did not diagnose displacement. The few that have excluded displaced fractures used radiographs to diagnose displacement, which are not as reliable as computed tomography.[7]

Several risk factors for scaphoid nonunion are based more on tradition and wisdom than on scientific data. Failure to seek medical attention after a fracture (for instance, assuming it's just a sprain) is considered a risk factor for scaphoid nonunion.[8,9] Many minimally displaced fractures are not visible on radiographs (at least initially), and these missed fractures may also be at risk for nonunion.[9] Finally, proximal pole fractures seem to be at higher risk of nonunion and avascular necrosis (AVN). The traditional explanation for this is a decreased arterial supply to the proximal pole that makes fractures in that area more likely to progress to nonunion and limits the potential healing.[8]

Presentation

Scaphoid fractures are most common in adult men between the ages of 15 to 40 years and are rare in those under 10 years of age.[10] Based on the fact that many patients present years or decades after fracture and nonunion, it seems safe to assume that many nonunions are either minimally symptomatic or that patients are able to adapt to the symptoms. The most common clinical sign of a scaphoid nonunion is restricted wrist motion but other suggestive findings include tenderness in the anatomic snuff box or scaphoid tubercle,[10] dorsal swelling, persistent pain at the extremes of motion (especially dorsal flexion), and decreased grip strength.[8]

Typical radiographic signs of nonunion are widening of the fracture cleft, cyst formation and sclerosis of the fracture surfaces.[9] Given that radiographic diagnosis of union is unreliable during the first four months after injury,[11] the diagnosis of nonunion requires an interval of at least 6 to 12 months after injury, or perhaps another diagnostic method such as computed tomography, although to date this is not well studied.[12]

Magnetic resonance imaging (MRI) is often used to diagnose AVN, especially in the proximal pole.[13] MRI has been reported to have a high correlation with intraoperative findings (i.e. punctuate bleeding of the proximal pole with the tourniquet released);

however, there are contradictory data on the ability of MRI to predict the rate of union after bone grafting.[14-16] Moreover, MRI is expensive, not available in all centers and poor in assessing bony fracture details.[17] It's unclear whether MRI is as good as CT for evaluation of alignment.

Advantages of CT include its increased availability, lower cost and more detailed imaging of bony anatomy. A preoperative CT is valuable to analyze the angular deformity, evaluate the pathologic scapholunate angle, and calculate the resection and size of the graft needed.

There are two different patterns of displacement, volar and dorsal.[18] The location of the fracture line relative to the dorsal apex of the ridge of the scaphoid seems to determine the nonunion pattern and the development of a dorsal intercalated segment (DISI) deformity.[18,19] The volar-type is usually seen in relatively distal scaphoid waist fractures in which the scaphoid forms a humpback deformity and the bone defects are large and triangular and are mostly seen along with a DISI deformity. The dorsal-type is seen in relatively proximal waist fractures in which the bone defects are much smaller and a flat, crescent-shaped pattern is seen (Figure 1).[20] Another recent study showed that a preoperative longitudinal CT of scaphoid nonunion is can be helpful in identifying AVN and predicting subsequent fracture union.[21] The two signs that significantly correlated with AVN were increased radiodensity of the proximal pole (often termed sclerosis) and the absence of converging trabeculae between the fragments. Increased radiodensity of the proximal pole on CT had a sensitivity of 60%, a specificity of 100% and an accuracy of 74% for diagnosing histologically proved AVN; thus this sign seems a good diagnostic method to rule in but not to rule out AVN.

Scaphoid nonunions can be defined as stable or unstable. In stable nonunions the length and shape of the scaphoid are preserved and there is a firm fibrous connection between the fracture fragments.[8] It is not clear whether stable, well aligned nonunions lead to arthrosis or cause symptoms.

Unstable nonunion show a distinct pattern of degenerative changes eventually leading to a scaphoid nonunion advanced collapse (SNAC) wrist. Initially, a DISI deformity of the wrist is commonly seen and may progress over time. Degenerative changes typically occur between the radius and distal scaphoid fragment first and eventually in the midcarpal joint, particularly between the capitate and proximal scaphoid fragment and between the lunate and capitate (Figure 2). The articulation of the proximal scaphoid fragment and the lunate with the distal radius is relatively spared.

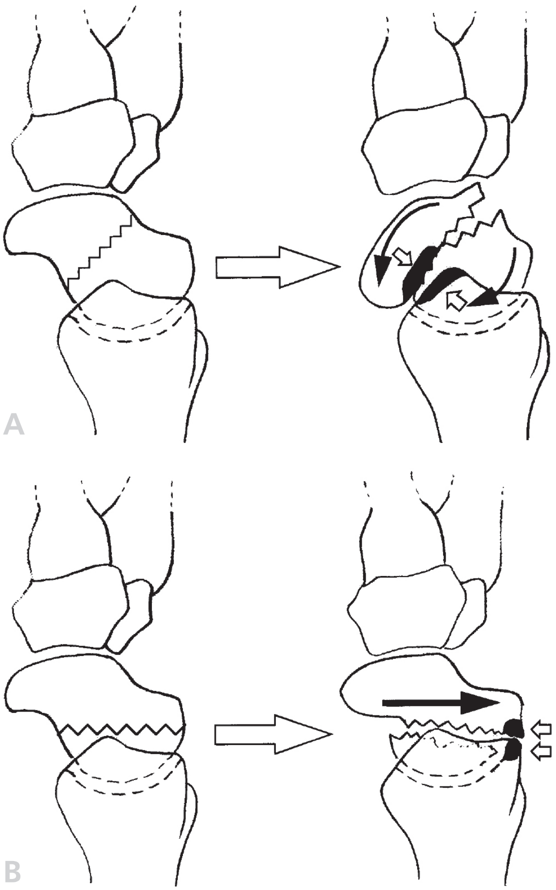

Figure 1A The volar type of scaphoid nonunion as seen from the lateral view showing the direction of fracture displacement (solid arrows) and the inferred contact area between the distal fragment of the scaphoid and the radius (open arrows). B The dorsal type of scaphoid nonunion as seen from the lateral view showing the direction of fracture displacement (solid arrow) and the inferred contact area between the distal fragment of the scaphoid and the radius (open arrows). Reprinted from Moritomo H, Viegas SF, Elder KW, Nakamura K, Dasilva MF, Boyd NL, et al. Scaphoid nonunions: a 3-dimensional analysis of patterns of deformity. J Hand Surg Am. 2000; 25:520-528. (The Journal of Hand Surgery has copyright permission.)

Nonunion Treatment

The goals of treatment for scaphoid nonunion include union, correction of deformity, relief of symptoms, and limitation of arthrosis.[8] The main factors that adversely affect outcome in scaphoid nonunion include a long duration of nonunion, no punctate bleeding of the proximal pole with the tourniquet released at surgery, and failed previous surgery.[22]

Surgery for scaphoid nonunion has short-term and long-term goals; however, most studies focus on union alone and not much is known about the ability of surgery for scaphoid union to diminish symptoms in the short term and limit arthrosis in the long-term. One study[23] reported a 97% rate of degenerative changes in thirty-two untreated symptomatic nonunions older than 5 years and another study found a clear correlation between increased degenerative changes and the duration of nonunion.[24] There is good evidence that scaphoid nonunion is associated with progressive degenerative changes, although there is wide variation in both the rate of progression and the associated symptoms. However, it is not so clear that these degenerative

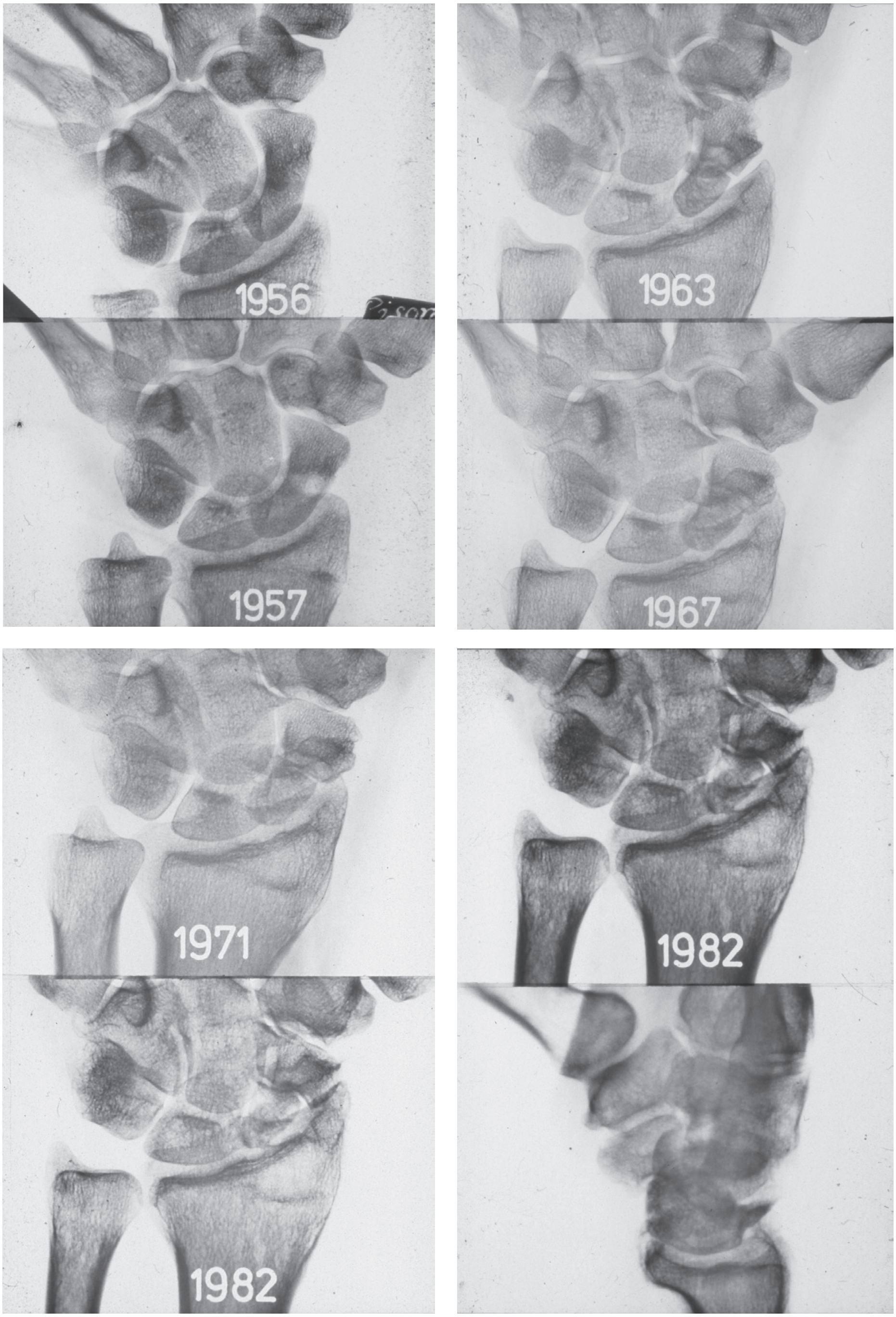

Figure 2A-D. Radiographs of an untreated and ununited scaphoid fracture illustrating the natural course of the degenerative process over several decades. Note the typical aspects of progression of a scaphoid nonunion advanced collapse (SNAC) including radioscaphoid osteoarthritis of the distal pole, dorsal intercalated segment instability (dorsal flexion of lunate) and avascular necrosis of the proximal pole.

changes arrest when union is achieved. Long-term follow-up studies (with a minimum of 5 years follow-up) suggest that, on average, the progression of arthrosis is slower in patients that have achieved union than in patients who have an untreated nonunion, but this is very difficult to study in an unbiased way.[25-27]
When the interval between injury and presentation is either several years or unknown, arthrosis may already be established—whether radiographically visible or not. Surgeons debate when salvage procedures (surgery that changes the anatomy of the wrist with the goal of symptom control) are favored over attempts to gain union.

Internal fixation without bone grafting

Percutaneous screw fixation without bone grafting has been suggested for stable or nascent (meaning less than 6 months) nonunions. The findings of a few small series published in preliminary form suggested that percutaneous repair of selected well-aligned scaphoid delayed unions and nonunions requires only rigid fixation to achieve healing.[28,29] To our knowledge, no fully peer-reviewed publications have addressed percutaneous treatment of stable well-aligned nonunions for that matter.

Non-vascularized bone grafting

The Matti-Russe procedure is the traditional treatment for scaphoid nonunion and some series suggest that the results correlate only with union and not with alignment.[27,30]
The Matti-Russe technique consists of a volar approach in which the nonunion is excavated with either hand or power-driven instruments, and the defect is packed with cortical struts and cancellous bone. Fixation with K-wires is recommended only when the scaphoid does not move as a unit after placement of the graft, otherwise it is optional. This procedure does not allow for accurate restoration of alignment.
Fisk followed by Fernandez suggested an anterior wedge graft intended to improve alignment of the scaphoid and decrease the dorsal tilt of the lunate.[31] Preoperative planning is used to measure the normal scaphoid to determine the amount of bone to be resected and the size and shape of the bone graft. Both the Matti-Russe and Fisk-Fernandez techniques emphasize the need to resect substantial portions of the scaphoid fracture surfaces in order to encourage healing, under the rationale that the sclerotic fracture ends will not support healing.
An attempt is made to use small screws, but Kirschner wires are acceptable and may be needed in revision cases where there is bone loss from a loose screw. Union rates of 80-90% can be achieved.[30,32,33] In a structured review of unstable nonunion series, screw fixation with grafting (94% union) was superior to K-wires and wedge grafting (77% union).[34]
One retrospective comparative study of non-vascularized grafts from different sources has been performed for treatment of scaphoid nonunions.[22] This study showed no

significant differences in union rate between grafts harvested at the iliac crest and grafts harvested at the dorsal side of the distal radius.
There is debate about the role of non-vascularized grafts in nonunions with AVN, as the Matti-Russe procedure has been associated with higher failure rates in cases of diminished or absence of punctuate bleeding at surgery.[33] Other disadvantages are postoperative short-term donor site morbidity, longer surgery, and technical demands of the carved grafts.[35]

Vascularized bone grafting

Vascularized bone grafts can be derived from several different locations. The most commonly used bone grafts are from the distal radius. One method of trying to enhance the vascular supply to an ununited fracture of the scaphoid is the superficial radial artery pedicle (Hori technique). In 1979, Hori et al. initially described active proliferation of blood vessels and new-bone formation when a bundle consisting of an artery, venae comitantes, and perivascular tissue was implanted into the bone in a canine model.[36] In 1988, Kawai and Yamamoto reported on a volar pronator quadratus pedicle with which they achieved union in all eight patients with a scaphoid non-union. In 1995, Fernandez and Eggli reported on eleven patients with scaphoid nonunion who were managed with inlay bone-grafting, internal fixation, and implantation of a vascular pedicle from the second dorsal intermetacarpal artery.[37] Union was achieved in ten patients at an average of ten weeks postoperatively.
In 1991, Zaidemberg et al. reported on a pedicle from the radial aspect of the distal radius including the 1,2 intercompartmental supraretinacular artery (1,2-ICSRA, Zaidemberg technique).[38] They achieved union in all eleven cases, with an average time to union of 6.2 weeks. In 2002, Steinmann et al. reported on the use of a 1,2-ICSRA pedicle in fourteen nonunions which all healed at a mean of 11.1 weeks[39]. Conversely, Straw et al. only achieved union in six (27%) of the 22 fracture nonunions with this technique after a follow-up of 1 to 3 years[40]. In 2006, Chang et al. reported on 48 scaphoid fractures treated with the 1,2-ICSRA pedicled vascularized bone graft of which 34 healed at an average of 15.6 weeks after surgery (71%).[41] In 2009, Waitayawinyu et al. reported on 30 scaphoid nonunions with MRI-documented proximal pole AVN treated with the 1,2-ICSRA pedicle of which 28 united after an average of 5.1 months.[42]
Thus, the reports on the use of distal radial pedicle grafts vary greatly in terms of success, with union rates ranging from 27% to 100%.[38-40] Similar to the outcomes of treatment with non-vascularized grafts, higher union rates are usually obtained in absence of AVN.[41] However, the use of a wide range of definitions of AVN (or the lack thereof) makes a valid comparison between series difficult.

Recently, free vascularized bone grafts have been reported from the iliac crest and the medial femoral supracondylar region with similar results in terms of union rates.[43-45] One retrospective comparative study of vascularized grafts has been performed and this study showed a significantly higher union rate and shorter time to healing for nonunions treated with the medial femoral condyle graft compared to the 1,2-ICSRA pedicle graft.[46]

There is one randomized controlled trial comparing vascularized to non-vascularized bone grafting for scaphoid nonunion.[47] In this study, 35 patients were allocated to treatment with a vascularized 1,2-ICSRA pedicle graft, and 45 to treatment with a non-vascularized iliac crest graft. All patients in the non-vascularized group healed, whereas three patients in the vascularized group failed to heal, all of which were related to technical difficulties. There were no significant differences between the groups in union rates, time to union and functional results, with the exception of a small and likely clinically insignificant greater radial deviation in the vascularized group.

Pediatric Nonunions

Scaphoid fractures in children are very uncommon.[48] Because of the high amount of cartilage present in the scaphoid in the immature skeleton, most fractures appear in the distal third and therefore nonunion is rare.[49] Optimal treatment is debated.[50]

Most pediatric nonunion studies evaluated operative treatment,[49,51,52] but successful conservative treatment has also been reported.[53] All series evaluating operative treatment have shown excellent results and few complications, and independent of the type of internal fixation, the use of additional bone graft, or bone graft without internal fixation.[49-51,54,55] These data show a great prognosis for children with this injury.

Revisions and salvage procedures

When surgery for nonunion is unsuccessful, bone stock and bone quality are further compromised, which may undermine conditions for further corrective surgery.[56] Another attempt to gain healing may be considered if there is felt to be adequate bone and minimal arthrosis.[56]

A salvage procedure is considered when union cannot be achieved after one or more attempts or when arthrosis becomes established.[8] Salvage options include wrist denervation, radial styloidectomy, excision of the distal pole of the scaphoid, proximal row carpectomy (PCR), scaphoid excision and so-called "four-corner" arthrodesis (capitate, hamate, triquetrum, and lunate), and total wrist arthrodesis. The data regarding each option are limited and there are advocates of each.

Summary

The scaphoid is notorious for trouble with healing. It seems that the majority of these are unstable and malaligned. There are many variations to nonunion surgery, which reflects the lack of satisfaction or consistency with any one strategy. Areas of debate include the role of vascularized bone grafts and the transition from attempts to gain union to salvage procedures.

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References

1. Dias JJ, Brenkel IJ, Finlay DB. Patterns of union in fractures of the waist of the scaphoid. J Bone Joint Surg Br 1989;71(2):307-10.
2. 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. J Bone Joint Surg Br 2004;86(5):705-13.
3. Geoghegan JM, Woodruff MJ, Bhatia R, Dawson JS, Kerslake RW, Downing ND, et al. Undisplaced scaphoid waist fractures: is 4 weeks' immobilisation in a below-elbow cast sufficient if a week 4 CT scan suggests fracture union? J Hand Surg Eur Vol 2009;34(5):631-7.
4. Eddeland A, Eiken O, Hellgren E, Ohlsson NM. Fractures of the scaphoid. Scand J Plast Reconstr Surg 1975;9(3):234-9.
5. Cooney WP, 3rd, Dobyns JH, Linscheid RL. Nonunion of the scaphoid: analysis of the results from bone grafting. J Hand Surg Am 1980;5(4):343-54.
6. Szabo RM, Manske D. Displaced fractures of the scaphoid. Clin Orthop Relat Res 1988(230):30-8.
7. Lozano-Calderon S, Blazar P, Zurakowski D, Lee SG, Ring D. Diagnosis of scaphoid fracture displacement with radiography and computed tomography. J Bone Joint Surg Am 2006;88(12):2695-703.
8. Pao VS, Chang J. Scaphoid nonunion: diagnosis and treatment. Plast Reconstr Surg 2003;112(6):1666-76; quiz 1677; discussion 1678-9.
9. Osterman AL, Mikulics M. Scaphoid nonunion. Hand Clin 1988;4(3):437-55.
10. Kawamura K, Chung KC. Treatment of scaphoid fractures and nonunions. J Hand Surg Am 2008;33(6):988-97.
11. Dias JJ, Taylor M, Thompson J, Brenkel IJ, Gregg PJ. Radiographic signs of union of scaphoid fractures. An analysis of inter-observer agreement and reproducibility. J Bone Joint Surg Br 1988;70(2):299-301.
12. Dias JJ. Definition of union after acute fracture and surgery for fracture nonunion of the scaphoid. J Hand Surg Br 2001;26(4):321-5.
13. Morgan WJ, Breen TF, Coumas JM, Schulz LA. Role of magnetic resonance imaging in assessing factors affecting healing in scaphoid nonunions. Clin Orthop Relat Res 1997(336):240-6.
14. Cerezal L, Abascal F, Canga A, Garcia-Valtuille R, Bustamante M, del Pinal F. Usefulness of gadolinium-enhanced MR imaging in the evaluation of the vascularity of scaphoid nonunions. AJR Am J Roentgenol 2000;174(1):141-9.
15. Singh AK, Davis TR, Dawson JS, Oni JA, Downing ND. Gadolinium enhanced MR assessment of proximal fragment vascularity in nonunions after scaphoid fracture: does it predict the outcome of reconstructive surgery? J Hand Surg Br 2004;29(5):444-8.
16. Megerle K, Worg H, Christopoulos G, Schmitt R, Krimmer H. Gadolinium-enhanced preoperative MRI scans as a prognostic parameter in scaphoid nonunion. J Hand Surg Eur Vol. 2011;36(1):23-8.
17. Anderson SE, Steinbach LS, Tschering-Vogel D, Martin M, Nagy L. MR imaging of avascular scaphoid nonunion before and after vascularized bone grafting. Skeletal Radiol 2005;34(6):314-20.
18. Moritomo H, Viegas SF, Elder KW, Nakamura K, Dasilva MF, Boyd NL, et al. Scaphoid nonunions: a 3-dimensional analysis of patterns of deformity. J Hand Surg Am 2000;25(3):520-8.
19. Oka K, Moritomo H, Murase T, Goto A, Sugamoto K, Yoshikawa H. Patterns of carpal deformity in scaphoid nonunion: a 3-dimensional and quantitative analysis. J Hand Surg Am 2005;30(6):1136-44.
20. Oka K, Murase T, Moritomo H, Goto A, Sugamoto K, Yoshikawa H. Patterns of bone defect in scaphoid nonunion: a 3-dimensional and quantitative analysis. J Hand Surg Am 2005;30(2):359-65.

21. Smith ML, Bain GI, Chabrel N, Turner P, Carter C, Field J. Using computed tomography to assist with diagnosis of avascular necrosis complicating chronic scaphoid nonunion. J Hand Surg Am 2009;34(6):1037-43.

22. Tambe AD, Cutler L, Stilwell J, Murali SR, Trail IA, Stanley JK. Scaphoid non-union: the role of vascularized grafting in recalcitrant non-unions of the scaphoid. J Hand Surg Br 2006;31(2):185-90.

23. Ruby LK, Stinson J, Belsky MR. The natural history of scaphoid non-union. A review of fifty-five cases. J Bone Joint Surg Am 1985;67(3):428-32.

24. Mack GR, Bosse MJ, Gelberman RH, Yu E. The natural history of scaphoid non-union. J Bone Joint Surg Am 1984;66(4):504-9.

25. Hooning van Duyvenbode JF, Keijser LC, Hauet EJ, Obermann WR, Rozing PM. Pseudarthrosis of the scaphoid treated by the Matti-Russe operation. A long-term review of 77 cases. J Bone Joint Surg Br 1991;73(4):603-6.

26. Stark A, Brostrom LA, Svartengren G. Scaphoid nonunion treated with the Matti-Russe technique. Long-term results. Clin Orthop Relat Res 1987;214(214):175-80.

27. Jiranek WA, Ruby LK, Millender LB, Bankoff MS, Newberg AH. Long-term results after Russe bone-grafting: the effect of malunion of the scaphoid. J Bone Joint Surg Am 1992;74(8):1217-28.

28. Slade JF, 3rd, Geissler WB, Gutow AP, Merrell GA. Percutaneous internal fixation of selected scaphoid nonunions with an arthroscopically assisted dorsal approach. J Bone Joint Surg Am 2003;85(Suppl 4):20-32.

29. Capo JT, Orillaza NS, Jr., Slade JF, 3rd. Percutaneous management of scaphoid nonunions. Tech Hand Up Extrem Surg 2009;13(1):23-9.

30. Russe O. Fracture of the carpal navicular. Diagnosis, non-operative treatment, and operative treatment. J Bone Joint Surg Am 1960;42:759-68.

31. Fernandez DL. A technique for anterior wedge-shaped grafts for scaphoid nonunions with carpal instability. J Hand Surg Am 1984;9(5):733-7.

32. Barton NJ. Experience with scaphoid grafting. J Hand Surg Br 1997;22(2):153-60.

33. Green DP. The effect of avascular necrosis on Russe bone grafting for scaphoid nonunion. J Hand Surg Am 1985;10(5):597-605.

34. Merrell GA, Wolfe SW, Slade JF, 3rd. Treatment of scaphoid nonunions: quantitative meta-analysis of the literature. J Hand Surg Am 2002;27(4):685-91.

35. Huang YC, Liu Y, Chen TH. Long-term results of scaphoid nonunion treated by intercalated bone grafting and Herbert's screw fixation–a study of 49 patients for at least five years. Int Orthop 2009;33(5):1295-300.

36. Hori Y, Tamai S, Okuda H, Sakamoto H, Takita T, Masuhara K. Blood vessel transplantation to bone. J Hand Surg Am 1979;4(1):23-33.

37. Fernandez DL, Eggli S. Non-union of the scaphoid. Revascularization of the proximal pole with implantation of a vascular bundle and bone-grafting. J Bone Joint Surg Am 1995;77(6):883-93.

38. Zaidemberg C, Siebert JW, Angrigiani C. A new vascularized bone graft for scaphoid nonunion. J Hand Surg Am 1991;16(3):474-8.

39. Steinmann SP, Bishop AT, Berger RA. Use of the 1,2 intercompartmental supraretinacular artery as a vascularized pedicle bone graft for difficult scaphoid nonunion. J Hand Surg Am 2002;27(3):391-401.

40. 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. J Hand Surg Br 2002;27(5):413.

41. 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. J Hand Surg Am 2006;31(3):387-96.
42. Waitayawinyu T, McCallister WV, Katolik LI, Schlenker JD, Trumble TE. Outcome after vascularized bone grafting of scaphoid nonunions with avascular necrosis. J Hand Surg Am 2009;34(3):387-94.
43. Jones DB, Jr., Moran SL, Bishop AT, Shin AY. Free-vascularized medial femoral condyle bone transfer in the treatment of scaphoid nonunions. Plast Reconstr Surg 2010;125(4):1176-84.
44. 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. J Bone Joint Surg Am 1999;81(10):1414-28.
45. Harpf C, Gabl M, Reinhart C, Schoeller T, Bodner G, Pechlaner S, et al. Small free vascularized iliac crest bone grafts in reconstruction of the scaphoid bone: a retrospective study in 60 cases. Plast Reconstr Surg 2001;108(3):664-74.
46. Jones DB, Jr., Burger 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(12):2616-25.
47. Braga-Silva J, Peruchi FM, Moschen GM, Gehlen D, Padoin AV. A comparison of the use of distal radius vascularised bone graft and non-vascularised iliac crest bone graft in the treatment of non-union of scaphoid fractures. J Hand Surg Eur Vol 2008;33(5):636-40.
48. Christodoulou AG, Colton CL. Scaphoid fractures in children. J Pediatr Orthop 1986;6(1):37-9.
49. Henderson B, Letts M. Operative management of pediatric scaphoid fracture nonunion. J Pediatr Orthop 2003;23(3):402-6.
50. Duteille F, Dautel G. Non-union fractures of the scaphoid and carpal bones in children: surgical treatment. J Pediatr Orthop B 2004;13(1):34-8.
51. Chloros GD, Themistocleous GS, Wiesler ER, Benetos IS, Efstathopoulos DG, Soucacos PN. Pediatric scaphoid nonunion. J Hand Surg Am 2007;32(2):172-6.
52. Toh S, Miura H, Arai K, Yasumura M, Wada M, Tsubo K. Scaphoid fractures in children: problems and treatment. J Pediatr Orthop 2003;23(2):216-21.
53. Mazet R, Jr., Hohl M. Fractures of the carpal navicular: analysis of ninety-one cases and review of the literature. J Bone Joint Surg Am 1963;45-A:82-112.
54. Garcia-Mata S. Carpal scaphoid fracture nonunion in children. J Pediatr Orthop 2002;22(4):448-51.
55. Mintzer CM, Waters PM. Surgical treatment of pediatric scaphoid fracture nonunions. J Pediatr Orthop 1999;19(2):236-9.
56. Reigstad O, Thorkildsen R, Grimsgaard C, Reigstad A, Rokkum M. Is revision bone grafting worthwhile after failed surgery for scaphoid nonunion? Minimum 8 year follow-up of 18 patients. J Hand Surg Eur Vol 2009;34(6):772-7.