ACTA ORTHOPAEDICA et TRAUMATOLOGICA TURCICA

ORIGINAL ARTICLE

Acta Orthop Traumatol Turc 2011;45(6):399-405
doi:10.3944/AOTT.2011.2437

Comparative evaluation of radiographic and functional outcomes in the surgical treatment of scaphoid non-unions

Ayhan KILIÇ[1], Sami SÖKÜCÜ[2], Atilla S. PARMAKSIZOĞLU[1], Murat GÜL[2], Yavuz S. KABUKÇUOĞLU[2]

[1]*Department of Orthopaedics and Traumatology, Taksim Training and Research Hospital, İstanbul, Turkey;*
[2]*Department of Orthopaedics and Traumatology, Baltalimanı Bone Diseases Training and Research Hospital, İstanbul, Turkey*

Objective: The aim of our study was to evaluate the correlation between the radiological signs of union and functional outcomes in patients with surgically treated scaphoid non-unions.

Methods: In our study, we evaluated 13 patients who underwent surgery at our clinic for complaints resulting from an unhealed scaphoid fracture. Of the scaphoid non-unions, 9 were on the scaphoid body and 4 were on the proximal pole. According to Slade's classification system, there were two Grade 4, eight Grade 5, and three Grade 6 fractures. The patients were all male with a mean age of 31, with 25 months of mean time between the onset of trauma and surgery. All fractures were treated through open reduction with autogenous bone grafting (cancellous in 4 cases; corticocancellous in 9 cases) and fixation with compression screws. Bone morphology and carpal alignment were assessed through radiography, using the scaphoid index and scapholunate angle measurements, respectively. Range of motion and grip strength measurements together with the modified Mayo wrist scores were used in the assessment of wrist functionality.

Results: Average duration of follow-up was 16 months. In 10 patients, radiological union was attained in a mean time of 12.4 weeks following the operation. There was a substantial improvement in grip strength and range of motion values after surgery. The preoperative mean modified Mayo wrist score of 41.5 improved to 79.2 postoperatively. Accordingly, 4 patients had perfect, 2 had good, 5 had fair and 2 had poor results. The surgical treatment allowed the preoperative mean scapholunate angle of 45.8° and the preoperative mean scaphoid index of 0.69 to be reduced to 32° and 0.6, respectively. The humpback deformity present in 11 patients before the surgery was restored in 10 patients by reconstruction of the scaphoid bone length. Abnormal carpal alignment was restored in 4 of these patients. No statistically significant correlation was found between the functional results and the surgically attained structural restorations and union process.

Conclusion: The surgical treatment of scaphoid fracture non-unions can correct bone morphology and resolve alignment problems but might not be sufficient for the improvement of functional results.

Key words: Degenerative arthritis; fracture; non-union; scaphoid; wrist.

Scaphoid fractures are the most common fractures of the carpal bones. Ten percent of these fractures lead to non-union.[1] The geometric structure of scaphoid fractures, which are highly subject to shearing forces, as well as the specific vascular supply of the bone, are the main reasons for this high rate. Other reasons include delayed diagnosis, inadequate treatment and fixation, excessive disintegration and fragmentation in the fracture site, carpal instability and the presence of accompanying lesions, such as avas-

Correspondence: Ayhan Kılıç, MD. Taksim Eğitim ve Araştırma Hastanesi, Ortopedi ve Travmatoloji Kliniği, Siraselviler Cad. No.112, Taksim, İstanbul, Turkey. Tel: +90 252 - 430 14 03 e-mail: kilicayhan@yahoo.com

Submitted: February 19, 2010 **Accepted:** March 17, 2011

cular necrosis.[1-6] Furthermore, aging and smoking are systemic causes with a negative impact on the union process.[2,7,8] Unhealed scaphoid fractures lead to wrist pain and functional limitations and may also result in carpal collapse and arthrosis.[4] Treatment is generally operative with autogenous bone grafting and fixation with compression screws.[1-6,8] Specific variations concerning the fracture and the patient should be taken into account when choosing the appropriate treatment method.[6] Even with proper treatment, non-union is still possible in 10 to 35% of all cases.[1] Another issue may be the failure to achieve complete restoration of wrist functions due to malunions and/or avascular necrosis.[1-4,9-13] Therefore, treatment strategies that not only ensure union but also provide satisfactory functional results are necessary.

In this study, we examined the correlation between the radiological signs of union and functional outcomes in patients with surgically treated scaphoid non-unions.

Patients and methods

In this retrospective study, records were scanned for patients who received surgical treatment after admission to our clinic for various complaints, due to an unhealed scaphoid fracture, from 2005 to 2008. Thirteen men (mean age: 31 years; range: 23 to 42 years) were included in the study. Inclusion criteria were the presence of scaphoid non-union without avascular necrosis (AVN) in fracture fragments,[14,15] absence of any former fracture and/or surgery on both wrists, absence of previous surgical treatment (open reduction, conventional bone grafting and fixation by compression screw), and attendance at follow-up examinations.

Non-union was defined as the absence of radiological union for a minimum of 6 months following the initial trauma.[14] The Dobyns and Linscheid[15] criteria was employed in the identification of radiological union. Non-union was determined when the distance between the fracture fragments was larger than the distance between the carpal bones, sclerosis on the bone ends was more prevalent than the subchondral sclerosis of other carpal bones, and degenerative changes in the bone and a change in the distance between two fragments were present as demonstrated by stress radiographs.[15]

Cases with height loss and increased density in the proximal fracture fragment were further reviewed for AVN, using unenhanced magnetic resonance imaging of 1.5 Tesla.[16] Patients with AVN were not included in the study.

Common complaints included weakness and wrist pain, occurring particularly with gripping. Eight patients (61.5%) had a history of chronic smoking. Six patients (46%) received prior cast treatment for a mean period of 6 (range: 1 to 10) weeks and the others were diagnosed in our clinic. Of the fractures with non-unions, 9 were in the scaphoid body (69.2%) and 4 in the proximal pole (30.8%). Mean interval between trauma and treatment was 29.4 (range: 8 to 120) months. Nine fractures (69.2%) were on the dominant wrist.

Fractures were classified according to Slade's treatment classification system for scaphoid non-unions.[6] Two fractures (15.4%) were Grade 4 (max. 5 mm of bone resorption and cyst formation in the fracture site, normal scapholunate association), eight (61.5%) were Grade 5 (max. 5 mm of bone resorption and 10 mm of cyst formation in the fracture site) and three (%23.1) were Grade 6 (pseudarthrosis).

Wrist motions were preoperatively measured using a standard goniometer. Comparative grip strength measurements were taken with a dynamometer (Jamar®; Sammons Preston Rolyan, Chicago, IL, USA). Functional assessment was made using a modified Mayo wrist score, consisting of four equally weighted (25 points each) sections on pain, treatment satisfaction, range of motion and gripping strength.[17] A score of 90 to 100 was considered excellent; 80 to 89, good; 65 to 79, fair; and less than 65, poor.

Wrist radiographs taken in the standard (anteroposterior, lateral) and scaphoid positions were used to evaluate the patients in terms of diagnosis, classification, arthrosis and carpal alignment.[18,19] Scapholunate angles were measured on the lateral radiographs of the wrist. Computerized tomography was used to measure scaphoid height and length, and the humpback deformity of the bone was interpreted on the basis of the ratio between two values (scaphoid index).[19]

Degenerative changes in the radiocarpal joint (Phase 0: no narrowing, Phase 1: extensive spur formation towards radiocarpal joint, Phase 2: narrowing in the radiocarpal joint space, Phase 3: closed radiocarpal joint space) were assessed.[5] Arthrosis in the radiocarpal joint was noted in 3 patients (%23; Grade 1 in one, Grade 2 in two patients).

All surgical interventions were performed by the same surgeon (AK). Patients were prepared for surgery in a sterilized environment with a tourniquet applied above the elbow. The scaphoid tubercle, thumb metacarpal base and the plane of the flexor carpi radialis (FCR) tendon were marked on the volar surface of the wrist, with a surgical marker. A skin incision starting from 3 cm above the wrist skinfold was extended along the FCR tendon to meet the formerly marked points. The deep plane was accessed with a dissection careful to protect the surrounding veins and superficial sensory nerves. The thenar muscle groups were freed to expose the scaphotrapezial joint. The scaphoid bone was accessed by incising the wrist volar capsule longitudinally. For cases with proximal pole fractures, the incision made in the capsule was extended to expose scapholunate joint. The fibrous tissues were then removed and several holes were made on the damaged surfaces of the fragments with a Kirschner wire (K-wire). The tourniquet was temporarily released to check the bleeding of the bone surfaces.[20] Subsequently, the dimensions and alignment of the scaphoid bone, as well as scapholunate stability, were examined under fluoroscopic control. Both fracture fragments were pulled slightly apart by means of the inserted K-wires to evaluate the quantity and type of graft required for restoring the bone structure. Corticocancellous wedge grafts harvested from the iliac crest were used for the fractures in the waist. Cancellous wedge grafts harvested from the radius were used both for the fractures located in the proximal pole and for those with minor bone loss. The fracture fragments were then fixed under fluoroscopic control with cannulated, headless compression screws (Acutrak® Acumed; Hillsboro, OR, USA). Mini and/or standard screws (20 to 30 mm in 22 cases) were used for fixation (two screws in 5 patients and one screw in 7 patients) (Fig. 1).

Two patients with radiocarpal arthrosis (15.4%) also had radial stiloidectomy during the same session.

A scaphoid cast was applied for six weeks postoperatively. Follow-up radiographs were taken at cast removal. Active motion exercises were then initiated and patients were allowed to return to daily activities using wrist braces. The union process was evaluated through monthly radiographs. Range of motion and grip strength measurements were repeated in the postoperative examinations. Wrist functions were evaluated in line with the modified Mayo wrist scores.

Data comparison was made using the Medcalc® (statistical software, v.10.0) medical statistics evaluation program. Significance level was set at $p<0.05$; chi-square and the Student's t-test were used to evaluate quantitative variables. Qualitative data were compared using the Fisher Exact Test and Pearson correlation coefficients.

Results

Mean follow-up time was 16 (range: 8 to 36) months. Radiological union was confirmed in 10 patients (76.9%) at the end of a mean follow-up time of 12.4 (range: 8 to 16) weeks. Union was not achieved in 1 fracture in the proximal pole (7.6%)

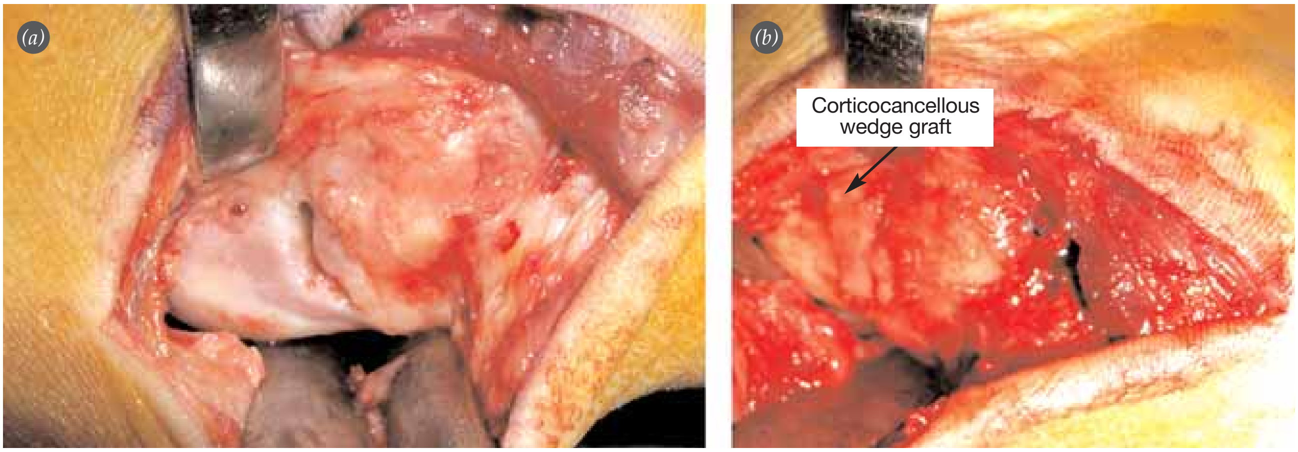

Fig. 1. Case 1. **(a)** Surgery images showing the scaphoid fracture non-union. **(b)** Bone fixation conducted with corticocancellous wedge graft from the iliac crest and 2 compression screws. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

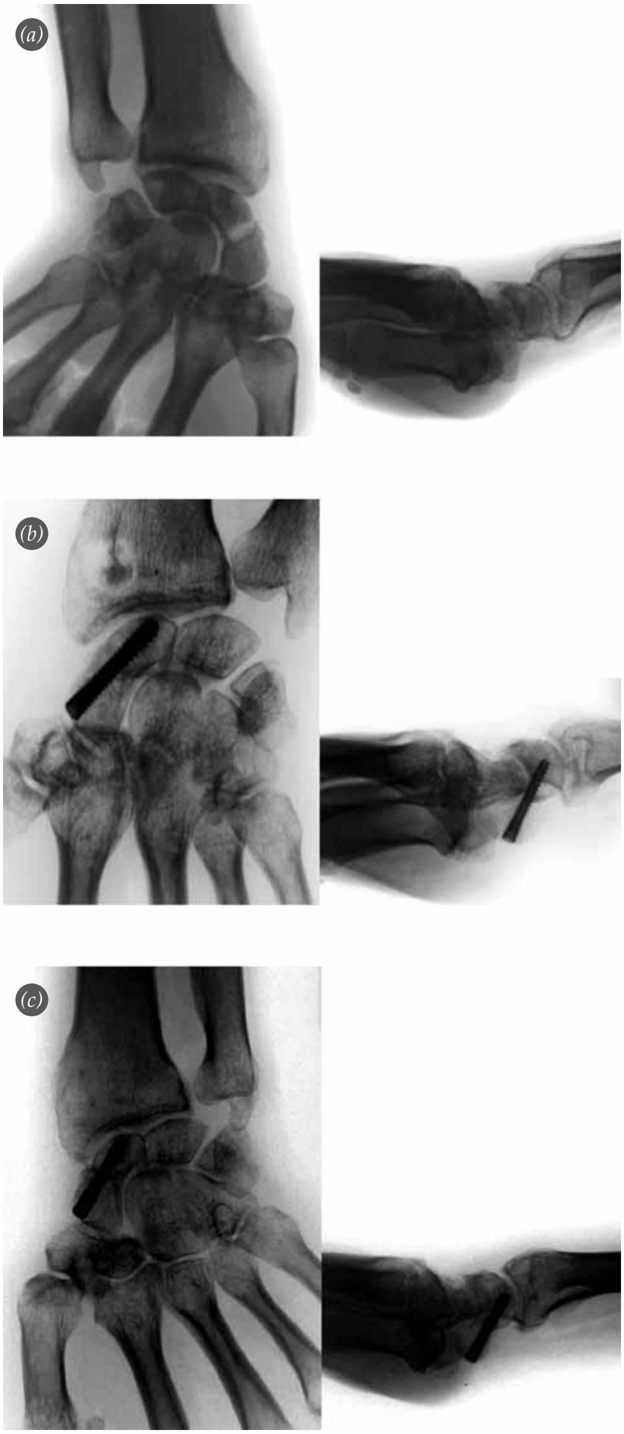

Fig. 2. Case 3. 34-year-old male admitted to our clinic with progressive complaints persisting for 8 months following a trauma of the right wrist. **(a)** Bilateral radiographs showing non-union located in the scaphoid waist, manifesting itself by cystic changes (Slade Grade 5). **(b)** Postoperative bilateral radiographs showing the carpal alignment and scaphoid bone morphology restored by application of a cancellous graft, harvested from the distal metaphyseal region of the radius and headless screws. **(c)** 12th week radiographs showing union and carpal alignment in the normal range.

with cancellous grafting and 2 fractures in the scaphoid waist (15.3%) with cancellous and cortico-cancellous grafting.

Mean wrist grip strength improved from 17.7 (range: 12 to 25) kg preoperatively to 22.5 (range: 10 to 35) kg postoperatively (p=0.04). Postoperative mean grip strength was improved, however, was still weaker than that of the healthy wrist (mean: 34 kg; range: 28 to 46 kg) (p=0.0001). Mean wrist flexion/extension range of motion improved from 59.6° (range: 10° to 120°) preoperatively to 111° (range: 70° to 160°) postoperatively (p=0.0003). There was a significant difference between the mean postoperative flexion/extension range of motion and that of the healthy wrist (mean: 166°; range: 158° to 175°) (p<0.0001). Mean radial/ulnar deviation range of motion improved from 22° (range: 16° to 27°) preoperatively to 29° (range: 25° to 33°) postoperatively (p=0.01). This mean value, however, was significantly less than that of the healthy side (mean: 38°; range: 32° to 44°) (p<0.001).

Mean scapholunate angle was 45.8° (range: 28° to 68°) at the time of admittance and 32° (range: 21° to 50°) postoperatively (p=0.001). The mean scaphoid height to length ratio (scaphoid index) of 0.69 (range: 0.55 to 0.82) preoperatively deteriorated to 0.6 (range: 0.5 to 0.72) in the final examinations (p=0.01). The humpback deformity present in 11 patients before the treatment was corrected in 10 patients (90.9%) by reestablishing the scaphoid length. The preoperatively abnormal carpal alignment (dorsal intercalated segment instability) was reestablished in 4 of these patients (36.3%) (Fig. 2).

Preoperative mean modified Mayo wrist score of 41.5 (range: 25 to 60) points improved to 79.2 (range: 60 to 100) points postoperatively. Accordingly, results were perfect in 4 patients (30.8%), good in 2 (15.4%), fair in 5 (38.4%) and poor in 2 (15.4%) (Fig. 3).

There was no significant correlation between the postoperative functional scores and the height/length ratio (r=-0.11, p=0.69) or between the functional results and the location and phase of the fracture non-union (p=0.37), (p=0.60). Correlation analysis revealed no significant correlation between non-union and the patients with poor results (r=0.19, p=0.59). According to the chi-square test, there was no significant correlation between radiocarpal arthrosis and functional results (p=0.65). No significant relation was found between a history of smoking and non-union in the statistical assessment conducted,

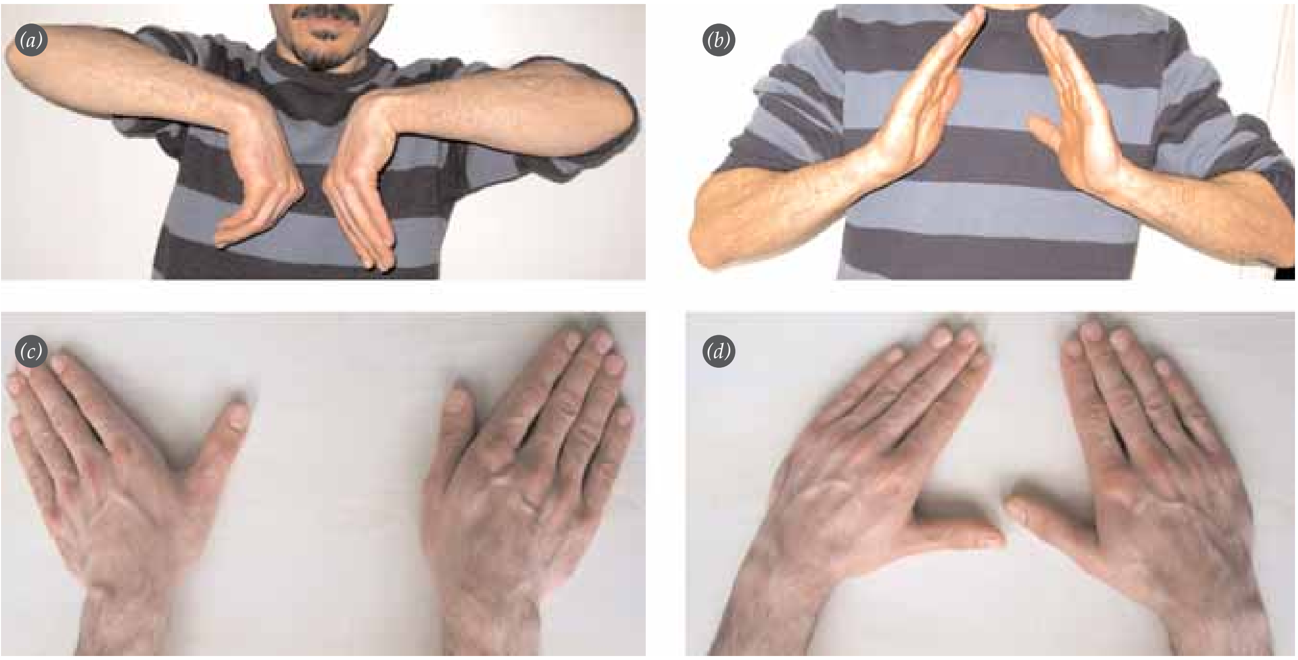

Fig. 3. Case 3. Evaluation of the wrist motions in **(a)** flexion, **(b)** extension and **(c, d)** deviation (final examination in 12th month). [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

which used unidirectional probability test with regards to smoking history present in the 3 patients (23%) in which union was not achieved (p=0.386).

Two of the 3 patients who did not achieve union at the end of the 6-month follow-up period had persistent pain. These two patients were treated by proximal fracture fragment excision and scapho-trapezio-trapezoid arthrodesis.

Radiographic narrowing and irregularity in the intercarpal and radiocarpal joints were found in 3 patients (23%), but did not lead to any complaints. In one patient (7.7%) the K-wire was broken during screw placement. The broken wire was left in place and another screw was inserted in the parallel direction.

Discussion

Avascular necrosis and humpback deformity are the two leading pathological changes seen in the non-union of scaphoid fractures.[1-6,8-12] These problems have a negative impact on load distribution at the site by disturbing the bone morphology and carpal alignment, causing pain and reducing grip strength and wrist range of motion, particularly during daily activities.[1,4,21-23] This progressive process leads to the eventual collapse of the radiocarpal joint and arthrosis within 10 years.[3,4,21]

The treatment of scaphoid non-union aims to ensure union and eliminate clinical complaints. Complaints arising from non-union are often persistent, even following subsequent union.[1,11-13,24,25] Presently, there is a consensus for surgical treatment in scaphoid non-unions.[1,6,8,13,15] Generally, applied surgical treatment methods include autogenous bone grafting (vascular/conventional) at the fracture site and fixation with compression screws.[1,24-33] Precise identification of the pathologies across the fracture site is key to defining the appropriate treatment strategy. The commonly employed classification systems of the fracture line location, however, tend to be insufficient for the identification of appropriate treatment.[1,6] Therefore, to propose a treatment scheme, we used Slade's classification which defines fracture site pathologies in grades.[6] According to this classification, 11 (84.6%) of the fractures were in advanced phases with apparent bone resorption and sclerosis. Union was achieved in 10 (76.9%) of the 13 fractures over a mean period of 12.4 weeks, through conventional grafting and fixation with compression screws. Carpal alignment was restored in all wrists with dorsal intercalary segmental instability deformity seen in preoperative radiographic analysis. Furthermore, subjective and objective evaluations demonstrated evident positive improvements in comparison to preoperative values. However, it was found that restoration of the scaphoid bone structure and carpal alignment had no explicit impact on functional results. Early phase degenerative changes in the wrist and intercarpal joints had no negative impact upon functional results throughout the brief 16-month follow-up period. However, degenerative changes are more prevalent and union is more challenging in patients who do not receive treatment for more than 5 years.[1,25]

As no prospective, comparative study on treatment exists in the literature, researchers tend to focus on treatment strategies and union rates. In a review of 5,246 patients in 147 specific studies, Munk et al. reported an 80% rate of union with cancellous graft alone, an 84% union rate using conventional grafting accompanied by compression screws, and a 91% union rate using vascular islet grafts.[25] Union rates vary widely, depending particularly on the presence of AVN in the fragments, graft type and the number of performed surgeries.[1,8,13]

Fixation with compression screws alone is employed in early phase fractures where bone circulation is maintained. Screw fixation is complemented with vascular islet grafting in fractures in the 1/3 proximal region, especially in cases with AVN. This method has a reported success rate of 90%, and aims to promote the vascularity in the fracture site by enhancing the amount of osteoprogenitor cells.[28-33] The most widely used technique is the 1,2-intercompartmental supraretinacular (1,2-ICSRA) artery islet graft, described by Zeidemberg.[28] For restoring bone morphology and further stabilizing fixation in fractures with prominent bone loss and humpback formation in the fracture site, corticocancellous wedge grafts are recommended. Union was achieved in 7 (77.7%) of the 9 patients in this study, who were treated with this method as described by Bindra et al..[3] For cases with limited bone loss at the fracture site, cancellous bone grafts can be used to benefit from their osteogenic effect.[1,13] In this study, unproblematic union was attained in 3 (75%) of the 4 patients treated with grafts, harvested from the distal metaphyseal radius. Fernandez reported that cancellous grafts of the iliac crest have better osteogenic potential than those harvested from other sites.[34] However, comparative studies by Tambe et al. demonstrated that there is no significant difference between graft sources in terms of osteogenicity, and that cancellous grafts can be harvested from the iliac crest, olecranon, or distal radius.[35]

Few studies exist on the comparison of functional results and union.[1,2,8,11-13] A union rate of 75% in fractures treated with various surgical methods was reported in a study of 138 patients.[1] The same study also reported a reduction in scaphoid humpback deformity and dorsal stability from a preoperative 79% and 41% to postoperative 16% and 12%, respectively. Tsuyuguchi et al., on the other hand, reported a limitation in wrist function in cases in which scapholunate alignment could not be restored.[11]

Limitations of the study were the small number of cases and the heterogeneity arising from general and local factors that influence wrist function.

In conclusion, bone morphology and alignment can be restored through the surgical treatment of scaphoid non-unions. However, the surgically attained restorations and even union might not be sufficient to provide satisfactory functional results.

Conflicts of Interest: No conflicts declared.

References

1. Schuind F, Haentjens P, Van Innis F, Vander Maren C, Garcia-Elias M, Sennwald G. Prognostic factors in the treatment of carpal scaphoid nonunions. J Hand Surg Am 1999;24:761-76.
2. Inoue G, Sakuma M. The natural history of scaphoid nonunion. Radiographical and clinical analysis in 102 cases. Arch Orthop Trauma Surg 1996;115:1-4.
3. Bindra R, Bednar M, Light T. Volar wedge grafting for scaphoid nonunion with collapse. J Hand Surg Am 2008; 33:974-9.
4. Ruby LK, Stinson J, Belsky MR. The natural history of scaphoid non-union. A review of fifty-five cases. J Bone J Surg Am 1985;67:428-32.
5. Amadio PC, Berquist TH, Smith DK, Ilstrup DM, Cooney WP 3rd, Linscheid RL. Scaphoid malunion. J Hand Surg Am 1989;14:679-87.
6. Slade JF 3rd, Dodds SD. Minimally invasive management of scaphoid nonunions. Clin Orthop Relat Res 2006;(445): 108-19.
7. 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.
8. Waitayawinyu T, Pfaeffle HJ, McCallister WV, Nemechek NM, Trumble TE. Management of scaphoid nonunions. Orthop Clin North Am 2007;38:237-49.
9. 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.
10. Bain GI, Bennett JD, MacDermid JC, Slethaug GP, Richards RS, Roth JH. Measurement of the scaphoid humpback deformity using longitudinal computed tomog-

raphy: intra- and interobserver variability using various measurement techniques. J Hand Surg Am 1998;23:76-81.

11. Tsuyuguchi Y, Murase T, Hidaka N, Ohno H, Kawai H. Anterior wedge-shaped bone graft for old scaphoid fractures or non-unions. An analysis of relevant carpal alignment. J Hand Surg Br 1995;20:194-200.
12. Tomaino MM, King J, Pizillo M. Correction of lunate malalignment when bone grafting scaphoid non-union with humpback deformity: rationale and results of a technique revisited. J Hand Surg Am 2000;25:322-9.
13. 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 Eur Vol 2007;32:148-54.Hand Surg Eur Vol 2007;32:148-54.
14. Cooney WP 3rd, Dobyns JH, Linscheid RL. Nonunion of the scaphoid: analysis of the results from bone grafting. J Hand Surg Am 1980;5:343-54.
15. Kawamura K, Chung KC. Treatment of scaphoid fractures and nonunions. J Hand Surg Am 2008;33:988-97.
16. Trumble TE, Salas P, Barthel T, Robert KQ 3rd. Management of scaphoid nonunions. J Am Acad Orthop Surg 2003;11:380-91.
17. Smith BS, Cooney WP. Revision of failed bone grafting for nonunion of the scaphoid. Treatment options and results. Clin Orthop Relat Res 1996;(327):98-109.
18. 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 1998;23A:76-81.
19. Rajagopalan BM, Squire DS, Samuels LO. Results of Herbert-screw fixation with bone-grafting for the treatment of nonunion of the scaphoid. J Bone Joint Surg Am 1999;81:48-52.
20. Günal İ, Özçelik A, Göktürk E, Ada S, Demirtaş M. Correlation of magnetic resonance imaging and intraoperative punctate bleeding to assess the vascularity of scaphoid nonunion. Arch Orthop Trauma Surg 1999;119: 285-7.
21. Daecke W, Wieloch P, Vergetis P, Jung M, Martini AK. Occurrence of carpal osteoarthritis after treatment of scaphoid non-union with bone graft and Herbert screw: a long-term follow-up study. J Hand Surg Am 2005;30:923-31.
22. 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 2008;33:1459-68.
23. Moritomo H, Murase T, Oka K, Tanaka H, Yoshikawa H, Sugamoto K. Relationship between the fracture location and the kinematic pattern in scaphoid nonunion. J Hand Surg 2008; 33A:1459-68.
24. Nakamura R, Horii E, Watanabe K, Tsunoda K, Miura T. Scaphoid non-union: factors affecting the functional outcome of open reduction and wedge grafting with Herbert screw fixation. J Hand Surg Br 1993;18:219-24.
25. Munk B, Larsen CF. Bone grafting the scaphoid nonunion: a systematic review of 147 publications including 5,246 cases of scaphoid non-union. Acta Orthop Scand 2004;75:618-29.
26. Tuncay İ, Doğan A, Alparslan S. Comparison between fixation with Herbert screws and Kirschner wires in the treatment of scaphoid pseudoarthrosis. [Article in Turkish] Acta Orthop Traumatol Turc 2002;36:17-21
27. Bagatur EA, Zorer G. Primary fixation of displaced carpal scaphoid fractures with the Herbert-Whipple screw. [Article in Turkish] Acta Orthop Traumatol Turc 2002;36: 341-5.
28. Zaidemberg C, Siebert JW, Angrigiani C. A new vascularized bone graft for scaphoid non-union. J Hand Surg Am 1991;16:474-8.
29. 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;34:387-94.
30. Yücetürk A, Tuncay C, Işıklar U, Tandoğan R. Treatment of scaphoid nonunions with a vascularized bone graft based on the first dorsal metacarpal artery. J Hand Surg Br 1997;22:425-7.
31. Mathoulin CL, Haerle M. Technique: vascularized bone grafts from the volar distal radius to treat scaphoid nonunion. J Hand Surg Am 2004;4:4-10.
32. 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;90:2616-25.
33. 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;31:387-96.
34. Fernandez DL. A technique for anterior wedge-shaped grafts for scaphoid nonunions with carpal instability. J Hand Surg Am 1984;9:733-7.
35. Tambe AD, Cutler I, Murali SR, Trail IA, Stanley JK. In scaphoid non-union, does the source of graft affect outcome? Iliac crest versus distal end of radius bone graft. J Hand Surg Br 2006;31:47-51.