Comparison of the results of percutaneous and open screw fixation in the treatment of scaphoid nonunion fractures

N. ATILGAN[1], N. DUMAN[2], T.S. COLAK[3], I.H. KORUCU[3], M. DEMIRYUREK[3], M. YILMAZ[4]

[1]Department of Hand Surgery, Sanliurfa Mehmet Akif Inan Training and Research Hospital, Sanliurfa, Turkey
[2]Department of Orthopedics and Traumatology, Faculty of Medicine, Uskudar University, Istanbul, Turkey
[3]Department of Orthopedics and Traumatology, Meram Faculty of Medicine, Necmettin Erbakan University, Konya, Turkey
[4]Department of Orthopedics and Traumatology, Private Deva Hospital, Gaziantep, Turkey

Abstract. – OBJECTIVE: Our study aims to compare the clinical results of percutaneous screw fixation and non-vascularized bone grafting with open screw fixation in patients who did not achieve union due to failure in diagnosis and treatment after a scaphoid fracture.

PATIENTS AND METHODS: Forty-three patients with scaphoid nonunion fractures corresponding to the first three Slade and Dodds classification were divided into two groups. Non-vascularized bone grafting with open reduction and internal fixation (ORIF) was applied to 24 patients in the first group, and 19 patients in the second group were treated with a closed reduction and internal fixation (CRIF) (percutaneous screw fixation). The patients were followed up for preoperative and postoperative functional scores and time to union.

RESULTS: Our study found that the scaphoid was most commonly fractured in the waist of the scaphoid. In our study, we found that distal scaphoid fractures had the highest union rate (100%), followed by the waist fractures (93.2%) and the weakest union (50%) in the proximal pole fractures. We observed that the fastest union had occurred in the fractures of the waist. We also observed that the union was completed earlier in patients who operated with ORIF than those with CRIF. We found union in 87.5% of patients who underwent ORIF, in 84.2% of patients who underwent CRIF. CRIF operation duration was shorter than expected from ORIF operation duration.

CONCLUSIONS: We found that similar union rates could be achieved in the patient groups who underwent percutaneous and open screw fixation by selecting the appropriate patient in scaphoid nonunion fractures. Union was faster and functional results were more satisfactory in the ORIF group. The operation time was shorter in the CRIF group.

Key Words:

Scaphoid, Nonunion, ORIF (open reduction and internal fixation), CRIF (closed reduction and internal fixation).

Introduction

Scaphoid fractures are the most common fractures of the carpal bones, accounting for 60% of all carpal bone fractures. Tenderness in the anatomical snuffbox, scaphoid tubercle, and longitudinal compression of the 1st metacarpine are findings helpful in the diagnosis of a patient with a scaphoid fracture[1]. Conventional radiographs should be the first-choice method in patients with post-traumatic pain on the radial side of the wrist. Gilbert et al[2] suggested posterio-anterior (PA), lateral, ulnar-deviated PA and semi-prone oblique (writing position) radiographs. First, the diagnosis can be supported by CT and MRI after radiography[3,4]. The most widely used classification system in clinical routine is Herbert classification, followed by Rousse and MAYO classifications[5].

Approximately 5-20% of scaphoid fractures cannot be healed with non-surgical treatment[6,7]. Patients without signs of union despite 6-month follow-up are considered non-union[8]. Surgical treatment is recommended in the majority of unstable scaphoid back fractures and proximal pole fractures with a displacement of more than one millimeter. There are different surgical techniques for its treatment[9]. Various surgical techniques, such as open reduction internal fixation (ORIF),

Corresponding Author: Numan Atilgan, MD; e-mail: doktor_dao@hotmail.com

minimally invasive surgery, dorsal minimally invasive opening, arthroscopic assisted screw fixation, volar minimally invasive opening have been described in the literature[8,10,11]. Our aim in choosing surgery is to heal the nonunion of the scaphoid fracture, correct the carpal deformity, prevent instability, and prevent the development of arthritis.

Patients and Methods

Forty-three cases treated for the diagnosis of scaphoid non-union between 2017 and 2020 were evaluated. The study received the approval of the ethics committee. The study did not include patients with open fractures, multiple hand fractures, or additional traumas such as head trauma. Patient selection was made per Slade and Dodds staging using X-Ray and Computer Tomography (CT). Nonunions other than stage 1, 2, 3 were not included in the study (Table I).

Union status, Mayo score, q-Dash score, visual analog score (VAS), scapholunate angles were calculated. The preoperative and postoperative clinical parameters were evaluated, and Quick Disabilities of Arm, Shoulder, and Hand (Quick DASH) scores were examined. Pain analysis was performed according to the VAS reported by the patients. The score was determined by measuring the distance (mm) on the 10 cm line between the "no pain" anchor and the patient's mark, providing a score range of 0 to 100.

Image interpretation, pre- and postoperative radiographic measurements, and evaluation of radiographic union were performed by the same orthopedic surgeon. Standard posteroanterior and lateral radiographic images were evaluated both preoperatively and postoperatively.

The scapholunate angle was measured pre- and postoperatively on a sagittal CT scan of the wrist along the longitudinal axis of the scaphoid.

Surgical Technique

The operation was performed under general anesthesia with upper arm tourniquet control. A cancellous bone graft taken from the iliac wing was used in all patients who underwent ORIF. In patients for whom screws and grafts were planned, the scaphoid was approached with a longitudinal incision centered on the tuberosity of the scaphoid, lateral to the volar flexor carpi radialis (FCR) tendon. In the percutaneous screw technique, a pink-tipped syringe needle was used as a guide over the volar tubercle, accompanied by scopy, and the fracture was passed with a retrograde K-wire, followed by drilling and a headless screw, and the final fixation of the fracture was made (Figure 1).

Follow-up

After the operation, the patients were followed up on a yearly routine at the third week, sixth week, 3rd Month, 6th Month, and 1st year. After surgery, a long arm splint was applied to each patient, elevation was applied, and analgesics were given for pain control. Active finger movement and shoulder exercises were allowed after surgery. Skin sutures were removed ten days later, and a shorter thumb-supported cast was applied for six weeks. Finally, thumb supported wrist splint was applied until the radiographic union was achieved.

Statistical Analysis

The data obtained from the research were transferred from the Excel file to the database created in the SPSS 18.0 (SPSS Inc., Chicago, IL, USA) package program, and statistical analyzes

Table I. Scaphoid Fractures Nonunion Classification (Slade and Dodds).

Stage	Category	Features of scaphoid non-union
1	Delayed non-union	Scaphoid fractures with a delayed union (4-8 weeks)
2	Fibrous non-union	Cartilage sheath is intact, minimal fracture lines at the non-union interface, no cysts, and sclerosis
3	Minimal sclerosis	<1 mm bone resorption at the non-union interface accompanied by minimal sclerosis
4	Cyst formation and sclerosis	<5 mm bone resorption at the non-union interface, cyst formation, scaphoid position preserved
5	Cyst formation and sclerosis	5-10 mm bone resorption at the non-union interface, cyst formation, scaphoid position preserved
6	Pseudoarthrosis	Separate bone fracture fragments with deep bone resorption at the non-union interface. Significant part shifts and deformities are often present.

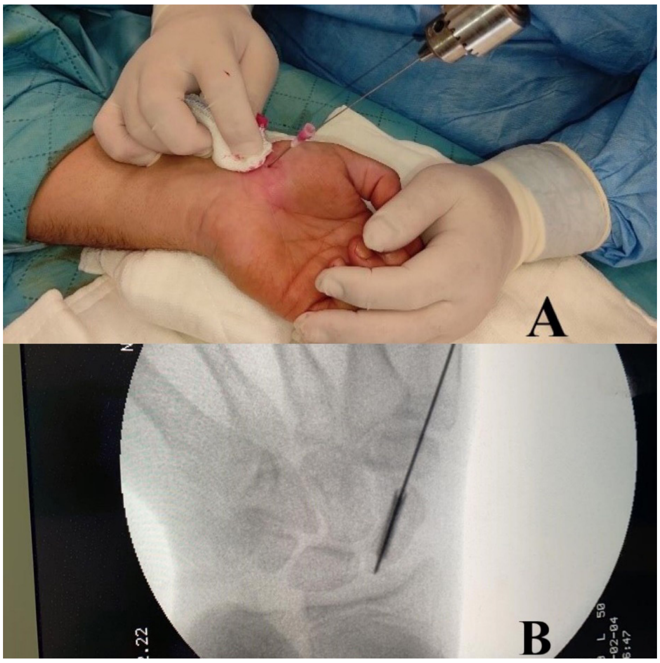

Figure 1. **A**, Percutaneous screw application technique. **B**, Fluoroscopy image.

were made with this program. As descriptive statistics, arithmetic mean ± standard deviation and median (minimum, maximum) were used to summarize numerical data, and numbers and percentages were used to summarize categorical data.

Chi-square (χ^2) test was used to compare categorical data. Compliance of numerical data with normal distribution was examined by visual (histogram graph) and analytical methods (Kolmogorov-Smirnov/Shapiro Wilk tests). In the comparison of the two groups, the student's *t*-test was used when numerical data were normally distributed, and Mann-Whitney U test was used when they were not normally distributed.

Since it was determined that the scapholunate angles, q DASH, mayo, and VAS scores of the patients showed normal distribution, the comparisons made at two separate times before and after the dependent groups were compared using the student's *t*-test. A *p*-value below 0.05 was considered statistically significant.

Results

The patients were divided into two groups, 24 patients (55.8%) underwent ORIF, and 19 patients (44.2%) CRIF. The mean age of the patients was 31.95±9.29 (min: 21; max: 62). 37 (86%) of the patients were male, and 6 were female (14%). 29 (67.4%) of the fractures were on the right side, and 14 (32.6%) were on the left side. The fracture was in the waist in 67.4% of the patients, proximal in 18.6%, and distal in 14%. 14% (n=6) of the patients were smokers. We could not detect a relationship between smoking status patients and non-union.

The mean union time of 29 fractures in the waist was 15.41±2.60 (min: 11; max: 21) months. Two (6.9%) fractures in the waist did not unite. Sixteen (55.2%) of 29 fractures in the waist were treated with ORIF; 13 (44.8%) of them had been operated with CRIF. Of the two non-union fractures, one was operated with ORIF and 1 with CRIF. The mean union time of patients operated with ORIF for fractures in the waist (n=16) was 14.00±1.77 (min: 11; max: 17) months. The mean union time of patients operated with CRIF for fractures in the waist (n=16) was 17.17±2.44 (min: 13; max: 21) months. We found that patients operated on with ORIF had a statistically shorter union time than the group operated with CRIF (z=-3.071, *p*=0.002).

The mean union time of the fractures in the distal region (n=6) was 15.67±2.73 (min: 12; max: 19) months. All the fractures in the distal region were unioned. Fractures in the distal region (n=6); 3 (50%) of them were operated with ORIF and 3 (50%) with CRIF. The mean union time of distal fractures operated with ORIF (n=3) was 13.67±2.08 (min: 12; max:16), and the mean union time of patients who were operated on with CRIF (n=3) was 17.67±1.52 (min: 16; max: 19). No statistically significant difference was found (z=-1.771, *p*=0.77).

The mean union time of the fractures in the proximal region (n=8) was 15.33±2.08 (min: 13; max: 17). Four (50%) of the fractures in the proximal region were non-union. Five (62.5%) of the proximal fractures (n=8) were operated with ORIF and 3 (37.5%) with CRIF. Of the four non-union fractures, two were operated with ORIF and 2 with CRIF. There was no statistically significant difference between the fractures in the proximal region who were operated on with ORIF and those operated on with CRIF (z=-1.342, *p*=0.180).

The mean union time of fractures in patients who underwent ORIF was 14.14±1.82 months, while the mean union time of fractures in patients who underwent CRIF was 17.19±2.19 months. The union time of the fractures in patients who underwent CRIF was longer than those who underwent ORIF (*t*=-4.604, *p*<0.001).

While the mean follow-up period of the patients who underwent ORIF was 16.00±1.95, the follow-up period of the patients who underwent CRIF was 18.95±1.81.

The mean operation duration of the patients who underwent ORIF was 68.54±11.56 minutes, while the operation duration of the patients who underwent CRIF was 45.26±10.60 minutes. Patients who underwent ORIF had longer operation durations. (*t*=6.798 *p*<0.001).

There was no statistically significant difference between the groups regarding preop q-dash, preop mayo, preop scapholunate angle, postop scapholunate angle, the time between fracture and operation time, age, postop mayo, and preop VAS scores, and follow-up times.

The mean of the preop q dash scores of the patients was 50.16±10.57 (min: 31; max: 69), while the mean of the postop q dash scores was 27.23±7.04 (min: 17; max: 44). The preop q dash scores of the patients were significantly higher. (*t*=14.72; *p*<0.001); GA (19.78-26.07). The median postop q dash scores of patients who underwent ORIF were 23.50 (min: 17, max: 44), while it was calculated as 27 (min: 18, max: 43) in patients who underwent CRIF. The postoperative q-dash score of the patients who underwent CRIF was statistically significantly higher than those who underwent ORIF (*p* = 0.041).

The mean preoperative mayo scores of the patients were 66.21±6.78 (min: 54; max: 80). The mean postoperative mayo scores of the patients were 76.19±7.65 (min: 60; max: 90). Postoperative mayo scores of the patients were found to be statistically significantly higher. (*t*=-10.92; *p* < 0.001); GA (-11.81 – -8.13). No statistically significant difference was found between the groups regarding mayo scores (*p* = 0.930).

While the mean preoperative vas scores of the patients were 5.81±1.35, the postoperative VAS scores were calculated as 3.42±0.98. The preoperative VAS of the patients was found to be statistically significantly higher. (*t*=10.48; *p* < 0.001); GA (1.93-2.85). While the median of postoperative VAS scores of patients who underwent ORIF was 3 (min: 2, max: 5), it was calculated as 4 (min: 2, max: 5) in patients who underwent CRIF. The postoperative VAS score of the patients who underwent CRIF was statistically significantly higher than those who underwent ORIF (*p* = 0.012).

The mean preop scapholunate angles of the patients were 54.74±6.63 (min: 42; max: 66). The mean preop scapholunate angles of the patients were 52.30±5.35 (min: 42; max: 62). The preop scapholunate angles of the patients were statistically significantly higher. (*t*=5.13; *p* < 0.001); GA (1.48-3.40).

The mean union time of the patients was 15.46±2.49 (min: 11; max: 21) months. The mean follow-up period of patients without union was 17.67±1.86 (min: 16; max: 21) months. The time between the fracture and operation time was 10.19 ±3.01 (min: 5; max: 15) months. The mean postoperative follow-up period of the patients was 17.30±2.38 (min: 12; max: 22). Complications developed in 6 (14%) of the patients. All of the complications that developed were non-union. Of the patients without the union, three were in the CRIF group, and 3 were in the ORIF group. The mean follow-up period of the patients without union was 17.67±1.86 (min: 16; max: 21) months.

Discussion

Although open surgical fixation using vascularized or nonvascularized bone grafts is still the most common method for nonunion of scaphoid fractures, percutaneous screw fixation has begun to take a wider place in the current literature. However, in our literature review, we observed that there are not enough publications comparing the percutaneous technique with the open surgical technique using nonvascularized bone graft. For this reason, we aimed to compare the results of percutaneous screw fixation and open surgical fixation treatment using nonvascularized bone graft in our study. We also compared postoperative union time, pain scores and complication rates.

Approximately two-thirds of scaphoid fractures occur in the lumbar region of the scaphoid[12,13]. In our study, we found that scaphoid fractures were most common in the lumbar part of the scaphoid (67.4%), which was consistent with the literature. In the literature[14,15], union rates of distal fractures after open and percutaneous surgical fixation have been reported to be close to 100%. While our postoperative union rate in distal fractures was 100% in both ORIF and CRIF groups, our rate of union in the lumbar region was 93.1% in total, while this rate was 93.7% in the ORIF group and 92.3% in the CRIF group. Our lowest union rate was 50% in proximal region fractures. In proximal region fractures, our union rate was 60% in the ORIF group, while it was 33.3% in the CRIF group. While our scaphoid lumbar union rate was 93.1% in total, it was 93.7% in the ORIF group and 92.3% in the CRIF group, which was close to each other and at similar rates. Although various rates of union have been reported for scaphoid lumbar fractures in the literature, generally lower rates of union have been reported than distal fractures and higher than proximal fractures. In the study of Surucu and Kehribar[16], it was observed that they provided 100% joint inflammation in 25 percutaneous patients, in the study of Galal Hegazy[17], the rate of union was 100% in the series of 21 cases, and Capo et al[18] reported that they achieved union at a rate of 92%. In the study of Matsuki et al[19], the union rate was reported as 100% in proxy pole fractures in which non-vascularized bone graft was used. However, while the union rate was 92% in the Demaagd and Engberin[20] series of 12 cases, the union rate was reported as 81% in the series of 16 patients by Inoue et al[21]. In the study by Somerson et al[22], it was observed that proximal pole lesions had the highest rate of non-union with a rate of 64.3%. In the study of Megerle et al[23], union was reported with a rate of 61%. In the study of Prabhakar et al[24], union was reported with a rate of 57%. It is known that proximal pole fractures have the lowest union rate due to the fact that the scaphoid blood flow is from distal to the proximal and the blood flow to the proximal region is weak. In the literature, unions ranging from 100% to 57% have been reported. In our study, our union rate in the ORIF group in proximal pole fractures was 60%, the lowest level compared to other region fractures. In the CRIF group, our union rate was 33%. Although our union rate in the CRIF group seems low, it is not possible for us to suggest that the union rate of CRIF treatment in proximal fractures will be low and the success rate of this treatment is low due to the lack of sufficient number of cases. There is a need for comparison of ORIF and CRIF union rates in proximal pole fractures in larger case series. However, in our study, we observed that the fastest union occurred in fractures in the waist of the scaphoid. In addition, we observed that the union was completed earlier in patients operated on with ORIF than those with CRIF. Of the patients without a union, three were in the CRIF group, and three were in the ORIF group. CRIF operation duration was shorter as expected compared to ORIF operation duration. When we look at the functional and pain scores, we see that the postoperative pain of patients who underwent CRIF was higher than those who underwent ORIF, while the functional recovery was higher in patients who underwent ORIF.

Percutaneous fixation can be performed without using bone graft in stable scaphoid fractures that are not displaced or minimally displaced[25,26]. Mahmoud and Kopton[6] performed percutaneous volar headless screw fixation in 27 patients with scaphoid non-union without humpback deformity and achieved radiographic union in 11.6 weeks. This detection method has the advantage of being less invasive and can be performed in a shorter time. They suggested that in the percutaneous technique, the union can be successfully debrided while a reamer is being made before sending the screw, and therefore open debridement is not needed[27,28]. In the study, Hegazy[17] applied a percutaneous headless screw to 21 patients due to nonunion of scaphoid waist fractures and observed that all non-union fractures healed without complications during the 25-month follow-up period. In our study, we found that 93.2% of the waist fractures were healed. Percutaneous screw fixation has many advantages. It is more invasive, has a short operative time, potentially preserves blood flow to the scaphoid, and is aesthetic because of the use of small incisions[22,26,27,29]. There are publications[8,9,17,27] showing that the percutaneous fixation technique is a successful treatment method in scaphoid nonunions. Considering this literature information while planning our study, we compared percutaneous screw fixation with graft and open reduction screw fixation in our selected cases. The fibrous union appears in the early stages of scaphoid fractures. If micro-movements occur at this stage, the union does not continue and remains as a fibrous union[14]. At follow-up, non-union is observed in half of these patients. Rigid fixation should be performed at this stage, and the union should be preserved and continued[9]. In most studies[9,17,26,27], if there is a gap of less than 1 mm at the non-union fracture line, a union can be achieved with a percutaneous headless screw or Herbert screw.

When necessary, stable fixation and support with bone graft are two important factors in the surgical treatment of scaphoid non-union to correct the scaphoid anatomy and prevent arthritis. Delayed union or non-union scaphoid fractures often require curettage and bone grafting. The fixation will be insufficient in fixations made without the use of grafts. Grafts can be used as vascularized or non-vascularized[8]. If non-union fractures are accompanied by radiocarpal or intercarpal arthritis, salvage surgical procedures should be considered if fracture fixation will not be sufficient[8,30,31]. Internal fixation using bone graft is the standard surgical treatment approach in unstable scaphoid nonunions[32,33]. Bone grafting and rigid fixation are recommended for cyst formation, malalignment, pseudoarthrosis, or unstable non-union scaphoid fractures if bone resorption is greater than 1 mm[32,34]. While planning this procedure, attention should be paid to the spacing, length, bone mass, alignment, and vascularity of the fractured fragments between the bone fragments.

The grafts used are evaluated in two groups as vascular and non-vascular. Avascular bone graft is generally used in scaphoid fractures. The reason for this preference is that it can be done easily and quickly, preparing the graft and placing it between the bone fragments. We also used an avascular bone graft from the iliac wing for our ORIF patients. In the Matti-Russe technique, the rectangular cortico spongiosis graft is grafted into the bone defect, and it has been reported that 90% union is achieved in this technique. Grafts can be taken from the distal radius and iliac wing. While the iliac wing was used frequently in the past, the distal radius has been used frequently recently. Similar results are seen in both regions[35,36]. We used iliac wing grafts from our patients. A vascularized bone graft may be preferred in cases with non-union due to proximal pole avascular necrosis[34,37]. It was observed that vascularized bone graft promotes bone healing in the proximal necrotic part of the fracture[38]. On the other hand, Pedicle grafts can be prepared as free vascularized bone grafts from the dorsal distal radius or medial femoral condyle[39]. The advantage of the medial femoral condyle graft is that it can contain enough cortico-cancellous bone tissue.

Limitations

There are some limitations in our study. Due to the insufficient number of patients in our study, the effect of smoking on union could not be evaluated. As the number of patients was not homogeneously distributed according to the fracture site, the evaluation of union rates differed greatly.

Conclusions

In order to prevent carpal instability and prevent the development of arthritis, the union of scaphoid fractures should be achieved. There are different treatment options for each stage in treating scaphoid fractures. For patients with failure in diagnosis and treatment, percutaneous headless screw application is increasingly taking place in clinical practice as a simple, fast, and safe surgical option for suitable cases. In our study, in which both methods were compared, it was shown that the percutaneous screw option could also achieve similar results with ORIF and grafting patients in the appropriate patient selection.

Conflict of Interest
The Authors declare that they have no conflict of interests.

Acknowledgements
None.

Funding
None.

Informed Consent
The authors declare that the patients included in the study signed informed consent forms to use their medical information in the studies.

Authors' Contributions
Concept: N. Atilgan, N. Duman, M. Demiryurek; Design: N. Atilgan, T.S. Colak, I.H. Korucu; Supervision: N. Duman, M. Demiryurek, T.S. Colak, I.H. Korucu; Funding: N. Atilgan, M. Yilmaz; Materials: N. Atilgan, N. Duman, M. Demiryurek, T.S. Colak, I.H. Korucu; Data: N. Atilgan, N. Duman, M. Demiryurek, T.S. Colak, I.H. Korucu; Analysis: N. Atilgan, N. Duman, M. Yilmaz; Literature search: N.A., N. Duman, I.H. Korucu, M. Yilmaz; Writing: N. Atilgan, N. Duman; Critical revision: M. Demiryurek, T.S. Colak, I.H. Korucu, M. Yilmaz.

Ethical Approval
The study protocol was approved by the Ethics Committee of Clinical Research Ethics Committee of Necmettin Erbakan University Faculty of Medicine (Approval No: 2020/2328).

ORCID ID
Numan Atilgan: 0000-0001-7184-978X
Numan Duman: 0000-0002-0183-4520
Tahsin Sami Colak: 0000-0001-7028-9397
Ismail Hakki Korucu: 0000-0002-3566-9391
Mehmet Demiryurek: 0000-0003-0464-1393
Mehmet Yilmaz: 0000-0002-1366-9163

References

1) Bergh TH, Lindau T, Soldal LA, Bernardshaw SV, Behzadi M, Steen K, Brudvik C. Clinical scaphoid score (CSS) to identify scaphoid fracture with MRI in patients with normal x-ray after a wrist trauma. Emerg Med J 2014; 31: 659-664.
2) Gilbert TJ, Cohen M. Imaging of acute injuries to the wrist and hand. Radiol Clin North Am 1997; 35: 701-725.
3) Russe O. Fracture of the carpal navicular. Diagnosis, non-operative treatment, and operative treatment. J Bone Joint Surg Am 1960; 42-A: 759-768.
4) Edlund R, Skorpil M, Lapidus G, Backlund J. Cone-Beam CT in diagnosis of scaphoid fractures. Skeletal Radiol 2016; 45: 197-204.
5) Ten Berg PW, Drijkoningen T, Strackee SD, Buijze GA. Classifications of Acute Scaphoid Fractures: A Systematic Literature Review. J Wrist Surg 2016; 5: 152-159.
6) Mahmoud M, Koptan W. Percutaneous screw fixation without bone grafting for established scaphoid nonunion with substantial bone loss. J Bone Joint Surg Br 2011; 93: 932-936.
7) 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: 241-245.
8) Kawamura K, Chung KC. Treatment of scaphoid fractures and nonunions. J Hand Surg Am 2008; 33: 988-997.
9) Liang K, Ke Z, Chen L, Nie M, Cheng Y, Deng Z. Scaphoid nonunion reconstructed with vascularized bone-grafting pedicled on 1,2 intercompartmental supraretinacular artery and external fixation. Eur Rev Med Pharmacol Sci 2013; 17: 1447-1454.
10) Moon ES, Dy CJ, Derman P, Vance MC, Carlson MG. Management of nonunion following surgical management of scaphoid fractures: current concepts. J Am Acad Orthop Surg 2013; 21: 548-557.
11) Singh HP, Taub N, Dias JJ. Management of displaced fractures of the waist of the scaphoid: meta-analyses of comparative studies. Injury 2012; 43: 933-939.
12) Clementson M, Bjorkman A, Thomsen NOB. Acute scaphoid fractures: guidelines for diagnosis and treatment. EFORT Open Rev 2020; 5: 96-103.
13) Garala K, Taub NA, Dias JJ. The epidemiology of fractures of the scaphoid: impact of age, gender, deprivation and seasonality. Bone Joint J 2016; 98-B: 654-659.
14) Oron A, Gupta A, Thirkannad S. Nonunion of the scaphoid distal pole. Hand Surg 2013; 18: 35-39.
15) Leslie IJ, Dickson RA. The fractured carpal scaphoid. Natural history and factors influencing outcome. J Bone Joint Surg Br 1981; 63-B: 225-230.
16) Surucu S, Kehribar L. Non-Displaced Scaphoid Waist Fractures: Percutaneous Screw Fixation Versus Cast Immobilization. Cureus 2022; 14: e22684.
17) Hegazy G. Percutaneous Screw Fixation of Scaphoid Waist Fracture Non-Union Without Bone Grafting. J Hand Microsurg 2015; 7: 250-255.
18) Capo JT, Shamian B, Rizzo M. Percutaneous screw fixation without bone grafting of scaphoid non-union. Isr Med Assoc J 2012; 14: 729-732.
19) Matsuki H, Ishikawa J, Iwasaki N, Uchiyama S, Minami A, Kato H. Non-vascularized bone graft with Herbert-type screw fixation for proximal pole scaphoid nonunion. J Orthop Sci 2011; 16: 749-755.
20) DeMaagd RL, Engber WD. Retrograde Herbert screw fixation for treatment of proximal pole scaphoid nonunions. J Hand Surg Am 1989; 14: 996-1003.
21) Inoue G, Shionoya K, Kuwahata Y. Ununited proximal pole scaphoid fractures. Treatment with a Herbert screw in 16 cases followed for 0.5-8 years. Acta Orthop Scand 1997; 68: 124-127.
22) Somerson JS, Fletcher DJ, Srinivasan RC, Green DP. Compression screw fixation without bone grafting for scaphoid fibrous nonunion. Hand (N Y) 2015; 10: 450-453.
23) Megerle K, Keutgen X, Muller M, Germann G, Sauerbier M. Treatment of scaphoid non-unions of the proximal third with conventional bone grafting and mini-Herbert screws: an analysis of clinical and radiological results. J Hand Surg Eur Vol 2008; 33: 179-185.
24) Prabhakar P, Wessel L, Nguyen J, Stepan J, Carlson M, Fufa D. Factors Associated with Scaphoid Nonunion following Early Open Reduction and Internal Fixation. J Wrist Surg 2020; 9: 141-149.
25) Janowski J, Coady C, Catalano LW, 3rd. Scaphoid Fractures: Nonunion and Malunion. J Hand Surg Am 2016; 41: 1087-1092.
26) Bond CD, Shin AY, McBride MT, Dao KD. Percutaneous screw fixation or cast immobilization for nondisplaced scaphoid fractures. J Bone Joint Surg Am 2001; 83: 483-488.
27) 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-A Suppl 4: 20-32.
28) Capo JT, Orillaza NS, Jr., Slade JF, 3rd. Percutaneous management of scaphoid nonunions. Tech Hand Up Extrem Surg 2009; 13: 23-29.
29) 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 e1793.
30) Buijze GA, Ochtman L, Ring D. Management of scaphoid nonunion. J Hand Surg Am 2012; 37: 1095-1100; quiz 1101.

31) Lane R, Tafti D, Varacallo M. Scapholunate Advanced Collapse. StatPearls. Treasure Island (FL)2022.
32) Hovius SE, de Jong T. Bone Grafts for Scaphoid Nonunion: An Overview. Hand Surg 2015; 20: 222-227.
33) Sayegh ET, Strauch RJ. Graft choice in the management of unstable scaphoid nonunion: a systematic review. J Hand Surg Am 2014; 39: 1500-1506 e1507.
34) Wagner ER, Spencer CC, Dawes AM, Gottschalk MB, Daly CA. Management of Proximal Pole Scaphoid Nonunions: A Critical Analysis Review. JBJS Rev 2021; 9.
35) Goyal T, Sankineani SR, Tripathy SK. Local distal radius bone graft versus iliac crest bone graft for scaphoid nonunion: a comparative study. Musculoskelet Surg 2013; 97: 109-114.
36) Zoubos AB, Triantafyllopoulos IK, Babis GC, Soucacos PN. A modified Matti-Russe technique for the treatment of scaphoid waist non-union and pseudarthrosis. Med Sci Monit 2011; 17: MT7-12.
37) Singh V, Moger NM, Jaisankar P, Rajkumar S, Chaudhary S, Azam Q. Non-Vascularized Tri-Cortical Iliac Crest Graft-A Reliable Option in the Management of Scaphoid Waist Non-Unions. J Hand Surg Asian Pac Vol 2021; 26: 383-389.
38) Testa G, Lucenti L, D'Amato S, Sorrentino M, Cosentino P, Vescio A, Pavone V. Comparison between Vascular and Non-Vascular Bone Grafting in Scaphoid Nonunion: A Systematic Review. J Clin Med 2022; 11.
39) 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: 1176-1184.