Scaphoid nonunion volar pedicle vascularized graft versus volar peg graft

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Received 15 June 2013
Accepted 20 July 2013

Egyptian Orthopedic Journal 2014, 49:53–60

Background
Scaphoid fracture nonunion often presents a therapeutic challenge. This is because the vascular supply of the scaphoid renders the proximal pole in many of these fractures avascular. Russe reported the use of an anterior inlay graft and, since then, other techniques of bone grafting have been devised. More recently, vascularized bone grafts for scaphoid nonunion have gained increasing popularity and many methods have been described on the basis of different pedicles.

Aim of the study
This study performs a comparison of the results of the treatment of scaphoid nonunion fractures using a volar radial vascularized pedicle bone graft and a volar peg graft.

Patients and methods
In a prospective study, 45 patients with nonunions scaphoid fractures were divided randomly into two equal groups: a group treated using a volar radial vascularized pedicle bone graft and a group treated using a volar bone peg graft technique.

Results
The final end result was assessed according to the Cooney score scale; in group A (volar peg graft), bone union was achieved in 15 patients (68.20%). There were five excellent, seven good, three fair, and seven poor results. In group B (volar vascularized graft), bone union was achieved in all patients (100%). There were 10 excellent, 10 good, and three fair results.

Conclusion
A volar vascularized pedicle bone graft is a viable option for the treatment of scaphoid nonunion that leads to rapid union and consolidation of proximal pole scaphoid nonunion, with better both clinical and radiological results.

Keywords:
scaphoid nonunion, volar pedicle vascularized graft, volar peg graft

Egypt Orthop J 49:53–60

1110-1148

Introduction

The natural history of a scaphoid nonunion is well established. However, reviews of articles have indicated that when left untreated, these nonunion fractures lead to adverse outcomes, resulting in carpal collapse and arthritis [1–6]. The initial development of osteoarthritis at the scaphostyloid joint is associated strongly with dorsiflexed intercalated segment instability [7]. The key points of successful surgery for scaphoid nonunion are to induce healing of the fracture and to restore normal carpal height and kinematics. Intervention is aimed at enabling a cartilage-wrapped bone to heal and maintain a smooth, articular surface. This has yielded varied success rates of proposed treatment options for scaphoid nonunion [8]. The diagnosis of scaphoid fractures accurately is of paramount importance. The conventional treatment method for scaphoid nonunion is autologous bone grafting [9–13]. The success rate of these bone grafts, however, is considerably decreased with reduced blood flow to the proximal segment of the scaphoid. Green reported a 92% union rate with good vascularity of the proximal pole, but he found that when the proximal pole had reduced blood supply, union rates utilizing a Russe bone graft decreased to 71% and when complete avascularity of the proximal segment was present, none of the fractures healed in his series [14].

Recently, vascularized bone grafts for the scaphoid have gained increasing popularity and many methods have been described on the basis of different types of pedicles [15–19]. In this study, we compared the results of treatment of scaphoid nonunion fractures using a volar vascularized bone graft from the volar aspect of the distal radius bases on the radial portion of the palmar carpal arterial arch and internal fixation by a Herbert screw and a volar bone peg graft technique from the lower fourth radius through the nonunion site.

Patients and methods

Forty-five patients with scaphoid nonunion were operated upon between January 2007 and January 2010 at the Orthopaedic Department, Damanhour National Medical Institute. The inclusion criteria were

as follows: established nonunion of the scaphoid and of more than 6 months' duration following the fracture. Our exclusion criteria were as follows: patients with systemic inflammatory disease (rheumatoid arthritis, systemic lupus erythematosus), idiopathic avascular necrosis, patients who had already developed advanced wrist degenerative changes, and patients who had undergone previous surgery. The patients were divided into two groups depending on the method of treatment. Group A included 22 patients who had been managed with the volar bone peg graft technique and group B included 23 patients managed with the volar vascularized pedicle bone graft technique and internal fixation by a Herbert screw.

The diagnosis of nonunion was confirmed both clinically and radiologically after at least 6 months of fracture.

Clinically, all the cases included had a limited range of motion, pain at the extremes of motion or with exertion, and tenderness at the anatomic snuffbox. The range of motions and grip strength were measured preoperatively. Wrist motion was measured using a goniometer in the sagittal and frontal planes of both the affected and the unaffected extremities [20]. We measured grip strength of both hands according to the technique of McRae [21]. At the latest follow-up visit, subjective complaints, range of motion of the wrist, and strength of grip were recorded.

Radiographs that were prepared preoperatively and during treatment as well as these that were prepared at the follow-up examination were reviewed for scaphoid length, lateral intrascaphoid angle, anteroposterior scaphoid angle, scapholunate angle, and carpal height ratio.

Intraoperatively, vascularity of the marrow in the proximal and distal scaphoid in each case was assessed by the quantity and quality of the punctate bleeding points found in the cancellous portion of the bone and was classified according to Green's criteria [14]. If the bleeding points are numerous and confer a slightly pinkish hue to the bone, vascularity is considered good; if the points are sparse but present, vascularity is rated as fair or poor; and if there are absolutely no punctate bleeding points, the scaphoid is considered totally avascular. In our series, in 11 cases, the scaphoid was found to be totally avascular. Six out of 11 patients were treated with a volar vascularized pedicle bone graft and internal fixation by a Herbert screw.

By the end of the follow-up period, the data collected from both groups of patients were gathered and assessed according to Cooney's scoring scale [12]. This is a scale of 100 points, in which 25 points are allocated to each of the following: pain, range of motion, grip strength, and function status. A score ranging from 90 to 100 points was considered to be excellent, 80–89 as good, 65–79 as fair, and less than 65 as poor. The results were analyzed in relation to rate of union, time to union, range of motions, scaphoid length, carpal height ratio, lateral intrascaphoid angle, anteroposterior scaphoid angle, grip strength, scapholunate angle, and maximum score.

In this study, there were 42 men (93.33%) and three women, with a mean age of 25.4 years (range 18–40 years) at the time of operation. The mean time from injury to surgery was 18.18 months (range 8–42 months).

The mean period of follow-up was 20.45 months (range 7–34 months). The two groups were similar with respect to age, sex, affected limb, fracture location, the mean time from injury to operation, mechanism of injury, and the mean duration of follow-up. Table 1 lists patient characteristics of the two groups.

Operative technique

The scaphoid was approached through a standard volar approach; the pseudoarthrosis tissue was resected up to normal-appearing bone. In the group of patients managed with a volar vascularized pedicle bone graft, dimensions of the graft needed were harvested off the radius from the most distal and ulnar area of the volar distal radius using a thin osteotome. The principle of this

Table 1 Patient demographics

	Group A (VPG)	Group B (VVG)
Number of patients	22	23
Age (years)	24.9 (range 19–40)	25.8 (range 17–40)
Sex (M:F)	20:2	22:1
Side (R:L)	14:8	16:7
Mechanism	Fall (17), hit by heavy object (2), unknown (3)	Fall (19), hit by heavy object (3), unknown (1)
Fracture location	Waist (12), distal pole (3), proximal pole (7)	Waist (11), distal pole (2), proximal pole (10)
Mean time from injury to operation (months)	16.8 (range 9–38)	19.6 (range 8–42)
Mean duration of follow-up (months)	21.7 (range 7–34)	19.2 (range 9–33)

VPG, volar peg graft; VVG, volar vascularized graft.

bone graft is based on the presence of an anastomotic arterial network on the palmar aspect of the distal part of the two bones of the forearm that perfuse the graft and provides a pedicle for the graft long enough to reach the scaphoid without excessive tension [15,22,23]. The scaphoid bone and volar radial vascularized pedicle graft stabilized with a Herbert screw (Figs. 1–3).

When using the volar bone peg graft technique, a bone tunnel was created using a 3.2-drill bit from the nonunion site to the distal and proximal poles with preservation of healthy tissues of the volar aspect of proximal and distal poles for stability of the peg graft. With a curved mosquito forceps, the bony tunnel was widened and changed to a core tunnel. A rectangular corticocancellous graft was harvested from the volar aspect of the lower fourth radius. The graft measured 2 cm in length and 3–4 mm in thickness and was trimmed to snuggly fit the bone tunnel. The graft was inserted into the core tunnel through the nonunion site at the distal pole and then it was snuggly fitted to the proximal pole. No hardware was applied. Postoperatively, the extremity was placed in a below-the-elbow thumb — spica cast for an average of 8 weeks. Patients were reviewed at 2 weeks after surgery and then at 6, 12, and every 4 weeks until the outcome was established. The final outcome, union at fracture site, was assessed both clinically and radiologically (Figs. 4–6).

Once immobilization was discontinued, patients were permitted to use the wrist for light activities, but strenuous activity was discouraged for an additional 2–3 months.

Figure 1

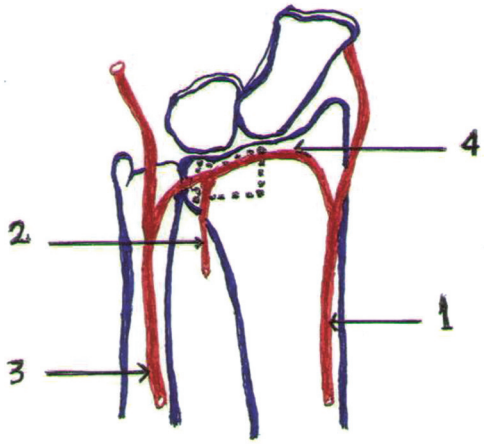


Diagram showing the anastomotic arterial network on the palmar aspect of the distal part of the two bones of the forearm. Dotted lines show the site of graft harvesting. 1, radial artery; 2, anterior interosseous artery; 3, ulnar artery; 4, radial portion of the palmar carpal arterial arch.

Results

The time lapsed before surgery

The mean time lapsed between injury and surgery was 13.27±2.42 months for patients treated using a volar bone peg graft (range 9–38 months). In the group of patients treated using a volar radial vascularized pedicle graft, the mean time that lapsed between injury and surgery was 12.39±2.66 months (range 3–42 months) and the difference in means was statistically insignificant (t = 1.06, P = 0.299).

Duration of follow-up

The mean duration of follow-up was 23.59±1.02 months for the group treated using a volar bone peg graft (range 7–34 months). In the group treated using a volar vascularized pedicle graft, the mean duration of follow-up was 22.52±1.35 months (range 9–33 months); there was no significance difference between the two groups in the duration of follow-up (t = 1.04, P = 0.304).

Figure 2

A 24-year-old male farmer who sustained a fracture of the right scaphoid after falling from a ladder. A nonunion of the proximal part of the scaphoid subsequently developed. A volar vascularized pedicle graft was used and fixation with a Herbert screw. Union after 9 weeks and the final result were excellent: (a) Preoperative radiographs (anteroposterior and lateral) views. (b) Postoperative 1 day showing the graft between proximal and distal fragments. (c) 4 weeks' follow-up. (d) 9 weeks' follow-up (motion views) with full fracture healing. (e) 18 months' follow-up with full range of motions.

Union

Union was achieved in 100% of cases using the volar vascularized pedicle bone graft and in 68.20% using the volar bone peg graft. There was an overall failure rate in seven cases, all in group A (two cases middle third nonunion, five cases proximal pole nonunion). The relation between site of fracture and fracture union is presented in Table 2.

Figure 3

A 32-year-old male with nonunion of the waist of the left scaphoid of 13 months' duration. Union was achieved 10 weeks after a volar vascularized pedicle bone graft was stabilized by a Herbert screw, and the final result was good. (a) Preoperative radiograph. (b) Postoperative radiograph (anteroposterior and lateral). (c) 1-month postoperative radiograph showing the vascularized graft between proximal and distal pole fragments stabilized by a Herbert screw. (d) 4-month follow-up radiograph (motion views). (e) 3-year follow-up radiograph. No arthritic changes were observed, with full range of motions.

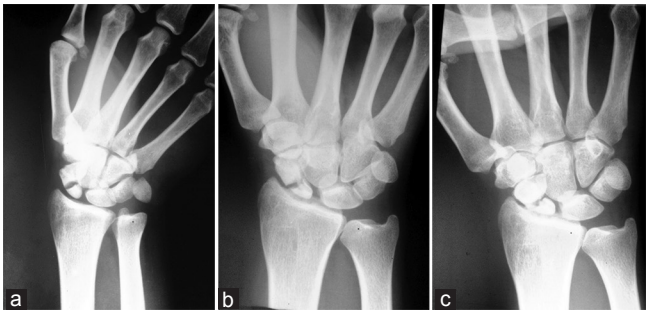
Time and speed of union

In terms of the mean time of union and speed of radiological union, there were highly statistically significant differences between the two groups studied (Table 3).

There were no statistically significant differences between the two treatment groups with respect to either the lateral intrascaphoid angle or the anteroposterior scaphoid angle. Patients who were treated with a volar radial vascularized pedicle bone graft had significantly better range of motions, strength of hand grip, scaphoid length, scapholunate angle, and carpal height ratio (Table 4).

Table 5 shows the percentage of improvement from the normal in the various parameters in the two groups studied.

Figure 4



(a) Preoperative plain radiograph shows scaphoid nonunion with loss of trabecular structure and formation of bone cyst, indicating avascularity of the fragment. (b) Postoperative radiograph after the use of a volar peg graft at the nonunion site. (c) Radiograph showing persistent nonunion; after a failed volar peg graft, the graft became displaced.

Table 2 Relation between the site of fracture and fracture union

	Union [*n* (%)]				
	Group A (VPG)		Group B (VVG)		
Sites of fracture	No	Yes	No	Yes	Total [*n* (%)]
Waist nonunion	2 (9.10)	10 (45.45)	–	11 (47.83)	23 (51.10)
Proximal pole	5 (22.70)	2 (9.10)	–	10 (43.47)	17 (37.79)
Distal pole	–	3 (13.53)	–	2 (8.70)	5 (11.11)
Total	7 (31.80)	15 (68.20)	–	23 (100)	45 (100)

VPG, volar peg graft; VVG, volar vascularized graft.

Table 3 Nonunion and time of radiological union in both groups

	Group A (VPG)	Group B (VVG)
Nonunion [*n* (%)]	7 (31.81%), 2 middle third, 5 proximal third	–
Time of radiological union (weeks)[a]		
Minimum	12	8
Maximum	16	10
Mean	14	9
SD	3.578	0.664

VPG, volar peg graft; VVG, volar vascularized graft; [a]Highly significant difference: *t,* 10.74; *P,* 0.0005.

Pain

By the end of the follow-up period, 30 patients were pain free; all of them showed complete union at the nonunion site. Mild pain was the complaint in eight patients, whereas permanent moderate pain was present in seven patients. The degree of pain was statistically related to bone union (Table 6).

In terms of the final end results in group A according to Cooney's scale scoring system, five cases were excellent, seven cases were good, three cases were fair, and seven cases were poor. In group B, 10 cases were excellent, 10 cases were good, and three cases were fair. The average preoperative Cooney score was 57 points, whereas the average postoperative Cooney score was 71 points (Table 7).

The maximum score was better in group B (volar vascularized graft) than in group A (volar peg graft). Table 8 presents the maximum score in relation to the type of operation.

Discussion

Management of scaphoid nonunions is a challenging task for the hand surgeon. One treatment strategy that may improve the chances of achieving bony union is the use of a volar vascularized pedicle bone graft. The results of this study showed that vascularized bone grafting from the volar aspect of the distal radius bases on the radial portion of the palmar carpal arterial arch is reliable in achieving consistent union of ununited scaphoid fractures even in the presence of complete avascularity of the proximal pole.

Conventional bone grafting was reported to achieve union rates as high as 90%, with good vascularity of the proximal pole, but this decreased in the presence of reduced blood supply of the proximal pole, and when complete avascularity of the proximal segment was present, none of the fractures seemed to heal [14]. Many clinical trials using different types of vascularized bone grafts have reported higher union rates compared

Figure 5

(a) Nonunion waist of the scaphoid 3 years preoperatively. (b) 1 day postoperative radiograph (lateral and anteroposterior) in the scaphoid cast after a peg graft technique. (c) 2-year follow-up radiographs showing complete union with good range of motions.

Figure 6

(a) Preoperative radiographs showing the nonunion distal pole of the scaphoid (anteroposterior and lateral). (b) Postoperative radiograph 3 months after the use of the volar peg graft technique. (c) 1-year follow-up radiograph with sound union.

Table 4 Improvement in various parameters after each operation

Parameters	Group A (VPG)		Group B (VVG)			
	Mean	SD	Mean	SD	*t*	*P*
Radial deviation motion	2.75	3.024	5.5	3.204	2.515	0.02**
Ulnar deviation motion	3.5	3.663	7.5	3.804	3.39	0.002***
Strength of hand grip	22.75	17.657	36.25	19.912	2.26	0.029**
Scaphoid length	1.8	1.322	3.25	1.372	3.4	0.002***
Carpal index	0.01	0.01	0.026	0.021	2.99	0.005***
Scapholunate angle	4.7	7.205	13	9.003	3.22	0.003***
Lateral intrascaphoid angle	4.5	9.902	7.05	4.186	1.06	0.299*
Anteroposterior scaphoid angle	6.2	5.307	8.15	6.467	1.04	0.304*
Volar–flexion motion	5	3.974	9.5	6.669	2.59	0.013**
Dorsi–flexion motion	4.75	4.128	10.5	6.048	3.51	0.001***

VPG, volar peg graft; VVG, volar vascularized graft; *Nonsignificance; **Significant difference; ***Highly significant difference.

Table 5 Mean preoperative and postoperative values of the clinical and radiological parameters in the two groups studied

Parameters	Group A (VPG)				Group B (VVG)			
	Normal wrist mean	Preoperative mean	Postoperative mean	Improvement (%)	Normal wrist mean	Preoperative mean	Postoperative mean	Improvement (%)
Radial deviation motion (deg.)	20SD ± 0	14SD ± 3.84	19SD ± 2.05	13.8	20SD ± 0	12.25SD ±4.13	17.75SD ±3.43	27.5
Ulnar deviation motion (deg.)	31SD ± 2.05	20SD ± 3.63	28.5SD ± 3.28	11.3	31.25SD ± 2.22	20SD ± 4.29	27.5SD ± 3.03	24
Strength of hand grip (mmHg)	283.75SD ± 13.46	205SD ± 19.37	228.25SD ± 22.78	8.17	244.5SD ± 27.81	196SD ± 11.31	232.25SD ± 33.08	14.8
Scaphoid length (mm)	22.35SD ± 2.78	20.15SD ± 2.78	22.15SD ± 2.33	8.53	23.20SD ± 1.91	20.9SD ± 1.92	24SD ± 1.28	14
Carpal index	0.50SD ± 0.04	0.47SD ± 0.04	0.48SD ± 0.04	0.02	0.50SD ± 0.04	0.48SD ± 0.04	0.50SD ± 0.03	0.052
Scapholunate angle (deg.)	49.65SD ± 7.16	57.9SD ± 11.65	53.20SD ± 9.96	9.47	50.70SD ± 6.68	64.55SD ± 9.21	52.45SD ± 8.55	24
Lateral intrascaphoid angle (deg.)	23.95SD ± 3.82	29.8SD ± 5.96	27.1SD ± 6.05	19	26.20SD ± 4.40	33.55SD ± 7.65	26.05SD ± 5.74	27
Anteroposterior scaphoid angle (deg.)	22.9SD ± 3.32	28.4SD ± 5.86	22.2SD ± 2.42	27.7	24.75SD ± 3.89	29.3SD ± 5.55	21.65SD ± 4.30	33
Volar–flexion motion (deg.)	80.5SD ± 1.54	64.5SD ± 4.56	69.5SD ± 4.84	6	81.25SD ± 2.22	64.75SD ± 5.73	74.25SD ± 5.68	11.7
Dorsi–flexion motion (deg.)	72SD ± 2.51	54.50SD ± 4.25	59.25SD ± 5.20	7	72SD ± 2.51	56.75SD ± 5.45	67.25SD ± 5.95	14.5

VPG, volar peg graft; VVG, volar vascularized graft.

with conventional grafts [24–30]. In this study, bone union was achieved in 100% in patients managed by a volar radial vascularized pedicle bone graft and 68.20% in patients managed by a volar bone peg graft. A several investigators have evaluated the utility of volar vascularized bone grafting in the treatment of scaphoid nonunion. Six studies reported 100% union rates of scaphoid nonunion treated with a volar vascularized pedicle bone graft [15,16,31–34].

This study showed a union rate of 100% with internal fixation using a Herbert screw in all patients; also, many contributed toward the high union rate in this study. This confirmed the finding of previous researchers who reported an improved healing rate of vascularized bone grafts for scaphoid nonunion with rigid internal fixation [35].

The high success rate of this case series may be partially attributed to the differences in scaphoid fracture location and the fact that this study did not include patients who had undergone previous surgery for their scaphoid nonunion. Previous surgery was considered an adverse factor for successful outcome of surgical treatment for scaphoid nonunions by Boyer *et al.* [36] and Straw *et al.* [37]. Poorer results in the group of patients treated by a volar bone peg graft are because of the large number of cases with avascular necrosis of the proximal pole (31.81%). In this work, five out of seven cases of fracture of the proximal pole of the nonunited scaphoid in group A failed to achieve union. This could be attributed to the poor blood supply of the proximal pole; besides, the graft was introduced through a nonunion site, giving less purchase to the small proximal fragment. Therefore, the results of this study proved that the volar bone peg graft technique was not a suitable technique for nonunited fracture of the proximal pole, with a high failure rate, and the volar radial vascularized pedicle graft technique is a suitable option for the management of scaphoid nonunion even in the presence of difficult conditions such as avascular necrosis.

The average time to union in our investigation was 12 weeks for nonunion of the scaphoid in the group of patients treated by a volar peg graft and 8 weeks for nonunions in the group of patients treated by a volar vascularized pedicle graft. This difference was highly statistically significant and is in agreement with reports in the literature [17,32,36].

In this study, on final review, the strength of the hand grips postoperatively appeared stronger than preoperatively, except in patients who failed to achieve union, where there was persistence of the preoperative strength. We could not compare the grip strength of

Table 6 Relation between pain and union of the fracture site

Residual pain	*n* (%)		
	Complete union	Nonunion	Total [*n* (%)]
None	30 (78.95)	0 (0)	30 (66.67)
Mild	8 (21.05)	2 (28.57)	10 (22.22)
Permanent	0 (0)	5 (71.43)	5 (11.11)
Total	38 (100)	7 (100)	45 (100)

Table 7 Comparison between the two groups studied in terms of the end result

Results	Group A (VPG) [*n* (%)]	Group B (VVG) [*n* (%)]	Total [*n* (%)]
Excellent	5 (22.73)	10 (43.48)	15 (33.33)
Good	7 (31.82)	10 (43.48)	17 (37.78)
Fair	3 (13.63)	3 (13.04)	6 (13.33)
Poor	7 (31.82)	–	7 (5.56)
Total	22 (100)	23 (100)	45 (100)

VPG, volar peg graft; VVG, volar vascularized graft.

Table 8 Maximum score in relation to type of operation

Maximum score	Methods of treatment	
	Group A (VPG)	Group B (VVG)
Minimum	4.00	8.00
Maximum	10.00	15.00
Range	6.00	7.00
Mean	8.00	11.95
SD	2.15	2.26

VPG, volar peg graft; VVG, volar vascularized graft; Highly statistically significant difference between the maximum score of both groups: *t*, 5.66; **P*, 0.0005.

our patients with that of other studies because specific measurements were not recorded.

In this study, the group of patients treated by a volar vascularized pedicle graft and stabilized by Herbert screw fixation showed better improvement in wrist motion, scaphoid length, carpal height ratio, and scapholunate angle than the group of patients treated with a volar peg graft, suggesting that a screw may maintain correction of the scaphoid more effectively than graft alone and also indicating advantages of vascularized grafts as shown clearly experimentally by fracture healing, revascularization, and osteogenesis [38].

The scaphoid bone was exposed in this work through the volar approach, which allows the scaphoid to be exposed from the proximal to the distal pole. Also, exposed the pathological changes at the volar aspect of the nonunion site. A volar bone graft was harvested from the volar aspect of the distal radius through the same approach, thus preventing the added morbidity of another wound for the patient.

In both groups, the graft applied volarly had the added advantage of correction of associated DISI that was evidenced by a decreased mean scapholunate angle from 74.55° preoperatively to 52.45° after surgery. Similar findings were also obtained in other grafts applied from the volar aspect [11,13,39–41].

This study shows that when healing of the nonunion is achieved, the clinical results are better, with improvement in range of wrist movement and grip strength combined with a decrease in pain level.

Although there was no radiographic progression of arthritis in this study as well as other series reported, we believe that a longer follow-up duration is needed before this can be firmly established.

Conclusion

This study confirmed the usefulness and the benefits of the volar vascularized pedicle bone graft, which might be superior to a volar peg graft as a method of treating scaphoid nonunion, especially proximal pole nonunion, because of correction of hump-back deformity and DISI, better union rate, speed of radiological union, less postoperative pain, and earlier return to activity.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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