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ORIGINAL PAPER

# Scaphoid nonunion: does open reduction, bone grafting and Herbert screw fixation justify the treatment?

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**Abstract**
*Purpose* Conventional bone grafting and Herbert screw fixation give satisfactory results for scaphoid nonunion; however, vascularized bone grafting has superior results, especially in the case of avascular necrosis of proximal fragment. Vascularized bone grafting is technically more demanding with small error of margin, problems of getting the appropriate graft, fixation and incorporation, and requires longer duration for wrist immobilization.
*Methods* Forty-five patients of scaphoid nonunion were treated by cancellous bone grafting, cortex containing graft if required and Herbert screw fixation. Functional outcomes were assessed at the latest follow up after surgery (minimum one year after surgery).
*Results* The average pre-operative and post-operative scapholunate angle, grip strength, flexion-extension movement, radio-ulnar movement, scaphoid index and modified mayo score were improved from 49.60 ± 6.40° (37–66) to 36.26 ± 4.73° (range 28–46), 20.66 ± 3.17 kg (15–27) to 31.11 ± 3.29 kg (range 25–40), 78.57 ± 14.22° (45–110) to 132.86 ± 13.90° (100–165), 30.06 ± 6.06° (20–44) to 44.95 ± 6.37°(range 35–59), 0.66 ± 0.076 (0.55–0.79) to 0.60 ± 0.065 (range 0.49–0.73) and 58.66 ± 5.24 (50–70) to 84.37 ± 5.01 (range 75–95), respectively, with $P$ value <0.001. Based on modified mayo score, 21 (46.7%) patients had excellent results, 19 (42.2%) had good results, 4 (8.9%) had fair results and one patient (2.2%) had poor results.
*Conclusion* Bone grafting and Herbert screw fixation provides a good option for treatment of scaphoid nonunion, especially in the absence of avascular necrosis of proximal fragment. More importantly, vascularized bone grafting in all scaphoid nonunion may not be necessary and could otherwise have been united uneventfully by this technique. However, avascular necrosis of proximal fragment must be ruled out pre-operatively as well as intra-operatively.

**Keywords** Bone grafting · Functional outcomes · Herbert screw · Scaphoid nonunion

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## Introduction

Scaphoid is most commonly fractured carpal bone that accounts for 60% of total such fractures [1]. Most case series report around a 10% nonunion rate; however, the majority of scaphoid fractures heal without surgery. Any fracture that does not heal more than six months after injury is considered as nonunion [2]. The anatomical properties such as tenuous blood supply, joint fluid dilution and inability to form the callus as well as biomechanical properties including the high shear stress and tendency to displace the fractured fragments are the main reasons for scaphoid nonunion. Delayed diagnosis, inadequate treatment, carpal instability, tendency of excessive disintegration and fragmentation at fracture site, delayed onset of treatment and presence of accompanying avascular necrosis are the extrinsic causes for nonunion [3, 4]. Older age and smoking habit are the systemic factors that may cause delayed union of scaphoid [5, 6].

Untreated nonunion can eventually lead to the distinct pattern of degenerative changes known as scaphoid nonunion advanced collapse (SNAC) of wrist joint [7]. In established nonunion treatment, the goal is to achieve bony union, restoration of the shape of the scaphoid, re-establishment of wrist function and ultimately normal activities of the patients [8]. Barton and Warren-Smith mentioned that open reduction, Herbert screw fixation and bone grafting give better functional results as compared to bone grafting alone [9]. In recent years several types of vascularized bone grafting have been reported to enhance the rate of scaphoid union with more than 90% success rate [10, 11].

Even though they have superior union rate, there are certain drawbacks and limitations regarding these techniques such as they are technically more demanding with small error of margin, require a long time for immobilization of wrist joint after surgery to incorporate the graft, have problems of getting appropriate graft size, fixation as well as incorporation into the scaphoid because of its curved boat-shaped morphology, and more importantly vascularized bone graft plays a possible role in established avascular necrosis of proximal pole of scaphoid which would otherwise be united quite well by bone grafting and Herbert screw fixation only [12]. So there should be definitive indications to treat the scaphoid nonunion with vascularized bone grafting.

We treated the scaphoid nonunion without avascular necrosis by doing thorough curettage of sclerotic bone and fibrous tissue, using healthy cancellous bone chips for impaction and an intercalated cortex-containing bone graft if required, and fixation by Herbert compression screws.

## Materials and methods

This was a level IV prospective analytical study performed in Civil Service Hospital from September 2011 to August 2015. We operated altogether 50 patients with scaphoid nonunion; however, five patients were lost during follow-up visit. Finally, 45 patients were enrolled into the study. All the patients of more than 16 years with scaphoid nonunion were included in the study. The patients with systemic inflammatory disease, previous fracture or surgery on both wrists, previous surgical treatment for scaphoid fractures, those with already developed advanced osteoarthritis of wrist joint and avascular necrosis of proximal pole of scaphoid were excluded from the study. Patients with increased density and loss of height in proximal pole were further re-evaluated using magnetic resonance imaging (MRI) for avascular necrosis (AVN). If results were consistent with the features of AVN, those cases were excluded from the study.

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 pre-operatively. Wrist motion was measured using a goniometer in the sagittal and frontal planes of both the affected and the unaffected extremities. We measured grip strength of both hands according to the technique of McRae [13]. Wrist radiographs taken in the standard (antero-posterior, lateral) and scaphoid positions were used to evaluate the patients in terms of diagnosis, classification, arthrosis and carpal alignment. Scapho-lunate 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).

All the surgeries were performed by the first and second authors either jointly or separately. Midshaft and proximal pole fractures were operated through the dorsal approach while distal pole fractures were operated through the volar approach. In dorsal side extensor pollicis longus tendon, distal articular margin of radius and anatomical snuff box were marked by surgical marker or pen. Incision was given 5 mm distal to articular margin of radius extending from its medial end to anatomical snuff box laterally in curvilinear fashion (Fig. 1). In the deeper plane extensor retinaculum was incised while the tendons within the second, third and fourth compartments were separated from each other. Capsule over the scaphoid bone was incised obliquely and the fracture site was identified by finding the soft gap within the scaphoid with use of 1.5-mm Kirshner wires (K wire). Fracture fragments were separated through the site of fibrous union by multiple drilling with K wires. Fibrous tissue around the fracture site was thoroughly removed and sclerotic bone was curetted until bleeding points were visible. The tourniquet was temporarily released to check the bleeding points from the fracture ends. In case of a volar approach, the scaphoid tubercle, thumb metacarpal base and the plane of the flexor carpi radialis (FCR) tendon were marked. A skin incision starting from 3 cm proximal to the wrist skinfold was extended along the FCR tendon to meet the base of the first metacarpal (Fig. 2). Now alignment and dimension of scaphoid bone as well as stability of scapho-lunate ligament were assessed under C arm control. In order to measure the appropriate-sized cortical bone graft, the fracture site was gently distracted with the help of two K wires inserted in proximal and distal fragments (Fig. 4). At this stage the gap between the two fragments was measured by using the small calibrated measuring tape. Exactly the same size of wedge-shaped cortical bone graft was harvested from the iliac crest and put in the fracture gap. But the accurate size and shape of bone graft is not so easy to be harvested to fit the gap well. For those cases with minimal bone loss around 2–3 mm of nonunion gap while distracting the fracture site and those without humpback deformity, only cancellous bone graft was used harvested from the distal radius of the same side while sparing the iliac crest to minimize post-operative pain. The fracture fragments were provisionally fixed with a guide wire in the central part of both the fragments followed by drilling with two separate sized cannulated drill bits and fixed with appropriate size, headless compression screw under fluoroscopic control. In order to prevent the graft dislodgement while drilling the bone, whole bone graft complex along

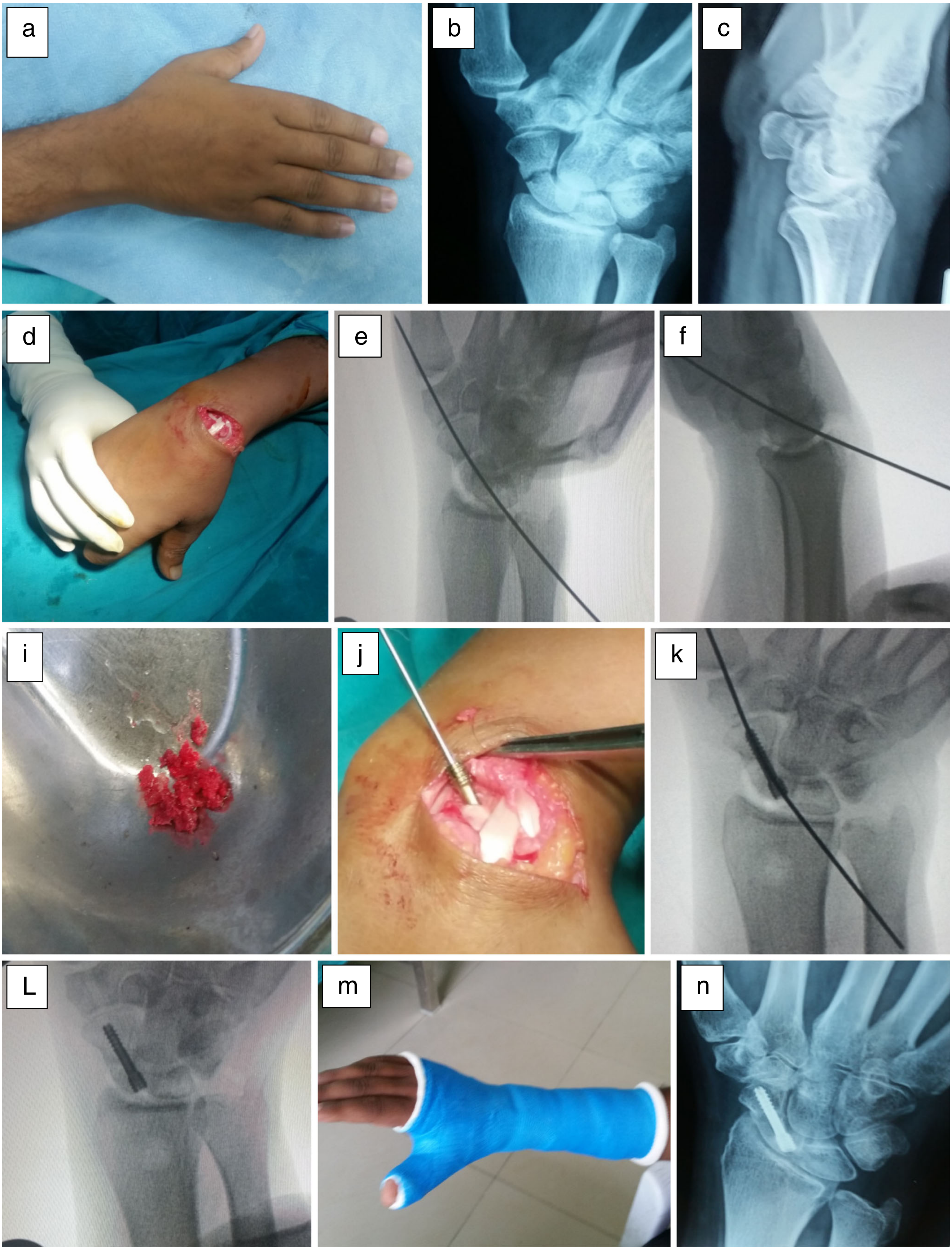
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**Fig. 1** Case 1: swelling localized to anatomical snuff box of wrist before surgery (**a**); X-ray of wrist joint showing scaphoid nonunion antero-posterior (**b**) and lateral views (**c**); incision on dorsal aspect of wrist separating the tendons on second, third and fourth compartments (**d**); passage of guide wire in antero-posterior (**e**) and lateral (**f**) views; cancellous chip bone graft (**i**); passage of Herbert screw through guide wire (j); passage of Herbert screw through guide wire in C arm (**k**); position of Herbert screw after removal of guide wire in C arm (**l**); immobilization of wrist with scaphoid cast (**m**); and union of scaphoid (**n**) at latest follow up visit

with proximal and distal scaphoid fragments were additionally fixed with 1.5-mm K wire in some cases. Scaphoid cast was applied at the time of surgery.

### Post-operative protocol

The scaphoid cast was removed six weeks after surgery. Radiographs including scaphoid series were taken at six weeks, three months, six months, one year and at latest follow-up visit. In case the fracture was expected to unite at a different time point than the routine follow-up, patients were advised to come for additional visits, e.g. two to four weeks before or after the scheduled time. Active as well as passive wrist motion exercises were initiated on the same day of cast removal while strength exercise was allowed two to three weeks after removal of cast when patients felt minimal pain at wrist joint (Figs. 3 and 4). However, strength exercise was not allowed if grafted bone did not heal properly at six weeks after surgery and was started only when fine trabeculae of bone were seen on the grafted site. Range of motion and grip strength measurements were repeated at respective follow-up visits. A pneumatic-type of dynamometer with air-filled compartment like bulb or bag connected to a mercury scale was used for measurement of grip strength. Final functional results were assessed using a modified Mayo wrist score at latest follow-up visit.

### Statistical analysis

Statistical analyses were performed using the SPSS software (version16.0). Quantitative variables were documented as mean ± standard deviation. Pre-operative and post-operative variables were compared using the paired t test, and those variables between the normal and operated wrist were analyzed using Student's t test. *P* values <0.05 were considered statistically significant.

## Results

The average age of patients in our study was 28.53 ± 7.46 years (range 17–48 years). There were 31 (68.9%) males and 14

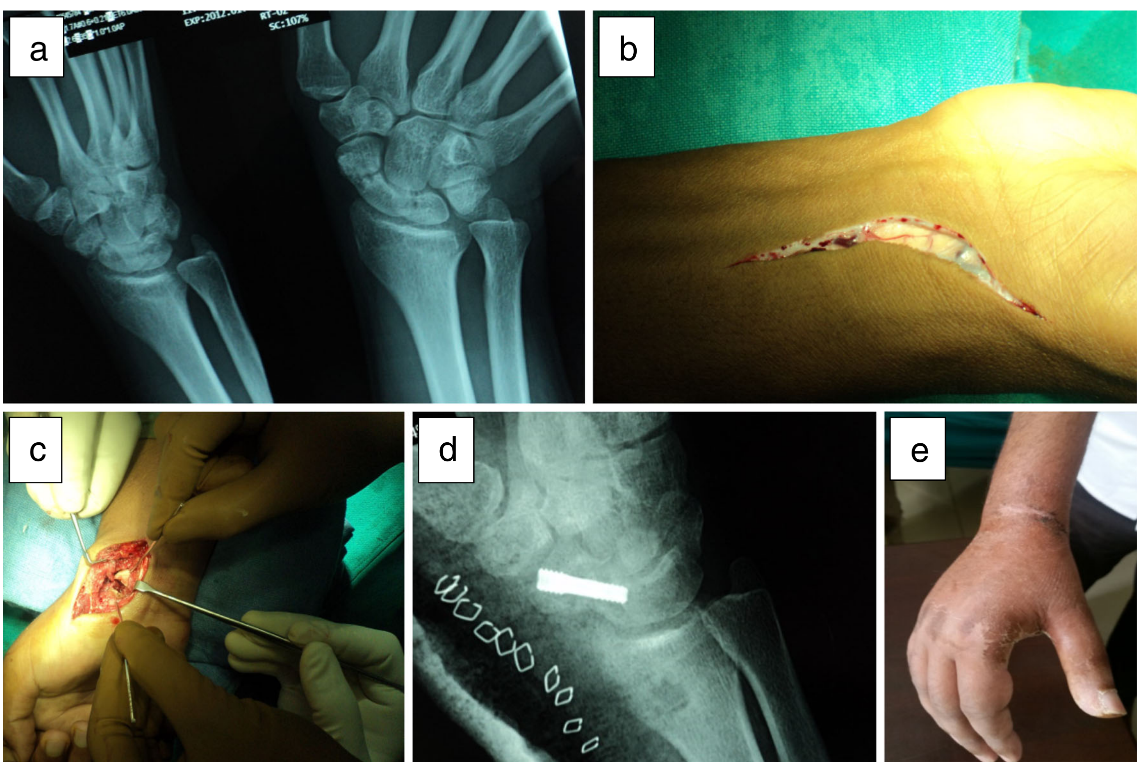


**Fig. 2** Case 2: X-ray of wrist joint showing scaphoid nonunion 14 months after initial injury (**a**); volar incision on wrist (**b**); exposure of fracture site through volar approach (**c**); fixation of fracture with Herbert compression screw and bone grafting (**d**); and wrist joint six weeks post-surgery after removal of cast (e)

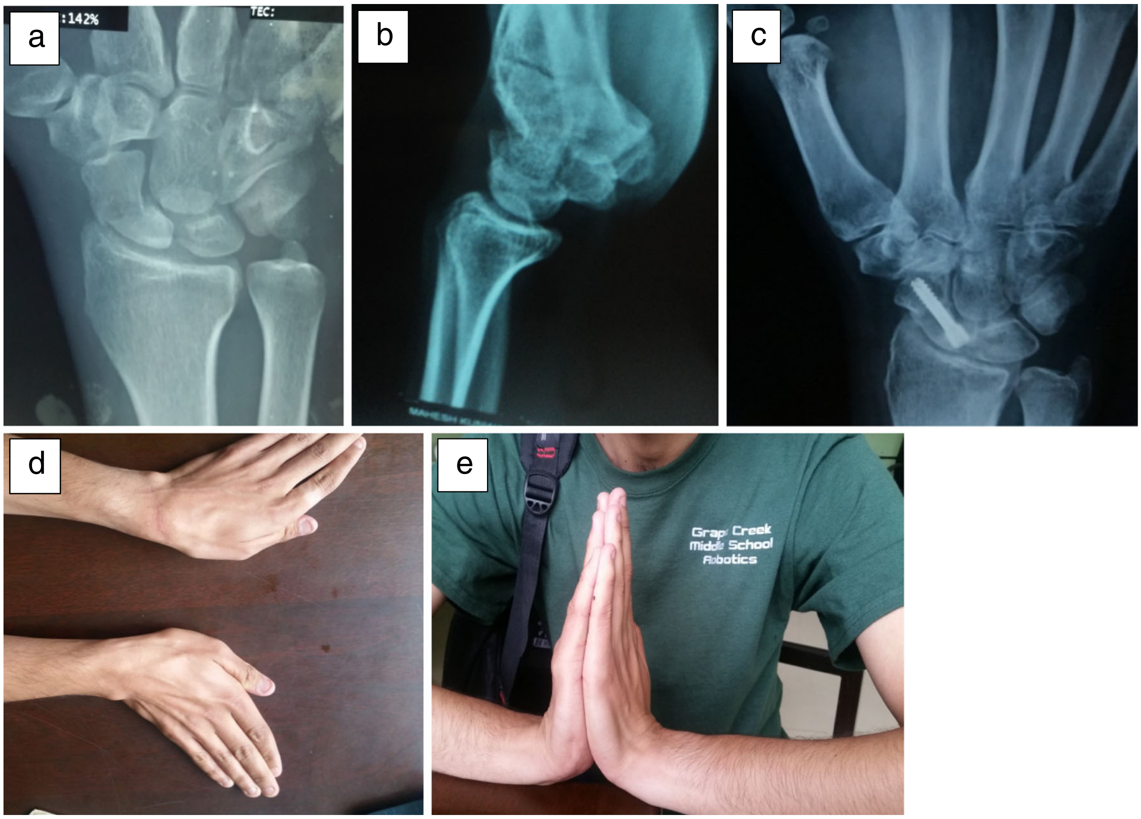


**Fig. 3** Case 3: X-ray of wrist joint antero-posterior (**a**) and lateral views (**b**) showing nonunion scaphoid fracture ten months after initial injury; union of scaphoid fracture after bone grafting and Herbert screw fixation at latest follow up visit (**c**); ulnar deviation of both wrist joint (**d**); and dorsiflexion of wrist (**e**)

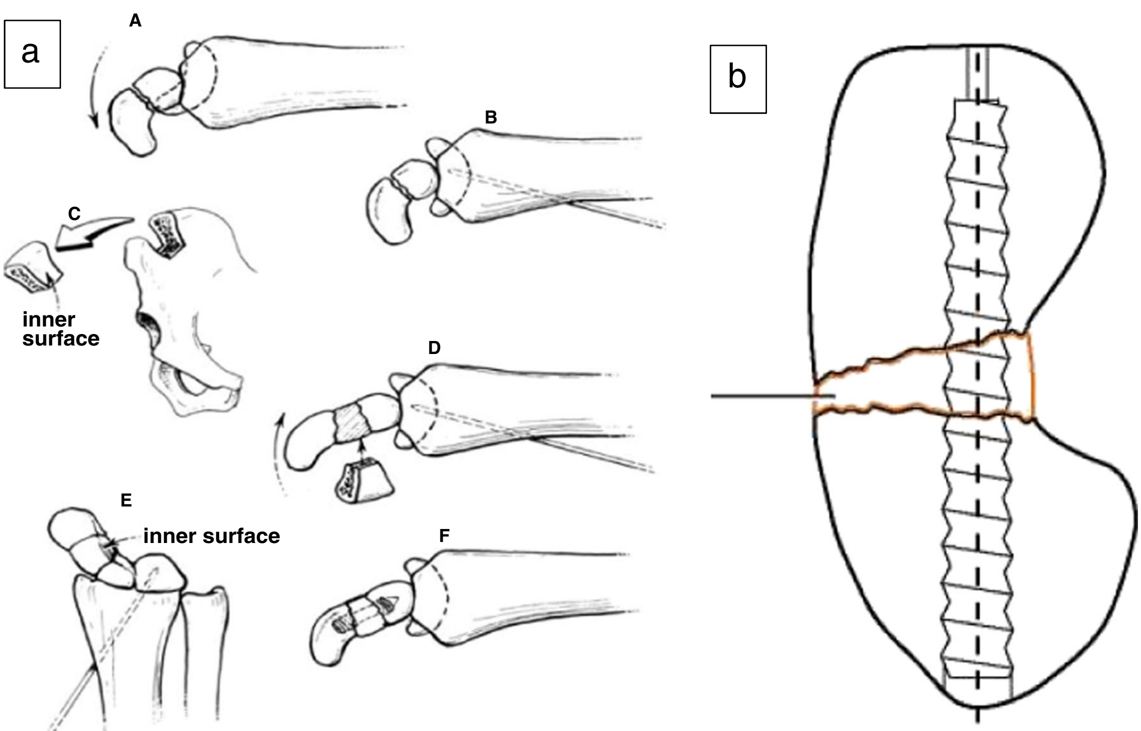


**Fig. 4** Schematic diagram showing preparation of nonunion site and application of appropriate-sized wedge-shaped bone graft from iliac crest (**a**); schematic diagram showing the correction of humpback deformity after placement of wedge-shaped bone graft and fixation with Herbert screw (**b**)

(31.1%) females. Twenty-six (57.8%) fractures were in the left side and 19 (42.2%) fractures were in the right side. Fifteen (33.3%) fractures were in the distal pole, 24 (53.4%) in the mid-shaft and six (13.3%) in the proximal pole. Average time interval between the initial injury and surgery was 7.73 ± 12.53 months (range 2–72 months). The average time for radiological union was 13.15 ± 2.68 weeks (range 8–22 weeks) and mean follow-up duration was 32.64 ± 11.66 months (range 12–60 months). The average time to complete the surgery was 75 ± 16.32 minutes (range 50–140 minutes). Humpback deformity was present in 17 (37.8%) patients pre-operatively, all of which were corrected after surgery. Cortico-cancellous graft from iliac crest was used in 14 (31.1%) and cancellous graft from distal radius was used in 31 (68.9%) patients. Forty-two of 45 (93.3%) fractures were finally united. The average pre-operative and post-operative scapho-lunate angle, grip strength, flexion-extension movement, radio-ulnar movement, scaphoid index and modified mayo score were mentioned in Table 1. Based on modified mayo score, 21 (46.7%) patients had excellent results, 19 (42.2%) had good results, four (8.9%) had fair results and one patient (2.2%) had poor results. One patient with the proximal pole fracture did not achieve union at the end of six months after surgery which was later treated by proximal fragment excision without further intervention. There were two cases of delayed union which were united six months after surgery. We had one case of comminuted fracture of proximal pole during surgery which was treated with proximal row carpectomy intra-operatively. Two patients had radio-carpal narrowing five years after surgery and one patient had transient reflex sympathetic dystrophy of wrist up to six months after surgery.

## Discussion

The treatment of scaphoid nonunion remains a big challenge to every orthopaedic surgeon particularly when it is associated with the vascular impairment of proximal fragment [2]. Dobyns and Linscheid [14] mentioned the criteria for identification of radiological union. Based on this criteria nonunion was anticipated when distance between the fracture fragments was greater than the inter-carpal bony distance, sclerosis on the fractured ends was more pronounced than the subchondral sclerosis of other carpal bones and degenerative changes as well as increase in fracture gap was more prominent in stress radiographs of wrist joint [14]. When consolidation of nonunion is not achieved, functional outcomes are not satisfying with development of joint stiffness, persistent pain, radio-carpal and inter-carpal arthritis [15].

Conventional bone grafting was found to achieve around 90% union rate with good vascular status of proximal fractured fragment; however, probability of union decreases with reduced blood supply of proximal fragment and union will be almost impossible in the presence of avascular necrosis of proximal fragment [4, 16].

In our study, 42 (93.3%) patients with scaphoid nonunion were finally united and 40 (88.9%) of them had good to excellent results based on the modified mayo scoring system. The Matti-Russe method of inlay bone grafting was reported to achieve 90% union rate and 88% satisfaction rate; however, joint stiffness was inevitable because of prolonged immobilization of wrist and inter-scaphoid angulation was inadequately corrected [17]. Warren-Smith and Barton reported the better functional outcomes with bone grafting and Herbert screw fixation as compared to inlay bone grafting only [9]. Excision of sclerotic bony tissue, replacement with osteo-inductive and osteo-conductive matrix, rigid fixation and re-establishment of vascular supply are the key factors for successful union. Filan and Herbert mentioned 431 scaphoid fractures and nonunion treated by bone grafting and Herbert screw fixation with better functional results and reduced progression of osteoarthritis than with the standard inlay grafting only [18]. Daly et al. found the 96% union rate in 26 patients with established nonunion treated with bone grafting and Herbert screw fixation [19]. Thus, we can maintain the anatomical reduction, correct the deformity and achieve the bony union owing to the impaction of cancellous bone grafting as well as cortex containing wedge graft, if required to fill the gap in scaphoid nonunion.

Kilic et al. [4] reported the superior functional results with volar vascularized pedicle bone graft as compared to volar peg graft only to treat the scaphoid nonunion, especially proximal pole nonunion in terms of better union rate, correction of hump-back deformity and dorsal intercalated segment instability (DISI), less post-operative pain, speed of radiological union and earlier return to activity. Bilic et al. [20] demonstrated in a clinical study that recombinant bone morphogenic protein (BMP) hastened radiological and clinical repair of scaphoid nonunion treated with vascularized bone grafts, especially associated with avascular proximal pole fragment. However, almost all studies mentioned the benefits of vascularized bone grafting in case of scaphoid nonunion with avascular necrosis of proximal fragment. Conventional non-vascularized bone graft along with Herbert screw fixation resulted more than 90% of union rate and excellent functional outcomes to treat the nonunion of scaphoid with vascularized proximal fragment. The results of our study showed that scapho-lunate angle, grip strength, flexion extension and radio-ulnar movement of wrist, scaphoid index and modified mayo scores were improved significantly from pre-operative to last follow up visit with $P$ value less than 0.001 and nearly comparable to the values of normal wrist joint. A number of other studies also strongly support the results of our study. The Hybrid Russe technique using a corticocancellous strut, cancellous autologous non-vascularized bone graft, and

**Table 1** Showing the pre-operative and post-operative scapho-lunate angle, grip strength, wrist movement, scaphoid index and modified mayo scoring

| Parameters | Pre-operative, mean (range) | Latest follow-up after surgery, mean (range) | *P*-value | Normal side | *P*-value (latest follow-up and normal side) |
|---|---|---|---|---|---|
| 1. Scapholunate angle in degrees | 49.6 ± 6.4 (37–66) | 36.2 ± 4.7 (28–46) | <0.001 | 35.8 ± 4.5 (28–45) | 0.094 |
| 2. Grip strength in kilograms | 20.6 ± 3.1 (15–27) | 31.1 ± 3.3 (25–40) | <0.001 | 32.3 ± 3 | 0.21 |
| 3. Flexion extension arc of wrist in degrees | 78.6 ± 14.2 (45–110) | 132.8 ± 13.9 (100–165) | <0.001 | 166.3 ± 5.6 (155–176) | <0.001 |
| 4. Radio-ulnar arc of wrist in degrees | 30.1 ± 6.1 (20–44) | 44.9 ± 6.4 (35–59) | <0.001 | 57.4 ± 5.8 (45–70) | <0.001 |
| 5. Scaphoid index (height/length) | 0.66 ± 0.07 (0.55–0.79) | 0.60 ± 0.06 (0.49–0.73) | <0.001 | 0.57 ± 1.2 (0.54–0.61) | 0.06 |
| 6. Modified Mayo score of wrist | 58.6 ± 5.2 (50–70) | 84.4 ± 5 (75–95) | <0.001 | 95 ± 3.4 (90–100) | <0.001 |

cannulated headless compression screw predictably restored radiolunate, scapholunate, and intrascaphoid angles with a 100% union incidence. The technique provides excellent functional results in patients with a challenging clinical problem, and they recommend it for scaphoid fracture waist nonunions with dorsal intercalated segment instability deformity [21]. Braga et al. [22] found similar union rates and functional outcomes in a prospective study comparing 35 patients treated with vascularized bone graft (VBG) and 45 patients with non-vascularized bone graft (NBG). The recent study of Hirche et al. found similar union rates, functional outcomes, and quality of life in a postoperative study comparing the vascularized and non-vascularized bone graft to treat the scaphoid nonunion [23]. The vascularized bone grafting method is technically more demanding with small margin of error, requires long-term immobilization of wrist joint, has difficulty of getting the appropriate graft size and fixation as well as incorporation into the scaphoid bone. More importantly, scaphoid nonunion with good vascularized status of proximal fragment has been united uneventfully with conventional bone graft and Herbert screw fixation. Based on these studies we can conclude that results of vascularized bone grafting are not superior as compared to non-vascularized bone grafting. It may not be necessary to treat all scaphoid nonunion without avascular necrosis of proximal fragment by vascularized bone grafting that otherwise has been united by this technique.

Arthroscopic bone grafting (even with injectable bone graft) and percutaneous internal fixation has recently been reported to have a good union rate and functional results [24]. However, this technique is useful only for minimally displaced scaphoid nonunion with minimal sclerosis at fracture site. So this minimally invasive technique has its own indications to treat the scaphoid nonunion and does not look worthy of directly comparing with the techniques of open reduction and bone grafting. Herbert classified the scaphoid nonunion into four categories [18]. Type 1 is fibrous union, type 2 is pseudo-arthrosis at fracture site, type 3 is DISI deformity and sclerotic fractured ends, while type 4 is avascular necrosis with collapse of proximal fragment. For practical purposes, scaphoid nonunion is classified into asymptomatic and symptomatic. The first group can be restored to normal level by surgical intervention while in the second group symptoms can be prevented from further deterioration of condition. Intra-operatively, vascularity of proximal and distal fragment of scaphoid was assessed by quantity and quality of punctate bleeding after release of tourniquet based on Green's criteria [16]. The nature of bleeding was assessed after release of tourniquet intra-operatively [25]. 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.

## Conclusion

Combination of thorough curettage of unhealthy bone, impaction of cancellous bone chip graft, cortical-containing bone grafting if required, and internal rigid fixation with Herbert's screw provides a good option for treatment of scaphoid nonunion especially in the absence of avascular necrosis of proximal fragment. This procedure provides sustained rebuilding of scaphoid length, correction of humpback deformity, avoidance of further collapse, and leads to promising bony union. More importantly vascularized bone grafting in all scaphoid nonunion may be unnecessary in what otherwise could have united uneventfully by this technique. However, avascular necrosis of proximal fragment must be ruled out pre-operatively as well as intra-operatively.

**Limitation** Lack of a control group is a major limiting factor of this study.

**Compliance with ethical standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

**Funding** There is no funding source.

**Ethical approval** All procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was taken from all individual participants included in the study.

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