Volar percutaneous screw fixation and autogenous bone marrow injection for acute scaphoid fractures

Mohamed I. Rakha, Mohamed S. El-Deeb, Samir M. El-Ghandour

Department of Orthopaedics, Faculty of Medicine, Suez-Canal University, Ismailia, Egypt

Correspondence to Samir M. El-Ghandour, MD, Post Box 1375, Port Said, Egypt
Tel: +20 100 951 8960;
e-mail: elghandour@hotmail.com

Received 28 May 2013
Accepted 25 June 2013

Egyptian Orthopedic Journal 2014, 49:112–119

Background

Scaphoid fractures are most common in young active men. Undisplaced or minimally displaced scaphoid fractures can be treated either conservatively or operatively by percutaneous screw fixation (PSF) rather than by open surgery. Advantages of PSF are earlier mobilization and return to work with avoidance of complications of prolonged casting and open surgery. The concept of bone marrow injection in cases of delayed healing, nonunion, and poor bone healing is well accepted.

Patients and methods

Twenty-four patients with undisplaced or minimally displaced scaphoid fractures were treated within 3 weeks of sustaining the injury with PSF using headless cannulated Herbert screws through a volar approach. The fixation procedure was augmented by injection of autogenous bone marrow aspirated from the iliac bone. There were 19 male and five female patients with a mean age of 27.5 years (average 19–47 years). These patients were followed up for a mean period of 10 months (average 7–12 months).

Results

All fractures united at a mean of 7 weeks (average 6–10 weeks) and all patients returned to sedentary work within 1 week and to manual work within 8 weeks. At last follow-up, average wrist range of motion was extension of 60° (range 50–70) and flexion of 55° (range 50–60) and the percentage of range of wrist motion as compared with the contralateral side was between 85 and 95%, with a mean of 90%. No complications from either procedure were encountered.

Conclusion

PSF for nondisplaced and minimally displaced scaphoid fractures augmented with bone marrow injection resulted in fast radiographic union and early return to work. The procedure was performed as day-case surgery with no complications. We recommend the use of this procedure for scaphoid fractures with delayed union and certain types of nonunion.

Keywords:
bone marrow injection, percutaneous screw fixation, scaphoid fractures

Egypt Orthop J 49:112–119

1110-1148

Introduction

Scaphoid fractures are the most common fractures of the carpal bones, accounting for 70–80% of all carpal fractures and 11% of all hand fractures. In adults, 70% of all scaphoid fractures involve the waist of the scaphoid, 20% involve the proximal pole, with the remaining 10% involving the distal pole [1]. The fracture usually results from a forceful extension of the wrist predominantly in young healthy adults between 10 and 19 years of age and is rare in young children and elderly people because of the relative weakness of the distal radius compared with the scaphoid bone in these age groups [2]. Scaphoid fracture is associated with a high incidence of delayed union, nonunion, and osteonecrosis. Besides the substantial morbidity, time off work and loss of earnings constitute other drawbacks [3]. The scaphoid bone has several unique characteristics that affect its healing potential. Approximately 80% of the bone surface is covered with articular cartilage (except for small bands on its dorsal and palmar aspects) and it has a tenuous blood supply [1]. Consequently, it does not have the capacity for periosteal healing, but depends on an intraosseous bone healing process [3]. Osteonecrosis occurs in 13–50% of cases of scaphoid fractures, and this incidence is even higher in those with involvement of the proximal one-fifth of the scaphoid. The incidence of scaphoid nonunion is reported to be between 5 and 25%, with various fracture-related, patient-related, and treatment-related factors affecting the union rate [4]. Appropriate and early diagnosis of scaphoid fractures is imperative to avoid a variety of adverse outcomes that include delayed union, nonunion, avascular necrosis, decreased grip strength, decreased range of motion, carpal collapse, and, subsequently, a predictable pattern of arthrosis [3]. If the diagnosis cannot be established by clinical and radiographic examination, bone scans are recommended [1].

Approximately 95% of undisplaced and minimally displaced acute scaphoid fractures will achieve union if they are properly immobilized. The average time for union varies with the level of the fracture: fractures of

 DOI: 10.4103/1110-1148.145309

the distal third heal in ~6–8 weeks, those of the middle third in 8–12 weeks, and those of the proximal third in 12–23 weeks [3]. Conservative treatment implies a long period away from work, besides the subsequent events of prolonged casting, including significant joint stiffness, reduced grip strength, local osteoporosis, and muscle wasting [1]. A cost/utility analysis of open reduction and internal fixation versus cast immobilization for acute nondisplaced fractures of the mid-waist of the scaphoid suggested that the former is cost saving from the social perspective [5]. Moreover, the true incidence of nonunion after conservative treatment may be in the order of 50% [6]. Generally, surgical treatment allows early mobilization of the wrist and is more indicated for patients who cannot afford to be away from work for long periods or who require early use of the injured hand because of multiple fractures of the extremities [6]. With improvement in the fixation techniques and image-guided procedures, the most appropriate treatment strategy for undisplaced and minimally displaced scaphoid fractures has become a controversial issue, with methods evolving from conventional cast immobilization to surgical intervention with percutaneous screw fixation (PSF). This surgical procedure has gained increasing popularity in recent years as an alternative to prolonged casting or open surgery. It has many advantages because it allows early mobilization of the wrist joint and early return to full function, besides improving the union rate of the fracture [6,7]. Percutaneous fixation of scaphoid fractures with headed cannulated screws was first performed in 1962 in Germany by von R. Streli by means of a small volar incision, as a modification of the technique of open reduction with solid bone screws developed by McLaughlin [8]. The procedure was first reported in 1970 [8], but reservations were expressed after poor preliminary results. In 1984, Herbert and Fisher first described the technique of PSF, and they proposed a classification of scaphoid fractures [6]. Herbert developed the headless compression bone screw, which was later modified into a headless cannulated screw by Whipple [9] and others [10,11]. Now, the technique is used commonly, with uniformly high union rates approaching 100%, excellent functional results, few complications, quicker time to union, and early return to manual work [12–15]. Moreover, the PSF technique was recently reported for scaphoid fractures with delayed or even established nonunion [16,17]. Biomechanical studies showed that greater fixation strength is obtained when the screw is placed centrally than eccentrically [18]. To verify the accuracy of screw placement, several experimental techniques were suggested, including conventional and modified two-dimensional fluoroscopy [19], intraoperative ultrasound [20], computer-assisted surgery [21], and an arthroscopic aid [9,11]. PSF can be performed following a volar [12–15] or a dorsal approach [11,16]. However, there has been controversy regarding the best approach for these fractures, and several studies have been carried out to determine the best one [22].

Bone healing is primarily a biological process, and depends upon cellular response. The most important cells that influence osteogenesis are osteoblasts (osteoprogenitor cells), which are considered the key elements in the process of bone healing. It was proven that autogenous bone marrow is a good source of these cells [23]. Cells aspirated from bone marrow are being shown to provide stimulus for osteogenesis both in animal experiments and in clinical evaluation, but its clinical use has remained limited. Autogenous bone marrow injection was tried in fractures with delayed and nonunion, in treatment of bone cysts, and in open fresh fractures in which expected delayed union may occur [23,24]. To our knowledge, there is no study in the published literature on the usage of bone marrow injection as an augmentation therapy for cases of scaphoid fractures either for acute treatment or for late therapy. The hypothesis of this study is that the PSF of nondisplaced and minimally displaced acute scaphoid fractures with augmentation by injection of aspirated autogenous bone marrow may enhance bone healing and shorten the union time for these difficult-to-treat fractures. The outcome of the technique is assessed on a clinical, radiological, and functional basis.

Patients and methods

Between March 2011 and April 2013, 24 cases of undisplaced and minimally displaced (<1 mm) acute scaphoid fractures were treated by percutaneous fixation using headless cannulated Herbert compression bone screws following a volar approach, from distal to proximal. The targeted axis of screw insertion was the middle third or center axis of the scaphoid. After screw fixation, the procedure was augmented by injection of aspirated autogenous bone marrow from the iliac crest. Inclusion criteria were patients with nondisplaced or minimally displaced (<1 mm) waist and proximal pole scaphoid fractures presenting within the first 3 weeks of their injuries. We excluded patients with displaced or comminuted fractures, patients presenting after 3 weeks, fractures of the scaphoid tuberosity, trans-scaphoid perilunate dislocation, or cases of scaphoid fractures associated with other injuries around the wrist. There were 19 male and five female patients with a mean age of 27.4 years (range 19–47). There were 15 manual workers (heavy laborers, farmers, or temporary registered workers) and nine patients engaged in nonmanual work (office employees). Fourteen fractures were in the dominant hand and 10 were in the nondominant hand. There were 18 patients with a waist fracture and six patients with proximal pole fractures. All patients underwent the surgery within a period of 0–21 days, an average of 8 days from their injury.

Preoperative planning

All imaging studies (anteroposterior, lateral, and scaphoid views) were reviewed to identify the location of the fracture and the size of the scaphoid bone.

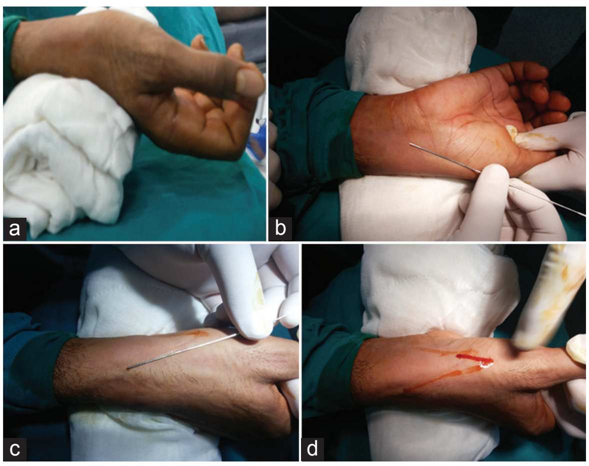
Operative technique

The patient was positioned in a supine position and the contralateral iliac crest was prepared for bone marrow aspiration. The shoulder was abducted, the forearm was supinated, and the wrist was gently extended over a folded towel and ulnarly deviated to slide out the scaphoid from under the radial styloid process (Fig. 1a). Anteroposterior and lateral views of the scaphoid were obtained by fluoroscopy to detect the anteroposterior and lateral axes of the scaphoid and both axes, were demarcated on the skin by a marker to make an acute angle (Fig. 1b-d).

In this position, a longitudinal skin incision of about 5–10 mm was made at the apex of this angle, which represented the scaphoid tuberosity. Blunt dissection was accomplished using a fine hemostat to expose the distal pole of the scaphoid and the scaphotrapezial articulation. The anterior capsule of the wrist joint was left intact. A guidewire of 1.1 mm diameter was introduced through the scaphotrapezial joint into the tubercle of the scaphoid with great care to avoid bending the thin wire. The goal was to have the wire within the scaphoid in all views and to be centered in the proximal pole. The wire was directed in the two views toward the center of the proximal pole of the fractured scaphoid and advanced until it arrived in an adequate position on both views. This required directing the wire at an angle of 45° in both anteroposterior and lateral planes and appreciating the 45° obliquity of the scaphoid to the forearm in the coronal and sagittal planes.

Because the lateral radiograph does not show the entire proximal outline of the scaphoid, the wire was advanced toward the center of the proximal pole aiming toward the middle of the distal articular surface of the radius or the tubercle of Lister (Fig. 2a). This is the most critical part of the operation as postulated by Wozasek and Moser [7]. The length of screw required was then determined by a depth gauge or the difference in length between a correctly placed wire with its tip at the proximal pole and a second parallel pin of the same length with its tip at the distal pole (Fig. 2b). A cannulated drill bit with a sleeve to protect the soft tissues was used to drill the scaphoid to within 2 mm of the proximal cortex. It was important to not drill closer than 2 mm from the proximal cortex as this may result in lack of compression during screw insertion. We used for all the cases self-tapping headless compression titanium Herbert screws of 2.7 mm diameter with a range in length of 16–30 mm. A screw of an appropriate length was then introduced over the k-wire with an image intensifier control until it reached the fracture site – that is, at the end of distal fragment; then the k-wire was withdrawn, leaving the screw in place. During the screw insertion, about 2–3 ml of bone marrow was aspirated from the contralateral anterior superior iliac spine and injected immediately without delay through the hole of the screw aiming the fracture site and the hole of the drill bit in the proximal fragment. Under fluoroscopy control, the guidewire was reinserted and the screw was completely inserted until good compression of the fracture was achieved. Compression was confirmed by means of an image intensifier and the end of the screw was buried beneath the distal surface of the scaphoid to avoid more damage to the scaphotrapezial joint. Skin closure usually required only a single suture covered with a sterile dressing.

Figure 1



(a) The wrist joint was gently extended over a folded towel. (b–d) The anteroposterior and lateral axes of the scaphoid were demarcated on the skin by a pen to make an acute angle.

Postoperative care

The hand was immobilized in a thumb slab for 2 weeks. All patients were discharged within 24 h of admission. Patients were encouraged to begin active finger exercises before discharge and were reviewed at 2-week intervals until radiological union was achieved, and then every 3 months for 1 year after surgery. The sutures were removed after 2 weeks, and a removable

Figure 2

(a) The lateral view does not show the entire proximal outline of the scaphoid, and hence the guide is directed toward the middle of the distal articular surface of the radius if it is to enter the proximal pole of the scaphoid. (b) The screw length is determined by the difference in protruding length between one k-wire with its tip at the proximal pole and a second parallel wire of the same length with its tip at the distal pole. Case-1: a 28-year-old male patient had a fracture in the waist of the right scaphoid after falling on an outstretched hand during sport. He was treated with a cannulated Herbert's compression bone screw with injection of aspirated bone marrow. (a, b) Preoperative plain radiographs in anteroposterior (AP) and lateral views in POP cast. (c, d) Immediate postoperative AP and lateral views. (e) Six-week postoperative plain radiograph in AP view revealing bone healing. The patient was rated as showing excellent clinical result. Case-2: a 26-year-old male reconstruction manual worker sustained a minimally displaced fracture in the waist of the right scaphoid after falling on an outstretched hand. (a) Plain radiograph in AP view of the right wrist revealing the fracture. (b) Postoperative plain radiograph in AP view after fixation with cannulated Herbert's headless compression screw and bone marrow injection. (c) Plain radiograph in AP view 6 weeks postoperatively revealing radiological union. The patient was rated as showing excellent clinical result.

wrist splint was applied until bony healing was achieved. The patients were then made to undergo physiotherapy to mobilize the wrist, but no full loading on the wrist was allowed before clinical and radiological union was achieved.

At each follow-up, the wrist was examined for snuffbox tenderness, and four radiographic views of the scaphoid (posteroanterior, lateral, semipronation oblique, and semisupination oblique) were taken. Union was defined both clinically (as a lack of local tenderness at the fracture site and no pain on movement or stressing) and radiologically (when trabeculae were seen to cross the fracture site in at least three views), although the limitations of plain radiography in the assessment of scaphoid fractures are well recognized [18]. Return to sedentary work was allowed when the patient felt ready or when 75% of the contralateral range of movement was achieved, but manual work and athletic activity were not permitted until there was evidence of union. At the last follow-up visit, we assessed the clinical outcome including local pain at the wrist or iliac crest, range of movement of the wrist joint, capability to return to preinjury work status, and subjective satisfaction,

Results

All patients were followed up for a mean time of 10 months, with an average of 7–12 months. The mean operating time was 25 min (20–40 min), with longer operating time recorded for early cases. There were no perioperative complications related to either procedure. Patients were able to return to sedentary work within 1 week and to manual work within 8 weeks, depending on the patient's occupation. At 6 weeks, in comparison with the contralateral side, 10 patients achieved more than 90% of the range of motion, nine patients achieved more than 80%, and five patients achieved more than 75%. Most of the delay was due to the wait for radiological evidence of fracture healing. None of the patients had pain (of either sites) at the time of the first review. The scaphoid fractures showed complete radiological bone healing between 6 and 10 weeks with a mean of 7 weeks after screw fixation. In only four patients (16.6%) did bone union occur in the last 8–10 weeks postoperatively but this delay did not postpone the early physiotherapy. Radiographs show the screw in the center position within the scaphoid in 21 patients, but somewhat peripheral in three cases. In all cases the fractures were bridged by the screw and no loosening was observed. At final follow-up, the average range of motion of the wrist joint was extension of 60° (range 50–70) and flexion of 55° (range 50–60). The percentage of range of wrist motion after union as compared with the contralateral side was between 85 and 95%, with a mean of 90%.

All nine patients engaged in sedentary work (office employees) were able to return to their previous jobs, and 11 of 15 heavy manual workers were able to return to the same work. The other four patients changed their jobs because they were temporary manual workers. All patients were satisfied with the procedure. There were no cases of wound infection, reflex sympathetic dystrophy, scar pain, or hypertrophy. There was no evidence of avascular necrosis, heterotopic ossification, or intra-articular calcification, and none of the screws had to be removed.

Discussion

The basic principles of management of scaphoid fractures are early diagnosis, anatomical reduction, and adequate immobilization. Displacement or comminution increases the risk of nonunion and requires closed reduction or, if this is not possible, open reduction and rigid fixation. The prerequisites for rapid union are anatomical reduction and compression of the fracture surfaces [3]. Generally, surgical treatment allows early mobilization of the wrist and is more indicated for patients who cannot afford to be away from work for long periods or who require early use of the injured hand because of multiple fractures of the extremities. Open surgery for acute scaphoid fractures is a technically demanding procedure that requires extensive soft-tissue stripping with possible damage to the anterior radiocarpal ligaments and compromising the blood supply of the scaphoid. Wound infection, painful scars, and reflex sympathetic dystrophy may be troublesome postoperative complications [10]. With advances in tools and techniques, the decision over the best treatment strategy for undisplaced and minimally displaced scaphoid fractures has become a controversial issue, with methods evolving from conventional cast immobilization to PSF. The procedure has many benefits. First, the advocators of PSF through several randomized prospective trials have reported that the technique has better results as regards union rate, union time, regain of wrist joint movements, and return to manual work and preinjury status – that is, it yields good functional, clinical, and radiological outcomes. Adolfsson *et al.* [13] in a randomized prospective study for the treatment of undisplaced scaphoid waist fractures [casting (n = 28) vs. PSF using the Acutrak screw (n = 25)] found that PSF allows early mobilization of the wrist joint without adverse effects on fracture healing. Bond *et al.* [14] in another prospective randomized study compared percutaneous fixation of acute fractures (11 patients) with cast immobilization (14 patients). They demonstrated an earlier time to union (7 vs. 12 weeks) and earlier return to work (8 weeks with percutaneous fixation vs. 15 weeks with casting). McQueen *et al.* [15] in a third prospective randomized study (total n = 60 patients) of patients treated by cast and PSF found that those undergoing PSF showed a quicker time to union (9.2 vs. 13.9 weeks, $P < 0.001$) compared with those treated with a cast and there was a trend toward a higher rate of nonunion in the nonoperative group, although this was not statistically significant. They also found that patients treated surgically had a more rapid return of function and to sport and full work compared with those managed conservatively. Inoue and Shionoya [10] in a comparative study of PSF and cast immobilization found that definite union was obtained in 38 of the 39 patients in the conservative group and in all of those undergoing surgery, with no complications. In their study, the average time for union in the conservative group was 9.7 weeks (6–22) and in the surgically treated group was 6.5 weeks (4–15) with a shorter time to union and an earlier return to manual labor. Majeed [25], in a systematic review of 60 relevant published articles, concluded that the best available evidence for PSF versus cast treatment suggests that percutaneous fixation allows a faster time to union by 5 weeks and an earlier return to manual work by 7 weeks, with similar union rates. The results of our study confirmed the previous findings that acute fixation of the scaphoid allows early return to work: all patients were able to return to sedentary work within 1 week and to manual work within 8 weeks, depending on the patient's occupation.

Studies comparing percutaneous fixation to cast immobilization did not identify any long-term radiographic or clinical benefits of surgical fixation over casting [10].

Second, another issue as regards surgical treatment of undisplaced scaphoid fractures is that early internal fixation of the scaphoid avoids the dilemma of when to discontinue cast immobilization. It has been clearly shown by many authors that the diagnosis of union can be very difficult to interpret even under direct vision, and such patients may be ideal candidates for percutaneous fixation [6,7]. Early intervention was also supported by Filan and Herbert [26] operative findings; it was observed that 82 acute fractures were often in a worse position than suggested by radiographs and that there was soft-tissue interposition in 28 cases.

During the technique, the target of screw insertion is the central axis of the scaphoid. Biomechanical studies showed that the greatest stability and fixation strength is obtained when the screw is placed centrally than eccentrically, especially screw position within the proximal pole [18]. This central screw placement provides good scaphoid alignment and is associated with excellent clinical outcome in terms of range of motion [19]. Although central screw placement is technically demanding, it can be achieved either by a volar or by a dorsal approach with no difference in functional outcome or bone union between the two approaches [22,27].

In this study, the volar approach was chosen for several reasons. First, the approach was technically less demanding and it was easy to find the entry of the guidewire because the wire did not cross the radiocarpal joint [28]. Second, the volar approach provides two options to overcome the difficulty of the trapezium and the shape of the scaphoid impeding central screw placement: the first is through the scaphotrapezial joint (avoiding the trapezium) and the second through the trapezium itself (transtrapezoid) route [29]. Third, the wrist extension, which is the wrist position during the volar approach, makes the scaphoid fracture stable [28]. Finally, there is no risk of injuring the posterior extensor tendons [22]. Meermans and Verstreken [29] in a cadaveric comparative study between the two routes of volar approach (avoid trapezoid vs. transtrapezoid) suggested a transtrapezial route for difficult cases as an alternative for optimum central placement. In our study, the fixation of all cases was performed through the standard scaphotrapezial joint. Geurts *et al.* [30], addressing the effect of the two routes on the scaphotrapezium joint, found that a transtrapezial approach does not lead to symptomatic scaphotrapezial osteoarthritis at short-term to medium-term follow-up. However, the volar approach has the disadvantage that it puts the important volar structures at risk and the most commonly injured structure is the superficial branch of the radial artery. The anatomy at risk using a percutaneous palmar approach to the scaphoid has been well described. Kamineni and Lavy [31], in an anatomical study on the important structures at risk during k-wire insertion, found that the mean distance of the entry point from the superficial branch of the radial artery was 5 mm (range, 0–8 mm). They recommended a 1 cm incision centered over the scaphotrapezial joint and dissection under direct vision to the entry point in the scaphoid rather than a completely percutaneous approach. In our study, we followed this recommendation and the procedure was performed through a skin incision of 5–10 mm, with no detrimental effect on any of the important volar structures.

Management of scaphoid fractures was transformed in the 1980s with the introduction of the specific scaphoid Herbert screw and subsequent screw variations. The headless compression screw generates interfragmentary compression through differential pitches between the leading and the trailing threads. The compression thereby provides rigid internal fixation without the intra-articular prominence of standard headed screws. In this study, we used the cannulated headless compression Herbert bone screw for fracture fixation and observed no complications related to this type of hardware.

Generally, the overall results of studies on PSF of scaphoid fractures have shown up to 100% union rate for surgically fixed fractures through both the palmar [5,10,12,14,33] and dorsal approach [11]. Our study reported 100% success of fracture union in a mean time of 7 weeks ranging between 6 and 10 weeks. In only four patients (16.6%) did union occur in the last 8–10 weeks postoperatively but these four patients started normal function from the first 2 weeks; this suggested that the fixation would give stability to the fracture until complete union was achieved, and it was safe to allow early return to function. These results are comparable to the results of other studies that used the volar PSF, as illustrated in Table 1.

We attributed our good results to several factors. First, our study was limited to undisplaced and minimally displaced (<1 mm) acute scaphoid fractures presented within 3 weeks of injury, although we believe that the procedure may be applicable for some displaced fractures if anatomical reduction can be achieved. The importance of anatomical reduction of the scaphoid with correction of any displacement before fixation has been emphasized, and a method of closed reduction has been reported by King *et al.* [34]. Second, we used Herbert's bone screws, which provide stability and help maintain apposition of the fracture fragments and compression of the fracture. Third, the good results can be attributed to the precise and accurate insertion of the compression screw. We had perfect screw placement in 21 cases and only three cases with some marginal placement. It has been proven that perfect screw placement provides the greatest stability and stiffness, which in turn improves the fracture alignments and decreases the time to union [10]. Finally, we may attribute this high union rate to the injection of autogenous bone marrow. The good effect of bone marrow as an adjuvant therapy to enhance the healing process and improve the union rates was reported in other studies on treatment of delayed and

Table 1 The union rate and union time of acute scaphoid fractures treated in other studies in comparison with the results of the current study

References	Patient's number	Union rate (%)	Union time (weeks)
Inoue and Shionoya [10]	40	100	6.5 (4–15)
Haddad and Goddard [12]	15	100	57 days (38–71)
Wozasek and Moser [7]	130	89	10
O'Brien and Herbert [32]	35	97	Not reported
McQueen *et al.* [15]	30	Not reported	9.2 (8–18)
Bond *et al.* [14]	11	100	7
This study	24	100	7 (6–10)

nonunited fractures [23,24,35], but its direct effect on acute scaphoid fractures as in this study needs further investigations.

In experimental and clinical studies three forms of bone marrow were investigated: the aspirated form, the concentrated one, and the cell culture type. In this study, we used the nonheparinized aspirated form of bone marrow as an adjuvant therapy for cases of acute scaphoid fracture. All fractures were united at a mean time of 7 weeks (range 6–10 weeks). This time was more or less similar to that reported by other studies and shorter than the time reported by some others. The effect of bone marrow injection to enhance the bone healing process in this study is not clear. The work of Hernigou *et al.* [35] showed experimentally that bone marrow injection produces optimal effect when used early in the fracture healing process, whereas Connolly *et al.* [24] stated that 'The ideal time for bone marrow injection should be after the initial inflammatory and osteoclastic resorption period of fracture repair has subsided, which is usually by 6–12 weeks'. To test the effect of bone marrow on fracture union in cases of acute scaphoid fractures, a control group is required to compare the results, and the idea needs further investigations. It may be a subject for studies of cases with delayed union and certain types of nonunion without bone deformity. In our study, because of the planned short interval between aspiration and injection procedures, we were able to use the nonheparinized form of bone marrow aspirate, thereby avoiding the potential impairment of heparin on the bone healing process reported by Stinchfield *et al.* [36].

In the current study, none of the patients had pain at the time of the first review (2 weeks postoperatively) and all of them were able to return to sedentary work within 1 week and to manual work within 8 weeks. These results showed that internal fixation using this technique gave rapid symptomatic relief and early function recovery. At 6 weeks, 10 patients reached more than 90% of the range of motion, nine patients reached more than 80%, and five patients reached more than 75% in comparison with the contralateral side. At final follow-up, the average range of motion of the wrist joint was extension of 60° (range 50–70) and flexion of 55° (range 50–60). The percentage of range of wrist motion after union as compared with the contralateral side was between 85 and 95%, with a mean of 90%. In this study, we had good functional results both at 6 weeks postoperatively and at final visit, which may be attributed to several factors: first, the early mobilization of the wrist joint (after 2 weeks) postoperatively; second, the near-perfect screw positioning in our cases. The importance of screw position in the scaphoid, especially the central placement of the screw in the proximal pole of the scaphoid, has been emphasized by various authors [7,18], who found that the perfect screw placement is directly related to good scaphoid alignment, which resulted in excellent radiological and functional outcome in terms of decreases in the time to union and improvement in the range of motion.

Many reports cite low complication rates, including no complications in some series. Injury to the superficial branch of the radial artery, delayed union, complex regional pain syndrome, and infection using the palmar approach have been reported in literature [11,21].

In this study, we found that the procedure of PSF and bone marrow injection has many advantages. First, there was early relief from pain, early return to work, and early regain of wrist joint movements. Second, it provided a high union rate (100%) in a shorter time in comparison with the conservative treatment reported in other studies. One more advantage of this procedure is that it avoids the morbidity of both prolonged casting and open surgery. All patients were discharged within 24 h of admission and the procedure can be performed as day-case surgery. In this study, we had no complications related to either screw fixation or bone marrow aspiration procedures, thus indicating that the technique is a safe one.

Our study had several limitations. First, the sample size is small (n = 24 patients), but we believe that the study has significance as consistent findings were observed in all cases. Second, the study did not include a control group for comparison of the results with other groups treated without bone marrow injection or treated conservatively. However, the advantages of PSF compared with cast immobilization has been proven by other comparative studies. Third, the accurate assessment of fracture union in cases of fracture scaphoid is difficult and prone to interobserver variability, although we took serial radiographs of all patients at 2-week intervals.

Conclusion

Volar percutaneous fixation of undisplaced and minimally displaced acute scaphoid fractures using headless compression Herbert bone screws augmented by injection of aspirated autogenous bone marrow is a safe procedure resulting in a high union rate and early return to work and activity in a short period of time. The procedure can be performed as day-case surgery. We recommend this technique in other studies with control groups. We believe that the procedure of autogenous bone marrow injection may be effective in cases of scaphoid fractures with delayed union and in certain cases of established nonunion.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

References

1 Kozin SH. Incidence, mechanism, and natural history of scaphoid fractures. Hand Clin 2001; 17:515–524.

2 Van Tassel DC, Owens BD, Wolf JM. Incidence estimates and demographics of scaphoid fracture in the U.S. population. J Hand Surg Am 2010; 35:1242–1245.

3 Haisman JM, Rohde RS, Weiland AJ. Acute fractures of the scaphoid. Instr Course Lect 2007; 56:69–78.

4 Simonian PT, Trumble TE. Scaphoid nonunion. J Am Acad Orthop Surg 1994; 2:185–191.

5 Davis EN, Chung KC, Kotsis SV, Lau FH, Vijan S. A cost/utility analysis of open reduction and internal fixation versus cast immobilisation for acute non displaced mid-waist scaphoid fractures. Plast Reconstr Surg 2006; 117:1223–1235.

6 Herbert TJ, Fisher WE. Management of the fractured scaphoid using a new bone screw. J Bone Joint Surg Br 1984; 66-B:114–123.

7 Wozasek GE, Moser KD. Percutaneous screw fixation for fractures of the scaphoid. J Bone Joint Surg 1991; 73-B:138–142.

8 Streli R. Percutaneous screwing of the navicular bone of the hand with a compression drill screw (a new method). Zentralbl Chir 1970; 95:1060–1078.

9 Whipple TL. Stabilization of the fractured scaphoid under arthroscopic control. Orthop Clin North Am 1995; 26:749–754. 16

10 Inoue G, Shionoya K. Herbert screw fixation by limited access for acute fractures of the scaphoid. J Bone Joint Surg Br 1997; 79-B:418–421.

11 Slade JFIII, Grauer JN, Mahoney JD. Arthroscopic reduction and percutaneous fixation of scaphoid fractures with a novel dorsal technique. Orthop Clin North Am 2001; 32:247–261.

12 Haddad FS, Goddard NJ. Acute percutaneous scaphoid fixation: a pilot study. J Bone Joint Surg Br 1998; 80-B:95–99.

13 Adolfsson L, Lindau T, Arner M. Acutrak screw fixation versus cast immobilisation for undisplaced scaphoid waist fractures. J Hand Surg Br 2001; 26:192–195.

14 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-A:483–488.

15 McQueen MM, Gelbke MK, Wakefield A, Will EM, Gaebler C. Percutaneous screw fixation versus conservative treatment for fractures of the waist of the scaphoid: a prospective randomised study. J Bone Joint Surg Br 2008; 90-B:66–71.

16 Altay T, Gunal I, Kayali C, Sense M. Dorsal percutaneous screw fixation of delayed or nonunion of scaphoid fractures: decision making with MRI. Int Orthop 2014; 38:1007–1010.

17 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-B:932–936.

18 Chan KW, McAdams TR. Central screw placement in percutaneous screw scaphoid fixation: a cadaveric comparison of proximal and distal techniques. J Hand Surg [Am] 2004: 29:74–79.

19 Lee JI, Lee YS, Cho SB, Rhyu IJ, Park JH, Kang JW, *et al.* Modified fluoroscopic imaging technique for the central screw placement in percutaneous screw fixation of scaphoid fracture. J Trauma 2010; 68:616–619.

20 Beek M, Abolaesumi P, Luenam S, Ellis RE, Sellens RW, Pichora DR. Validation of a new surgical procedure for percutaneous scaphoid fixation using intra-operative ultrasound. Med Image Anal 2008; 12:152–162.

21 Smith EJ, Allan G, Gammon B, Smith EJ, Allan G, Gammon B, *et al.* Investigating the performance of a wrist stabilization device for image-guided percutaneous scaphoid fixation. Int J Comput Assist Radiol Surg 2014; 9:155–164.

22 Joen IH, Micic ID, Oh CW, Park BC, Kim PT. Percutaneous screw fixation for scaphoid fracture: a comparison between the dorsal and the volar approaches. J Hand Surg Am 2009; 34:228–236.

23 Bhargava R, Sankhla SS, Gupta A, Changani RL, Gagal, KC. Percutaneous autologus bone marrow injection in the treatment of delayed or nonunion. Indian J Orthop 2007; 41:67–71.

24 Connolly Jf, Guse R, Tiedeman J, Dehne R. Autologous marrow injection for delayed unions of the tibia: a preliminary report. J Orthop Trauma 1989; 3:276–282.

25 Majeed H. Non-operative treatment versus percutaneous fixation for minimally displaced scaphoid waist fractures in high demand young manual workers. J Orthop Trauma 2014.

26 Filan SL, Herbert TJ. Herbert screw fixation of scaphoid fractures. J Bone Joint Surg 1996; 78-B:519–529.

27 Vaynrub M, Carey JN, Stevanovic MV, Ghiassi A. Volar percutaneous screw fixation of the scaphoid: a cadaveric study. J Hand Surg Am 2014; 39:867–871.

28 Drac P, Manak P, Cizzmar I, Hrbek J, Zapletalova J. A Palmar percutaneous volar versus a dorsal limited approach for the treatment of non- and minimally-displaced scaphoid waist fractures: an assessment of functional outcomes and complications. Acta Chir Orthop Traumatol Cech 2010; 77:143–148.

29 Meermans G, Verstreken F. A comparison of 2 methods for scaphoid central screw placement from a volar approach. J Hand Surg Am 2011; 36:1669–1674.

30 Geurts G, van Riet R, Meermans G, Verstreken F. Incidence of scaphotrapezial arthritis following volar percutaneous fixation of nondisplaced scaphoid waist fractures using a transtrapezial approach. J Hand Surg Am 2011; 36:1753–1758.

31 Kamineni S, Lavy CB. Percutaneous fixation of scaphoid fractures. An anatomical study. J Hand Surg Br 1999; 24:85–88.

32 O'Brien L, Herbert T. Internal fixation of acute scaphoid fractures: a new approach to treatment. Aust N Z J Surg 1985; 55:387–389.

33 Ledoux P, Chahidi N, Moermans JP, Kinnen L. Percutaneous Herbert screw osteosynthesis of the scaphoid bone. Acta Orthop Belg 1995; 61:43–47.

34 Hernigou P, Poignard A, Beaujean F, Rouard H. 2005; Percutaneous autologous bone-marrow grafting for nonunions. Influence of the number and concentration of progenitor cells. J Bone Joint Surg Am 87-A:1430–1437.

35 Stinchfield FE, Sankaran B, Samilson R. The effects of anticoagulant therapy on bone repair. J Bone Joint Surg Am 1956; 38-A:270–276.

36 King RJ, Mackenney RP, Elnur S. Suggested method for closed treatment of fractures of the carpal scaphoid: hypothesis supported by dissection and clinical practice. J R Soc Med 1982; 75:860–867.