Scaphoid nonunions treated with corticocancellous graft and Herbert screw fixation: results at the 10-year follow-up

Salah A. Zakzouk

Damanhour National Medical Institute, Damanhour, Egypt

Correspondence to Salah A. Zakzouk, MD, Damanhour National Medical Institute, El-Bohira Governorate, El-Rahman Mosque St., 22511 Damanhour, Egypt
Tel: +20 100 650 9746;
e-mail: mohammedghool@yahoo.com

Received 02 November 2014
Accepted 10 October 2014

Egyptian Orthopedic Journal 2014, 49:292–298

Background
Fracture of the scaphoid bone is the most common fracture of the carpus and frequently, diagnosis is delayed as the unique anatomy and blood supply of the scaphoid itself predisposes to delayed union or nonunion. The Herbert screw is a double-threaded screw that provides superior compression compared with other devices used for internal fixation of scaphoid nonunion.

Objectives
The aim of this study was to evaluate the outcome and presence or progression of degenerative changes in the wrist after corticocancellous bone grafting and Herbert screw fixation.

Patients and methods
This study reviewed 20 patients with scaphoid nonunion who had been operated with a corticocancellous graft and Herbert screw fixation 10 (3.5–11) years previously, all free from arthritic changes preoperatively. The age of the patients at surgery ranged from 17 to 38 years, mean 24.9 years. The interval between trauma and surgery ranged from 8 to 60 months, mean 19.55 months.

Results
The function of the operated wrist was evaluated according to the scaphoid outcome score (SOS). Only three patients failed to show union. The mean (SOS) was 8.3 (5–10). Flexion was 11.7%, extension was 14.5%, ulnar deviation was 24%, radial deviation was 27.5%, and gripping force was 14.8% to the normal side. Osteoarthritis was present in six patients; this was related to the absence of correction of the preoperatively existing dorsiflexed intercalated segment instability. There was a correlation between the radiological presence of osteoarthritis and the clinical outcome.

Conclusion
Herbert screw fixation and volar wedge corticocancellous grafting of scaphoid nonunion is a successful operation, with few complications, that produces excellent to good long-term results because of correction of dorsiflexed intercalated segment instability deformity and reduced progression of osteoarthritis in most cases.

Keywords:
bone graft, Herbert screw, nonunion; scaphoid

Egypt Orthop J 49:292–298

1110-1148

Introduction

The natural history of scaphoid nonunion involves an eventual carpal collapse and degenerative arthritis usually within 10 years [1]. Osteoarthritis may lead to complications in untreated symptomatic and asymptomatic nonunion of the scaphoid [2,3]. The initial development of osteoarthritis at the scaphostyloid joint is associated strongly with a dorsiflexed intercalated segment instability (DISI) [4]. For this reason, surgery to achieve union of scaphoid nonunion is frequently performed, particularly in younger patients. Surgical treatment of scaphoid nonunion by excision back to bleeding bone, insertion of a corticocancellous bone graft, and stabilization, usually with a screw, can be highly successful in achieving union [5]. The ideal entry point is, therefore, through the articular surfaces of the scaphoid; still, there are some concerns that opening the scaphotrapezial joint and inserting a screw through the articular surface may lead to osteoarthritis of the joint [6,7]. The aim of this study is to evaluate:

(a) the outcome and the presence or progression of degenerative changes after standard corticocancellous bone grafting and Herbert screw fixation and
(b) the influence of the presence and correction of a DISI deformity on the radiological and clinical outcomes.

Patients and methods

A total of 86 patients were operated on for pseudarthrosis of the scaphoid in our department between 1999 and 2009. The 60 patients who underwent an operation by a volar peg graft technique, vascularized graft methods, pronator quadratus muscle pedicle graft, bone chip grafting, and K-wires

DOI: 10.4103/1110-1148.154078

fixation were excluded. The remaining 26 patients had been operated with corticocancellous bone graft and stabilization with Herbert screw. Three patients were lost to follow-up and three patients required further surgery: one proximal row carpectomy (32 months postoperatively) and two vascularized bone grafts for proximal pole necrosis. Also, all patients with arthritic changes preoperatively were excluded.

Thus, 20 patients were included in this study, all free from arthritic changes preoperatively, and were reviewed over a median of 10 years (range 3.5–11 years) after the operation. There were 16 males and four females. Their age at surgery ranged from 17 to 38 years, mean 24.9 years. The interval between trauma and surgery ranged from 8 to 60 months, mean 19.55 months. There had been 14 (70%) waist pseudarthrosis, four (20%) of the proximal pseudarthrosis (through or proximal to the junction of the proximal and middle thirds of the bone) and two (10%) of the distal third of the scaphoid. There had been 12 (60%) with DISI more than 60°, 13 (65%) with carpal collapse. Table 1 shows the data of the patients included in this study.

Surgical technique

The scaphoid was approached through a volar approach (Matti-Russe), lateral to the flexor carpiradialis tendon (Fig. 1). The bed of the flexor carpiradialis was incised in line with the skin incision. This opened the radiocarpal joint (Fig. 2). The scaphoid was inspected and the pseudarthrosis tissue was resected up to normal-appearing bone. The scaphoid was reduced and its length was restored by introducing a corticocancellous graft that was harvested from the ipsilateral iliac crest or from the volar aspect of the lower fourth radius (Fig. 3). The incision was deepened distally, dividing the origin of the thenar muscles in line with their fibers, along the anterior surface of the trapezium. The joint between the scaphoid and trapezium was then identified; it is essential that this joint is mobilized sufficiently to allow correct application of the instrumentation used for insertion of the screw (Figs. 4 and 5). Free hand instrumentation and insertion of the screw was used in some cases. After application of the screw, the joint and skin were closed. The wrist was immobilized for 4 weeks in a below-elbow cast without thumb immobilization.

Table 1 Data of the patients included in this study

Parameters	Au patients
Number	20
Age (years)	Mean 24.9Range 17–38
Sex [*n* (%)]	
Male	16 (80)
Female	4 (20)
Side affected [*n* (%)]	
Right (dominant)	14 (70)
Left (nondominant)	6 (30)
Occupation [*n* (%)]	
Heavy worker	14 (70)
Light workers	4 (20)
Students	2 (10)
Mechanism of injures [*n* (%)]	
Forced dorsiflexion	15 (75)
Hit by a heavy object	2 (10)
Unknown	3 (15)
Nonunion location [*n* (%)]	
Proximal	4 (20)
Waist	14 (70)
Distal	2 (10)
Previous treatment [*n* (%)]	
Crepe bandage	7 (35)
Scaphoid cast (weeks)	12 (60), mean 6Range 5–12
Previous surgery	1 (5)
Time between injury and operation (months)	Mean 19.55Range 8–60

Assessment

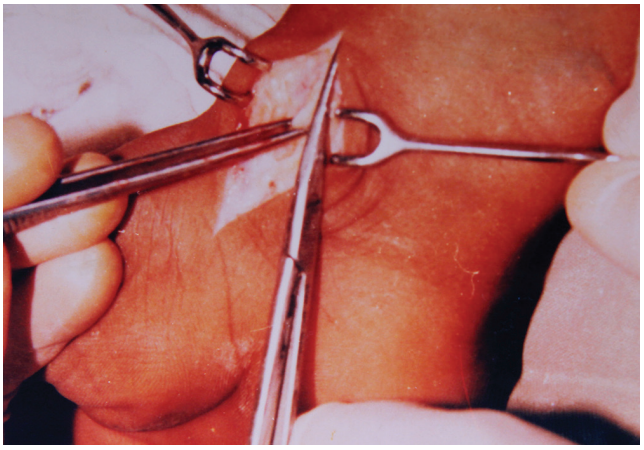
At the final follow-up, the range of motion of both wrists was measured using standard hand-held goniometry from a position of reference [8] and expressed as a percentage of the contralateral side. Grip strength was assessed using a sphygmomanometer according to the Mcrae technique [9]. By the end of the follow-up period, patients were evaluated with the scaphoid outcome score (SOS) of Robbins *et al.* [10]. In this scale, 40% of the total score was based on pain, 20% on motion and strength, 20% on patients presented occupation, and 20% on the patient's overall satisfaction (SOS: 10 = best outcome; 0 = worst outcome).

Standard preoperative radiographs were available for all patients. On the radiographs, the following parameters were evaluated (Table 2):

Figure 1

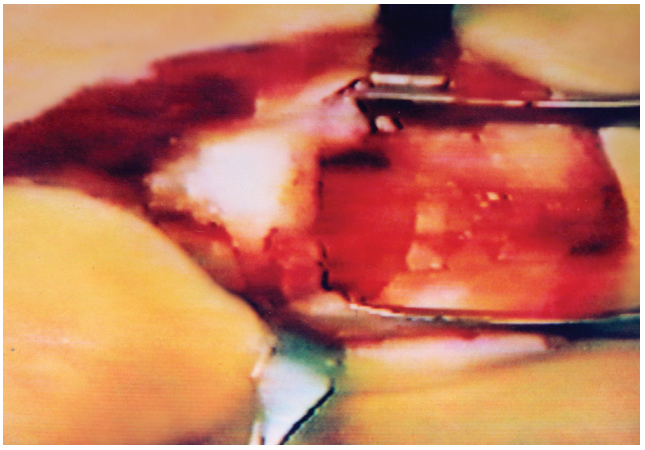
Volar approach lateral to the flexor carpiradialis tendon.

Figure 2



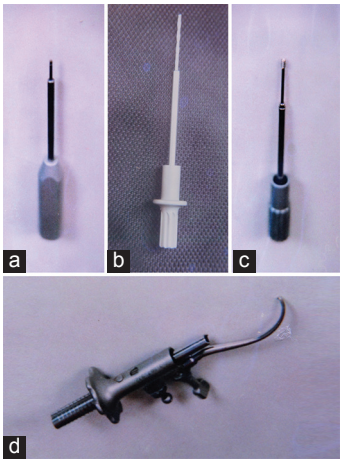
The bed of the flexor carpiradialis incised in line with the skin incision.

Figure 3



Length restored by corticocancellous bone graft.

Figure 4



Instrumentation. (a) Screw driver. (b) Drill 1.9 mm. (c) Tap. (d) The Huene alignment guide.

Figure 5

After application of the Jig, which compressed both fragments and the bone graft.

(1) The location of the scaphoid nonunion.
(2) The stage of nonunion was classified into four types according to the modified Herbert and Fisher classification for scaphoid nonunion type [11] (Table 2).
(3) From final follow-up radiographs, healing of the scaphoid nonunion was evaluated.
(4) On both the preoperative and end of follow-up films, the following were determined:
    (a) Severity and location of osteoarthritis according to Lindström and Nyström [12]. Grade I is the presence of one of the following features:
    (i) Narrowing of the joint space,
    (ii) Sclerosis, or
    (iii) Osteophytes. In grade II, two features are present. In grade III, all three features are present. Grade IV includes complete collapse of the carpus.
    (b) Scapholunate angle.
    (c) Carpal height index.

Results

Clinical assessment

Of the patients with a complete final follow-up, 15 (75%) were satisfied with the result, two (10%) had a fair result, and three (15%) were not satisfied. When the 20 patients who provided sufficient information were evaluated by the SOS, there were eight excellent, six good, three fair, and three poor results. The mean SOS score was 8.3 (5–10) and eight patients scored 10 (no dysfunction or symptoms). The median period of absence from work after surgery was 11.4 (12–24) weeks. Most patients returned to their previous occupation, but two had to find different work and three could not work full time because of pain in the wrist (Tables 3 and 4).

Of the 20 patients, eight patients reported no pain in the wrist whereas six had occasional aches or pain and six had pain after work or activity (Table 5).

Table 2 Location and grade of nonunion according to Herbert and Fisher [11]

Herbert and Fisher	Distal third	Middle third	Proximal third	Total
D1	–	4	–	4
D2	–	–	–	0
D3	2	10	2	14
D4	–	–	2	2
Total	2	14	4	20

Table 3 Scaphoid outcome score [10]

Pain rating 40%	Cases
No pain	4
Occasional ache	3
Ache after work or sports	2
Pain after work or sports	1
Daily pain not associated with activity	0
Wrist motion and strength 20%	
Able to return to preinjury work without limitations	2
Unable to return to preinjury work	1
Unable to work	0
Occupation (with respect to wrist injury) 20%	
Never limits work and activities	2
Occasionally limits work or activities	1
Always limits or activities	0
Overall satisfaction 20%	
Surgery improved quality of life	2
Surgery did not change quality of life	1
Surgery worsened quality of life	0
Maximum score	10
Results	
Excellent	10
Good	8–9
Fair	6–7
Po or	≤5

The range of motion was significantly reduced in all directions compared with the contralateral side: improved extension 14.5% to the normal, flexion 11.7%, ulnar deviation 24%, and radial deviation 27.5%. Grip force improved by 14.8% on the contralateral side (Tables 6–9).

Radiological assessment

(1) Bone healing occurred in 17 (85%) of the 20 scaphoid bones (Table 7).
(2) The scapholunate angle and the carpal height ratio in the preoperative radiographs of 12 patients (60%) showed DISI deformity more than 60°. Among these, correction was observed in the postoperative film of nine patients; the percentage of improvement to normal was 24%. The carpal height index was corrected in nine (69.2%) out of 13 wrists with preoperative carpal collapse. The percentage of improvement to the normal was 0.052% (Table 8).
(3) For the grades of osteoarthritis, no arthritic changes were observed preoperatively. The grades of osteoarthritis at follow-up are listed in Table 9.
(4) All cases at the end of follow-up complicated with osteoarthritis was noted in patients without correction of the DISI deformity compared with the wrists where correction was achieved.

The patients were assessed for any persistent pain including grade of pain, any restriction of daily activities, and osteoarthritis. All the patients who achieved union were able to resume normal activities and only three out of 20 patients had restriction of

Table 4 End results of the patient according to the scaphoid outcome score [10]

Cases	Pain rating	Wrist motion strength	Occupation regard to wrist injury	Overall satisfaction	Maximum score	Result
Case 1	3	2	1	1	7	Fair
Case 2	2	2	2	2	8	Good
Case 3	3	2	1	2	8	Good
Case 4	2	1	1	1	5	Poor
Case 5	4	2	2	2	10	Excellent
Case 6	4	2	2	2	10	Excellent
Case 7	2	1	1	1	5	Poor
Case 8	4	2	2	2	10	Excellent
Case 9	3	2	2	2	9	Good
Case 10	4	2	2	2	10	Excellent
Case 11	3	2	2	2	9	Good
Case 12	4	2	2	2	10	Excellent
Case 13	3	2	2	2	9	Good
Case 14	4	2	2	2	10	Excellent
Case 15	3	2	1	1	7	Fair
Case 16	2	1	1	1	5	Poor
Case 17	4	2	2	2	10	Excellent
Case 18	2	2	2	2	8	Good
Case 19	2	2	1	1	6	Fair
Case 20	4	2	2	2	10	Excellent

daily activities such as carrying heavy weights and pushing heavy objects. The final clinical outcome is detailed in Table 10.

Figure 6

(a) A 21-year-old man with nonunion waist of the scaphoid of 18-month duration; DISI 74&#1618. Union after 9 weeks and the final result was excellent, scaphoid outcome score = 10. (a) Preoperative (PA; lateral and ulnar deviation). (b) Postoperative adiograph. (c) Two-month follow-up. (d) One-year follow-up. (e) Eight-year follow-up.

Table 5 Presence of follow-up residual pain

Residual pain	Union [*n* (%)]		Total count
	No count	Yes count	
Pain free	0 (0)	8 (47.06)	8 (40)
Occasional pain	0 (0)	6 (35.29)	6 (30)
Pain after activity	3 (100)	3 (17.65)	6 (30)
Total	3 (100)	17 (100)	20 (100)

Fishers exact test = 0.005 significant.

Table 6 Wrist mobility and strength measures: mean, SD, and improvement

fx1

Table 7 Bone healing versus site and grade of nonunion according to Herbert and Fisher [11]

Site of fracture	Union [*n* (%)]		Total count
	No count	Yes count	
Waist (4D1+10D3)	1 (33.33)	13 (76.48)	14 (70)
Proximal (2D3+2D4)	2 (66.67)	2 (11.76)	4 (20)
Distal (2D3)	0 (0)	2 (11.76)	2 (10)
Total	3 (100)	17 (100)	20 (100)

Fishers exact test = 0.10.

Discussion

Internal fixation of the scaphoid is recommended for acute fractures that are unstable or displaced and for those with delayed healing or established nonunion. Most scaphoid nonunions heal with a corticocancellous graft and Herbert screw fixation [13–16]. Union rates alone are not an absolutely valid criterion for assessment of the results of the treatment of scaphoid nonunion. Scaphoid is the focus of ligamentous attachment governing carpal kinematics; preservation of its anatomy is critical for normal wrist function [17]. Restoration of carpal anatomy, avoidance of arthritis, and correction of DISI deformity as well as function should be taken into consideration [13,18–20]; for these reasons, this study was carried out. Although the Herbert screw lacks a protrusive head, concerns have been raised that this technique may cause osteoarthritis changes in the future [21]. In addition, significant damage to the articular surface of the proximal pole may occur following unsuccessful attempts to hook the guide Jig. This has been a concern, but the application of the Jig and insertion of the screw through the articular surface of the tubercle do not cause significant damage, as confirmed by other investigators [22,23]. In the present study, there was no evidence of degenerative changes in the scaphotrapezial joint. This is in agreement with the study of Filan and Herbert [13].

Compared with the preoperative status, an increase in osteoarthritis was noted at the radiocarpal joint in six cases (30%): grade 1 (10%), grade 2 (5%), and grade 3 (15%). This result cannot be compared with the results of Daecke *et al*. [24] and Schreuder *et al*. [25] because the preoperative grade of osteoarthritis in these groups was 43 and 37.5%, respectively, and no patient in this study presented with arthritis preoperatively.

Currently, a volar wedge graft and screw fixation is the procedure of choice for correction of scaphoid nonunions with flexion deformity. Tsuyuguchi *et al*. [26] reported a relationship between the wrist score and postoperative scapholunate angulations, stressing the importance of correction of the Humpback deformity. Correction of the DISI deformity was achieved in nine out of 12 cases. Only one other study is available comparing the preoperative and postoperative DISI deformity, which describes a correction in five out of six wrists with a preoperative carpal instability in a total population of 50 patients [24].

Table 8 Postoperative scapholunate and carpal height ratio of involved and uninvolved wrists (*n* = 20)

Parameters	Normal wrist	Injures wrist		Improvement	*t*
		Preoperative	Postoperative		
Scapholunate angle	50.7 ± 6.68	64.55 ± 9.21	52.45 ± 8.55	13 ± 9.03	5.9
Carpal height ratio	0.50 ± 0.04	0.48 ± 0.04	0.50 ± 0.03	0.026 ± 0.021	5.44

CHR, carpal height ratio; SL, scapholunate; *P* = 0.005 highly significant.

Figure 7

A 38-year-old man with nonunion associated with cyst formation of 3-years duration. Union was achieved 10 weeks after operation and the final result was good, scaphoid outcome score = 9. (a) Preoperative radiograph (PA; lateral and ulnar deviation). (b) One day postoperatively. (c) Three weeks postoperatively, bone graft sandwich between distal and proximal poles was stabilized with a Herbert screw. (c) Three weeks postoperatively, bone graft sandwich between distal and proximal poles was stabilized with a Herbert screw. (d) Two months postoperatively. (e) Six months postoperatively. (f) Ten-year follow-up (PA and oblique). (g) Ten-year follow-up (flexion and ulnar deviation). (h) Ten-year follow-up (PA and extension).

Table 9 Osteoarthritis grades at follow-up

OA grade	At follow-up (*n* = 25) [*n* (%)]
None	14 (70)
Grade 1	2 (10)
Grade 2	1 (5)
Grade 3	3 (15)
Grade 4	– (0)

OA, osteoarthritis.

Table 10 Outcome of the studied group at the end of follow-up

Pain grade	Functional outcome	Osteoarthritis	Number of patients [*n* (%)]
No pain	Normal	None	14 (70)
Mild pain	Normal	Grade 1	2 (10)
Moderate pain	Some restriction of daily activities	Grade 2	1 (5)
Severe pain	Severe restriction of daily activities	Grade 3	3 (15)

In this study, there was a difference in the progression of osteoarthritis in the uncorrected wrists compared with those that corrected completely. These observations have been confirmed by other authors [11,13,15].

In this study, a union rate of 85% was achieved. This results compares well with the union rates reported in larger series such as Filan and Herbert [13], 70%, Preisser *et al*. [27], 89%, Shah and Jones [28], 80%, Daecke *et al*. [24], 84%, and Chantelot *et al*. [29] 64%.

Three patients had a SOS (≤5) all associated with DISI that did not correct postoperatively; this is in agreement with the finding of Schreudr *et al*. [25].

Functional recovery is excellent, as shown by measures of mobility, carpal height ratio, and strength, compared with the uninjured wrist (Figs. 6 and 7). These observations have been confirmed by other authors [11–13,30].

The results of this study suggest that the treatment of scaphoid nonunion by a Sandwich graft and Herbert screw fixation is a useful method of treatment that reconstitutes scaphoid anatomy and leads to excellent wrist function; because of early mobilization, rigid fixation does not actually accelerate healing but helps to reduce the factors (osteoporosis and joint stiffness) that may affect the rates of union to a significant extent, but it has other advantages: 83.33% incidence of corrected DISI deformity compares very favorably with the 50% reported by Jiranek *et al*. [31], who used standard grafting technique. The results also show that the progress of osteoarthritis is reduced by successful internal fixation.

Conclusion

(1) Herbert screw fixation and volar wedge corticocancellous grafting of scaphoid pseudarthrosis is a successful operation, with few complications, that produces good to excellent long-term results because of increased incidence of correction of DISI deformity and reduced progression of osteoarthritis.
(2) Treatment of scaphoid nonunions with a corticocancellous graft and Herbert screw fixation can provide enough fixations to allow healing with

early mobilization, with no pain or only slight pain in activities of daily living.

(3) Healing of nonunion is similar to that after the use of other techniques, but functional improvement is greater and the progress of osteoarthritis is reduced.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

References

1 Monreal R. Treatment of scaphoid nonunions with closed-wedge osteotomy of the distal radius: report of six cases. Hand (N Y) 2008; 3:91–95.

2 Düppe H, Johnell O, Lundborg G, Karlsson M, Redlund-Johnell I. Long-term results of fracture of the scaphoid. A follow-up study of more than thirty years. J Bone Joint Surg Am 1994; 76:249–52.

3 Inoue G, Sakuma M. The natural history of scaphoid non-union. Radiographical and clinical analysis in 102 cases. Arch Orthop Trauma Surg 1996; 115:1–4.

4 Sukul DM, Johannes EJ, Marti RK. Corticocancellous grafting and an AO/ASIF lag screw for nonunion of the scaphoid. A retrospective analysis. J Bone Joint Surg Br 1990; 72:835–838.

5 Daly K, Gill P, Magnussen PA, Simonis RB. Established nonunion of the scaphoid treated by volar wedge grafting and Herbert screw fixation. J Bone Joint Surg Br 1996; 78:530–534.

6 Kehoe NJS, Hackney RG, Barton NJ. Incidence of osteoarthritis in the scaphotrapezial joint after Herbert screw fixation of the scaphoid. J Hand Surg 2003; 28B:496–498.

7 Nicholl JE, Buckland-Wright JC. Degenerative changes at the scaphotrapezial joint following Herbert screw insertion: a radiographic study comparing patients with scaphoid fracture and primary hand arthritis. J Hand Surg Br 2000; 25:422–426.

8 Kauer JMG. Functional anatomy of the wrist. Clin Orthop 1980; 149:9–19.

9 McRae R. The hand, clinical orthopedic examination. 2nd ed. Edinburgh, London, Melbourne, NewYork; 1987; 56–70.

10 Robbins RR, Ridge O, Carter PR. Iliac crest bone grafting and Herbert-screw fixation of nonunion of the scaphoid, with a vascular proximal poles. J Hand Surg 1995; 20-A:818–831.

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

12 Lindström G, Nyström A. Natural history of scaphoid non-union, with special reference to 'asymptomatic' cases. J Hand Surg Br 1992; 17:697–700.

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

14 Bunker TD, McNamee PB, Scott TD. The Herbert screw for scaphoid fractures. A multicentre study. J Bone Joint Surg Br 1987; 69:631–634.

15 Dent JA, Mitchell CA, Sharma MM. Herbert screw: results of a single centre trail. Injury 1992; 23:228–230.

16 DeMaagd RL, Engber WD. Retrograde Herbert screw fixation for treatment of proximal pole scaphoid nonunions. J Hand Surg Am 1989; 14:996–1003.

17 Wong WY, Ho PC. Minimal invasive management of scaphoid fractures: from fresh to nonunion. Hand Clin 2011; 27:291–307.

18 Herbert TJ, Fisher WE, Leicester AW. The Herbert bone screw: a ten year perspective. J Hand Surg Br 1992; 17:415–419.

19 GA Builze, L Ochtman, D Ring. Management of scaphoid nonunion. J Hand Surg Am 2012; 37:1095–1100.

20 M Bumbasirevic, S Tomic, A Lesic, V Burbasirevic, Z Rakocevic, H Datkinson. The treatment of scaphoid nonunion using the Ilizarov fixation without bone graft, a study of, 18 cases. J Orthop Surg Res 2011; 6:149. 57

21 Barton NJ. Twenty questions about scaphoid fractures. J Hand Surg Br 1992; 17:289–310.

22 Martini AK, Schiltenwolf M. Intermediate results in treatment of scaphoid pseudarthrosis and fracture with the Herbert screw. Aktuelle Traumatol 1993; 23:317–323.

23 Callanan I, Lahoti O, McElwain J. The Herbert screw in the scaphotrapezial joint: a cause for concern? Proceedings of the 6th Congress of the International Federation of Societies for Surgery of the Hand (IFSSH). 1995:p. 162.

24 Daecke W, Wieloch P, Vergetis P, Jung M, Martini AK. Occurrence of carpal osteoarthritis after treatment of scaphoid nonunion with bone graft and herbert screw: a long-term follow-up study. J Hand Surg Am 2005;30:923–931.

25 Schreuder M, Degreef I, De Smet L. Treatment of scaphoid non-unions with a corticocancellous graft and Herbert screw fixation: results at five years follow-up. Acta Orthop Belg 2008; 74:24–28.

26 Tsuyuguchi Y, Murase T, Hidaka N, Ohno H, Kawai H. Anterior wedge-shaped bone graft for old scaphoid fractures or non-unions. An analysis of relevant carpal alignment. J Hand Surg Br 1995; 20:194–200.

27 Preisser P, Rudolf KD, Partecke BD. Surgical treatment of scaphoid pseudarthrosis – long term outcome with the Herbert screws. Handchir Mikrochir Plast Chir 1998; 30:45–51.

28 Shah J, Jones WA. Factors affecting the outcome in 50 cases of scaphoid nonunion treated with Herbert screw fixation. J Hand Surg Br 1998; 23: 680–685.

29 Chantelot C, Frebault C, Limousin M, Robert G, Miguad H, Fontaine C. Long term outcome non-vascularized grafts for carpal scaphoid non-union: 58 cases with 8.8 year follow-up (French). Rev Chir orthop 2005; 91:724–731.

30 Garcia-Elias M, Vall A, Salo JM, Lluch AL. Carpal alignment after different surgical approaches to the scaphoid: a comparative study. J Hand Surg Am 1988; 13:604–612.

31 Jiranek WA, Ruby LK, Millender LB, Bankoff MS, Newberg AH. Long-term results after Russe bone-grafting: the effect of malunion of the scaphoid. J Bone Joint Surg Am 1992; 74:1217–1228.