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ORIGINAL PAPER

Kirschner wire versus Herbert screw fixation for the treatment of unstable scaphoid waist fracture nonunion using corticocancellous iliac bone graft: randomized clinical trial

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Abstract

Purpose The study compared the impact of the Kirschner wires versus Herbert screw fixation on the rate of union, time to union, correction of deformity, and clinical outcome in adults with unstable scaphoid waist fracture nonunions without avascular necrosis.

Methods We prospectively randomized 122 patients to undergo corticocancellous iliac bone grafting and internal fixation either with multiple Kirschner wires or Herbert screw. Radiographs, clinical outcome measures (pain, range of motion, and grip strength), and the Quick DASH score were taken pre- and post-operatively.

Results The rate of the scaphoid union in the Kirschner wire group was 91% versus 88% in the Herbert group. No difference was detected between the two groups with respect to the time to union, deformity correction, pain analysis, range of motion, grip strength, return to work, and complications.

Conclusion Using of multiple Kirschner wires as a fixation method for unstable scaphoid waist fracture nonunion that was treated by open reduction and corticocancellous iliac bone grafting had a shorter operative time and lower cost as compared with the Herbert screw fixation. Herbert screw fixation was technically more demanding in terms of technique than K-wires. However, because of easy application of Kirschner wires, and low cost, especially in developing countries, it may be a good alternative to Herbert screw.

Keywords Scaphoid · Nonunion · Scaphoid nonunion · DISI · Herbert screw · Kirschner wire · Scaphoid waist fracture

Level of evidence: I

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Introduction

The scaphoid is the most commonly fractured carpal bone and account for 60% of all carpal fractures [1, 2]. Approximately about 10% of undisplaced scaphoid fractures fail to unite despite appropriate immobilization [3]. The natural history of the untreated scaphoid waist fracture nonunion often involves apex dorsal angulation with bone loss and collapse (humpback or flexion) deformity [4]. The conventional treatment of scaphoid waist fracture nonunion with humpback deformity typically involves the use of bone graft and internal fixation. The goal of surgery is first adequately to reduce the scaphoid, thereby restoring the carpal height and alignment. Fernandez [5] described a method of fixation using a volar wedge bone graft secured with Kirschner wires; however, Herbert and Fisher [6] described the use of Herbert screw fixation. The purpose of this study is to compare the impact of multiple Kirschner wires versus Herbert screw fixation on the rate of union, time to union, wrist pain, grip strength, range of motion (ROM), correction of deformity, complications, and return to work in adults with unstable scaphoid waist fracture nonunions treated by corticocancellous iliac bone graft.

Materials and methods

The study received the approval of the ethics committee of our university hospital before commencement. Procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 and 2008. The inclusion criteria were patients between the ages of 18 and 60 years with unstable scaphoid waist fractures that had not healed six months after the initial injury, persistent wrist pain, ROM ≤ 70% of the healthy side, and grip strength ≤ 70% of the healthy side. The unstable scaphoid waist fracture nonunion had to have scapholunate angle ≥ 60° [7], lateral intrascaphoid angle ≥ 45° [8], radiolunate angle ≥ 15° [7], and/or with a carpal height index ratio ≤ 0.51 [4]. The exclusion criteria were bilateral scaphoid fractures, history of open fractures, trans-scaphoid perilunate or lunate dislocations, associated fractures in the hand or upper extremities, previous surgical treatment, stage II or higher scaphoid nonunion advanced collapse (SNAC), and scaphoid nonunions with avascular necrosis (AVN). One hundred seventy-three consecutive patients with scaphoid waist fracture nonunion were evaluated to participate in the study between April 2013 and December 2018. Diagnosis of the unstable scaphoid waist fracture nonunions was based on the posteroanterior and lateral radiographs of the wrist, CT scan of the wrist along the longitudinal axis of the scaphoid, and MRI of the wrist to exclude AVN.

Patients who did not meet the entry criteria were 45 patients (nine patients were less than 16 years old, 13 presented less than six months after the initial injury, five had trans-scaphoid perilunate dislocation, 11 had proximal pole nonunion with AVN, five had stage II SNAC, and two had stage III SNAC wrist). Patients who met our inclusion criteria ($n = 128$) were given an information sheet and informed about the risks and benefits of operative treatment. Further, full written consents were obtained from them. Six patients refused to participate in the study; therefore, 122 patients with unstable scaphoid waist fracture nonunion were randomized to undergo open reduction, corticocancellous iliac bone grafting, and internal fixation with multiple Kirschner wires or Herbert screw. Sixty-one patients were randomized to receive Kirschner wires fixation (K-wire group), and 61 patients were randomized to receive Herbert screw fixation (Herbert group). A random number sheet generated by computer, and the random numbers blocked to ensure equal distribution. Three patients discontinued the intervention and three were lost to follow-up after four weeks. Finally, 116 patients (K-wire group [$n = 58$] and Herbert group [$n = 58$]) were analyzed (Fig. 1). Patients' demographics was listed in Table 1.

The assessment of the clinical parameters (pain, ROM, grip strength) and the interpretations of the disabilities of the arm, shoulder, and hand (Quick DASH) scores [9] were performed pre- and post-operatively. Pain analysis was performed according to the self-reported VAS score [10]. The score was determined by measuring the distance (mm) on the 10-cm line between the "no pain" anchor and the patient's mark, providing a range of scores from zero to 100. The total and differential arcs of motion of the wrist (extension/flexion, ulnar/radial deviation, and pronation/supination) were measured using a two-arm goniometer [11]. A hand Jamar dynamometer (Sammons Preston, Bolingbrook, Illinois, Chicago) used to evaluate the single maximal effort of grip strength correction for limb dominance [12]. Two orthopaedic surgeons with level-three experience [13] evaluated and interpreted the pre-operative clinical parameters for all the patients. Other two orthopaedic surgeons with level-three experience [13] who were blinded to the pre-operative clinical findings evaluated and interpreted the post-operative clinical parameters. The observers made the measurements independently with no interchange of information, and the average measurements were recorded. Image interpretation, radiographic measurements pre- and post-operative, and the evaluation of the radiographic union were performed by radiologist and orthopaedic surgeon with level-three experience [13]. They were blinded to the clinical findings and surgical results, and the average measurements of the two observers were recorded. The standard posteroanterior and lateral radiographic views evaluated both pre- and post-operative scapholunate angle [7], radiolunate angle [7], and the carpal height index ratio according to Youm et al. [14]. The lateral intrascaphoid angle was [8] measured pre- and post-

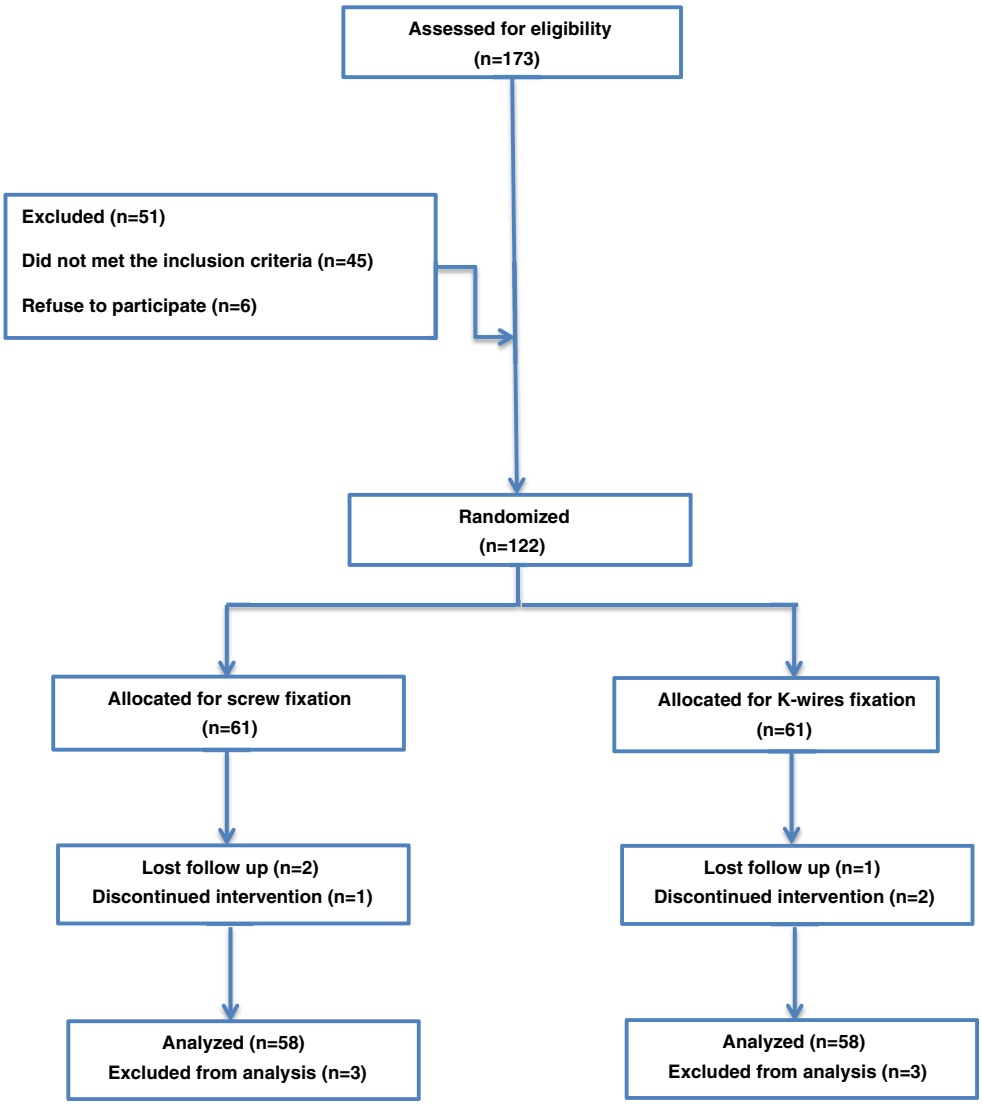

Fig. 1 Flow chart of the study

operatively on the sagittal CT scan of the wrist along the longitudinal axis of the scaphoid.

Surgical technique

Surgery was performed under general anaesthesia with upper arm tourniquet control. The scaphoid approached through a 4-cm longitudinal volar incision centered over the tuberosity of the scaphoid lateral to the flexor carpi radialis (FCR) tendon. The bed of the FCR was incised in line with the skin incision, and the radioscaphocapitate ligament was incised longitudinally to expose the fracture. The scaphoid was inspected, and the fibrous tissue and sclerotic bone resected up to the normal-looking bone. Generous curettage of each scaphoid pole was essential to expose the healthy bleeding cancellous bone and prepare an adequate cavity to accept the graft (Fig. 2). The scaphoid reduced, and its length restored by introducing a lamina spreader in the gap. A corticocancellous wedge graft was harvested from the ipsilateral iliac crest and packed into the prepared cavity. Satisfactory scaphoid and lunate alignment confirmed by a C-arm image intensifier. In patients randomized for K-wires fixation, the scaphoid was fixed with three 0.045-in. K-wires under image intensify guidance in a retrograde manner with convergent K-wire placement (Fig. 3), and the K-wires cut off beneath the skin. In patients randomized for Herbert screw fixation, the scaphoid was fixed with Herbert bone screw 3 mm (Zimmer, Swindon, Wiltshire, UK) in a retrograde manner. The final screw position was checked and confirmed with the use of an image intensifier. Finally, the capsule and radioscaphocapitate ligament were repaired and the skin was sutured. The procedures were performed either by the senior author (G.H) with level of experience 4 [13] or under his direct supervision.

Table 1 Patients demographics of K-wire versus Herbert group

Item	K-wire group ($n = 58$)	Herbert group ($n = 58$)	p value
Sex M/F	43/15	47/11	0.631[#]
Age	28 (18 to 60)	27.5 (18 to 60)	0.569[†]
Occupation (no. of patients)			0.844[#]
• Manual labor	28	30	
• Office workers	13	11	
• Students	7	8	
• Housewife	8	7	
• Retired	2	2	
Injured side (no. of patients)			0.668[#]
• Rt	41	43	
• Lt	17	15	
Dominance (no. of patients)			0.325[#]
• Dominant	45	44	
• Nondominant	13	14	
Mechanism of injury (no. of patients)			0.290[#]
• Fall	31	33	
• Twisting	10	12	
• Punch	7	5	
• MVA	6	6	
• Uncertain	4	2	
Herbert classification			0.565[#]
• D2 (fibrous nonunion)	40	41	
• D3 (sclerotic psudoartherosis)	18	17	
Time from initial injury to surgery (months)	18.5 (9 to 32)	19 (9 to 33)	0.486[†]

M male, *F* female, *no*. number, [†] independent *t* test; [#] Chi-square test

Follow-up

After surgery, each patient's arm was placed in a dorsal plaster splint that extends above the elbow, and medication for pain control was prescribed. The patients were advised to elevate their arms as much as possible throughout the day to reduce

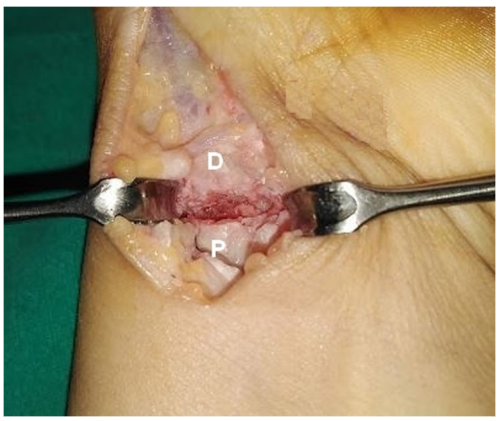

Fig. 2 Generous curettage of each scaphoid pole to prepare an adequate cavity to accept the graft. P proximal pole and D distal pole

Fig. 3 Fluoroscopic PA view of the wrist shows the K-wires inserted in a convergent direction

swelling. Active finger motion and shoulder exercises were allowed immediately after surgery several times a day. Further, the skin sutures were removed two weeks after surgery, and a short arm thumb spica cast had to be worn for an additional six weeks and then a short arm removable splint until the radiographic union. In the K-wire group, the wires were removed after radiographic union. Patients commenced hand physiotherapy sessions under the supervision of a specialized hand physiotherapist with gentile hand and wrist exercises followed by aggressive wrist exercises, and heavy activities were allowed after scaphoid union. Gradual return to an office job was allowed within the confines of the cast but manual work was allowed after scaphoid union and within the limits of pain. Full return to work and recreational activities were allowed after union and pain relief. The time of immobilization of both groups, the date of bony union, the time of removal of the K-wires, return to work, and the time needed after the return to work to be able to perform work tasks comfortably documented, and the complications were recorded.

Four radiographic views of the wrist (standard PA, lateral, 45° pronation oblique, and PA with ulnar deviation) were obtained at two week intervals until union. Scaphoid union was defined on the radiographs (in at least three of the four views [15]) as the absence of adverse features such as a gap at graft interface, lucency around or shifting of the screw, or displacement of the graft. Patients underwent CT scans of the wrist along the longitudinal axis of the scaphoid at the follow-up visit when the adverse features disappeared on the radiographs to confirm the union. The time to union was recorded when the CT demonstrated > 50% trabecular bridging across the graft interface. Nonunion was defined when adverse features on the radiographs or < 50% trabecular bridging on CT scan was identified at 24 weeks after surgery.

Statistical analysis

The sample size calculation indicated that 53 patients were required in each group to provide a 95% power of detecting 10% difference with $p < 0.05$ in separate evaluation of ROM, grip strength, Quick DASH score, and lateral intrascaphoid angle. These four outcomes had a respective standard deviation of 13%, 14%, 20 points, and 14°. The independent *t* test used to compare the clinical and radiographic measures of both groups pre- and postoperative. The rate of union and complications in each group was compared using the Chi-square test. The paired *t* test used to compare the pre- and post-operative clinical and radiographic outcome measures for each group. The values are given as mean (range) with confidence interval 95%. *p* value < 0.05 is considered statistically significant.

Results

No differences were found between the K-wire group and Herbert group with respect to age, sex, hand dominance, side of injury, mechanism of injury, occupation, fracture classification, or time elapsed from initial injury to surgery (Table 1). Both groups were similar in terms of pre-operative clinical and radiographic parameters (VAS, ROM, grip strength, Quick DASH score, scapholunate angle, radiolunate angle, carpal height index, and lateral intrascaphoid angle) (Tables 2 and 3). The mean duration of the surgery for the K-wire group was 46 minutes (40 to 60), and for the Herbert group, it was 67 minutes (55 to 85) ($p = 0.001$). The mean follow-up period for the K-wire group was 34 months (24 to 57) and for Herbert group was 35 (24 to 39) ($p = 0.643$). The rate of union in the K-wire group was 91% ($n = 53$); however, in the Herbert group was 88% ($n = 51$) ($p = 0.544$). The two groups were similar regarding the time to union, return to work, and post-operative complications (Table 4). No statistically significant differences were found between the two groups regarding the post-operative clinical and radiographic outcomes. There was significant improvement in the clinical and radiographic outcome measures pre- to post-operative for both groups (Tables 2 and 3). Twelve patients had superficial wound

Table 2 Pre- and post-operative clinical outcome measures of both groups

Parameters	Measurements		*p* value
	Preoperative	Postoperative	
VAS score (mm)			
K-wire	64 (55 to 73)	5 (3 to 14)	0.001*
Herbert	62 (53 to 72)	4 (2 to 12)	0.001*
p value	0.761†	0.547†	
ROM % of healthy side			
K-wire	62% (50 to 69)	88% (76 to 92)	0.001*
Herbert	61% (51 to 69)	89% (76 to 95)	0.001
p value	0.776†	0.466†	
Grip strength % of healthy side			
K-wire	49% (35 to 68)	90% (85 to 96)	0.001*
Herbert	50% (35 to 69)	91% (85 to 97)	0.001*
p value	0.197†	0.138†	
Quick DASH score			
K-wire	70 (62 to 81)	28 (15 to 35)	0.001*
Herbert	68 (61 to 80)	25 (15 to 33)	0.001*
p value	0.563†	0.667†	

VAS visual analogue scale score, *mm* millimeters, *ROM* range of motion, *DASH* disabilities of the arm, shoulder, and hand, † independent *t* test to compare the measures of both groups, * Paired *t* test to compare the pre- and postoperative measures within the same group, *p* value < 0.05 is statistically significant

Table 3 Pre- and post-operative radiographic outcome measures of both groups

Parameter	Measurements		*p* value
	Pre-operative	Post-operative	
Scapholunate angle			
K-wire	81° (71 to 8 7°)	52° (43 to 61°)	0.001*
Herbert	81° (67 to 88°)	51° (44 to 60°)	0.001*
p value	0.883†	0.726†	
Radiolunate angle			
K-wire	29° (22 to 33°)	13° (9 to 17°)	0.001*
Herbert	30° (23 to 30°)	11° (9 to 16°)	0.001*
p value	0.643†	0.342†	
Carpal height index			
K-wire	0.45 (0.43 to 0.50)	049 (0.46 to 0.52)	0.004*
Herbert	0.45 (0.42 to 0.50)	0.49 (0.47 to 0.52)	0.003*
p value	0.819†	0.844†	
Lateral intrascaphoid angle			
K-wire	68° (59 to 74°)	40° (33 to 50°)	0.001*
Herbert	68° (60° to 74°)	36° (32 to 46°)	0.001*
p value	0.866†	0.126†	

† independent *t* test to compare the measures of both groups, * Paired *t* test to compare the pre-and postoperative measures within the same group, *p* value < 0.05 is statistically significant

infections that treated with oral antibiotics and wound cleaning. Five patients had mild complex regional pain syndrome treated with physiotherapy, NSAID, and bisphosphonates. Five patients had scar hypertrophy at the wrist wound, and three patients had sensitive scars at the graft site wounds. They were treated by a dermatologist. Nonunion was diagnosed six months post-operatively in five patients of the K-wire group versus six patients of the Herbert group. However, the computed tomography scanning showed no bony bridging across the scaphoid in one more patient of the Herbert group. The nonunions were treated by revision surgeries (open reduction and corticocancellous iliac bone graft with K-wires fixation).

Discussion

Adequate bone graft and stable internal fixation are two important factors for the surgical management of scaphoid nonunion to achieve bony union, restore scaphoid anatomy, improve wrist function, and prevent arthritis. The common sites of bone graft harvesting for scaphoid nonunion are the distal radius and iliac crest. Iliac crest graft permits greater retrieval of marrow and more osteogenic cells [16]. Therefore, iliac crest graft can provide superior osteogenic properties compared with distal radius bone graft. Although several studies [17–20] reported earlier union rate in some instance of unstable scaphoid nonunion with the use of cancellous iliac bone graft. Our preference was to use corticocancellous graft, as this may be more appropriate in the setting of large intercalary defects causing significant carpal collapse. There are three fixation methods used in the treatment of scaphoid fracture nonunion (Kirschner wires, screw, plate) but there is no study in the current literature directly compares these methods. The Herbert screw was significantly stronger in resisting bending forces as compared to paired parallel Kirschner wires but is unable to withstand cyclical multiaxis loading or rotation [21]. Therefore, our follow-up protocol was to continue immobilization until radiographic union achieved. Despite using the same post-operative immobilization protocol in two different fixation techniques decreases the confounding in determining imobilization time it can adversely affect the ROM and time for return to work in one group. However, our protocol of rehabilitation and return to work can avoid these adverse effects. Moreover, the time taken for return to work is dependent on many factors including the nature of the patient's occupation and the attitudes of the patient, employer, and insurance company, which makes the time taken to return to work a questionable outcome measure in any event. It has reported that the union time with Kirschner wires is longer and less predictable than Herbert screw. A meta-analysis in 2002 of 36 papers reported that bone graft with screw fixation achieved 94% union, and wedge graft with Kirschner wires achieved 77% union with the average time to union as

Table 4 The follow-up data and complications of K-wire versus Herbert group

Parameter	K-wire group (*n* = 58)	Herbert group (*n* = 58)	*p* value
Interval to union (weeks)	14 (12 to 20)	14 (11 to 20)	0.873†
Time of K-wires removal (weeks)	–	17 (14 to 20)	–
Full return to work (weeks)	28 (25 to 36)	26 (23 to 36)	0.139†
Complications (no. of patients)			0.877#
Superficial wound infection	7	5	
Sensitive scar	2	1	
Hypertrophic scar	3	2	
Complex regional pain syndrome	3	2	

no. numbers, † independent *t* test, # Chi-square test

Table 5 Comparison between K-wire group in the present study and studies used K-wires fixation and nonvascularized corticocancellous bone grafting

Studies	Study design	Numbers of nonunions in the study	Site of nonunion W/P/D	Age Mean (range)	Graft site	Follow-up (months) Mean (range)	Primary union rate	Interval to union Weeks Mean (range)
The present study	PS	58	58/0/0	28 (18—60)	IC. Cor-Can	34 (26—57)	91%	14 (12—20)
Reigstad et al. [24]	RS	81	53/25/3	29 (15—71)	IC. Cor-Can.	12 (6—48)	88.9%	Not reported
Takami et al. [25]	RS	43	34/3/6	22 (13—47)	IC. Cor-Can	30 (12—108)	97.7%	Not reported
Ritter and Giachino [26]	RS	24	14/6/4	26.5 (13—45)	IC. Cor-Can	34 (24—46)	67%	8.2 (16—24)
Chen et al. [27]	RS	26	12/5/9	34 (17—67)	IC. Cor-Can	45.6 (36—72)	100%	14 (12—16)
Petcu [28]	RS	25	15/5/5	24 (18—49)	IC. Cor-Can	24 (14—36)	92%	12.5 (9—18)

PS prospective, *RS* retrospective, *W/P/D* waist/proximal pole/distal pole, *IC* iliac crest, *Cor-Can*., corticocancellous

20 weeks [3]. In contrast, our study reported no significant difference between the two groups regarding the union rate (91% union with Kirschner wires versus 88% with Herbert screw fixation [0.54]) and the mean time to union was14 weeks. The explanation of this result might relate to the use of three Kirschner wires in a convergent direction to fix the scaphoid. This allows the K-wires to pass through more surface area of the scaphoid and allows for a more targeted placement into the proximal pole, thus increasing the fracture reduction stability and accelerating the union. Meisel et al. [22] used the same fixation technique and reported 100% union rate with cancellous iliac bone grafting in the treatment of scaphoid nonunion. Moreover, our reported result regarding the union rate was consistent with Munk and Larsen [23]; they systematically reviewed 147 publications and found that in the K-wire analysis, there was a higher union rate as compared to the groups fixed with screws. The K-wire group had a higher estimated incidence of union than the screw group (91% versus 88%, respectively), a difference that persisted when used with vascularized grafts (K-wire 94% versus screw 87%). Tables 5 and 6 showed comparison between the present study and other studies in the literature. The thickness of K-wire should be taken into consideration because of the risk of breakage, and we recommend that the K-wire should be removed before mobilizing the joint. The most frequent complications after treatment of fractures with K-wires are pin track infection, pin loosening, or migration. However, migration is not usually toward the joint, it is usually toward the outside, distally from the introduction point. Careful regular follow-up may minimize the incidence of such complications. Based on the proportion of patients who achieved an osseous union and the assessment of the outcomes, the use of multiple K-wires as a fixation method for unstable scaphoid waist nonunion that was treated by open reduction and corticocancellous iliac bone grafting had a shorter operative time and lower cost as compared with the Herbert screw fixation. However, there were no differences in the impact of one method on the time to union, deformity correction, and the clinical outcomes as measured by the Quick DASH score. We thought that the Herbert screw fixation was technically more demanding in terms of technique than K-wires, and the incidence of technical errors may play an eminent role in the occurrence of nonunion.

Table 6 Comparison between Herbert group in the present study and studies used Herbert screw fixation with nonvascularized corticocancellous bone grafting

Studies	Study design	Number of nonunions	Site of nonunion W/P/D	Age Mean (range)	Graft site	Follow-up (months) Mean (range)	Primary union rate	Interval to union weeks Mean (range)
The present study	PS	58	58/0/0	27.5 (18 to 60)	IC. Cor-Can	34 (24 to 57)	88%	14 (11 to 20)
Watanabe [29]	RS	38	38/0/0	24 (15 to 59)	IC. Cor-Can.	16 (12 to 36)	100%	12 (8 to19)
Wada et al. [30]	RS	22	16/5/1	27 (14 to 62)	IC. Cor-Can	20 (6 to 57)	90.9%	13 (10 to 22)
Inoue et al. [31]	RS	103	123/20/17	24 (13 to 63)	IC. Cor-Can	24 (6 to 47)	85.4%	Not reported
Trumble et al. [32]	RS	34	34/0/0	27.8 (15 to 48)	IC. Cor-Can	47.8 (26 to 84)	94.1%	22 (14 to 26)
Nakamura et al. [33]	RS	26	17/0/9	29.3 (13 to 57)	DR. Cor-Can	25 (12 to 48)	95%	Not reported
Adams et al. [34]	RS	15	Not reported	27 (15 to 69)	IC Cor-Can	17 (13 to 27)	67%	Not reported

PS prospective, *RS* retrospective, *W/P/D* waist/proximal pole/distal pole, *IC* Iliac crest, *DR* distal radius, *Cor-Can*. corticocancellous

However, because of easy application of Kirschner wires, and low cost, especially in developing countries, it may be a good alternative to Herbert screw. The limitation of the study includes its single -center nature that limits its external validity. Future studies need to compare the using of corticocancellous graft against cancellous only graft in the treatment of unstable scaphoid waist fracture nonunion.

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Compliance with ethical standards

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

Ethical considerations Our institutional review board approved this retrospective study before commencement.

Consent All patients were given an information sheet; the risks and benefits of operative treatment were discussed and full written consent was obtained.

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