Bone grafting the scaphoid nonunion

A systematic review of 147 publications including 5 246 cases of scaphoid nonunion

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ABSTRACT **In order to elucidate the history of scaphoid nonunion and to evaluate whether or not the problem has been solved, we have reviewed the literature from 1928 to 2003 for union rates, postoperative immobilization periods and complications of the different scaphoid bone grafting procedures. The outcomes of 5 246 scaphoid nonunions were evaluated in three treatment groups. In the first group involving nonvascularized bone grafting without internal fixation, we found a union rate of 80% (95% CI: 78–82) after an average immobilization period of 15 weeks. In the second group involving nonvascularized bone grafting with internal fixation, the figures were 84% (CI: 82–85) and 7 weeks, respectively. In the last group involving vascularized bone grafting with or without internal fixation, the figures were 91% (CI: 87–94) and 10 weeks, respectively. We found no prospective randomized studies comparing different operative treatments of scaphoid nonunion. We conclude that there still is a need for improvement in the treatment of scaphoid nonunion.**

The incidence of scaphoid fracture is 38 per 100 000 males per year and 8 per 100 000 females per year (Larsen and Lauritsen 1993). The diagnosis may be missed by the patient not seeking medical examination and by the physician diagnosing a sprained wrist. Nonunion occurs in approximately 5% (0–22) (Stewart 1954, Eddeland et al. 1975, Morgan and Walters 1984, Dias et al. 1989, Larsen et al. 1992, Duppe et al. 1994, Barton 1997, Khan and Harby 1995, Raudasoja et al. 1999, Roolker et al. 1999).

Adams and Leonard (1928) first described operative treatment of the scaphoid nonunion by bone grafting. In 1935, Cole and Williamson wrote: "Bone grafting of the fragments has been done with some success but will never be a choice for routine procedure and it is mainly a surgical stunt". Different methods of bone grafting have been described. The methods of Matti (1937) and Russe (1951) changed the general attitude towards bone grafting. Bone grafting with internal fixation has been used since 1943, but the Herbert screw especially has been used more or less worldwide as the primary procedure for the treatment of scaphoid nonunion. As a secondary procedure and/or in cases with a poorly vascularized proximal fragment, a vascularized bone graft with or without internal fixation has been used in the last decades (Shin and Bishop 2001).

The aim of this review has been to try to answer the following questions. What is the union rate and the postoperative immobilization period of the different scaphoid bone grafting procedures, and has the union rate increased during the last 75 years? Have the procedures reviewed here solved the problem of scaphoid nonunion, or is there still a need for new methods?

Material and methods

A PubMed search for: "scaphoid and surgery" revealed 896 articles, from which we selected 119. We did not exclude literature in languages other than English, as a substantial number of articles

have been published in journals using other languages. The first selection criterion was that the article should concern the treatment of scaphoid nonunion by vascularized or non-vascularized bone graft, with or without internal fixation. Secondly, papers should have a clear separation of scaphoid nonunion from fresh and delayed union. Furthermore, if the exact number of scaphoid nonunion and union rates could not be calculated, the article was not included. Finally, articles concerning previously published cases of scaphoid nonunion were excluded. The reference lists from the 119 articles that were selected according to these criteria yielded further 28 articles, thus giving the 147 articles on which this study is based. We found no prospective randomized studies comparing different operative treatments of scaphoid nonunion, but there were 12 retrospective comparative studies.

The number of scaphoid nonunions, type of graft and its donor site, presence and type of internal fixation, period of postoperative immobilization, union rate, comments as to the material/operative method, and finally, complications were extracted from each article. This yielded data involving 5 246 scaphoid nonunions. As there is no strict consensus of how to distinguish between delayed union and nonunion, we decided to let the authors' judgement be the truth in this matter, and so we have not included the cases called "delayed union" by the authors. The concept of using the authors' judgement was also enforced in the issue of union, in as much as there is no firm definition or generally accepted standard for deciding whether or not a scaphoid nonunion has healed after treatment. Furthermore, in the first half of the investigation period, advanced imaging techniques did not exist.

Data were divided into three groups: one for nonvascularized bone graft without internal fixation, a second for nonvascularized bone graft with internal fixation, and the third for vascularized bone graft with or without internal fixation. Each scaphoid nonunion is its own entity regarding size and orientation of the fragments, vascularization of the fragments etc. Each surgeon has his/her way of performing a standard operation, often with minor or major variations. Even Dr. Otto Russe modified his operations over the years, and for these reasons we decided not to divide data further into subgroups of standardized operative methods, type of internal fixation etc.

Numerical data are presented with sample size and proportion of unions in per cent. The statistical software program CIA (British Medical Journal) was used to calculate 95% confidence intervals for the proportions.

Results

In the first group concerning nonvascularized bone grafting without internal fixation, we found a union rate of 80 (CI: 78–82) %after an average immobilization period of 15 weeks (Table 1). In the second group concerning nonvascularized bone grafting with internal fixation, the figures were 84 (CI: 82–85)% and 7 weeks, respectively (Table 2). In the last group concerning vascularized bone grafting with or without internal fixation, the figures were 91 (CI: 87–94)% and 10 weeks (Table 3). In the first half of the investigation period (the 37 years from 1928 to 1965), the union rate of 322 nonunions was 76 (CI: 71–81)% (Table 1).

The articles mostly dealt with nonunions in all parts of the scaphoid, but there were a few that exclusively concerned proximal pole scaphoid nonunion with a union rate of 78 (CI: 73–84)% after an average immobilization period of 9 weeks in 223 cases (Bohler and Ender 1986, DeMaagd and Engber 1989, Robbins et al. 1995, Inoue et al. 1997b, Herbert and Filan 1999, Krimmer et al. 1999, Wilhelm and Wilhelm 1999, Del Pinal 2001) (Table 2).

Discussion

The classification of scaphoid fracture including nonunion has been well described by Herbert and Fisher (1984), but there is no consensus of how and when to diagnose a scaphoid nonunion, nor as to when it has healed. Barton (1996) stated "Even with the scaphoid in front of you, it can be difficult to decide whether it has united or not." Dias (2001) has pointed out that "it is the absence of adverse features over time that assists the surgeon in inferring that the graft has incorporated." In the inclu-

Table 1. Nonvascularized bone graft without internal fixation

Reference	Non–unions	Graft / donor site	Immobi–lization (weeks)	Union (%)	(95% CI)	Comments and complications
Adams 1928	1	Tibia	6	100		Dorsal approach; limited excavation of scaphoid fragments
Burnett 1934	4	Tibia	8	25	(1–81)	Dorsal approach; limited excavation of scaphoid fragments
Murray 1934	9	Tibia	8	100	(66–100)	Dorsal approach; drilled a hole in the scaphoid, bone peg
Matti 1937	3	Trochanter	4–6	100	(29–100)	Dorsal approach; pronounced excavation, cancellous graft
Hueck 1941	7	Trochanter	8–12	57	(18–90)	Matti's method
Soto-Hall 1941	8	Distal radius		75	(35–97)	Dorsal approach; drilling plus 1 or 2 bone pegs
Dickison 1944	21		9–33	38	(18–62)	
Robertson 1944	3		20–40	67	(9–93)	
Fehr 1945	6	Trochanter	8–14	50	(12–88)	Matti's method
Cobey 1946	10	Distal radius	10	70	(35–93)	Dorsal approach; drilled a hole in the scaphoid, bone peg
Murray 1946	100	Tibia	11–34	96	(90–99)	Dorsal approach; drilled a hole in the scaphoid, bone peg
Barnard 1948	10	Distal radius	12–32	90	(56–100)	Radial approach; drilled a hole in the scaphoid, bone peg
Goeringer 1949	20	Tibia	16	95	(75–100)	Murray's method
Russe 1951	25	Iliac crest	12–16	80	(59–93)	Volar approach; cancellous bone graft
Scaglietti 1954	6	Iliac crest	8–12	67	(22–96)	Drilling from volar site
Palmer 1955	20	Tibia	12–48	100	(83–100)	Murray's method
Smith 1956	13	Distal radius	76		(47–95)	Barnnard's method
Mazet 1960	13	Distal radius	61		(32–86)	Barnnard's method
Russe 1960	22	Iliac crest	12–16	91	(71–99)	Volar approach; cancellous bone graft
Donaldson 1962	21	Distal radius	28	76	(53–92)	Barnnard's method
Dooley 1968	23	Iliac crest	20	87	(66–97)	Russe method
Mulder 1968	100	Iliac crest	16	97	(92–99)	Matti-Russe method
Verdan 1968	45	Iliac crest	16	98	(88–100)	Matti-Russe method
Unger 1969	42	Iliac crest	18	79	(63–90)	Russe method
Buck-Gramcko 1972	64	Iliac crest	81		(70–90)	Matti-Russe method
Sprague 1974	13	Distal radius	10	92	(64–100)	Barnnard's method
Torngren 1974	41	Tibia or ulna	78		(62–89)	Murray's method
Eddeland 1975	23	Iliac crest	14	87	(66–97)	Matti-Russe method
McDonald 1975	48	Iliac crest	14	90	(77–97)	Russe method
Hull 1976	22	Iliac crest	73		(50–89)	Russe method
Herness 1977	40	Iliac crest	18	100	(91–100)	Russe method
Glass 1978	23	Iliac crest	14	96	(78–100)	Russe method
Mehdi 1979	20	Iliac crest	100		(83–100)	Matti-Russe method
Cooney 1980	24	Iliac crest	17	86	(68–97)	Russe method
Russe 1980	200	Iliac crest	12	95	(91–98)	Russe-I method
Russe 1980	20	Iliac crest	16	95	(75–100)	Russe-II method; all were with necrotic proximal fragments
Schneider 1982	31	Ilium or radius	16	87	(70–96)	Russe method
Kvarnes 1983	14	Ilium or radius	12	50	(23–77)	Murray's method (n=9), Matti-Russe method (n=5)
Boeckstyns 1984	28	Iliac crest	11	86	(67–96)	Matti-Russe method
Hoang 1984	17	Iliac crest	12	82	(57–96)	Matti-Russe method
Andrews 1985	40	Ilium or radius	12	72	(56–85)	Russe (n=26) or Barnard (n=14) method
Green 1985	45	Ilium or radius	12–16	76	(61–87)	Russe method
Jaroma 1985	20	Iliac crest	9–20	90	(68–99)	Matti-Russe method
Rasmussen 1985	28	Iliac crest	13	71	(51–87)	Russe method
Condamine 1986	106	Ilium or radius	10–12	74	(65–82)	Matti-Russe method
Steichen 1986	18	Distal radius	20	92	(73–100)	Russe method
Pechlaner 1987b	182	Iliac crest	12	79	(73–85)	Matti-Russe (n=112), plus styloidectomy (n=70)

Table 1. Continued

Reference	Non–unions	Graft / donor site	Immobi–lization (weeks)	Union (%)	(95% CI)	Comments and complications
Stark 1987	27	Iliac crest	12	82	(62–94)	Matti-Russe method
Warren-Smith 1988	23	Iliac crest	18	61	(39–80)	Russe method
Parkinson 1989	19	Iliac crest	16	74	(49–91)	Matti-Russe method
Fuhrmann 1990	123	Iliac crest	80		(73–87)	Matti-Russe method
Steiger 1990	16	Iliac crest	52		(25–75)	Matti-Russe method
Buchholz 1992	215	Iliac crest	12	95	(91–97)	Matti-Russe method
Jiranek 1992	21	Ilium or radius	8–32	81	(58–95)	Russe method
Schaller 1993	27	Iliac crest	12	89	(71–98)	Matti-Russe method
Groner 1995	60	Iliac crest	12	85	(73–93)	Matti-Russe method
Mirly 1995	8	Distal radius		100	(63–100)	Russe method
Barton 1997	56	Ilium or radius	8 or more	54	(40–67)	Russe method; 28 cancellous, 28 corticocancellous bone
Sauerbier 1999	32	Iliac crest		81	(64–93)	Matti-Russe method
Maruthainar 2000	20	Iliac crest	6	80	(56–94)	Precision bone grafting technique
Total	2246		15	80	(78–82)	

CI: confidence interval.

sion of articles, we have chosen to let the judgement of the authors rule in these matters; otherwise it would require selection only of studies where tomography/computed tomography was used and/or studies with considerable follow-up time. This would have markedly reduced the number of papers included in our study (Merrell et al. 2002).

With the large number of cases included in the articles reviewed, covering a time span of 75 years (1928–2003), we expected a clearcut increase in union rate throughout the period and a marked reduction in immobilization time. In the first period up to 1965, we found a surprisingly high union rate of 76%. When we compare the whole group (1928–2000) of nonvascularized bone grafting without internal fixation (Table 1) to the group of nonvascularized bone grafting with internal fixation (Table 2), the addition of internal fixation did not significantly increase the union rate. The two groups are comparable in size, but one could argue that sex and age distribution of the patients, location of the nonunion within the scaphoid, time span from trauma to operation, distribution of surgical approach etc, are not comparable in the two groups. These parameters were not found to differ, but we are aware of the limitations in comparing retrospective studies with a substantial number of uncontrolled parameters. While there was (surprisingly) no significant increase in the union rate by adding internal fixation to a nonvascularized bone graft (compare Tables 1 and 2), there was a significant increase in the union rate when adding blood supply to the bone graft (compare Tables 1–3). A secondary procedure of bone grafting using nonvascularized methodology has been found by Preisser et al. (1999) to produce union of the scaphoid in 64% of cases. The cases in the group involving vascularized bone grafting are almost exclusively cases with prior surgery and/or nonunions with avascularity of the proximal pole. Still, the methods using vascularized bone grafts yielded union in 91% of cases and the problem of scaphoid nonunion seems to have been solved (Table 3). Yet some of the articles in the group involving vascularized bone grafting reported union rates of 60–80% (Braun 1983, Boyer et al. 1998, Gabl et al. 1999a), and in the last paper from 2002, Straw et al. found a union rate of 27 (CI: 11–50)% in 22 patients—indicating that improvement in the treatment for scaphoid nonunion is still necessary (Table 3). Immobilization was reduced from 15 to 7 weeks due to internal fixation, and as Merrell et al. (2002) have recently reported: "Immediate mobilization versus 6 weeks or more of casting showed the same union rate" in a meta-analysis of 12 studies with 519 patients having compression screw fixation and grafting. This strongly indicates that immobilization can be further reduced or

Table 2. Nonvascularized bone graft with internal fixation

Reference	Non–unions	Graft / donor site	Internal fixation	Immobi–lization (weeks)	Union (%)	(95% CI)	Comments and complications
Spier 1979	26	Distal radius	AO screw	2–6	73	(52–88)	Additional radial styloidectomy
Zolczer 1981	31		AO screw		84	(66–95)	
Linscheid 1982	6	Iliac crest	Kirschner wires		83	(36–100)	Wedge-shaped graft correcting DISI
Fernandez 1984	6	Iliac crest	Kirschner wires	8	100	(54–100)	Wedge-shaped graft correcting DISI
Herbert 1984	105	Iliac crest	Herbert screw	4	68	(59–77)	
Leyshon 1984	32		AO screw	1	88	(71–97)	Early active wrist movements
Bohler 1986	212	Iliac crest	Ender blade plate	6–12	99	(97–100)	Removal of plate after union
Bohler 1986	15	Iliac crest	Ender double plate	6–12	87	(60–98)	All proximal pole nonunions
Geisl 1986	37	Iliac crest	Ender blade plate	7	89	(75–97)	Pain in 27%, even with minimal load
Bunker 1987	33	Iliac crest	Herbert screw	≥3	85	(68–95)	Multicentre study, 17 surgeons
Ford 1987	9	Iliac crest	Herbert screw	4	78	(40–97)	
Adams 1988	15	Ilium or radius	Herbert screw	8	67	(38–88)	
Cooney 1988	21	Ilium or radius	Herbert screw	14	71	(48–89)	The majority had additional K-wires
Lennert 1988	48	Iliac crest	Fibrin adhesive	12	87	(75–95)	
Manske 1988	22	Distal radius	Herbert screw	12	73	(50–89)	Including proximal avascular necrosis
Moran 1988	29	Iliac crest	Herbert screw	5	79	(60–92)	Screw may not be adequate
Stark 1988	151	Ilium	Kirschner–wire	17	97	(93–99)	Proximal necrosis did not affect result
Warren-Smith 1988	22		Herbert screw	12	82	(60–95)	
DeMaagd 1989	9	Iliac crest	Herbert screw	11–21	100	(66–100)	Note: all proximal pole nonunions
Korkala 1989	11	Iliac crest	Compression staple	8	100	(72–100)	Late removal of staple in 1
Parkinson 1989	16	Distal radius	Herbert screw	3	71	(41–89)	
Van der 1989	16	Iliac crest	Herbert screw	6	81	(54–96)	
Fernandez 1990	20	Iliac crest	ASIF screw	2	95	(75–100)	Selection and technique crucial
Massart 1990	25	Iliac crest	Herbert screw	3	88	(69–98)	
Radford 1990	26	Ilium or radius	Herbert screw	6	84	(65–96)	Problems with the Herbert jig in 28%
Sukul 1990	42	Iliac crest	ASIF screw	4–32	91	(77–97)	
Huene 1991	20		Ender blade plate	6–8	95	(75–100)	9 had previous surgical attempts
Inoue 1991	70	Iliac crest	Herbert screw	5	90	(81–96)	
Richards 1991	10	Iliac crest	Herbert screw	≥4	90	(56–100)	
Dent 1992	17	Iliac crest	Herbert screw	6	76	(50–93)	
Korkala 1992	5	Iliac crest	Compression staple	7	80	(28–100)	
Braun 1993	16	Iliac crest	Plate and screws	≥4	94	(70–100)	
dos Reis 1993	13	Iliac crest	Herbert screw	3	85	(55–98)	Dorsal approach
Martini 1993	34		Herbert screw	4–6	94	(80–99)	
Nakamura 1993	50	Ilium or radius	Herbert screw	4–8	94	(84–99)	74% had DISI deformity
Schaller 1993	11	Herbert screw		7	64	(31–89)	
Stankovic 1993	39	Iliac crest	Ender blade plate	≥6	95	(83–99)	
Watson 1993	36	Radius	Kirschner wires	10	89	(74–97)	
Carpentier 1995	38	Iliac crest	Compression staple	5	95	(82–99)	Middle third scaphoid nonunions
Mintzer 1995	5	Iliac crest	Herbert screw	9	100	(48–100)	All scaphoid nonunions in children
Mirly 1995	39	Distal radius	Screw and/or wire		74	(61–89)	K-wires alone or with screw: best
Robbins 1995	17	Iliac crest	Herbert screw	12	53	(28–77)	Note: avascular proximal poles
Pelto-Vasenius 1995	10	Iliac crest	Herbert screw	6	60	(26–88)	
Pelto-Vasenius 1995	14	Iliac crest	Polyglycolide pin	7	64	(35–87)	Results found unsatisfactory
Sakuma 1995	32		Herbert screw		91	(75–98)	

Table 2. Continued.

Reference	Non–unions	Graft / donor site	Internal fixation	Immobi–lization (weeks)	Union (%)	(95% CI)	Comments and complications
Sennwald 1995	11	Distal radius	AO mini–screw	10	82	(48–98)	Dorsal approach; 1 or 2 screws
Tsuyuguchi 1995	24	Iliac crest	Herbert screw	4	93	(73–99)	Another screw type used in 12
Daly 1996	26	Iliac crest	Herbert screw		96	(80–100)	7 had pervious bone grafting
Filan 1996	234	Iliac crest	Herbert screw	2	70	(64–76)	Low union rate of sclerotic poles
Trumble 1996	16	Ilium or radius	Herbert screw	6–8	88	(62–98)	Additional K-wire for 8 weeks
Trumble 1996	18	Ilium or radius	AO/ASIF screw	6–8	100	(82–100)	Additional K-wire for 8 weeks
Beris 1997	28	Ilium or radius	Herbert screw	12	82	(63–94)	
Feldman 1997	19	Distal radius	Herbert screw	4–12	68	(44–87)	Best: 9 with an additional K-wire
Inoue 1997	8	Iliac crest	Herbert screw	7	75	(35–97)	Note: all were second procedure
Inoue 1997a	160	Ilium or radius	Herbert screw	6	90	(84–94)	Additional K-wire in 15 cases
Inoue 1997b	16	Ilium or radius	Herbert screw	7	81	(54–96)	Note: all proximal poles, 8 avascular
Petcu 1998	25	Ilium or radius	Kirschner wires	12–16	92	(74–99)	
Preisser 1998	105	Iliac crest	Herbert screw	9	89	(83–95)	Radiocarpal arthritis in 58%
Shah 1998	50	Ilium or radius	Herbert screw	6–12	80	(66–90)	Proximal pole in 13; avascular in 5
Casteur 1999	14	Iliac crest	Herbert screw	4	86	(57–98)	
Chen 1999	26	Iliac crest	Kirschner wires	6	100	(87–100)	
Gupta 1999	40		Herbert screw		75	(59–87)	Worst: unstable/displaced nonunions
Herbert 1999	69		Herbert screw	0	49	(37–62)	All proximal pole; avascular in 28%
Krimmer 1999	23	Ilium or radius	Herbert screw	7	74	(52–90)	All proximal pole
Low 1999	11	Ilium or radius	Herbert screw	0	100	(72–100)	
Rajagopalan 1999	21	Iliac crest	Herbert screw	6	86	(64–97)	
Wilhelm 1999	67	Iliac crest	Herbert screw	7	81	(54–96)	All proximal pole nonunions
Bickert 2000	14	Iliac crest	AO/ASIF screw	12	93	(66–99)	Additional washer used
Maruthainar 2000	20	Iliac crest	Herbert screw	6	60	(36–81)	
Ritter 2000	24	Iliac crest	Kirschner wires		67	(45–84)	Length of graft no outcome effect
Ritter 2000	24	Iliac crest	AO or Herbert screw		67	(45–84)	AO screw in 5; Herbert screw in 5 cases
Takami 2000	43	Iliac crest	Kirschner wires	7	98	(88–100)	Unstable nonunions no outcome effect
Tomaino 2000	6	Iliac crest	Herbert Whipple	12	100	(54–100)	
Del Pinal 2001	7	Iliac crest	Herbert screw	12	100	(59–100)	All had proximal small fragments
Kuntscher 2001	22	Ilium or radius	Herbert screw	9	82	(60–95)	Three were second procedure
Eggli 2002	37	Ilium or radius	Screw and/or wire	11	95	(82–99)	Screw and wire in 29; wire alone in 8
Total	2669			7	84	(82–85)	

CI: confidence interval. K–wire: Kirschner wire.

eliminated if the osteosynthesis of the scaphoid nonunion is stable.

Not only is there a need for a consensus on defining scaphoid union/nonunion, but as there have been no prospective randomized studies comparing different operative treatments, there is also a need for this type of study. These studies would benefit from a reduction in the number of non-controlled parameters, an increase in the number of patients studied, and finally, an increase in the time of observation after surgery. Thus, there appears to be a need for improvement of the treatment of scaphoid nonunion.

Table 3. Vascularized bone graft with or without internal fixation

Reference	Non–unions	Graft / donor site	Internal fixation	Immobilization (weeks)	Union (%)	(95% CI)	Comments and complications
Hori 1979	1	Cancellous bone			100		Vascular bundle of dorsal index artery
Braun 1983	5	Distal radius	Kirschner wires		80	(28–100)	Pronator quadratus pedicle blood supply
Kuhlmann 1987	3	Distal radius	Kirschner wires	12	100	(29–100)	All had prior failed surgery for nonunion
Pechlaner 1987a	25	Ilium	Kirschner wire	8	100	(86–100)	Most were with necrotic proximal pole
Kawai 1988	8	Distal radius	Kirschner wires	9	100	(63–100)	Pronator quadratus pedicle blood supply
Guimberteau 1990	8	Distal ulna		12	100	(63–100)	All were third or fourth procedure
Zaidemberg 1991	11	Distal radius	Kirschner wires	6	100	(72–100)	All were long-standing nonunions
Fernandez 1995	11	Ilium	Kirschner wires	10	91	(59–100)	Vascular bundle of dorsal index artery
Smith 1996	4	Distal radius	Kirschner wires		100	(40–100)	All were second procedure
Yuceturk 1997	4	First MC	Screw or K-wires	12	100	(40–100)	None with prior surgical attempts
Boyer 1998	10	Distal radius	Herbert screw	12	60	(26–88)	Additional K-wire. All necrosis of pole
Mathoulin 1998	15	Second MC	Kirschner wires	12	93	(68–100)	All were second procedure
Mathoulin 1998	17	Distal radius	Herbert screw	9	100	(81–100)	Additional K-wire. Ten had prior surgery
Gabl 1999a	15	Iliac crest	Kirschner wire	12	80	(52–96)	All were with an avascular proximal pole
Gabl 1999b	56	Iliac crest		12	85	(74–94)	Observation time: 8.8 years
Doi 2000	10	Distal femur	Kirschner wires	6	100	(69–100)	All were with an avascular proximal pole
Uerpairojkit 2000	10	Distal radius	Screw or K-wires	6	100	(69–100)	5 with an avascular proximal pole
Harpf 2001	60	Iliac crest	Kirschner wires	12	92	(82–97)	26 with an avascular proximal pole
Malizos 2001	22	Distal radius	Kirschner wires	8	100	(85–100)	All were long-standing nonunions
Steinmann 2002	14	Distal radius	Screw or K-wires	11	100	(77–100)	5 second procedure; 8 proximal
Straw 2002	22	Distal radius	Screw or K-wires	7–12	27	(11–50)	Vascularization of the bone graft may not improve the union rate
Total	331			10	91	(87–94)	

CI: confidence interval. K–wire: Kirschner wire. MC: metacarpal

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