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REVIEW ARTICLE

Surgical fixation techniques in four-corner fusion of the wrist: a systematic review of 1103 cases

Octavian Andronic[a]*, Raffael Labèr[a]*, Philipp Kriechling[a], Daniel Karczewski[b], Andreas Flury[a], Ladislav Nagy[a] and Andreas Schweizer[a]

[a]Department of Orthopaedics, Balgrist University Hospital, Zürich, Switzerland; [b]Center for Musculoskeletal Surgery, Department of Orthopaedic Surgery, Charité – Universitaetsmedizin Berlin, Berlin, Germany

ABSTRACT

Background: Four-corner fusion (4CF) is a known treatment option for degenerative wrist conditions. Different techniques may be used and there is no general consensus on best implant. As such, it was the purpose of the current systematic review to compare fusion rates and outcomes depending on the fixation technique.

Methods: The systematic review was registered in the international prospective register of systematic reviews (PROSPERO): CRD42020164301. It followed the PRISMA guidelines. Original articles were screened using the following databases: Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE, EMBASE and Web of Science Core Collection. Studies reporting on outcome for 4CF surgery were included. Studies with a minimum Level IV of evidence were considered eligible. Quality assessment was performed using the Methodological Index for Non-Randomized Studies (MINORS) criteria.

Results: A total of 29 studies met the inclusion criteria, for a total of 1103 wrists. The mean age was 41.8 years (range 19–83). Mean follow-up overall was 43.5 months (range 24–146 months). Reported fusion weighted rates were >90% and did not differ significantly between techniques. Reoperations due to different reasons occurred in 135 (12%) of all 1103. There was significant data heterogeneity regarding fusion rates ($I^2 = 70\%$). Inconsistency and heterogeneity in data reporting did not allow meta-analysis with direct data pooling and comparison of subgroups.

Conclusions: Satisfactory fusion rates (over 90%) can be achieved independent of the fixation technique used in 4-corner arthrodesis. Due to the high data heterogeneity and reporting inconsistency across studies, no statements regarding PROMs, ROM or grip strength can be made.

Level of evidence: Systematic Review of Level IV Studies.

Abbreviations: 4CF: four corner fusion; CT: computertomographie; DASH: disabilities of arm, shoulder and hand; DISI: dorsal intercalated segment instability; MINORS: methodological index for non-randomized studies; PROMs: patient-reported outcomes; PRWE: patient-rated wrist evaluation; ROM: range of motion; RL: radiolunate; SNAC: scaphoid nonunion advanced collapse; SL: scapholunate; SLAC: scapholunate advanced collapse; VAS: visual analog scale

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KEYWORDS
Four-corner fusion; partial wrist arthrodesis; SLAC wrist; SNAC; scaphoid nonunion

Introduction

Scaphoid excision and four-corner fusion (4CF) technique were developed for treatment of scapholunate advanced collapse (SLAC) and scaphoid nonunion advanced collapse (SNAC) [1], but has subsequently become a surgical option for other wrist conditions such as nondissociative carpal instability. Like its alternative treatment (proximal row carpectomy), the midcarpal arthrodesis has the purpose of achieving a stable joint, alleviate pain and preserve the range of motion (ROM) (through preserved articulation between lunate and distal radius) and strength [2,3]. Multiple fixation techniques are being inconsistently used, including: fixation with Kirschner wires [4,5], the use of headless screws [6–8], the placement of circular [7,9,10] or rectangular plates [11]. Reported fusion rates vary across literature with regard to the fixation technique and reports were inconsistent when trying to determine a superior method: some support compression screws [12], whilst other authors are favoring the usage of plate fixation [13,14].

As there is no general consensus among the best method for fixation, it was the aim of this study to systematically analyze and compare clinical outcomes (patient-reported outcomes [PROMs], ROM, grip strength), as well as radiographic outcomes of patients treated with a 4CF using different types of fixation techniques.

Methods

Search strategy

A systematic computer-based database search was conducted using Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE, EMBASE and Web of Science Core Collection. A total of fifteen combinations for each database using the following key-words were used: 'four corner', '4 corner', 'midcarpal', 'scapholunate advanced collapse' and 'scaphoid nonunion advanced collapse' with the terms, 'surgery', 'fusion', 'arthrodesis'. All published studies from inception until 1 January 2020 were

CONTACT Raffael Labèr raffael.laber@gmail.com Department of Orthopaedics, Balgrist University Hospital, University of Zürich, Zürich, 8008, Switzerland
*These authors contributed equally to this study.

included in the systematic search. First, a blinded and independent process of selection was carried out by two authors (O.A. and A.F.) based on title and abstract. Next, a thorough analysis of eligible studies was performed by evaluating full texts. Any excluded study together with the reason of exclusion was noted and compared between readers. Studies reporting clinical or radiographic outcomes of 4CF for the treatment of degenerative wrist conditions were selected based on predefined eligibility criteria. The protocol of this systematic review has been published and registered in the international prospective register of systematic reviews (PROSPERO) under the registration number: CRD42020164301.

Inclusion criteria were (1) human studies in English or German language; (2) minimum Level IV case series studies using Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence; (3) 4CF surgery using any technique; (4) a minimum average of 2 years of follow-up and a minimum sample size of $n = 10$; and (5) grip strength, (6) ROM data and (7) fusion rates have been reported.

Exclusion criteria were (1) presentations, cadaveric or review articles; (2) average follow-up of less than 2 years or sample size smaller than 10 patients; (3) inflammatory arthritis as etiology and (4) no sufficient outcome data reported.

Data extraction and quality assessment

Data collection was performed by R.L. for fusion rates, reoperation/revision rates and all PROMs encountered, including: Patient-Rated Wrist Evaluation (PRWE), disabilities of arm, shoulder and hand (DASH) and visual analog scale (VAS) scores. The following ROM values were included: hand flexion and extension, radial and ulnar deviations, forearm supination and pronation. Pinch and grip strengths, as well as complications were also assessed. Where available, data regarding incidence of radiolunate (RL) arthritis was included.

Complications were further grouped into minor and major complications. Minor complications were defined as events that were treated conservatively, whereas major complications were defined as events leading to surgical revisions. Implant removal in case of K-wires was not considered as reoperation, as it was a planned step of postoperative care.

The quality of all the studies was then assessed using the methodological items for non-randomized studies (MINORS) criteria [15]. MINORS criteria assess eight critical aspects of study design for non-comparative clinical studies and an additional four aspects of study design for comparative clinical studies. Each item is given a score of zero if information is not reported, one if information is reported but inadequate, and two if information is reported and adequate. Therefore, the maximum possible score is 16 for comparative studies and 24 for non-comparative studies. Each score was then converted into a percentage to harmonize the scoring system.

Data analysis and synthesis

The statistical analysis was performed using SPSS (IBM SPSS Statistics version 24.0; Chicago, IL) and R Software. Two authors

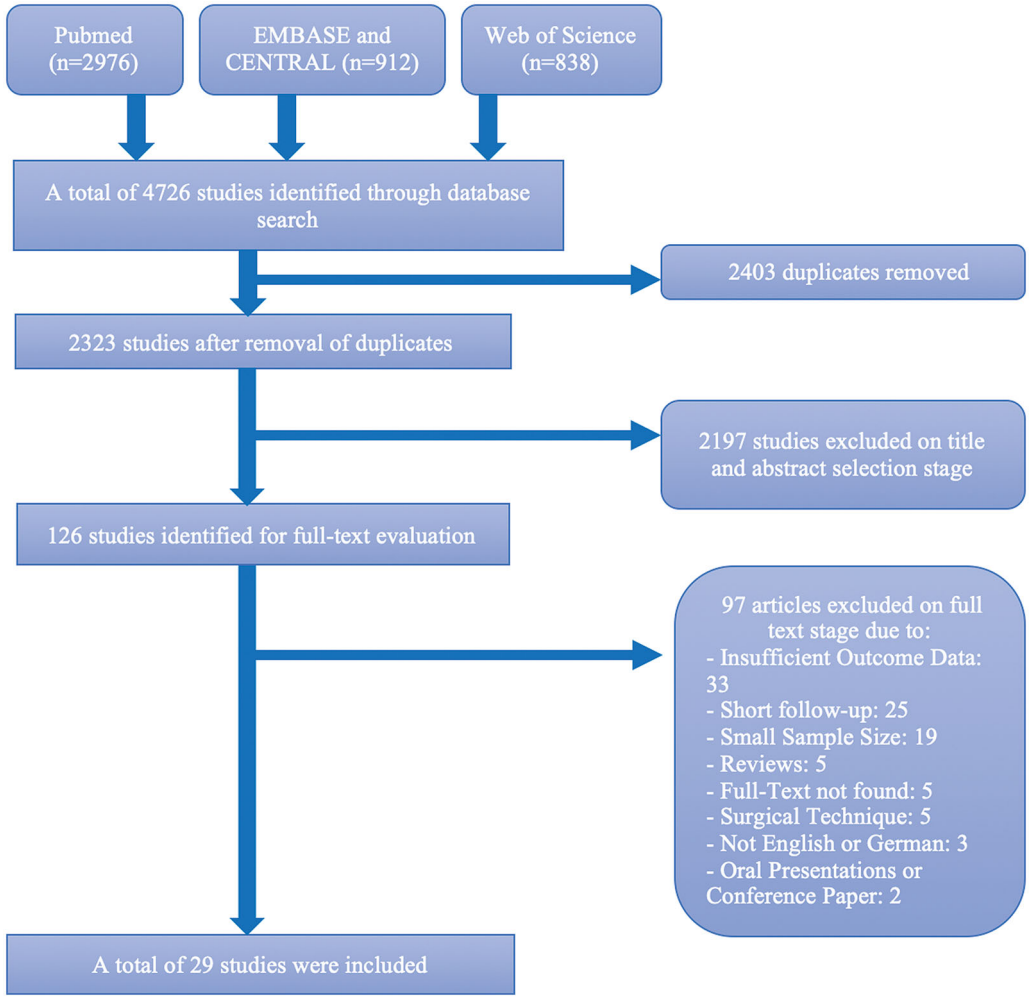

Figure 1. PRISMA flowchart of the systematic search.

Table 1. Demographics of included studies and quality assessment (MINORS criteria).

Author and year of publication	Study design (level of evidence)	Nr. of wrists	Mean age (range)	Indications	Fixation technique	Mean follow-up (months)	MINORS (%)
[4]	Retrospective case series (IV)	100	49 (19–82)	SLAC, SNAC	K-wires and silicon implant	44	69
[25]	Retrospective case series (IV)	252	19–82	SLAC, SNAC ± fracture fossa scaphoidea, Preiser	K-wires	44	50
[26]	Retrospective case series (IV)	36	47 (27–64)	SLAC, SNAC	K-wires	25	81
[19]	Case–control study (III)	19	47 (24–70)	SLAC, SNAC, Preiser	K-wires	28	75
[28]	Retrospective case series (IV)	16	52 (31–64)	SLAC, SNAC, Preiser, Jonsson	Screws, ECRL-tendon interposition	38	62
[27]	Retrospective case series (IV)	49	49 (29–67)	SLAC, SNAC	K-wires	47	87
[20]	Case–control study (III)	17	44 (29–67)	SLAC, SNAC	K-wires	42	92
[21]	Case–control study (III)	15	38 (21–49)	SLAC	K-wires	42	92
[10]	Retrospective case series (IV)	26	47	SLAC, SNAC, midcarpal osteoarthritis	Non-locking circular plate (Spider)	54	87
[11]	Retrospective case series (IV)	35	56 ± 11	SLAC, SNAC, midcarpal osteoarthritis	Plate non-locking (rectangular)	55	87
[29]	Retrospective case series (IV)	12		SLAC, SNAC	K-wires	60	75
[30]	Retrospective case series (IV)	24	55 (35–70)	SLAC, SNAC, midcarpal instability, failed SL-Reconstruction	2x plate (2-hole) non-locking	36	81
[31]	Retrospective case series (IV)	18	36 (21–63)	SLAC, SNAC, Perilunate Injury	NiTi-AlloPlate	30	69
[32]	Retrospective case series (IV)	24	53 (37–78)	SLAC, SNAC, SCAC	Locked DCP circular plate (Xpode1)	76	87
[33]	Retrospective case series (IV)	40	46 (42–61)	SLAC	K-wires	147	75
[14]	Case–control study (III)	35	53	SLAC, SNAC	Staples	80	87
[34]	Retrospective case series (IV)	25	50 (29–73)	SLAC, SNAC, midcarpal instability or osteoarthritis	Locked DCP circular plate (Xpode1)	28	69
[17]	Prospective Cohort Study (II)	10	28 (20–37)	Neglected Perilunate Injury	K-wires	24	75
[35]	Retrospective case series (IV)	36	48 (35–68)	SLAC, SNAC, Perilunate Dislocation	Circular plate	56	75
[22]	Case–control study (III)	37	58 (41–80)	SLAC, SNAC	Shape-memory quadripodal staple (4Fusion1, MemometalTM) $n = 37$	51	79
		15	59 (47–70)	SLAC, SNAC	Locked DCP circular plate (Xpode1, Biotech OrthoTM)	37	
[16]	Randomized clinical trial (*I*)	14	40 (25–56)	SNAC II	Conventional carpal button® by SBI®, or blocked carpal button by Biotech®	74	92
[23]	Case–control study (III)	10	47 (31-73)	SLAC, SNAC	K-wires	54	92
[36]	Retrospective case series (IV)	15	49 (25-67)	SLAC, SNAC	K-wires	216	62
[37]	Retrospective case series (IV)	40	52 (22–76)	SLAC, SNAC	K-wires	53	75
[24]	Case–control study (III)	20	59 ± 11	SLAC, SNAC	Non-locking circular plate (Spider)	49	67
		19	59 ± 11	SLAC, SNAC	Locking plate (Flower, KLS)	49	
[18]	Prospective cohort study (II)	20	54 (35–83)	SLAC, SNAC	Circular plate	30	75
[38]	Retrospective case series (IV)	20	53	SLAC/SNAC III	Three different locking plates	72	75
[39]	Retrospective case series (IV)	21	58 (54-74)	SLAC, SNAC	K-wires	35	100
		26	55 (49-72)	SLAC, SNAC	Locking plate (Medartis)	32	
		17	50 (49-69)	SLAC, SNAC	Compression screws	27	
[40]	Retrospective case series (IV)	40	57 (33–80)	SLAC, SNAC	Locking plate (Medartis $n = 5$/ Xpode $n = 35$)	70	87
Totals and averages	1 RCT (I) 2 prospective cohort studies (II) 7 retrospective cohort studies with comparison groups (III) 19 retrospective case series (IV)	1103	42 (19–83)	In 18 (62%) of the studies SNAC or SLAC-wrist were the only indication	14 – locking (50%) and/or non-locking plates (50%); 14 – K-wires; 2 – compression screws; 2 – staples; 1 – carpal button	43.5 (range 24–146)	78

SNAC: scaphoid nonunion advanced collapse; SLAC: scapholunate advanced collapse; SCAC - scaphoid chondrocalcinosis advanced collapse; ECRL: extensor carpi radialis longus; MINORS: methodological items for non-randomized studies; Carpal button is a circular plate available in locking or non-locking type.

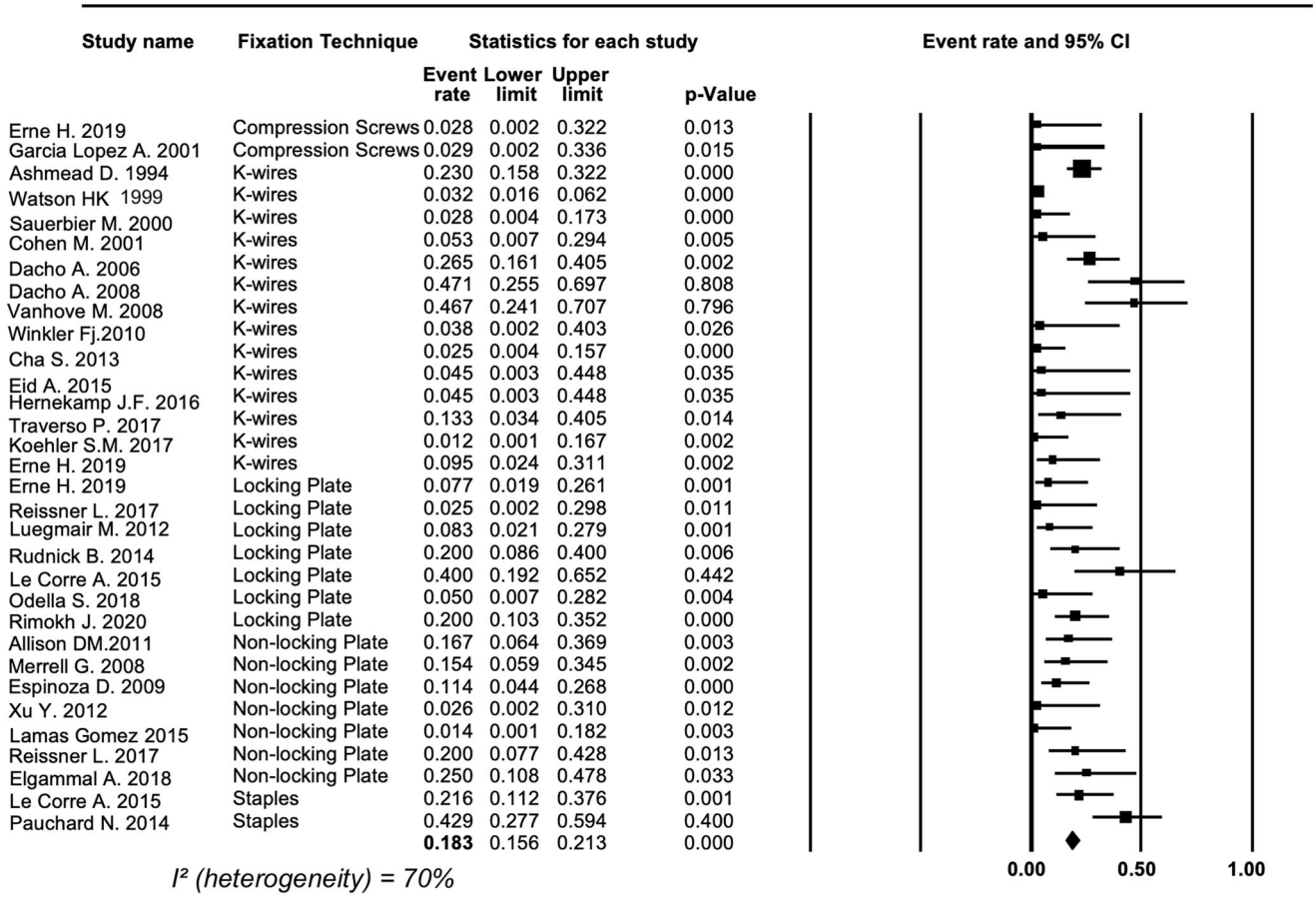

Figure 2. Forest plot summarizing all revision rates based on fixation technique. Event – surgical revision. The size of the square represents the weight that the corresponding study exerts. I^2 – value of calculated heterogeneity.

(O.A. and R.L.) blindly and independently extracted PROMs, diseases stages, radiographic outcome and comparative results from the included studies and performed comparisons. The senior author (A.S.) was consulted in instances of discrepancy. In these cases, a confidence interval of $p<.05$ was considered statistically significant. Due to the clinical heterogeneity, high risk of bias and low levels of evidence of the included studies, we do not provide pooled effect estimates for our clinical outcomes of interest. A random-effects-model of meta-analysis was used. The methodological inconsistency and heterogeneity were quantified using a I^2 test, with a p value of $p=.10$. Values more than 40% were considered significant for moderate heterogeneity and over 75% were considered to be highly heterogenous. This evaluated whether observed differences in results are compatible with chance alone.

Results

Systematic database search

The initial database search yielded 4726 studies. After removal of duplicates there were 2323 studies. Next, screening based on title and abstract was performed and 126 studies remained for further assessment. These were then screened for eligibility against the inclusion and exclusion criteria based on abstract and full-text review. After thorough full-text analysis 29 studies were included in the final analysis (Figure 1). The reasons for exclusion were also separately emphasized (Figure 1).

Risk of bias assessment and data heterogeneity

A quality assessment was performed in all included studies. There were no randomized controlled trials, one randomized prospective cohort study, [16] 2 prospective case series, [17,18] 7 retrospective cohort studies with comparison groups [14,19–24] and 19 retrospective case series [4,10,11,25–40]. The calculated average from scores according to MINORS Criteria Tool was 78.6% (Table 1), demonstrating lack of consistency in reporting outcome and patient demographics. There was also significant heterogeneity among studies with I^2 values surpassing 60% (Figure 2).

Demographics and indications

Over the 29 included studies, a total of 1103 wrist were analyzed. The mean age was 41.8 years (range 19–83 years). In 20 (68%) of the studies, 4CF was indicated for either SNAC or SLAC-wrist. In three studies (10%), 4CF was performed because of avascular necrosis (M. Preiser, M. Jonsson). Seven of the studies (24%) performed 4CF due to midcarpal instability and/or midcarpal osteoarthritis, failed scapholunate (SL) ligament reconstruction or perilunate injury. Thirteen studies used solely K-wires, 6 – non-locking plates, 4 – locking plates and 1 for each of the following – carpal button, compression screws and staples (Table 1). Next, there were three studies that reported on multiple fixation techniques: Reissner [24] for locking and non-locking plates; Le Corre et al. [22] for locking plates and staples and Erne [39] for K-wires,

Table 2. Fusion rates, grip strength and complication rates.

Author and year of publication	Nr. of Wrists	Fixation Technique	Fusion Rate (%)	Radiographic Fusion Assessment	Pinch Strength (% of contralateral)	Grip Strength (% of contralateral)	Postoperative Radiolunate joint (RL) Degeneration (%)	Minor Complications Nr. (%)	Major Complications (Revisions) Nr. (%)
[4]	100	K-wires	97	X-ray	–	81	2	9 (9)	23 (23)
[25]	252	K-wires	97	X-ray	–	80	0	6 (3)	8 (3)
[26]	36	K-wires	97	X-ray	–	65	n/a	0	1 (3)
[19]	19	K-wires	95	X-ray	–	79	0	0	1 (5)
[27]	49	K-wires	90	X-ray	–	76	n/a	3 (6)	13 (26)
[20]	17	K-wires	88	X-ray	–	72	n/a	0	8 (47)
[21]	15	K-wires	93	X-ray	–	71	n/a	3 (20)	7 (46)
[29]	12	K-wires	100	X-ray	82	90	0	3 (25)	0 (0)
[33]	40	K-wires	100	X-ray	–	85	5	1 (2)	1 (2)
[17]	10	K-wires	100	X-ray	–	77	n/a	1 (10)	0 (0)
[23]	10	K-wires	100	x-ray	–	62	n/a	1 (10)	0 (0)
[36]	15	K-wires	100	X-ray	–		27	0	2 (13)
[37]	40	K-wires	100	X-ray	–	82	0	2 (5)	0 (0)
[39]	21	K-wires	95	CT	–	26 kg	n/a	1 (5)	2 (9)
Totals and Averages	*636*		*97 (weighted)*		–	*77*		*30 (5)*	*66 (10)*
[10]	26	Non-locking Plate	100	X-ray	–	82	4	0	4 (15)
[11]	35	Non-locking Plate	100	X-ray	90	79	n/a	0	4 (11)
[30]	24	Non-locking plate	100	X-ray	–	69	8	0	4 (16)
[31]	18	Non-locking Plate	100	X-ray	–	80	n/a	0	n/a
[35]	36	Non-locking Plate	97	X-ray	–	89	3	9 (24)	0 (0)
[24]	20	Non-locking Plate	95	X-ray	–	23 kg	n/a	14 (70)	4 (20)
[18]	20	Non-locking Plate	90	X-ray	–	68	0	0	5 (25)
Totals and Averages	*179*		*98 (weighted)*			*78*		*23 (13)*	*21 (12)*
[32]	24	Locking Plate	92	X-ray	–	70	0	0	2 (8)
[34]	25	Locking Plate	80	X-ray	82	77	4	0	5 (20)
[22]	15	Locking Plate	86.6	X-ray	–	19 kg	n/a	3 (20)	6 (40)
[24]	19	Locking Plate	100	X-ray	–	29 kg	n/a	6 (31)	0
[38]	20	Locking Plate	100	X-ray	–	75	n/a	0	1 (5)
[39]	26	Locking Plate	96	CT	–	28 kg	n/a	0	2 (8)
[40]	40	Locking Plate	97.5	X-ray ± CT	–	64	n/a	1 (3)	8 (20)
Totals and Averages	*169*		*94 (weighted)*		–	*72*		*10 (6)*	*24 (14)*
[28]	16	Compression Screws	100	X-ray	–	22 kg	0	3 (19)	0 (0)
[39]	17	Compression screws	100	CT	–	29 kg	n/a	0	0 (0)
[22]	37	Staples	95	X-ray	–	24 kg	n/a	2 (5)	8 (20)
[14]	35	Staples	94	X-ray ± CT	–	64	n/a	0	15 (42)
[16]	14	Carpal Button	92.9	X-ray	–	65	n/a	0	1 (7)
Summary	1103	14 – K-wire; 7 – locking plates; 7 – non-locking plates; 2 – staples; 2 – compression screws; 1 – carpal button							135 (12)

n/a: not available; CT: computer tomography.

locking plates and compression screws. Mean follow-up overall was 43.5 months (range 24–146 months) (Table 1).

Fusion rates

The overall fusion rate found in the reviewed studies was 96%. Twenty-six studies used conventional radiographs, 2 studies [14,40] also performed CT scans in case of doubt and only one study has performed CT scans in all patients to confirm fusion [39]. Subgroup comparison demonstrated no benefit in using locking plates versus non-locking plates, achieving an average fusion rate of 94% and 98%, respectively (Table 2). Studies using compression screws and staples reported a 100% (2 studies; $n = 16$ and $n = 17$) and 95% (2 studies; $n = 35$ and $n = 37$) fusion rate, respectively. K-wire fixation showed an overall weighted fusion rate of 97% (Table 2).

Patient-reported outcomes

The outcome scores differed in terms of assessment tools. Huge heterogeneity was, therefore, encountered. Five reports used PRWE and scored an average of 29.81 postoperatively. Four studies used Mayo Wrist and averaged 69.85, [20,26,27,33] 4 used Krimmer Wrist Score and had a mean of 68.25 [20,23,26,27]. In 19 studies, the DASH score was reported, averaging 24.13 at the final follow-up. 1 scored 19 on QuickDASH [32] and 3 other reported a Cooney-Score with a mean of 69.42 [21,29,40]. Due to heterogeneous data and reporting tools, no further correlation analysis was employed.

Grip strength

Grip strength was reported in 28 (96%) studies. Most of the studies (86%) reported grip strength relative to the contralateral side. A few presented their results as kilogram and were excluded from the average calculation, but were reported in the provided table of grip strength (Table 2). The postoperative grip strength for all techniques was 72% of the contralateral side. In the group of plate fixation, strength was 78% for non-locking ($n = 6$) and 72% ($n = 4$) for locking plates. For staples and k-wires, grip strength was 64% ($n = 1$, 35 wrists) and 77% ($n = 12{,}600$ wrists) when compared to the healthy wrist, respectively.

Mean pinch strength was 84% compared to the contralateral side (reported in only three studies).

Radiolunate joint degeneration and complications

RL joint degeneration was evaluated and reported in 14 studies (48%). The average calculated incidence of RL joint arthritis was 3.7% (range 0 – 27%) at final follow up (range 24–146 months).

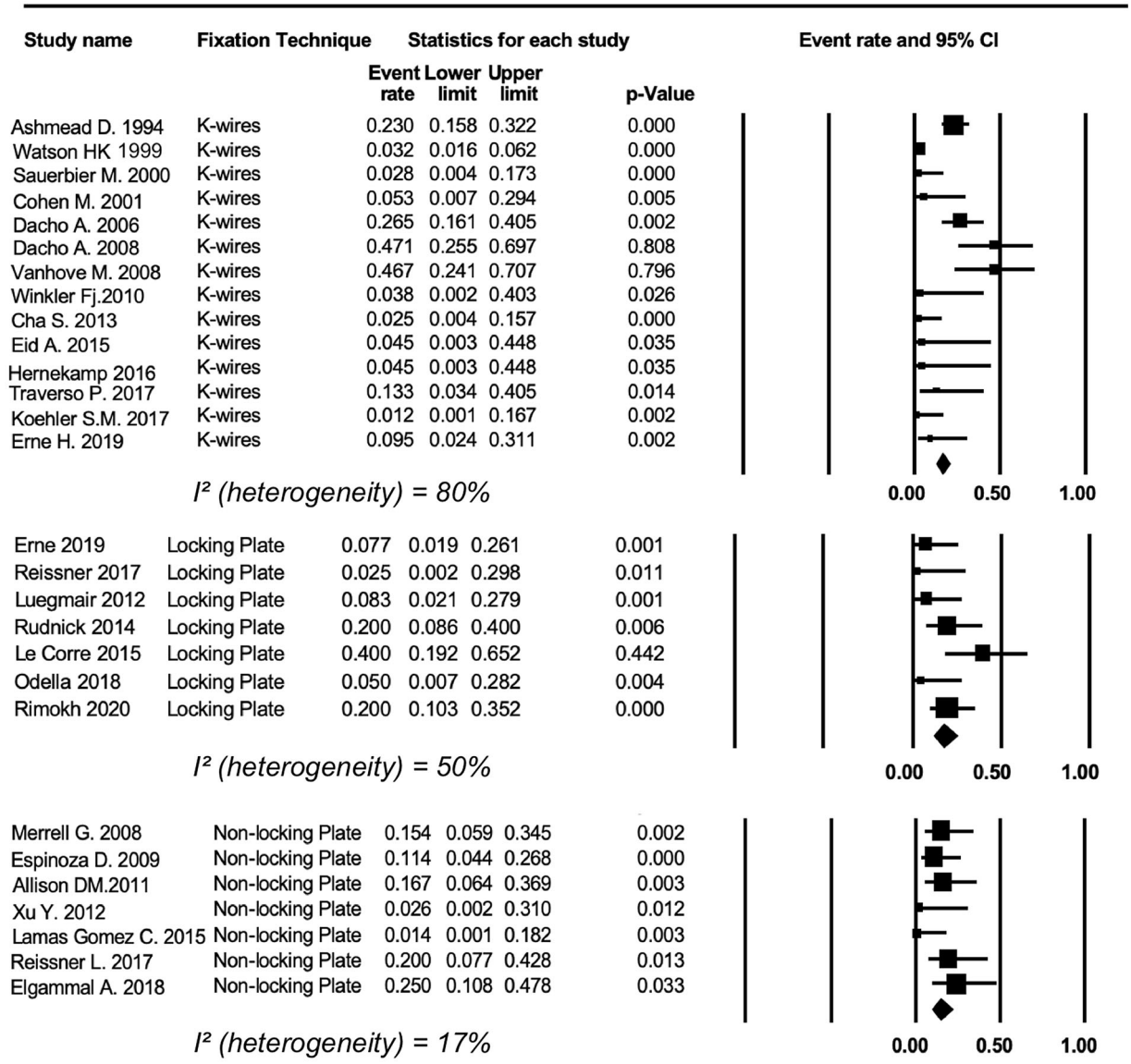

Figure 3. Forest plot for reoperation rates stratified for each surgical technique separately. Event – surgical revision. The size of the square represents the weight that the corresponding study exerts. I^2 – value of calculated heterogeneity.

RL degeneration occurred in 3.1% of cases when using plates and in 4.8% when using K-wires. One study using compression screw reported no degenerative changes in the RL joint. This average value should be interpreted with caution due to the significant heterogeneity and differences in follow-up across studies.

Major complications were indications that required revision surgery, whilst minor complications were treated conservatively. Revision rates had an occurrence rate of 10% for K-wires, 12% for non-locking plates and 14% for locking plates (Table 2). Minor complications occurred in 5% of cases fixed with K-wires, in 13% for non-locking plates and 6% for locking-plates of cases (Table 2).

In the group treated with a compression screw, one study reported no complications at all, whereas the other had 19% of minor complications. Studies using staples as fixation technique had 2.5% of minor complications and a revision rate of 31% (Figure 2).

There was a slightly lower reoperation rate in the K-wire fixation group when compared to other fixation techniques. However, due to significant heterogeneity concerning indications and reported outcome parameters, as well as data (Figure 3), extrapolation into clinical practice needs to be made with caution.

Range of motion

All 29 studies reported ROM either as total flexion–extension arc or with single values for flexion and extension. Two studies reported their values as percentage of the contralateral side and were excluded in the calculation performed but reported in Table 3. Total flexion-extension arc in the locking plate group was 63° (range 48 – 79°), non-locking plates 62° (range 52 – 78°), compression screws 53° (range 49 – 57°), staples 64° (range 60 – 68°) and k-wire 68° (range 45 – 80°), respectively. Radial- and ulnar deviation was reported in 24 studies. Two of them reported values as percentage of contralateral side (Table 3). The mean arc was 31° (range 24 – 53°). Radio-Ulnar-Arc was 28° (range 25 – 30°), 31° (range 27 – 37°), 31° and 36° (range 24 – 53°) for

Table 3. Range of motion.

Author and year of publication	Nr. of wrists	Fixation technique	Flexion/extension preoperative arc°	Flexion/extension postoperative arc°	Extension°	Flexion°	Radial/Ulnar deviation° (arc)	Radial deviation°	Ulnar deviation°
[4]	100	K-wires	–	74	32	42	37	15	22
[25]	252	K-wires	88	53% of contralateral	–	–	59% of contralateral	–	–
[26]	36	K-wires	–	54% of contralateral	–	–	45% of contralateral	–	–
[19]	19	K-wires	–	80	49	31	53	23	30
[27]	49	K-wires	78	56	–	–	33	–	–
[20]	17	K-wires	–	61	–	–	32	–	–
[21]	15	K-wires	–	76	31	45	35	14	21
[29]	12	K-wires	76	75	37	38	38	15	23
[33]	40	K-wires	84	66	35	31	39	17	22
[17]	10	K-wires	34	45	–	–	29	–	–
[23]	10	K-wires	–	57	–	–	30	–	–
[36]	15	K-wires	–	69	–	–	33	–	–
[37]	40	K-wires	88	77	37	40	24	10	14
[39]	21	K-wires	38	45	20	25	–	–	–
	636		–	*68*	*33*	*36*	*36*	*16*	*22*
[10]	26	Non-locking Plate	–	61	–	–	–	–	–
[11]	35	Non-locking Plate	–	64	–	–	37	18	19
[30]	24	Non-locking plate	85	66	35	31	35	17	18
[31]	18	Non-locking Plate	87	52	24	28	28	10	18
[35]	36	Non-locking Plate	–	78	42	36	27	12	15
[24]	20	Non-locking Plate	–	50	25	25	29	14	15
[18]	20	Non-locking Plate	–	65	35	30	–	–	–
	179			*62*	*33*	*32*	*31*	*14*	*17*
[32]	24	Locking Plate	57	64	30	34	30	12	18
[34]	25	Locking Plate	63	70	–	–	29	13	16
[22]	15	Locking Plate	67	59	38	21	25	8	17
[24]	19	Locking Plate	–	60	32	28	27	14	13
[38]	20	Locking Plate	–	79	37	42	–	–	–
[39]	26	Locking Plate	40	48	23	25	–	–	–
[40]	40	Locking Plate	79	58	29	29	29	12	17
	169			*63*	*31*	*23*	*28*	*12*	*15*
[28]	16	Compression Screws	55	49	22	27	32	12	20
[39]	17	Compression screws	39	57	28	29	–	–	–
[22]	37	Staples	95	–	24	n/a	30	10	20
[14]	35	Staples	–	60	–	–	31	–	–
[16]	14	Carpal Button	51	118	–	–	–	–	–
Totals and averages	1103	14 – K-wire; 7 – locking plates; 7 – non-locking plates; 2 – staples; 2 – compression screws; 1 – carpal button							

locking plates, non-locking plates, staple fixation and k-wire fixation, respectively (Table 3).

Discussion

Defining a gold standard for midcarpal arthrodesis is wanted since SLAC-wrist is the most frequently encountered degenerative condition of the wrist, and 4CF it's a reliable and commonly performed treatment modality [41]. Including a total of 29 studies with 1103 examined wrists, this systematic review is the biggest to date dealing with this topic. However, the findings demonstrate no superiority of one specific fixation technique in case of 4CF. In detail, all fixation techniques seem to be feasible with a reliably high fusion rate. The usage of plates also does not provide any other benefits in terms of clinical outcome (for example ROM), apart from not needing implant removal as K-wires do. Nevertheless, it is important to notice that hardware removal was not considered a reoperation for K-wires, whereas for other implants it was, as the removal was not planned and as the implants were often causing dorsal impingement [11,14,24,30]. This have may influence the observed difference between reoperations rates. However, we believe that hardware impingement and hardware irritation should be differentiated.

A large part of the studies was of low quality and showed significant heterogeneity, which did not allow neither a meta-analysis nor a conclusive statement. In specific, the studies varied not only in surgical fixation technique, but also regarding bone grafting and postoperative rehabilitation protocol.

However, the current literature review gives valuable information about implant-specific parameters. K-wires seem to cause slightly lower complication rates, achieve a satisfactory high fusion rate with functional outcomes above the average for both grip strength and ROM. However, between the most commonly used techniques, namely plates or K-wires, no statistically significant differences could be shown. This is interesting due to the fact, that locking plates should bring certain biomechanical advantages [42]. On the other hand, K-wires allow easier reposition and correction of the dorsal intercalated segment instability (DISI), facilitates the secondary bone stock compression and provides larger surface contact between fragments [43]. Only two studies used staples [14,22], whereas two studies used compression screws [28,39], leading to a numerical mismatch of compared populations. This has occurred probably due to the rigorous selection criteria with a minimum follow-up of 2 years postoperatively, as a significant number of studies using screw and staple osteosynthesis had to be excluded during the selection process. We still believe that a minimum follow-up of 2 years would be appropriate to not only assess the fusion rates but to also unmask possible technique related complications that would present later (for example dorsal impingement for plates), as well as clinical outcomes after the rehabilitation period would be completed. Nevertheless, those respective studies reported the highest major

complication rates and lowest grip strength compared to other fixation methods. On the other hand, compression screws achieved the highest fusion rate [28,39]. However, due to the small patient cohort, these results should be interpreted with caution.

There is concern about the bony fusion surface of the Lunate, whereas it is considerably reduced by drilling anterograde screws and therefore theoretically reducing chances of fusion.

Apart from the fixation technique, further elements need to be explored, because they influence the results. Nonunion may be caused by incomplete removal of the cartilage and subchondral bone, which is a key step of the procedure [7,40]. Also, the importance of using bone grafts, its quality, compression and carpal height achieved [44], as well as the location (distal radius) need to be elucidated, as they might play an important role in the success of fusion [45]. Another issue that is leading to revision is implant impingement, occurring mostly with dorsal plates. Optimal placement has to be defined in future studies to avoid surgical revisions because of impingement [46]. Furthermore, it should be noted that studies used different types of assessment of radiographic fusion: the majority [26] used conventional radiographs, 2 studies [14,40] also performed CT scans in case of doubt and only one study has performed CT scans in all patients to confirm fusion [39]. We believe that both assessment modalities were sufficient into diagnosing a successful fusion when correlated with the clinical picture of a pain-free osteosynthesis. There is scarce literature regarding the optimal radiological assessment of midcarpal fusion but Henry M. and Ekelund et al. reported a clear advantage of CT scans [47,48]. However, in order to avoid methodological heterogeneity, equivalent outcome measurement techniques should be employed in future studies.

After 4CF, wrist motion occurs through the preserved articulation between lunate and distal radius. However, only half of the studies reported on degenerative changes of the RL fossa at latest follow-up with a wide range of incidence ($0-7\%$). Also, there was a lack of objective assessment and reporting of the RL joint status pre- and intraoperatively. The average calculated value (4%) should be interpreted with caution due to the significant heterogeneity and differences in follow-up across studies. After a minimum follow-up of 10 years after 4CF, Traverso showed a high incidence (27%) of degenerative changes in the RL fossa [36].

In summary, satisfactory fusion rates (over 90%) can be achieved independent of the fixation technique used in 4-corner arthrodesis. The fusion rates presented moderate to high heterogeneity ($I^2 = 70\%$). Due to the high data heterogeneity and reporting inconsistency across studies, no statements regarding PROMs, ROM or grip strength can be made. Future studies should focus on achieving consensus regarding a common PROMs measure, as well as consistency in reporting pre- and postoperative ROM, grip strength, as well as RL degeneration status.

High-level evidence including prospective randomized controlled trials is necessary to elucidate implant-specific advantages and disadvantages for 4CF in terms of functional outcome.

Ethical approval

Not applicable.

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Disclosure statement

The author(s) declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article. OA conceived the study, established the protocol, performed literature research, quality assessment, wrote first draft of manuscript. RL extracted data, performed analysis, quality assessment and wrote first draft of the manuscript. PK established protocol and performed literature research. DK performed statistical analysis and literature search. AF and LN reviewed and edited the manuscript. AS was involved in establishing the protocol and reviewed and edited the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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