



ARTICLE

## Progressing arthrosis and a high conversion rate 11 (4–19) years after four corner fusion

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### ABSTRACT

Four corner fusion (4CF) is a limited wrist arthrodesis offered to patients with painful wrists due to scaphoid non-union advanced collapse (SNAC) or scapho-lunate advanced collapse (SLAC). A retrospective study of 42 wrists (in 36 patients), operated with 4CF using K-wires and autologous bone graft followed up after 11 (4–19) years was performed, 25 were male and mean age at surgery was 51 (22–71) years. During the follow-up period, 13 wrists were converted to total wrist arthrodesis or wrist arthroplasty, and one is scheduled for conversion (14/42, 33%) due to non-union (3), DISI and progressing arthrosis (7) or progressing arthrosis (4). Non-union was seen in 3/42 (93%) wrists, all were later converted. At the final follow-up, the patients reported residual pain, VAS = 15 and 36 at rest and activity, respectively, and QDASH/PRWHE = 32 and 31, respectively. Active range of motion (AROM) was 38% and grip-strength was 76% compared to the uninjured side. Degenerative changes were seen in 88% on CT scans at follow-up. 4CF renders an acceptable pain reduction and function in the majority of patients, but increased degeneration and a high number of conversions after a longer follow-up time is concerning.

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### Introduction

Untreated scapholunate ligament injury or scaphoid non-union often lead to painful wrist arthrosis. Limited wrist arthrodesis or resections can reduce pain and preserve motion and function [1]. Four corner fusion (4CF), described by Watson and Ballet [2] or proximal row carpectomy (PRC), described by Stamm [3] are treatment alternatives. 4CF has a wider indication than PRC being a treatment option also in scaphoid non-union advanced collapse (SNAC 3) and scapho-lunate advanced collapse (SLAC 3) patients where the midcarpal joint is also affected. In Watson's original description the scaphoid was replaced with a silicon implant, the implant was later abandoned due to complications [4]. Bone fusion in 4CF is achieved by different means including K-wire fixation, staples, headless compression screws and circular plates with screws [5]. The latter has demonstrated the highest non-union and hardware complication rate [6–8]. The clinical result after 4CF varies considerably, ranging from no gain after surgery to satisfactory results; the majority report reduced motion, strength and pain scores [6,9]. Although numerous case series have demonstrated good clinical results, long-term follow is rarely reported. The aim of our study was to evaluate whether the good short to midterm results reported after 4CF surgery could be expected after longer term follow-up. We performed a retrospective follow-up of patients operated with 4CF due to SNAC and SLAC grade 2 or 3.

### Patients and methods

All patients operated with 4CF due to SLAC or SNAC wrist arthrosis were identified in the hospital data register and operation protocols during 1998–2013. 36 patients with 42 (28 dominant)

wrists, were operated due to pain and radiological SLAC (28) or SNAC (14) degeneration and intact radiolunate joint. In the majority (28 patients) a preoperative CT scan was also obtained. 25 (71%) were male and the mean age at surgery was 51 (22–71) years. Prior to the 4CF surgery, 9 wrists had been operated once and 4 wrists twice including fracture/non-union surgery (11), arthroscopy with resection of cartilage/TFCC (5) and ligament reconstruction (1). Bilateral wrist arthrosis was seen in 14 patients (13 SLAC/1 SNAC), six were operated with 4CF bilaterally, none simultaneously. The preoperative radiological grading was SNAC/SLAC 2 in 17 and SNAC/SLAC 3 in 19 wrists according to Watson and Ballet [2], preoperative radiographs of the 6 oldest wrists had been maculated.

### Surgery

With the arm exsanguinated and no antibiotic prophylaxis a dorsal incision was used, the space between the third and fourth extensor compartment opened followed by a longitudinal incision in the capsule. The scaphoid was excised, and cartilage and subchondral bone removed in 'the cross' between the lunate, triquetrum, hamatum and capitatum as described by Watson and Ballet followed by reposition of the dorsal intercalated segmental instability (DISI) deformity. A minimum of 3 (3–6) K-wires (1.1 mm) were used for fixation. Bone from the scaphoid (20), radius and scaphoid (8) or the iliac crest (14) was transplanted and the position and fixation verified with fluoroscope. The patients wore a cast for 8 weeks, if the radiographs confirmed healing the K-wires were removed after an additional 4 weeks (around 12 weeks after surgery), after which free mobilization was encouraged. There



**Figure 1.** (a) Preoperative SLAC 2 wrist. (b) Postoperative k-wire fixation, prior to removal due to deep infection. (c) Follow-up CT 6 years after surgery/deep infection. Despite deep staph aureus infection, surprisingly well-preserved cartilage surfaces and good clinical function.

were no peroperative complications. After primary surgery, all wrists were considered fused.

Complications and surgery during the follow-up period were recorded. At follow-up, active range of movement of the wrist (AROM: flexion, extension, radial and ulnar deviation) and forearm rotation (pro- and supination) were measured using a hand-held goniometer. Grip strength was assessed with JAMAR grip strength dynamometer and key pinch with a JAMAR Key pinch dynamometer (JA 88 Preston Corp., Clifton, New Jersey). The patients graded radial and ulnar-sided wrist pain at rest and at activity using a VAS scale from 0 to 100 (0 indicating no pain) and completed the Quick Disabilities of the Arm Shoulder and Hand (QDASH) and Patient Rated Wrist and Hand Evaluation (PRWHE) scores [10,11]. Preoperative radiographs were compared with new ones of both wrists (anteroposterior, lateral, supinated, and oblique) and a CT scan was obtained of the affected wrist. We evaluated union of the 4CF and DISI position as well as degenerative changes in the wrist at surgery (SNAC/SLAC grading) and degenerative changes (irregular or narrowing of joint space, osteophytes, subchondral sclerosis) in the radiolunate joint at surgery and follow-up. Twelve of the patients were daily smokers at surgery, and they were still daily smokers at follow-up. The study was approved by the hospital's data authority (2013/16882) and all patients gave written informed consent.

### Statistical method

Parametric data (as demonstrated by histograms and q-q plots) is presented as mean (SD), or median (range) where the numbers are low or the data is not parametric. Independent *t*-test was used for comparison of means and non-parametric tests (Mann-Whit U) for other comparisons.

### Results

There were five early complications. Three patients had infections, two were superficial and healed with oral antibiotics, one patient had a deep infection complicated with a septicemia (*staphylococcus aureus*) necessitating multiple wound revisions, intravenous antibiotics, negative-pressure wound therapy and secondary wound closure. The infection was treated successfully and the 4CF healed. He has been satisfied at follow-up (Figure 1(a-c)). Two patients had tendon ruptures, One extensor pollicis longus (EPL) rupture over Listers tubercle 2 weeks after surgery was sutured, functioning well at follow-up. Another had a flexor digitorum superficialis (FDS) 2 rupture due to K-wire irritation, which was sutured and has a normal function at follow-up. Two others had additional bone removed (one radial styloidectomy and one intraarticular exostosis). In three patients the fusion did not heal,



**Figure 2.** (a) Frontal radiographs, 1 year follow-up, 4CF considered healed. (b) Frontal CT projection demonstrating non-union around the lunate. Later conversion to arthroplasty confirmed non-union.

all were initially considered healed, one pseudarthrosis was evident on radiographs at later follow-up, two were only seen on CT scans (Figure 2(a–b)), giving a total non-union rate of 3/42 wrists (7%).

During the follow-up period, one patient died (8 years after surgery) of an unrelated cause. 13 wrists (13 patients) were converted to total wrist arthrodesis (5) or total wrist arthroplasty (8) due to non-union, DISI, pain and arthrosis (3), DISI, pain and arthrosis (6) or pain and increasing arthrosis (4), at median 1.5 (1.1–17.1) years after primary surgery (Figure 3(a–e)), one is awaiting conversion. One of the total wrist arthrodesis patients was later rearticulated with a wrist arthroplasty. Eight of the conversions were performed within 2 years in patients with continuous pain after surgery. The remaining five were converted 7–17 years after long periods of relatively well-functioning wrists.

At the final follow-up median 11 (4–19) years after surgery, 3 patients (4 wrists) completed questionnaires (VAS, QDASH, PRWHE) and telephone interviews, but did not want clinical and radiological examination. The remaining 19 patients (24 wrists) also attended the clinical examination and had radiographs/CT taken. The clinical results in the non-converted wrists are given in Table 1 and 2. The majority of patients reported residual pain and functional impairment, in six wrists the PRWHE was less than 10 and radial pain at activity < 10. Forearm rotation was not affected by the surgery. One patient was scheduled for wrist arthroplasty after the final follow-up.

In 11 (out of 21) patients with normal contralateral wrist at follow-up (8 were converted, one was dead, two had telephone interviews) the AROM was 38% and the grip strength 76% of the uninjured side (Table 3).

These unilateral affected patients had mean QDASH and PRWHE of 30 (20) and 28 (21), respectively. The working status at surgery and follow-up is given in Table 4. Two patients were permanently disabled due to wrist problems during the follow-up.

The median QDASH and PRWHE at follow up for the converted patients were 18 (0–89) and 13 (0–92) for the nine arthroplasty

and 43 (34–73) and 34 (19–62) for the three (one missing schemes) arthrodesis patients, respectively.

### Radiology

Preoperatively none of the wrists demonstrated radiologically degenerative changes in the radiolunate joint. The 28 preoperative CT scans revealed dorsal and/or volar lip osteophytes in 12. At follow-up degenerative changes were noticed on 5/24 wrist radiographs, but visible on 21/24 CT scans (Figure 3). The AROM was higher ( $120^\circ$  vs  $88^\circ$ ,  $p = 0.01$ ) in the patients without degenerative changes on CT, they had a lower QDASH (26 vs 33) and PRWHE (19 vs 34) but these latter differences were not statistically significant. At follow up DISI position on lateral standard radiographs were seen in 2 out of 24 wrists (Figure 4 (a–c)).

### Discussion

Few long-term results on 4CF have been published. Watson and coworkers reported excellent results 18 years after 4CF in 15 wrists, with an average QuickDASH = 7.8 and ROM =  $102^\circ$ . They found radiologically degenerative changes in the radiolunate joint in 73%, and one patient required a total wrist fusion. Unfortunately, these 15 patients were the only ones out of 480 operated [12] returning for the long-term follow-up making extrapolation of the results difficult. Bain and Watts found similar clinical results in a follow-up of 31 (22 SLAC) patients after 10 years (11 by telephone interview), achieving excellent pain reduction (VAS reduction from 6 to almost 0), functional range of motion and preserved grip strength using staples for fixation. 3/31 had a non-union and two were converted to total arthrodesis due to pain. Radiological assessment was not performed, and bilateral affection was not reported. These excellent long-term pain results have been difficult to reproduce [13].

We use 4CF as the standard procedure for SNAC and SLAC patients. PRC is an alternative in patients with intact lunate fossa



**Figure 3.** Follow-up radiographs prior to conversion. (a) 6 years healed 4CF, some radiolunate arthrosis. (b) Lateral projection demonstrates DISI position. (c) CT reveals massive arthrosis. (d) 18 months follow-up frontal radiographs healed 4CF in another patient, little/no arthrosis. (e) Irregular and narrowed joint surface, cysts and arthrosis on frontal CT projections.

and intact midcarpal joint (which we rarely see on preoperative CT). Examining radiographs alone will overlook degenerative changes visible on CT, clearly demonstrated in our patients both preoperatively and at final follow-up. Standard radiographs could not explain the pain experienced by the majority of patients we converted, while non-union (3) and increased radiolunate arthrosis on CT scans could. Only 1/3 of the non-unions in our material

was detected on plain radiographs emphasizing the higher precision of CT. Non-union and degenerative changes are probably underreported in studies relying on plain radiographs. Ozyurekoglu and Turner experienced the same, using CT in almost half their patients to confirm healing [14]. The additional information obtained by CT has been demonstrated in two studies evaluating degenerative changes after operated scaphoid non-

**Table 1.** Subjective outcome,  $n$  = patients,  $x$  = wrists, mean (SD).

QDASH ( $n = 23$ )	PRWHE ( $x = 28$ )	Pain radial rest ( $x = 28$ )	Pain radial activity ( $x = 28$ )	Pain ulnar rest ( $x = 28$ )	Pain ulnar activity ( $x = 28$ )
32 (23)	31 (21)	15 (21)	36 (29)	15 (22)	28 (27)

**Table 2.** Objective outcome,  $x$  = wrists, mean (SD).

AROM (in °, $x = 24$ )	Flexion (in °, $x = 24$ )	Extension (in °, $x = 24$ )	Radial deviation (in °, $x = 24$ )	Ulnar deviation (in °, $x = 24$ )	Supination (in °, $x = 24$ )	Pronation (in °, $x = 24$ )	Grip strength (in kgs, $x = 24$ )	Key pinch (in kgs, $x = 24$ )
92 (21)	25 (12)	34 (12)	18 (11)	15 (10)	85 (8)	83 (8)	29.6 (11.8)	7.9 (2.9)

**Table 3.** Clinical results compared to unoperated/normal opposite wrist in 11 patients,  $n$  = patients, mean (SD).

	AROM (in °)	Flexion (in °)	Extension (in °)	Radial deviation (in °)	Ulnar deviation (in °)	Jamar grip strength (kgs)	Key Pinch (kgs)	Supination (in °)	Pronation (in °)
Operated side ( $n = 11$ )	88 (27)	27 (15)	30 (14)	18 (13)	13 (11)	28.2 (13.1)	8.2 (3.0)	87 (5)	85 (7)
Non-operated side ( $n = 11$ )	233 (35)	76 (12)	75 (9)	37 (14)	45 (8)	37.0 (14.8)	8.6 (3.5)	88 (3)	85 (7)
$p$ -value	0.000	0.000	0.000	0.003	0.000	0.001	0.74	0.34	1.00

**Table 4.** Working status at surgery and at follow-up for the patients with 4CF.

	At surgery	At follow up
Blue collar	8	3
White collar	7	7
Retired	3	8
Disabled	5	5
Total	23	23

union patients. An increased SNAC grading in 15/42 and 6/14 when comparing radiographs and CT scans, also explained the difference in the clinical results, which emphasized the value of CT [15,16]. We suggest that CT should be obligatory in the follow-up after extensive wrist surgery.

Degenerative changes in the mid-carpal joint seen on CT should be a contraindication to PRC and reduces the number of patients eligible for PRC. Radio-capitate incongruence, increased contact pressure and reduced contact area, as well as translation within the carpus following PRC described in biomechanical studies [17] have made us somewhat hesitant to the procedure. The latest systematic review comparing the two methods found a higher complication rate, but better grip strength and radial deviation as compared to better flexion-extension arch for 4CF versus PRC [18], the review did not evaluate the patients arthritic stage.

We achieved a CT verified union-rate of 93% which is comparable to other fixation methods [13,14]. This is a higher union rate than reported using spider plates [7]. Not surprisingly, persistent non-union was a predictor for a poor clinical result and a high conversion rate in our material. Neubrach et al found a similar trend in their chart review of 594 4CF patients, demonstrating significantly higher conversion to total arthrodesis amongst the non-union patients [19]. The weakness of their study was the complete follow-up of less than 10% of the patients. Although successful union is an important predictor for good clinical function, high union rate does not guarantee good results. Siegel et al achieved union in all operated 4CF patients but converted 4 out of 11 wrists within 3 years after fusion due to continuous pain [20]. Dacho et al. converted 6/43 patients after 4 years, reporting residual pain (>50 at activity) and DASH = 35 in the remainder. The follow-up comprised 55% of the initial population operated. The majority of studies report some residual pain and reduced AROM and grip strength compared to the contralateral side. AROM of 110° around neutral is considered functional, rendering

minor difficulties in activities of daily living [21]. Cohort studies and reviews on 4CF consistently report AROM between 80 and 90° [1,5,18], better than AROM 110° is anecdotal. The patients can expect a reduced AROM which gives functional limitations after 4CF.

If the surgeon avoids using circular plates [5,6,8], the different modes of fixation renders similar clinical and radiological results. K-wires are cheap, easily inserted and removed and a good alternative for fixation. K-wires should be cut short and buried under the skin [5] to reduce skin perforation and local infections. To avoid later osteosynthesis removal the use of headless compression screws or staples may be an alternative [13,14].

Kitzinger et al found the source of bone graft to be independent of the non-union rate [22]. In our series we used local host bone (scaphoid/radius) in 75% of the cases and iliac crest bone in the remainder. The three non-unions had scaphoid bone grafts in two and crista graft in one. The union rate in our patients was independent of the source of bone graft, and the advantage of local bone graft reducing the associated donor-site morbidity and pain has led to a shift in our praxis, now limiting bone graft to local bone (ie scaphoid/radius) in accordance with the findings of Kitzinger et al.

We noticed an increased degeneration during the follow-up period, we converted 13/42 wrists, and one patient is awaiting conversion, which gives a total conversion rate of more than 30%. We found DISI malposition as a major predictor for later conversion, out of 8 patients with a union in DISI position, 6 were converted. A lunate in extension gives impingement on the dorsal part of the radius and maintains the malposition of the proximal row, the cause of SLAC/SNAC degeneration in the first place. Residual pain and functional disability were seen in most of the patients in our long term follow-up, while the absence of arthrosis on CT yielded a better outcome.

A majority of the studies with longer follow-up rely on telephone interviews and some outpatient clinical examination without any radiological follow-up [13]. This could overestimate the clinical result and underestimate the patients' problems. We saw more problems than we expected, and we now routinely do follow-up after 1, 2- and 5-years offering conversion to patients with persistent pain. Whether the degeneration inevitably progresses unaffected by the surgery or it is the reduced area for load-transmission that sparks the degeneration is difficult to determine. In



**Figure 4.** Follow-up 18 years after 4CF. (a,b) Frontal and lateral radiographs reveal arthrosis and DISI malposition. (c) Frontal CT confirms extensive arthrosis.

scaphoid non-union surgery the degeneration is slowed down by successful surgery [15] indicating that reduced area for load transmission is a major contributor to the increased degeneration. In our series, the lunate/DISI position was a substantial factor, but this has not been evaluated by others either due to lack of follow-up radiographs, high numbers of telephone interviews or a high number of drop outs. The follow-up study of 60/594 wrists by Neubrech et al after 15 years demonstrated radiolunate degeneration in 67% on standard radiographs [19]. They postulated an inevitable increase in degeneration with time. The patients comprised 10% of the initial cohort operated, rendering extrapolation of the results uncertain.

The major limitation of this study is the retrospective design and the lack of a comparative group. We did not systematically evaluate wrist or forearm motion, grip or pinch strength, nor pain levels preoperatively. QDASH and PRWHE were not available at the time of surgery. The strength of the study is the relatively high number of patients and high rate of follow-up, the long follow-up time, and the combination of subjective, objective, and radiological parameters that were evaluated.

### Conclusion

K-wire fixation of 4CF gives satisfactory a predictable union rate, pain control, functional motion and postpones total wrist arthrodesis or wrist arthroplasty for the majority of patients, but they can expect some residual pain and reduced wrist function. A relatively high conversion rate and increased degenerative changes in the load-bearing radiolunate joint with time is concerning and limited arthrodesis should be postponed if possible. The follow-up revealed patients with substantial wrist problems, and the 4CF patients should be following up regularly.

### Disclosure statement

None of the authors have conflicts of interest to declare regarding this paper.

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