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HANDSURGERY

Clinical outcome of rearthrodesis in cases of non-union following four-corner fusion

Frank Unglaub · Stefanie Manz · Franck Marie Leclère · Adrian Dragu · Peter Hahn · Maya B. Wolf

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Abstract
Purpose Four-corner fusion is a proven treatment option for degenerative arthritis of the wrist (SLAC/SNAC); however, in some cases, non-union occurs. The purpose of this study was to evaluate the clinical outcome of rearthrodesis in cases of non-union following four-corner fusion. Furthermore, the goal was to identify the cause of non-union and the location of pseudarthrosis within the fusion.
Methods Seven patients (5 males, 2 females) who experienced pseudarthrosis following a four-corner fusion procedure and subsequently elected a rearthrodesis procedure were clinically and radiologically examined. The average age was 58 years (range 48–71 years). Average follow-up after rearthrodesis was 27 months (range 4–60 months). All patients experienced persistent wrist pain and non-union was diagnosed via radiography or CT scan. Range of motion, grip strength, the Modified Mayo Wrist score, and the DASH score were evaluated. The level of pain was determined by using a visual analogue scale. Patients were also asked whether they were satisfied with the procedure and if they would elect it again.
Results In all patients, the rearthrodesis procedure led to proper bone consolidation, which was verified by radiological examination. Due to persistent wrist pain, one patient required additional procedures (denervation, wrist arthroscopy). In four cases, the location of pseudarthrosis occurred between the triquetrum and hamate. In three cases, the location of pseudoarthrosis was between the capitate and lunate and, additionally, between the triquetrum and hamate. The average DASH score value was 38 and the average Modified Mayo Wrist score was 66. Grip strength was reduced to 85 percent of the contralateral, unaffected side. Three patients indicated that they are dissatisfied with the results and would not elect the procedure again.
Conclusions The most frequent location of pseudarthrosis was between the triquetrum and the hamate, which was caused by incomplete cartilage debridement. Proper bone consolidation could be attained by means of rearthrodesis in cases of non-union following four-corner fusion. However, clinical results remain only moderate.

Keywords Four-corner fusion · SLAC · SNAC · Rearthrodesis · Wrist score

F. Unglaub (✉) · S. Manz · F. M. Leclère · P. Hahn · M. B. Wolf
Department of Hand Surgery, Vulpius Klinik,
Vulpiusstrasse 29, 74906 Bad Rappenau, Germany
e-mail: unglaub@vulpiusklinik.de

F. Unglaub
Medical Faculty Mannheim, University of Heidelberg,
Mannheim, Germany

A. Dragu
Department of Plastic and Hand Surgery,
University of Erlangen, Erlangen, Germany

M. B. Wolf
e-mail: wolfwolf2000@yahoo.com

Introduction

Four-corner fusion (4CF) was introduced by Watson et al. [1] in the early 80s. It is a common, motion-preserving, salvage procedure for the treatment of wrist arthrosis. Mainly, this procedure is performed in cases of symptomatic scaphoid non-union (SNAC) [2] or advanced scapholunate collapse (SLAC) [3]. It is also a proven treatment option for degenerative arthritis of the wrist [4–7]. For good clinical results, bone consolidation at least between the lunate versus capitate and the triquetrum versus hamate is a prerequisite

[8]. The use of K-wire fixation with subsequent removal, staples, screws and spiderplate osteosynthesis are possible options to attain 4CF [9–14]. Many studies describe the clinical outcome of successful arthrodesis or rates of non-union following 4CF [15–19]. However, only very few studies deal with the treatment options for non-union following 4CF [20–23]. The goal of this study was to evaluate the clinical outcome of rearthrodesis in cases of non-union following 4CF. Additionally, this study aimed to identify the cause of non-union and the location of pseudarthrosis within the wrist.

Methods

Surgical technique

Four-corner fusion

The operation was conducted under regional or general anaesthesia. A pneumatic tourniquet was routinely used with a mean pressure of 300 mmHg. The primary 4CF was done by means of a dorsal approach to the wrist with a lazy S, followed by a mobilisation of the retinaculum and an opening of the second, third and fourth tendon compartment. After resecting the posterior interosseous nerve, the scaphoid was removed and the articular cartilage between capitate, lunate, hamate and triquetrum was resected. The correction of intercarpal malposition (DISI) was achieved by using a K-wire as a joystick and a rongeur (see "Discussion"). This was followed by the interposition of cancellous bone grafts from the radius. Internal fixation with at least two Kirschner wires (1.6 mm) was achieved by inserting them from the distal to the proximal end of the capitate and lunate, respectively, hamate and triquetrum. A forearm cast had to be worn for 6–8 weeks.

A radiological examination was followed after 6 weeks to ensure a proper bone consolidation progress. Active and passive exercises were allowed as soon as full bone consolidation was reached. The K-wires were removed 2–3 months postoperatively.

Rearthrodesis

During the revision surgery, the scar and the extensor compartment, as well as, the scarred capsule were opened. The pseudarthrosis (Fig. 1) was resected far enough to see vital bone. Cancellous bone from the iliac crest was inserted and a K-wire fixation was performed following the correction of DISI or an ulnar translocation.

Evaluation

Between 2003 and 2010, 221 patients underwent 4CF at our clinic. In six patients, a rearthrodesis based on a pseudarthrosis had to be performed. One additional patient with pseudarthrosis was referred to us from another clinic. In three patients, the 4CF was indicated due to SLAC, and in three patients due to SNAC. In one patient, the indication remained unclear. The diagnosis of pseudarthrosis was made by radiography and CT scan (Figs. 2, 3a, b). The demographics of the patients are given in Table 1. All clinical evaluations included the following parameters: range of motion (ROM), grip strength, visual analogue scale pain score [24], Mayo Modified Wrist score (MMWS) [25] and patient-reported disabilities of the arm, shoulder and hand score (DASH) [26–28]. ROM was measured using a standard goniometer. Grip strength was determined on the affected side, as well as, the unaffected, contralateral side.

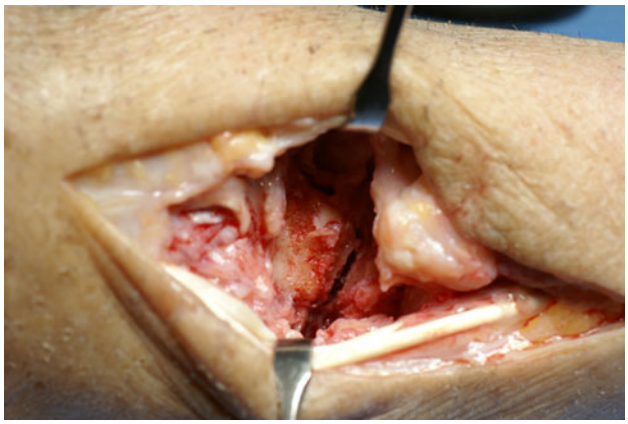

Fig. 1 Intraoperative view of the non-union between triquetrum and hamate

Fig. 2 Radiograph of non-union in four-corner fusion (anteroposterior)

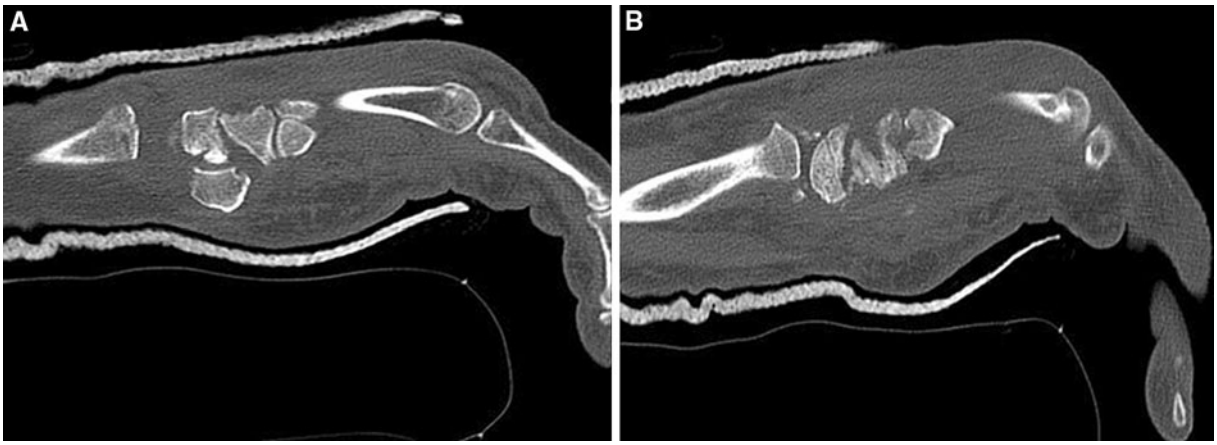

Fig. 3 **a** CT scan (sagittal) non-union between triquetrum and hamate **b** CT scan (sagittal) non-union between lunate and capitate

Table 1 Patient demographics

Patient	Age	Sex	SLAC/SNAC	Profession	Injured side (is)	Dominant hand	Time period between 1st and 2nd 4CF (months)	Time between last OP and follow up examination (months)
1	49	M	?	Craftsman	R	R	144	60
2	49	M	SNAC	Policeman	R	R	4	18
3	69	M	SNAC	Retiree	L	R	14	60
4	63	M	SLAC	Retiree	L	R	8	18
5	48	W	SLAC	Educator	R	R	6	24
6	71	M	SNAC	Retiree	L	R	3	4
7	59	W	SLAC	Housewife	R	R	12	60

R right, *L* left

This was done using the Jamar™ dynamometer at level 2 (Sammons Preston, Inc., Bollingbrook Illinois). Pain, as measured on a visual analogue scale, was defined as exertional. Patients were asked whether they were satisfied with the procedure and if they would re-elect it. A clinical and radiological examination of the rearthrodesis was conducted after an average of 27 months (range 4–60 months) postoperatively.

Results

In all patients, the rearthrodesis led to proper bone consolidation following the first revision. However, in one patient, the lunate showed evidence of partial necrosis. Another patient required additional procedures due to persistent wrist pain (denervation, wrist arthroscopy). All other patients rejected further surgical interventions. In four cases, pseudarthrosis occurred between the triquetrum and hamate. In the other three cases, however, it was located between the capitate and lunate and, additionally, between the triquetrum and hamate. The DASH score was on average of 38 (range 14–68), and the MMWS reached an average value of 66 (range 20–95). On average, grip strength was reduced to 85% of the contralateral, unaffected side. Even though the procedure reduced the functionality of the wrist, none of the patients required a professional re-education. When asked if the patients were satisfied with the procedure, three indicated that they were not. These same patients expressed that they would not re-elect rearthrodesis. Two patients complained of persistent pain and decreased functionality of the hand. One patient saw no improvement following the procedure. In particular, patients complained of the prolonged treatment time and the fact that a wrist cast had to be worn for a total of 13.7 weeks on average. Further clinical results are given in Tables 2 and 3.

Discussion

The rate of pseudarthrosis following 4CF by means of traditional osteosynthesis is between 3 and 9% [15, 22, 29, 30]. Till date, however, only few publications deal with the consequences and treatment options available for this particular complication.

Table 2 Clinical results

Patient	Total time of immobilization (weeks)	DASH	MMWS overall	SLAC/SNAC	Professional re-education necessary	Pain	Function	Satisfied?	Would patient re-elect the procedure?
1	10	22	60	?	No	Improved	Improved	Yes	Yes
2	16	53	50	SNAC	No	Impaired	Impaired	No	No
3	12	14	95	SNAC	No	Improved	Improved	Yes	Yes
4	12	25	90	SLAC	No	Improved	Improved	Yes	Yes
5	16	68	20	SLAC	No	Consistent	Consitent	No	No
6	14	25	85	SNAC	No	Improved	Improved	Yes	Yes
7	16	60	60	SLAC	No	Impaired	Impaired	No	No

MMWS Modified Mayo Wrist score

Table 3 Grip strength (kg) and ROM (°), injured side (is), unaffected side (as)

Patient	Ø grip strength (is)	Ø grip strength healthy side (as)	Grip strength % of as	Ex hs	Flex hs	Ex is	Flex is	Ulnarabd as	Rabd as	Ulnarabd is	Raabd is
1	47.3	53.3	88	85	60	40	30	40	30	40	20
2	34.3	40	86	70	85	45	35	60	30	35	20
3	36.7	39.3	93	40	40	35	50	30	10	30	10
4	32	34	94	50	50	50	45	30	0	30	20
5	22.7	37.3	61	90	70	55	40	60	10	45	0
6	33.5	41.3	81	60	75	40	40	20	10	20	10
7	20.3	22	92	35	50	20	30	25	15	20	10

Ex extension, *Flex* flexion, *Ulnarabd* ulnarabduction, *Radialabd* radialabduction

Fig. 4 Schematic drawing illustrating the importance of careful resection at the ulnar border between the hamate and triquetrum to enable full reduction of the carpal bones [22]. Courtesy of Thieme-Verlag, Stuttgart, Germany

This study shows that moderate clinical results can be achieved by performing a rearthrodesis procedure in such cases. When compared with clinical outcomes of 4CF with direct union, our results clearly show a decreased DASH and MMWS [15–18]. Grip strength and ROM results are decreased, as well, when compared with the respective results of direct union following 4CF. In addition, functionality of the wrist is limited when the patient performs daily activities. The results of our study showed most cases of non-union are located between the hamate and triquetrum (4 cases). One reason that this particular location is so frequently involved in pseudarthrosis is that it is often difficult to reach via the rongeur. This can lead to incomplete cartilage removal, thus impeding proper bone consolidation. Tünnerhoff and Haussmann [22] pointed out the importance of careful and complete resection of the very ulnar part between the triquetrum and hamate to enable full reposition of the four carpal bones (Fig. 4).

The importance of a correct and full reduction of the lunate from the DISI position is well known. Frequently, the lunate is fixed in a DISI position, which yields poor clinical results of 4CF and causes an increase of its non-union rate. As a result, reduction of the lunate to its neutral position is an important step and a prerequisite not only for proper bone consolidation, but also to improve postoperative wrist flexion and a reduction of pain. By ensuring a correct reduction, an impingement of the capitate against the dorsal rim of the radius can be avoided [31]. K-wire fixation as a joystick can bring about the reduction of the lunate. However, using the K-wire, it is often difficult to reach a neutral position because of adhesions of the lunate to the palmar capsule. For this reason, we recommend using

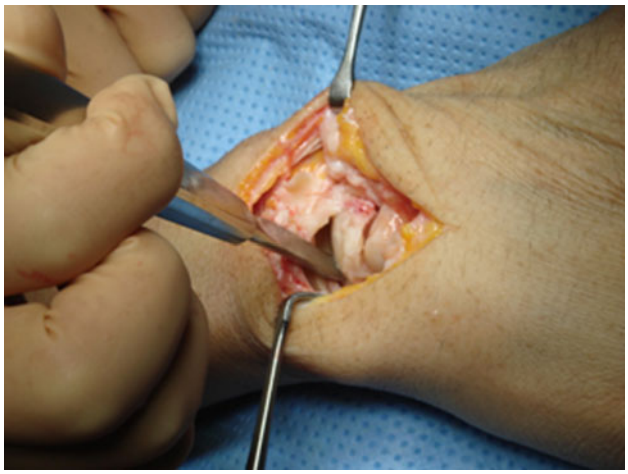

Fig. 5 Under wrist distraction, a rongeur is being inserted into the radiocarpal joint between the lunate and lunate fossa

Fig. 6 Intraoperative neutral position after reduction of the lunate (lateral view)

a rongeur for the reduction manoeuvre. Following the exposure of the carpal bones and excision of the scaphoid, a rongeur is inserted into the radio-carpal joint between the lunate and lunate fossa of the radius. This is done under wrist distraction. One must be sure to place the rongeur deeply into the joint to dissolve all adhesions (Fig. 5). Also, the lunate needs to be leveraged with a curved movement against the radius, so that the dorsal tilt of the lunate is corrected (Fig. 6). We have found that this manoeuver facilitates lunate reduction and improves the clinical results of 4CFs. Additionally, it leads to a reduction of non-union rates.

Conventional radiographs are of limited use in the detection of non-unions in 4CFs. It is particularly difficult to diagnose the cases of non-union when a spider plate osteosynthesis was performed. A CT scan proves more reliable in detecting non-unions, especially, when this particular type of osteosynthesis is involved [32]. This finding could be confirmed in this study. As a result, we recommend performing a CT scan, in particular, in unclear cases.

A systematic review by Mulford et al. [4] suggests that the results for grip strength, pain relief and subjective outcome are comparable for proximal row carpectomy (PRC) and 4CFs. Furthermore, Mulford et al. could show that PRC result in a higher rate of postoperative osteoarthritic changes than 4CFs. Four-corner fusions, however, were associated with more complications overall due to non-union, dorsal impingement, and complications related to surgical hardware [4].

Purported advantages of plate fixation in context of a spider osteosynthesis include a more stable fixation, a reduction of the non-union rate, and a shorter immobilization time overall [5]. Strauch [5], however, stated that plate fixation results in higher non-union and reduced wrist motion.

Capitolunate arthrodesis is an alternative to 4CF and showed better results with respect to ROM, grip strength, DASH score, and visual analogue scale values [33]. Ferreres et al. [34] recommended capitolunate arthrodesis with no excision of the triquetrum so as to not impair proprioceptive function (radiotriquetral ligaments). However, non-unions are associated with this technique, as well.

In literature, we found no studies comparing radius versus iliac bone grafting for non-union rates in 4CF. Based on our clinical experience, we suggest using bone grafts from the distal radius for the first procedure. This is an effective method, which is associated with only minimal complications [35]. The rearthrodesis procedure, however, often requires a larger quantity of cancellous bone, which is why we prefer using bone grafts from the iliac region in this instance.

All in all, we performed 221 4CFs in a large group of patients, which included rather younger patients. Interestingly, however, we observed that non-union tends to occur in older patients. The average age of our study's patient collective was 58 years. Age is a relevant factor, as cancellous bone from the distal radius tends to be of limited supply in an older age group. As a consequence, an iliac bone grafting might be indicated even for the first procedure. In addition, when treating older patients, it is worthwhile to consider performing a PRC rather than a 4CF. Literature shows that PRC is often a treatment option with good clinical results and should be considered, in particular, in older patients because it does not involve any type of arthrodesis. However, a disadvantage of the PRC is that the capitate may not exhibit any signs of arthrosis.

With either PCR or 4CF, it is critical to perform a thorough debridement of the adjacent joint surfaces so as to remove all debris prior to fixing the carpal bones.

All in all, 4CF is a proven treatment option, especially in SLAC/SNAC grade III with osteoarthritis at the capitate. In cases of non-union, a rearthrodesis procedure can lead to proper bone consolidation, but only moderate clinical results.

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