



Four-corner fusion: Comparing outcomes of conventional K-wire-, locking plate-, and retrograde headless compression screw fixations



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KEYWORDS

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Summary Purpose: Several operative approaches and various implants for osseous fixation have been described to achieve four-corner fusion of the wrist. Given the discordance and to aid in further standardizing the technique, this study directly compares the outcomes of K-wire, fusion plate, and headless retrograde compressive screw fixations to achieve four-corner arthrodesis.

Methods: Sixty-four patients underwent four-corner fusion over a period of 5 years and were reviewed retrospectively. Twenty-one patients underwent bone fixation with conventional K-wires, 26 with locking plates, and 17 patients were treated by headless retrograde compressive screw fixations. Patients of the different groups were comparable regarding age, sex, hand dominance, and stage of disease.

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Results: All study groups showed significant improvements in grip strength, decrease in pain (NRS) at rest and with activity, range-of-motion of the wrist, and wrist function (measured by the DASH-score). When evaluating the three groups amongst each other, overall complication and nonunion rates were low and revealed no significant differences between the groups of patients. However, regarding postoperative NRS at activity, dorsal flexion, and DASH-scores, the “screw” group showed significantly better results than the “wire” group.

Conclusion: The results show that all examined techniques of four-corner fusion can improve wrist function when compared to preoperative baseline (NRS at rest and activity, postoperative DASH-scores). However, headless retrograde compressive screw fixation had significant better results regarding pain relief (NRS) at activity and postoperative DASH-scores.

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Introduction

When treating scapho-lunate advanced collapse (SLAC) and scaphoid nonunion advanced collapse (SNAC) wrists, four-corner fusion (4CF) has been shown to have good results overall.¹ It allows for appropriate residual wrist motion and grip strength while reducing pain and wrist instability. Since Watson introduced the 4CF in 1986,¹ various fixation techniques have been described, including K-wire fixation,^{2,3} staples,^{4,5} plates,⁶⁻⁸ and headless screws.⁹⁻¹¹ Several authors reported different functional results and complication rates depending on the respective technique employed.^{1,2,4,6,12-15} Therefore, as of yet no standard technique exists for 4CF,⁹⁻¹¹ while K-wire fixation remains the one most frequently employed.¹⁵ K-wires provide an economical option; however, main disadvantages include the need of an additional surgery to remove the wires and the lower compressive pressure that can be achieved between the carpal bones.^{2,4} An alternative approach would be to consider to leave the wires exposed to avoid an additional surgery. However, this option may result in increased infection risk.^{2,4}

In 1999, a nonlocking plate was implemented,^{7,16-18} but several studies reported high complication rates, resulting in this technique being used less frequently.^{7,16-18} In 2011, Allison published good results using a compression plate with screws,⁷ and more recently, different authors reported on promising results using a specially designed locking plate (Aptus, Medartis, Basel, Switzerland).^{2,4,6,13} Also, in 2011, Richards et al. introduced 4CF using antegrade drilled headless compressive screws.¹⁰ Given various complications secondary to the drilling angle of the screws,¹⁹ several modifications have been suggested since.^{9,20} Main advantage of using locking plates or headless screws is a theoretically stable fixation, allowing for increased stability and faster as well as higher fusion rates, thus resulting in a better active range of motion (ROM).^{6,20-22}

Given the discordance regarding the different techniques and the fact that to date no uniformly accepted standard approach exists, the presented study aimed at directly comparing the mid-term functional outcomes of K-wire, fusion-plate, and headless retrograde compressive screws fixations to achieve 4CF of the wrist.

Materials and methods

The study protocol conformed to the guidelines of the 1975 Declaration of Helsinki, the STROBE guidelines and was

presented to the local medical ethics committee, which granted a waiver. Over a period of five years, 64 patients (59 male and 5 female) underwent 4CF for the treatment of SLAC- or SNAC wrists and were analyzed. Patients were treated by either conventional K-wire (21), Aptus-plates® (Aptus®, Medartis, Basel, Switzerland) (26) or retrograde headless compression screw fixations (17). Radial bone graft was used in each case. Individual patient allocation was done by personal preference of the surgeon.

Medical files and patient data were evaluated retrospectively. There were no distinct exclusion criteria. However, a complete preoperative dataset for every patient to be included was mandatory. The cases were divided into three groups depending on the employed techniques. The patient groups were comparable regarding age, sex, hand dominance, origin of disease (SLAC vs. SNAC wrist), and the length of follow-up (Table 1). All patient groups were equivalent in terms of preoperative grip strength, ROM (palmar as well as dorsal flexion), NRS (at rest as well as activity), and DASH score.

Regarding the surgical approach, the techniques of conventional K-wire fixation (Figure 1),¹ Aptus-plate® (Figure 2(A) and (B))², or retrograde headless compression screws (Figure 3)²⁰ were performed in previously described standard fashion. In short, K-wire fixation was performed by dorsoradial incision of the skin and release of the second, third, and fourth tendon compartments. Then, the mediocarpal articulating area was dissected until cancellous bone was visible. Finally, we placed 3K wires into the carpal bones (2 capitate/lunate and 1 hamate and triquetrum) from distally. Aptus-plates®: incision and dissection were performed as described above. The plate panel was then milled from dorsally. Finally, screws were set from dorsally as well, fixating all carpal bones to the plate. Retrograde headless compression screws: Incision, dissection and K-wire placement were performed as described above. Then, K-wires were replaced by screws.

The fixation method for each patient was elected by the performing surgeon; there was no standardization for choosing one of the fixation techniques. After surgery, the wrist was immobilized by a volar forearm cast including the thumb MP-joint and sparing the finger MP-joints.

Mobilization

Suture removal and X-ray control were performed 14 days postoperatively in all cases. In the “screw” and the “plate”

Table 1 Demographic parameters.

	K-wires	Aptus-plate® ^a	Compressive screws	<i>p</i>
<i>n</i> (64)	21	26	17	
Age (years) (median)	58 (54-74)	55 (49-72)	50 (49-69)	< 0.001
Sex (male: female)	19: 2	24: 2	16: 1	1.00
Dominant hand	6: 15	4: 12	7: 10	0.469
SLAC ^b : SNAC ^c	13:8	15: 11	13: 4	0.486
Follow-up (months) (median)	35 (24-52)	31.5 (24-49)	27 (24-41)	0.011

^a Aptus®, Medartis, Basel, Switzerland.

^b Scapho-lunate advanced collapse.

^c Scaphoid nonunion advanced collapse.

Table 2 Comparison of median preoperative data to underline that the groups were comparable.

	K-wires	Aptus-plate® ^a	Compressive screws	<i>p</i>
<i>n</i> (64)	21 Preoperative	26 Preoperative	17 Preoperative	
Grip strength (kg)	16.9 IQR ^d 10.6	21.7 IQR ^d 14.4	21.4 IQR ^d 12.4	0.544
Palmar flexion	20.0 IQR ^d 9	20.0 IQR ^d 21	19.0 IQR ^d 8	0.994
Dorsal flexion	18.0 IQR ^d 9	20.0 IQR ^d 15	20.0 IQR ^d 15	0.600
NRS ^b (at rest)	6 IQR ^d 2	7 IQR ^d 3	6 IQR ^d 3	0.281
NRS ^b (activity)	8 IQR ^d 3	8 IQR ^d 2	8 IQR ^d 2	0.843
DASH ^c score	70.3 IQR ^d 32.2	72.6 IQR ^d 19.9	74.2 IQR ^d 26.3	0.464

^a Aptus®, Medartis, Basel, Switzerland.

^b Numerical rating scale.

^c Disability of Arm, Shoulder, and Hand.

^d Interquartile range.

groups, immobilization of the wrist was discontinued 21 days after surgery and passive physical therapy was started. After an additional 7 days, passive and active physical therapy of the wrist was initiated. Seven weeks after surgery, a CT-scan of the wrist was performed and evaluated by the responsible surgeon in conjunction with the radiologist to better determine union and bony consolidation. If bone consolidation could be confirmed from the scan, sports and strenuous physical activities were allowed immediately.

In the “wire” group, the wrist was immobilized including the thumb MP-joint and sparing the finger MP-joints for a total of 6 weeks after surgery, at which point physical therapy was started. Approximately 8 weeks after surgery, X-ray was performed and, in case of adequate consolidation, the wires were removed with a short out-patient surgery under local anesthesia. After an additional 12 days of rest to allow for wound healing, passive and active physical therapy of the wrist was started.

Follow-up

All patients underwent standardized pre- and postoperative exams by two senior hand surgeons. The examinations included measurements of ROM of the wrist by means of a goniometer (dorsal vs. palmar flexion). Grip strength was measured with a dynamometer (Jamar dynamometer; Sammons, Preston Roylan, Bollingbrook Illinois) in kilogram (kg). CT-scans were performed and evaluated by the radiologist and the two hand surgeons. Subjective outcomes were assessed with the Numerical Rating Scale (NRS 0-10) at rest as well as activity and the DASH (Disability of Arm, Shoulder and Hand) score (0-100). All patients had at least one two-year follow-up exam.

Statistical tests

For patient age, follow-up months, grip strength, operative times, ROM (palmar and dorsal flexion), NRS at rest



Figure 1 Postoperative wrist radiographs anterior/posterior (right) and lateral (left) view: four-corner fusion with conventional K-wire.

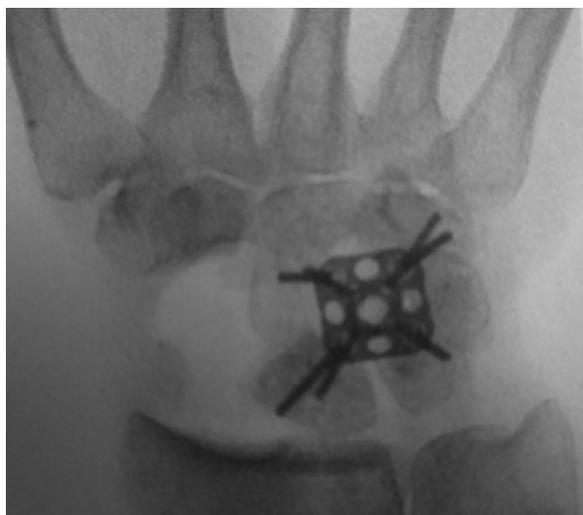


Figure 2 (A) Postoperative wrist radiographs anterior/posterior view: bone fixation in case of four-corner fusion with Aptus-plate® (Aptus®, Medartis, Basel, Switzerland). (B) Postoperative wrist radiographs lateral view: bone fixation in case of four-corner fusion with Aptus-plate® (Aptus®, Medartis, Basel, Switzerland).

and activity as well as DASH scores, median and interquartile range (IQR) or range were set. Differences between the three treatment approaches for 4CF were determined using the Kruskal-Wallis test. In case of significant different results, Bonferroni-corrected post-hoc pairwise comparison was performed. Inner group differences between pre- and postoperative values were assessed using the Wilcoxon test for grip strength and ROM and the sign test for NRS and DASH scores.

Chi-squared analysis with Fisher's exact test assessed differences in patients' sex, dominant hand, and underlying wrist disorder (SLAC or SNAC) between the three techniques for CF4. Data were collected and analyzed using Microsoft Excel (Microsoft Corp., Redmond, Wash.). All statistical analyses were performed using IBM SPSS version 24 (IBM Corp., Armonk, N.Y.). Statistical significance was defined for p-values of <0.05 . Power analysis was performed using G-Power.²³

Results

The study included 64 patients, (59 males and 5 females; median age: 55 range 49-74 years) divided into three groups. The "K-wire" group included 21 patients



Figure 2 (continued)

(19 males and 2 females; median age: 58 years, range 54-74 years). Median follow-up time for this group was 35 (range 24-52) months. In the “plate” group, 26 4CF’s were performed with Aptus-plates® (24 males, 2 females; median age: 55 years, range: 49-72 years), with a median follow-up of 31.5 (range 24-49) months. The “screw” group included 17 patients (16 males and 1 female; median age: 50 years, range 49-69 years). Median time for follow-up was 27 (range 24-41) months in this group. The statistical analysis revealed significantly longer follow-up in the “wire” compared to the “screw” group ($p=0.010$; power=0.98) without any difference between “wire” and “plate” ($p=0.986$; power=0.29) as well as “plate” and “screw” group ($p=0.093$; power=0.92) (Table 1).

Median operative time was significantly longer in the “plate” group than in the “wire” and “screw” group (median 120 IQR 29 vs. median 62 IQR 14; $p < 0.001$; power = 1; median 120 IQR 29 vs. 67 IQR 21; $p < 0.001$; power = 1). Meanwhile, the comparison of operative times between the “screw” and “wire” group did not reveal a significant difference in operative times ($p = 0.582$; power = 0.97).

The pre- and postoperative data are shown in Table 3, respectively. Compared to the preoperative findings, every study group showed a significant improvement in grip strength ($p < 0.001$, power = 0.92-0.97), a significant decrease in pain (NRS) at rest as well as pain with activity ($p < 0.001$; power = 1), and a significant improvement in overall function of the wrist (measured by the DASH-score)

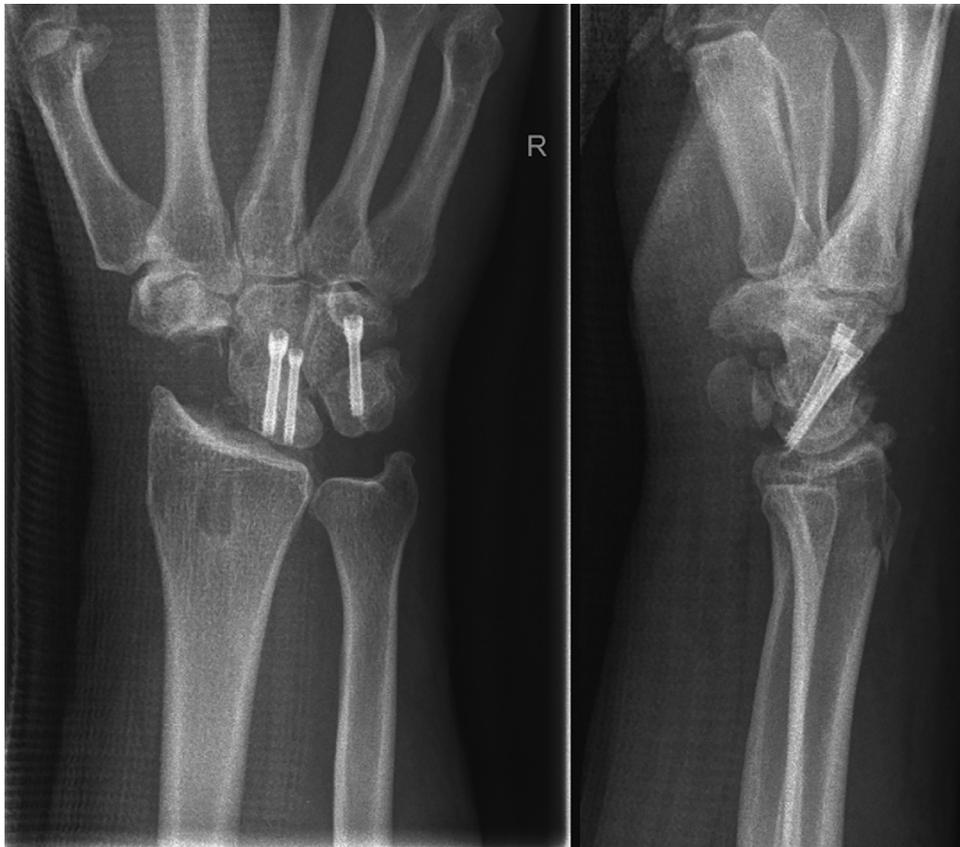


Figure 3 Postoperative wrist radiographs anterior/posterior (right) and lateral (left) view: showing the final position of the headless retrograde compressive screw fixation.

Table 3 Comparison of median operative times as well as pre- and postoperative examination results.

	K-wires			Aptus-plate® ^a			Compressive screws		
<i>n</i> (64)	21			26			17		
Operative time (min.)	62			120			67		
	IQR ^d 14			IQR ^d 29			IQR ^d 21		
	Preoperative	Postoperative	<i>p</i>	Preoperative	Postoperative	<i>p</i>	Preoperative	Postoperative	<i>p</i>
Grip strength (kg)	16.9 IQR ^d 10.6	26.4 IQR ^d 9.9	<0.001	21.7 IQR ^d 14.4	28.3 IQR ^d 13	<0.001	21.4 IQR ^d 12.4	29.3 IQR ^d 8.8	<0.001
Palmar flexion	20.0 IQR ^d 9	25.0 IQR ^d 9	0.004	20.0 IQR ^d 21	25.0 IQR ^d 19	<0.001	19.0 IQR ^d 8	29.0 IQR ^d 9	<0.001
Dorsal flexion	18.0 IQR ^d 9	20.0 IQR ^d 12	<0.001	20.0 IQR ^d 15	23.0 IQR ^d 15	<0.001	20.0 IQR ^d 15	28.0 IQR ^d 8	0.001
NRS ^b (at rest)	6 IQR ^d 2	1 IQR ^d 1	<0.001	7 IQR ^d 3	0 IQR ^d 1	<0.001	6 IQR ^d 3	0 IQR ^d 1	<0.001
NRS ^b (activity)	8 IQR ^d 3	5 IQR ^d 3	<0.001	8 IQR ^d 2	3 IQR ^d 3	<0.001	8 IQR ^d 2	2 IQR ^d 2	<0.001
DASH ^c score	70.3 IQR ^d 32.2	31.2 IQR ^d 17.9	<0.001	72.6 IQR ^d 19.9	25.2 IQR ^d 17.9	<0.001	74.2 IQR ^d 26.3	8.6 IQR ^d 12.3	<0.001

^a Aptus®, Medartis, Basel, Switzerland.

^b Numerical rating scale.

^c Disability of Arm, Shoulder, and Hand.

^d Interquartile range.

Table 4 Comparison of median postoperative data to compare the effect of the different 4 CF techniques.

	K-wires	Aptus-plate® ^a	Compressive screws	<i>p</i>
<i>n</i> (64)	21	26	17	
	Postoperative	Postoperative	Postoperative	
Grip strength (kg)	26.4 IQR ^d 9.9	28.3 IQR ^d 13	29.3 IQR ^d 8.8	0.121
Palmar flexion	25.0 IQR ^d 9	25.0 IQR ^d 19	29.0 IQR ^d 9	0.121
Dorsal flexion	20.0 IQR ^d 12	23.0 IQR ^d 15	28.0 IQR ^d 8	0.014
NRS ^b (at rest)	1 IQR ^d 1	0 IQR ^d 1	0 IQR ^d 1	0.045
NRS ^b (activity)	5 IQR ^d 3	3 IQR ^d 3	2 IQR ^d 2	0.009
DASH ^c score	31.2 IQR ^d 17.9	25.2 IQR ^d 17.9	8.6 IQR ^d 12.3	0.001

^a Aptus®, Medartis, Basel, Switzerland.

^b Numerical rating scale.

^c Disability of Arm, Shoulder, and Hand.

^d Interquartile range.

($p < 0.001$; power = 1). Additionally, the comparison of pre- and postoperative dorsal and palmar flexion of the wrist showed a significant improvement ($p < 0.05$; power = 0.18–0.73) in all groups.

The comparison of postoperative data between the groups is demonstrated in Table 4. When evaluating the postoperative grip strength, no statistically significant differences were observed between all groups ($p > 0.05$). Regarding ROM, palmar flexion did not reveal any significant

changes between the groups, but dorsal flexion was significantly better in the “screw” group than in the “wire” group (median 28 IQR 8 vs. median 20.0 IQR 12; $p = 0.011$; power = 1).

Regarding the NRS at rest, initial statistical analysis revealed significant differences between the groups ($p = 0.045$; power = 1). However, the post-hoc test including Bonferroni-correction showed no significant difference between the groups ($p > 0.05$).

The comparison of NRS at activity showed significant improvement for the “screw” group compared to the “wire” group ($p=0.008$; power=0.98). However, the comparison between the “wire” and the “plate” group ($p=0.847$; power=0.29) as well as the “screw” and the “plate” revealed no significant difference ($p=0.095$; power=0.78).

Additionally, the “screw” group had significantly better postoperative DASH-scores than the “wire” group ($p<0.001$; power=0.98) and the “plate” group ($p<0.01$; power=0.99) group, while patients in the “plate” group had not statistically significant better DASH-scores than the patients in the “wire” group ($p=1.00$; power=0.32).

Complications

Overall, there was no significant difference between the three groups of patients regarding the rate of surgical complications during the follow-up time ($p>0.05$).

In the “wire” group, one patient suffered a nonunion and one patient an impingement because of wire displacement, requiring secondary surgery in both cases. Additionally, one patient had a postoperative wound infection around the insertion sites of the wires, which improved by daily wound cleansing without antibiotics. In the “plate” group, two revision surgeries had to be performed. One because of a nonunion and another one because of fracture of a bolt of the Aputs-plate®. In all cases, after revision surgery further follow-up was uneventful and the patients had good outcomes eventually. In the “screw” group, there occurred no complications.

Discussion

In 1986, Watson and Ballet initially described 4CF by the use of K-wires.¹ The technique of K-wire 4CF results in an acceptable rates of bone union, ranging from 84% to 97%.^{1,2,4,12-15} However, wires can also cause complications (e.g., migration, skin irritation or perforation, impingement with tendons, or joint gap formation), and a second surgery is needed to remove them.⁵ Within the presented study, three patients (14.3%) of the “wire” group suffered such complications during the follow-up. One patient had a nonunion and another impingement with joint gap formation because of displacement of the wires. In the first case, uneventful compressive screw 4CF was performed. In the other case, the disturbing K-wire was removed and not replaced. The encountered complications are comparable to the ones cited by other authors having examined the outcomes of K-wire 4CF.^{1,2,15} However, the analysis of complication rates between all three techniques did not reveal any statistical significant difference ($p>0.05$). Therefore, all techniques are equal regarding complication rates.

Besides the complications, another possible disadvantage after K-wire 4CF can be the prolonged need for immobilization, which may cause problems such as stiffness and restriction of wrist motion.^{4,5,21} Given the associated drawbacks of 4CF by means of K-wires, various authors promoted the use of small plates and screws to avoid nonfusion and to improve the functional outcomes.^{1,2,4} [6,10,12,15,20,21,24,25,26] Initially, nonlocking

plates were used.^{2,7,16-18} However, the results were disappointing because of significantly higher complication rates as well as higher nonunion rates than the traditional K-wire technique.^{7,16-18} Also, the postoperative immobilization period did not differ from the standard K-wire technique.^{17,18} With regard to the bony healing of the carpus, it is essential that there is a long-lasting stability. In contrast to other bones (e.g., long bones), especially in carpal bones, any kind of movement seems to have a negative effect on fusion that can potentially cause formation of pseudoarthrosis. Therefore, the authors concluded that the suboptimal results might be influenced by the nonlocking character of the device.^{7,16-18} Hence, different locking plates were designed and introduced for 4CF to promote long-lasting stable 4CF.² One of such locking plates is the low profile Aputs-plate®, which has been associated with good outcomes^{2,4,6,15} and allows for sufficient internal fixation and multidirectional screw positioning, promoting higher fusion rates, stability, shorter immobilization, and increased ROM compared to K-wire fixation.^{2,4,6,15} In contrast to the K-wire fixation, given the fact that screws can generate higher compression forces, larger contact surface can be generated, resulting in better stability with time.^{2,4,6,15} Possible described complications include nonunion, fracture of the bolts, and dorsal impingement.^{2,6} In our patients' having received Aputs-plate® 4CF, during mean follow-up of 33.8 (range: 24-49) months, two required revision surgery (7.7%). One patient showed a bone nonunion and another one a fracture of a bolt. In case of the nonunion and the fractured bolt, 4CF by the use of compressive screws and the removal and reinsertion of a different bolt were performed, respectively. In both cases, after revision surgery, follow-up was uneventful, and the patients had good outcomes.

Similar to the locking plates, different authors reported on 4CF using headless compression screws. However, most studies are limited to a description of the surgical technique only and, thus, have a low number of patients as well as lack of control groups.^{9,10,20,27,28} Two recent retrospective studies of 4 CF with headless compression screws showed good functional results and high fusion rates of 89% to 94%.^{21,22} Both studies concluded that compressive screw 4CF is a reliable technique with very good fusion rates, adequate alleviation of pain, improvement of grip strength, as well as good residual wrist motion and function.^{21,22} The technique exploits the theoretical advantages of strong compression between the carpal bones, resulting in improved stability, thus shorter immobilization and possible increased ROM compared to fusion-plates as well as compared to K-wire techniques.^{9,10,20-22} Another advantage of the headless screws consists in the fact that they are completely recessed in the bone and they do not affect the joint surface between the lunate, lunate fossa, and triquetrum as well as the TFCC.²⁹ Thus, the screws do not harm the joint surface,^{9,20,22} and there is no need for metal removal.²⁹ Additionally, plate fixation requires longer operating times, are more expensive, and are, therefore, possibly less favorable regarding cost-effectiveness.

In this study, patients having received 4CF with retrograde compressive screws were mobilized according to the Aputs-plate® protocol. Given the stability of the fusion because of the strong compression forces between the carpals, passive physical mobilization was started with lim-

ited ROM and reduced grip force as soon as 14 days after surgery. From the third week onward, active physical therapy of the wrist was possible. Following a CT-scan of the wrist seven weeks after surgery, after proven bony consolidation, sports and strenuous physical activities can be started. Compared to the other postoperative treatment regimen, this more aggressive protocol may improve function because it allows for early mobilization with minimal risk of motion between the bones and subsequent nonunion. In the “screw” group, during average follow-up of 28.8 (range: 24-41) months, there occurred no complications. No significant difference was seen with regard to complication and fusion rates between the examined techniques for 4CF, which in part could also be because of the relatively small sample size.

Regarding patient composition, our cohort of patients was similar to other reports.^{2,6,15,21,22} The condition predominantly affects middle-aged males (92.2%), mostly because of SLAC wrist formation (67.2%) (Table 1). Compared to the preoperative findings, all groups showed a significant improvement in grip strength ($p < 0.05$), a significant decrease in pain (NRS) at rest as well as with activity ($p < 0.0001$), and a significant improvement in function of the wrist (measured by the DASH-score) ($p < 0.0001$). Additionally, the comparison of pre- and postoperative ROM of the wrist showed a significant improvement for all groups ($p < 0.05$).

Surgical procedures that result in shorter times to fusion are associated with less muscle atrophy, less risk of formation of fascial- and tendon adhesions, and less neural disruption.^{6,15} However, contrary to our assumptions, the evaluation of grip strength yielded no significant differences for the “plate” and the “screw” groups compared to the “wire” group. (Table 3)

Additionally, we did not find a significant better active ROM in the “screw” group and/or the “plate” group than in the “wire” group. The average postoperative flexion-extension arc in our study was between 50° (wire) and 61° (screw), comparable to the 49° to 80° reported in the literature,^{14,18,20,22} which is important because the remaining postoperative wrist mobility is paramount to achieve good patient satisfaction and wrist function.²⁴

The pain scores (NRS) at rest as well as with activity improved significantly in all groups ($p < 0.001$). However, the postoperative NRS at rest showed no significant difference between the groups ($p > 0.05$). NRS with activity showed significant improvement for the “screw” compared to the “wire” group ($p = 0.008$). Between the “wire” and “plate” ($p = 0.847$) as well as the “screw” and the “plate” group ($p = 0.095$), no significant advantage was found for the plate. These results generally match the literature; however, especially the NRS results for the “screw” group are better than previously reported averages.^{6,14,16,18,22,24,29,30}

Regarding wrist function as assessed by the DASH-score, significantly better scores were found in the “screw” group than the “wire” group ($p < 0.001$) and “plate” ($p < 0.01$) group. Patients in the “plate” group achieved no statistically significant better DASH-scores than patients in the “wire” group ($p = 1.00$).^{2,6,14,15,18,22}

The nonunion rates of 4.8% in the “wire,” 3.8% in the “plate,” and 0% in the “screw” group are similar to reported technique-dependent nonunion rates of 0% to 63%

in the literature,^{8,14,16,18,22,27,30} and we could not detect a significant difference between the groups ($p > 0.05$). However, our nonunion rate might be falsely low or high because of the relatively short follow-up period, while it should be kept in mind that Bain and Watts demonstrated wrist ROM, function, and pain scores after 4CF at 10 years were not different from those at 1-year follow-up.³¹ Other limitations of the presented study lie in its retrospective design and, therefore, a possible subject to selection bias, the relative small number of patients, the bias, that these measurements were taken by the operating senior hand surgeon, the unstructured selection of operative technique, and the relatively short follow-up period.

Taken together, there currently does not yet exist a definite answer to which operative technique provides the best long-term benefits for patients suffering from SLAC or SNAC wrists. Large multi-center, prospective randomized studies would be helpful to elucidate this matter further.

Conclusion

The outcomes of our study suggest that all three techniques for 4CF improve functionality of wrist. With regard to grip strength, pain relief (NRS) at rest as well as complication and fusion rates all three techniques showed similar results. However, the technique of retrograde compressive screw 4CF shows better results in terms of pain relief (NRS) at activity as well as postoperative DASH-scores. Theoretically, because of the stability resulting from the strong compression between the carpal bones, with screw fixation fast postoperative mobilization is possible, which may improve function further. But it must be assumed that increased compression generated by screw fixation diminishes with time, and the type of fixation, thus, does not increase the surface area for fusion.

Conflict of interest

All named authors hereby declare that they have no conflicts of interest to disclose.

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References

1. Watson HK, Ryu J. Evolution of arthritis of the wrist. *Clin Orthop Relat Res* 1986;Jan(202):57-67.
2. Hernekamp JF, Reinecke A, Neubrech F, et al. Four-corner fusion: comparison of patient satisfaction and functional outcome of conventional K-wire technique vs. a new locking plate. *Arch Orthop Trauma Surg* 2016;136:571-8.
3. De Smet L, Deprez P, Duerinckx J, Degreef I. Outcome of four-corner arthrodesis for advanced carpal collapse: circular plate versus traditional techniques. *Acta Orthop Belg* 2009;75:323-7.

4. Pauchard N, Lecoanet-Strugarek C, Segret J, et al. Dorsal locking plates versus staples in four-corner fusion: a comparative clinical and radiological study. *Orthop Traumatol Surg Res* 2014;100:593-7.
5. Le Corre A, Ardouin L, Loubersac T, Gaisne E, Bellemere P. Retrospective study of two fixation methods for 4-corner fusion: shape-memory staple vs. dorsal circular plate. *Chir Main* 2015;34:300-6.
6. Chaudhry T, Spiteri M, Power D, Brewster M. Four corner fusion using a multidirectional angular stable locking plate. *World J Orthop* 2016;7:501-6.
7. Allison DM. A new plate for partial wrist fusions: results in midcarpal arthrodesis. *J Hand Surg Eur Vol* 2011;36:315-19.
8. Bedford B, Yang SS. High fusion rates with circular plate fixation for four-corner arthrodesis of the wrist. *Clin Orthop Relat Res* 2010;468:163-8.
9. Ball B, Bergman JW. Scaphoid excision and 4-corner fusion using retrograde headless compression screws. *Tech Hand Up Extrem Surg* 2012;16:204-9.
10. Richards AA, Afifi AM, Moneim MS. Four-corner fusion and scaphoid excision using headless compression screws for SLAC and SNAC wrist deformities. *Tech Hand Up Extrem Surg* 2011;15:99-103.
11. Henry M. Internal headless compression screw method for 4-corner fusion. *J Hand Microsurg* 2009;1:45-9.
12. Watson HK, Ballet FL. The SLAC wrist: scapholunate advanced collapse pattern of degenerative arthritis. *J Hand Surg Am* 1984;9:358-65.
13. Ashmead D, Watson HK, Damon C, Herber S, Paly W. Scapholunate advanced collapse wrist salvage. *J Hand Surg Am* 1994;19:741-50.
14. Cohen MS, Kozin SH. Degenerative arthritis of the wrist: proximal row carpectomy versus scaphoid excision and four-corner arthrodesis. *J Hand Surg Am* 2001;26:94-104.
15. Trail IA, Murali R, Stanley JK, et al. The long-term outcome of four-corner fusion. *J Wrist Surg* 2015;4:128-33.
16. Chung KC, Watt AJ, Kotsis SV. A prospective outcomes study of four-corner wrist arthrodesis using a circular limited wrist fusion plate for stage II scapholunate advanced collapse wrist deformity. *Plast Reconstr Surg* 2006;118:433-42.
17. Shindle MK, Burton KJ, Weiland AJ, Domb BG, Wolfe SW. Complications of circular plate fixation for four-corner arthrodesis. *J Hand Surg Eur Vol* 2007;32:50-3.
18. Vance MC, Hernandez JD, Didonna ML, Stern PJ. Complications and outcome of four-corner arthrodesis: circular plate fixation versus traditional techniques. *J Hand Surg Am* 2005;30:1122-7.
19. Schulze-Tanzil G. Activation and dedifferentiation of chondrocytes: implications in cartilage injury and repair. *Ann Anat* 2009;191:325-38.
20. Ehl D, Erne H. Four-corner fusion using retrograde headless compression screws. *Handchir Mikrochir Plast Chir* 2016;48:185-7.
21. Iordache SD, Nam D, Paylan J, Axelord T. Four-corner arthrodesis using two headless compression screws. *Acta Orthop Belg* 2016;82:332-8.
22. Ozyurekoglu T, Turker T. Results of a method of 4-corner arthrodesis using headless compression screws. *J Hand Surg Am* 2012;37:486-92.
23. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39:175-91.
24. Brinkhorst ME, Singh HP, Dias JJ, Feitz R, Hovius SE. Comparison of activities of daily living after proximal row carpectomy or wrist four-corner fusion. *J Hand Surg Eur Vol* 2016.
25. Collins ED, Nolla J. Spider plate fixation: no significant improvement in limited wrist arthrodesis. *Tech Hand Up Extrem Surg* 2008;12:94-9.
26. Rhee PC, Shin AY. The rate of successful four-corner arthrodesis with a locking, dorsal circular polyether-ether-ketone (PEEK-Optima) plate. *J Hand Surg Eur Vol* 2013;38:767-73.
27. Dutly-Guinand M, von Schroeder HP. Three-corner midcarpal arthrodesis and scaphoidectomy: a simplified volar approach. *Tech Hand Up Extrem Surg* 2009;13:54-8.
28. Korus LJ, Ball B, Morhart M. Exclusion of the hamate in 4-corner fusion: technique and outcomes of a novel approach to intercarpal arthrodesis. *Tech Hand Up Extrem Surg* 2013;17:102-5.
29. Mavrogenis AF, Flevas DA, Raptis K, et al. Four-corner fusion of the wrist: clinical and radiographic outcome of 31 patients. *Eur J Orthop Surg Traumatol* 2016;26:859-66.
30. Krakauer JD, Bishop AT, Cooney WP. Surgical treatment of scapholunate advanced collapse. *J Hand Surg Am* 1994;19:751-9.
31. Bain GI, Watts AC. The outcome of scaphoid excision and four-corner arthrodesis for advanced carpal collapse at a minimum of ten years. *J Hand Surg Am* 2010;35:719-25.