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HANDSURGERY

Functional and radiological outcome of distal radius fractures stabilized by volar-locking plate with a minimum follow-up of 1 year

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Abstract

Introduction Distal radius fractures (DRF) are the most common fractures of the upper extremities and incidence is expected to continue rising as life expectancy increases. Palmar locking plate stabilizing has since become the standard treatment for dorsally displaced DRF. Main aim of this study was to investigate correlation between radiological and clinical outcome in patients stabilized by palmar locking plate with a minimum follow-up of one year.

Methods A total of 524 patients with DRF, stabilized using palmar angular stable locking plate fixation were included in the study. Of these, 117 patients had to be excluded and another 177 were not accessible. The study group thus compromised 230 patients who returned for the follow-up investigation and were followed-up clinically and radiologically with a mean follow-up interval of 20 months. Outcome was evaluated using pain, range of motion (ROM) and grip strength parameters. In addition, self-assessment by patients was registered on the *Quick*DASH, PRWE and Mayo Score. The immediate postoperative and final checkup radiographs were scrutinized for alignment and intra-articular step-off.

Results Bivariant correlation analysis showed a significant correlation between ulnar variance and *Quick*DASH ($r=0.18$, $p=0.01$), grip strength ($r=-0.18$, $p=0.04$) and Mayo Score ($r=-0.23$, $p=0.001$). No significant differences could be found between an unacceptable (> 2 mm) and acceptable (< 2 mm) ulnar variance in respect of pain, ROM, grip strength and patient-reported outcome measurements. Age, gender, additional fracture to the ulnar styloid, or type of postoperative immobilization showed no significant or clinical important impact on the final patient-reported outcome. No significant differences in incidence of complications, ROM or loss of reduction could be found in any patients over or under 65 years of age.

Conclusions Stabilization of DRF by palmar angular stable locking plate is a safe form of treatment and results in a good clinical and radiological outcome with low complication rate. Ulnar variance showed a significant correlation to grip strength, *Quick*DASH and Mayo Score, but an unacceptable ulnar variance (> 2 mm) was not associated with a worse clinical important outcome. Age (< 65/> 65 years), gender and type of immobilization had no impact on the complication rate or in the final functional or radiological outcome.

Keywords Distal radius fracture · Volar locking plate · Complications · Outcome · Radiological

Introduction

Distal radius fractures (DRF) are the most common type of fracture of the upper extremities and incidence is expected to rise due to a growing elderly population [1]. Especially white women over 60 years of age have a 15% higher lifetime risk of DRF, than men of similar age. In addition, DRF in the elderly are often associated with poor bone quality and osteoporosis [2–4].

Historically, DRF were conservatively treated by closed reduction and immobilization or K-wires. Following the introduction of palmar angular stable locking plates in the

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2000s and the excellent results using internal fixation, a treatment shift occurred away from K-wires or external fixator to palmar plate fixation. Thus, dorsally displaced DRF can be stabilized from palmar, without the increased risk of irritation to the extensor tendons [5–12]. In addition, stabilization by palmar locking plates provides enough stability to enable early active wrist rehabilitation without immobilization. Multiple studies showed a significantly improved functional outcome compared to immobilization and an early mobilization post-surgery has no increased risk of secondary loss of reduction and complications [13–15].

As incidence of DRF rises and the number of patients treated by palmar locking plate increases, literature remains interested in the optimal treatment method, clinical outcomes and complication rates [13, 16]. Complication rates after palmarly stabilized DRF are reported up to 39%, whereas other studies documenting outcome after DRF showed good functional and radiological results [5, 8, 17–22].

Main aim of this study was to investigate correlation between radiological and clinical outcome with a minimum follow-up of one year.

Materials and methods

Institutional review board approval was obtained for this retrospective follow-up study. All patients treated with a palmar angular stable locking plate from 01. January 2015 to 31. December 2016, that met inclusion/excision criteria, were included in this study and invited in writing and by telephone to attend the follow-up investigation. Three invitation letters were sent to each patient. Failure to reply after the third invitations was classified as a non-responder.

Written informed consent was obtained from all participating patients. They were treated exclusively at our hospital, which is certified as a European Hand Trauma Center by the Hand Trauma Committee of the Federation of European Societies for Surgery of the Hand (FESSH).

Indications for surgery included a displaced DRF with a dorsal tilt of more than 15 degrees, an intra-articular step of more than 1 mm, a radial shortening of more than 2 mm or an incongruency in the distal radioulnar joint in the standard radiographs.

Inclusion criteria stipulated: (1) follow-up interval of at least one year (2) age 18 or older, (3) isolated acute displaced DRF, (4) surgical procedure by open reduction and stabilization using only palmar locking plates. Exclusion criteria included: (1) below 18 years of age, (2) open fractures, (3) patients who received the palmar plate fixation in another hospital, (4) polytrauma, (5) additional injuries to the involved hand, (6) corrective osteotomies, (7) bilateral DRF, (8) DRF stabilized with additional k-wires, screws or external fixator, and (9) past injuries or diseases which could influence the outcome.

From 2015 to 2016, a total of 524 patients were stabilized by palmar locking plate. Of these, 117 patients had to be excluded (not eligible), 11 lived in another country and 25 refused to attend the follow-up investigation. Another 141 could not be contacted or did not respond after three written invitations. Therefore, the final analysis totalled 230 patients.

Surgical procedure

All procedures were performed using either general or regional anesthesia in a supine position, with fluoroscopic assistance and a pneumatic arm tourniquet of 250 mmHg.

A standard palmar-radial approach over the flexor carpi radialis tendon was chosen. The flexor carpi radialis tendon was retracted ulnarly and the forearm fascia was dissected. The pronator quadratus was incised radially and elevated off the radius.

The fracture was reduced under image intensification and, when necessary, temporarily fixed with K-wires. The angular stable plate (Medartis® Aptus® 2.5 trilock distal radius locking plate) was placed on the palmar aspect of the distal radius and initially fixed with a bicortical screw through the gliding hole. After ensuring exact positioning of the plate under image intensifier, the remaining plate holes were filled with angular stable screws. Care was taken that the screws at the articular surface were placed subchondrally to prevent dorsal protrusion. Screw length was taken 2 mm shorter to prevent a dorsal protruding. The pronator quadratus was sutured if possible. Previous studies already showed no influence of a pronator quadratus refixation on the outcome [23, 24]. Thus, a refixation was not analyzed.

In 209 patients the Medartis® Aptus® (Medartis®, Basel, Switzerland) 2.5 correction plate, in 14 the flexor pollicis longus (FPL) plate, in 5 the fracture plate and in 2 the adaptive plate was used.

Carpal tunnel release was only performed if the patients showed preoperative symptoms of median nerve compression.

On the first postoperative day, the initial dressing was exchanged for either a thermoplastic splint or a nonremovable plaster cast for 5 weeks. Type of fixation was determined by the operating surgeon.

All patients started hand therapy of the free joints (shoulder, elbow, fingers) for both upper extremities on the first postoperative day. After cast or splint removal the wrist was then included in the specialized hand therapy programme.

Outcome evaluation

Each of the patients, who returned for the follow-up investigation, underwent a standard X-ray of the wrist in two planes

(anteroposterior and lateral view). Range of motion (ROM) was measured in extension, flexion, supination, pronation, radial- and ulnar deviation at the follow-up investigation. Demographic data included age, gender, injured hand, interval between surgery and follow-up. In addition, pain according to the visual analog scale [VAS, ranging from 0 (no pain) to 10 (worst possible pain)], grip strength in kilograms [Jamar; Sammons Preston Rolyan, Mississauga, Ontario, Canada; minimal clinical important difference (MCID) 6.5 kg or 19.5% decrease [25]] were analyzed.

To analyze the incidence of complications and functional outcome depending on age, the patients were divided into younger than 65 (< 65 years) or equal or older than 65 years (≥ 65 years) according to the definition of the World Health Organization (WHO) for geriatric designation [26].

Self-assessment by patients was registered on the Shortened Disabilities of the Arm, Shoulder and Hand (*Quick*-DASH) questionnaire (0–100 points, MCID 10 points [27]) [28], the Patient-Rated Wrist Evaluation (PRWE) Score (0–100 points; MCID 11.5 points [29]) [30], and modified Green O' Brien (Mayo) Wrist Score (0–100 points) [31].

All the intraoperative and postoperative complications that were documented in the surgical write ups were recorded and each return evaluation was analyzed for complication. All types of revision surgeries were documented. Complex regional pain syndrome (CRPS) was diagnosed clinically on the basis of the Veldman's criteria [32, 33].

Frequency and reason for hardware removal was gleaned from the medical records, although hardware removal was not regarded as a complication in itself. Complications associated with hardware removal were analyzed separately.

Radiological reviews

The primary (pre-reduction), immediate postoperative as well as final radiographs were checked for alignment and intra-articular step-off. The fractures were classified according to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification by Müller et al. [34]. In addition, fractures of the ulnar styloid process were documented and classified into fractures of the tip and base.

An acceptable reduction was defined as 10 degrees of dorsal tilt, 15 degrees in radial inclination, 2 mm ulnar variance and 2 mm of articular incongruity [17, 35].

In the anteroposterior radiographs, radial inclination and ulnar variance according to Gelberman and in the lateral radiographs, the palmar tilt was measured [36]. Fracture healing was defined as bony bridging of the radial, ulnar, and dorsal cortical aspects of the distal part of the radius [17].

The lateral X-ray verified the plate position and was subsequently classified according to Soong et al. in Grade 0, I and II [37]. The Medartis® Aptus® FPL plate was excluded from the Soong classification. The specific design of the FPL plate (gap in the plate for the FPL tendon), allows for positioning distal to the Watershed line [38].

Statistical analyses

Shapiro-test was used to test the assumption of normal distribution of scaled parameters. Since this assumption could not be maintained, the outcome was analyzed non-parametrically using Mann–Whitney *U* test. Data is presented as mean ± standard deviation, significant results in addition with mean difference (MD) and 95% or 99% Confident Interval (CI).

To compare scaled parameters between AO fracture types and Soong grades (grade 0, I and II) the Kruskal–Wallis-test was used. If Kruskal–Wallis test was significant, post-hoc analysis was performed using the Mann–Whitney *U* test. Chi-square was used for testing categorical data.

Pearson's bivariant correlation was run for analyzing relations between radiological parameter, ROM, grip strength and patient-reported outcome measures (PROMs) at the final check-up. Strength of the Pearson correlation coefficient (r) was classified according to Cohen [39] in small ($0.1 < |r| < 0.3$), medium ($0.3 < |r| < 0.5$) and strong ($|r| > 0.5$).

Due to multiple testing, p was corrected according to Bonferoni: threshold for statistical significance for clinical results was a $p < 0.004$ and radiological results a $p < 0.006$. For all other tests threshold for statistical significance was $p < 0.05$.

Results

A total of 230 patients (154 female, 76 male) returned for the follow-up investigation with a mean age of 59 years (range 18–83 years) and follow-up interval of 20 months (range 12–50 months).

Detailed demographic data is presented in Table 1

Radiological results

At the final check, all DRF and 105/123 (85%) of the ulnar styloid showed bony healing. Radial inclination was a mean of 24.8° ± 4.2°, palmar tilt 7.6° ± 7.3° and ulnar variance 1.8 ± 1.4 mm. From post-operative measures to the last follow-up there was a mean loss of reduction in radial inclination of 2.6° ± 3.4°, in palmar tilt of 1.9° ± 4.6° and ulnar variance of 0.64 ± 3.0 mm.

Bivariant correlation analysis showed a significant small positive correlation between radial inclination/flexion ($r = 0.18$, $p = 0.01$) and ulnar variance/*Quick*DASH ($r = 0.18$, $p = 0.01$). A significant small negative correlation was additionally registered between ulnar variance/grip strength ($r = -0.18$, $p = 0.04$) and ulnar variance/Mayo

Table 1 Patients demographic and fracture classified according to the AO classification

Age in years*		59 ± 14 (18 to 83)
Patient classified	< 65/≥ 65 a	155/75
Complications	Y/N	29/201
Gender	F/M	154/76
Injured hand	R/L	108/122
Plate removal	Y/N	52/178
Fracture ulnar styloid	Y/N	123/107
Soong classification	0/I/II	93/96/27
Postoperative immobilization	S/C	128/102
AO classification	A2	25
	A3	13
	B1	1
	B2	32
	B3	18
	C1	10
	C2	28
	C3	103

SD standard deviation, *a* years, *Y* yes, *N* no, *F* female, *M* male, *R* right, *L* left, *S* thermoplastic splint, *C* cast, *AO* Arbeitsgemeinschaft für Osteosynthesefragen

*Age in years scaled as mean value ± SD (range)

Score ($r = -0.23$, $p = 0.001$). No significant differences could be found between an acceptable (< 2 mm) and unacceptable (> 2 mm) ulnar variance in VAS ($p = 0.74$), grip strength ($p = 0.23$), *Quick*DASH ($p = 0.04$), PRWE ($p = 0.05$) and Mayo Score ($p = 0.04$).

Detailed functional outcome is summarized in Table 2.

Subgroup analysis for acceptable/unacceptable ulnar variance in patient under and over 65 years of age was performed. No significant differences could be found in respect of VAS ($p = 0.82$; 0.65), grip strength ($p = 0.67$; 0.35), *Quick*DASH (p = 0.35; 0.03), PRWE ($p = 0.33$; 0.02) and Mayo Score ($p = 0.10$; 0.17).

Kruskal–Wallis Test showed significant differences in loss of reduction in ulnar variance for fracture type ($p = 0.03$). Post-Hoc analysis showed a significant higher loss of reduction for ulnar variance comparing type B3/A2 ($p = 0.01$), C3/A2 ($p = 0.04$), B3/A3 ($p = 0.04$), B3/C2 ($p = 0.02$) or C3/C2 ($p = 0.03$) fractures.

However, no significant difference in facture type in general [AO Type A vs. B vs. C] and loss of reduction in palmar tilt ($p = 0.47$), radial inclination ($p = 0.66$) or ulnar variance ($p = 0.13$) could be found.

Loss of reduction depending on AO type fracture is summarized in Table 3.

Table 2 Range of motion [(mean ± SD) degree], pain, grip strength and patient-reported outcome in patients with distal radius fractures stabilized by palmar angular stable plate

	No fracture PSU	Fracture PSU	$p^{\#}$	Ulnar variance (< 2 mm)	Ulnar variance (> 2 mm)	$p^{\#}$	< 65 years	≥ 65 years	$p^{\#}$
Extension	77.2 ± 6.9	75.1 ± 10.6	0.21	75.7 ± 10.0	76.6 ± 7.7	0.84	76.2 ± 9.5	75.9 ± 8.2	0.29
Flexion	76.1 ± 10.9	72.0 ± 14.1	0.03	74.9 ± 11.9	72.6 ± 13.9	0.11	74.0 ± 12.5	73.7 ± 13.4	0.75
Extension/flexion	153.2 ± 15.0	147.1 ± 21.8	0.08	150.6 ± 19.7	149.2 ± 18.2	0.17	150.2 ± 19.6	149.6 ± 17.9	0.24
Supination	89.8 ± 1.4	89.1 ± 5.2	0.20	89.7 ± 2.2	89.1 ± 5.5	0.25	89.3 ± 4.5	89.7 ± 2.4	0.24
Pronation	89.6 ± 1.9	89.3 ± 4.9	0.89	89.6 ± 2.0	89.3 ± 5.3	0.77	89.2 ± 4.5	90.0 ± 0.0	0.05
supination/pronation	179.4 ± 2.7	178.4 ± 9.8	0.66	179.3 ± 3.1	178.3 ± 10.7	0.96	178.5 ± 8.8	179.7 ± 2.4	0.07
Radial deviation	9.9 ± 1.3	9.7 ± 1.4	0.38	9.9 ± 1.3	9.6 ± 1.3	0.17	9.6 ± 1.4	10.1 ± 1.2	0.005
Ulnar deviation	42.6 ± 5.4	42.2 ± 6.5	0.73	42.6 ± 5.3	42.11 ± 6.8	0.83	42.2 ± 6.0	42.8 ± 5.9	0.20
radial/ulnar deviation	52.5 ± 5.6	51.9 ± 6.6	0.88	52.5 ± 5.3	51.7 ± 6.9	0.47	51.8 ± 6.2	52.9 ± 6.1	0.02
Pain (VAS)	0.44 ± 1.26	0.38 ± 1.07	0.96	0.35 ± 1.00	0.48 ± 1.35	0.74	0.48 ± 1.26	0.25 ± 0.91	0.27
Grip strength (%)*	26.9 ± 12.3 (89)	25.2 ± 10.9 (92)	0.38	26.4 ± 11.0 (91)	25.3 ± 12.3 (91)	0.23	28.5 ± 12.2 (90)	20.5 ± 7.6 (93)	**< 0.001**[#]
*Quick*DASH	11.1 ± 13.8	11.2 ± 14.8	0.83	9.7 ± 13.5	13.1 ± 15.2	0.04	11.5 ± 15.4	10.4 ± 11.8	0.81
PRWE	10.7 ± 15.7	8.3 ± 12.6	0.34	8.7 ± 13.5	14.2 ± 14.1	0.05	10.6 ± 15.4	7.0 ± 9.1	0.53
Mayo Score	85.7 ± 13.3	86.0 ± 13.5	0.86	87.3 ± 13.2	83.9 ± 13.5	0.04	85.6 ± 14.3	86.3 ± 11.4	0.85

SD standard deviation, *PSU* Processus Styloideus Ulnae, *VAS* Visual Analogue Scale, *QuickDASH* Shortened Disabilities of the Arm, Shoulder and Hand questionnaire (0–100 points), *PRWE* Patient-Rated Wrist Evaluation (PRWE) Score (0–100 points), *Mayo Score* modified Green O' Brien (Mayo) Wrist Score (0–100 points)

*Grip strength is presented as mean ± SD (percentage of the uninjured wrist)

#Threshold for statistical significance was $p < 0.004$

Table 3 Loss of reduction (mean ± SD) at final follow-up according to AO fracture type

Fracture type (AO)	Palmar tilt (degrees)	Radial inclination (degrees)	Ulnar variance (mm)
A2	2.99 ± 4.17	2.10 ± 3.31	0.47 ± 1.06
A3	1.35 ± 4.39	2.17 ± 2.36	0.46 ± 1.02
B1	0.00 ± 0.00	0.40 ± 0.00	1.60 ± 0.00
B2	1.69 ± 4.60	2.53 ± 3.22	0.61 ± 1.03
B3	0.43 ± 3.22	3.81 ± 3.13	1.27 ± 1.44
C1	2.74 ± 4.79	2.44 ± 2.69	1.17 ± 1.18
C2	3.45 ± 4.89	2.37 ± 2.40	0.34 ± 1.35
C3	1.54 ± 4.77	2.77 ± 3.94	0.66 ± 4.28
*p**	0.36	0.69	0.03*

AO Arbeitsgemeinschaft für Osteosynthesefragen, *SD* standard deviation

*Statistical significance at a threshold of $p < 0.05$

No significant differences in radial inclination, palmar tilt, ulnar variance or loss of reduction could be found between men/women, under/over 65 years of age and type of immobilization.

Detailed radiological results are summarized in Table 4.

Clinical results

At the final follow-up mean pain according to the VAS was 0.41 ± 1.16, ROM in extension/flexion 150.0° ± 19.1°, in pro-/supination 179.9° ± 7.4° and radial-/ulnar deviation 52.2° ± 6.2°. Grip strength was a mean of 26.0 ± 11.6 kg or 91% of the uninjured hand. The mean *Quick*DASH was 11.2 ± 14.3 points, PRWE 9.5 ± 14.2 points and Mayo Score 85.8 ± 13.4 points.

Patients under 65 years of age showed a significantly better grip strength than patients over 65 (MD 8.0 kg, 99% CI 4.5–11.4, p < 0.001), but there was no significant difference compared to the uninjured hand ($p = 0.53$). For ROM, pain and PROMs no significant differences could be found between the groups.

Between women/men, with/without an additional fracture of the ulnar styloid or patients with/without complications no significant differences with regard to ROM, pain, grip strength and PROMs could be found. In addition, no differences between a tip or base of the ulnar styloid fractures were observed.

Detailed clinical results for each group are presented in Table 2.

Complications

A total of 30 complications (13.0%) occurred in 29 patients. Most common complications included CTS in 10 patients (4.3%), intra-articular screws in 7 patients (3.0%) and CRPS in 4 patients (1.7%). Complications are summarized in Table 5.

AO type C showed the highest complication rate of 20/30 (67%), whereas 14/20 (70%) were found in AO type C3 fractures. However, only 9/30 (30%) occurred in AO type B and 1/30 (3%) in AO type A. No significant differences could be found in complication rate between AO type A, B or C ($p = 0.10$) fractures.

Eight of the 10 patients with a CTS were treated by endoscopic carpal tunnel release and hardware removal, the remaining two were treated conservatively (splitting and physiotherapy) and showed a complete regression. All patients with CRPS were treated conservatively with splinting, hand therapy, dimethylsulphoxide (DMSO) ointment, non-steroidal anti-inflammatory drugs and vitamin E.

Table 4 Radiological outcomes [Mean ± SD] in patients with distal radius fractures stabilized by palmar angular stable plate

	Male	Female	*p**	< 65 years	≥ 65 years	*p**
Palmar tilt (degrees)						
Post surgery	3.04 ± 6.30	4.44 ± 5.83	0.07	4.05 ± 6.33	2.89 ± 5.17	0.06
Follow-up examination	1.95 ± 7.61	2.14 ± 7.22	0.95	2.93 ± 7.13	0.33 ± 7.50	0.01
Loss of reduction	1.09 ± 4.40	2.30 ± 4.64	0.04	1.12 ± 4.22	2.56 ± 5.24	0.26
Radial inclination (degrees)						
Post surgery	25.60 ± 4.28	24.37 ± 4.16	0.47	25.06 ± 3.68	24.19 ± 5.18	0.07
Follow-up examination	22.41 ± 4.51	22.00 ± 4.33	0.03	22.54 ± 4.01	21.32 ± 5.00	0.28
Loss of reduction	3.19 ± 3.41	2.37 ± 3.39	0.29	2.53 ± 3.16	2.87 ± 3.89	0.36
Ulnar variance (mm)						
Post surgery	0.98 ± 2.34	1.27 ± 2.68	0.97	1.00 ± 2.74	1.54 ± 2.15	0.09
Follow-up examination	2.05 ± 2.23	1.70 ± 2.58	0.23	1.58 ± 2.66	2.31 ± 1.95	0.04
Loss of reduction	1.07 ± 1.40	0.43 ± 3.51	0.01	0.58 ± 3.54	0.77 ± 1.30	0.43

SD standard deviation

*Threshold for statistical significance was $p < 0.006$

Table 5 Complications after distal radius fractures stabilized by palmar angular stable plate

	N	Plate related Y/N	Percentage
CTS	10	N	4.3
Intra-articular screw	7	Y	3.0
CRPS	4	N	1.7
Dorsally protruding screw	3	Y	1.3
Transient hyposensitivity (Thumb and palmar branch of the median nerve)	2	Y	0.9
Tendon irritation	2	Y	0.9
Superficial infection	1	N	0.4
Tendon rupture (EPL)	1	N	0.4
Total	30/230	14/230	13.0/6.1

N number, *Y* yes, *N* no, *CTS* carpal tunnel syndrome, *CRPS* complex regional pain syndrome, *EPL* extensor pollicis longus tendon

Intra-articular screws were seen in seven patients. In four cases screws protruded into the distal radioulnar joint and were subsequently removed. The other three presented with a loss of reduction, which necessitated plate removal.

Tendon irritation was seen in five patients. In three cases there was irritation of the extensor tendons (caused by protruding screws) the other two cases irritation of the flexor digitorum profundus tendon of the index finger. All tendon irritations were treated by plate removal.

Only one rupture of the extensor pollicis longus (EPL) tendon occurred and was treated by an extensor indicis transfer and plate removal. In the performed CT scans no protruding screws as a cause for the tendon rupture were found. No flexor tendon ruptures were observed.

A superficial infection was observed in one hand, which was treated conservatively (antibiotics and splinting).

No significant differences could be found in incidence of complications and plate type ($p = 0.22$), age [(over/under 65 years of age); $p = 0.47$], gender ($p = 0.50$), or post-operative immobilization [cast/thermoplastic splint ($p = 0.31$)].

Plate removal was performed in 52 of the 230 (23%) patients. 20/93 (22%) of the plates with Soong grade 0, 22/96 (23%) of the Soong grade I and 5/27 (19%) with Soong grade II had been removed. No significant differences in frequency of plate removal were found between the Soong groups ($p = 0.84$).

Discussion

Distal radius fractures are one of the most common fractures in the upper extremities and the incidence is expected to continue rising due to the growing elderly population [40–45]. Since the introduction of the palmar plates in the early 2000s plus the initial reports of low complication rates and good functional outcomes, palmar plate fixation has gained popularity in treating DRF [5, 46, 47]. Palmar locking plate fixations enables a stabilization of dorsally displaced fractures without the increased risk of tendon irritation compared to dorsal stabilization [5, 6, 48]. Thus palmar fixation of DRF provides enough stability to allow an early rehabilitation with active wrist mobilization. Thereby, better functional outcomes can be achieved in the early rehabilitation phase without the increased risk of a loss of reduction or further complications [13, 49]. Therefore, functional outcome and reported complications after operatively treated DRF remain current in the literature including a comparison of the various available treatment options.[8, 50]. Today the optimal treatment options for DRF are under debate, but a recent Network Meta-analysis concluded, that plate fixation offers the best results in terms of early functional outcome and reduction of fracture healing complications [51].

Patients in this study, with a mean age of 59 years and a minimum follow-up of one year (mean 20 months) showed a good functional and in mean an "acceptable" radiological outcome. The *Quick*DASH averaged 11 points, PRWE 10 points and Mayo Score 86 points.

Several studies compared relations between radiological parameters and functional outcome and suggested that an unacceptable reduction would lead to poorer results in PROMs [52, 53]. Mulders et al. [53] demonstrated in a systematic review and meta-analysis a significant correlation between an unacceptable reduction and PROMs, but all differences were minor, under the MCID, and therefore unlikely to be clinically relevant.

A positive ulnar variance after DRF is directly related to ulnar sided wrist pain, decreased grip strength and poorer PROMs, especially, in patients under 65 years of age with higher functional demands [35, 54]. Grewal and Mac Dermid's study [55] reported significant and clinically important differences of 13 points for ulnar variance in both the DASH and PRWE. Our study also included a significant correlation between ulnar variance and grip strength, *Quick*DASH and Mayo Score in terms that a higher ulnar variance results

in a lower grip strength and worse *Quick*DASH and Mayo Score. Although, an unacceptable ulnar variance showed no significant greater pain scores, lower grip strength or worse PROMs compared to the acceptable ulnar variance and all results were under the MCID. Even subgroup analyses in ulnar variance in patients under/over 65 years of age showed no significant or clinical important differences.

Complications after palmar stabilized DRF are well reported in the literature. First reports from Orbay et al. suggested a complication rate of 3% [56], respectively 4% [57], but later studies reported complications up to 60% [5, 8, 17, 19–21, 38, 50, 58–61]. In a recent systemic review Alter et al. [50] analyzed complications after palmarly stabilized DRF. They reported a complication rate of 15% in 3.911 operatively treated DRF with palmar locking plate. Complication rate of 13% in this study is comparable to previously published studies and the low complication rate reflects the familiarity with the implant and large numbers of treated DRF by palmar locking plate (average 262 DRF per year). Only one implant system was used, which is known to lower the risk for complications [62]. The most common complications in this study included CTS (4.3%), intra-articular screws (3.0%) and CRPS (1.7%). No significant impact on the complication rate could be found for age (over/under 65 years), gender or type of post-operative immobilization. Occurrence of a complication showed no significant or clinical important influence on the final functional outcome.

CTS is a very widespread condition, but is also known to occur in patients with DRF. Incidence after surgically treated DRF ranges from 7 to 15% [63], regardless of the treatment method. CTS after DRF is not attributed to the hardware itself, but more to the trauma to the median nerve caused by the fracture and/or fracture healing with callus bone formation or residual malunion [50]. On the other hand, because CTS is so common, it is quite possible that many patients with DRF have a pre-existing undiagnosed/asymptomatic CTS that only becomes symptomatic or to their attention after the injury [64]. We therefore, doubt that CTS is a direct complication after surgically treated DRF and it is questionable that the palmar plate can actually cause CTS.

Intra-articular screws are also frequently reported in the literature between 0.5 and 1.3% [5, 18, 62] and not only caused by malpositioning, but also due to loss of reduction or secondary fracture dislocation. Even the use of angular stable screws does not preclude secondary displacement [5]. Intra-articular screw penetration can result in a destruction of the radiocarpal joint, causing malunion, osteoarthritis and clinical failure. In these cases when conservative treatment fails (besides screw removal), salvage procedures are often necessary to relieve symptoms and improve ROM [58, 65]. Our study showed a slightly higher rate than in a previously published study with 7/230 (3%). Four out of seven were due to penetration into the distal radioulnar joint and 3 occurred due to a loss of reduction resulting in a dorsal shift of the screws into the radiocarpal joint.

CRPS is closely associated to fractures of the distal radius with an incidence between 1 and 6% [5], but is also commonly seen in injuries to the upper extremities in general [5, 8, 50, 66, 67]. However, it remains a clinical diagnosis and the pathomechanism is still not fully researched. This may, however, be related to an over excretion of cytokinins, mitochondrial dysfunction in the affected upper extremity, as well a genetic predisposition does exist [68–70]. We agree with Esenwein et al. that CRPS is a complication, that cannot be influenced by the surgeon [5].

Some of the limitations should be addressed before interpreting this study. Firstly, it's based on the retrospective type of the study. The most serious drawback in retrospective studies at big trauma centers is the loss of follow-up. The study included a total of 524 operatively treated DRF in the study period. Of these 117 had to be excluded, resulting in 407 potential candidates. Of these 177 (43%) couldn't be followed-up for several reasons. Thus, clinical results and complication rate could be biased. On the one hand, one might assume that patients who do not return have no complications and are asymptomatic, indicating that the complication rate is overestimated and the clinical results are better than reported. Alternatively, patients with complications or problems could simply have been transferred to another hospital.

In addition, there is no unique definition in the literature for an "acceptable" postoperative radiological result and a wide range for cut-off values does exist. It would be desirable, that further studies focus on specific cut-off values to determine which radiological parameters would affect PROMs.

At the follow-up radiographs were only taken of the injured wrist and not from the contralateral wrist. Therefore, no comparison with the uninjured wrist was possible. This might explain the discrepancy in the results in ulnar variance, showing a significant correlation to grip strength and PROM, but no differences between an unacceptable and acceptable ulnar variance. Further studies should consider this issue and investigate the impact of radiological differences between the injured and healthy wrist to PROMs.

Another limitation is that the study was not focused on one particular outcome parameter (e.g., *Quick*DASH Score at the last follow-up), resulting in multiple testing. P-value had to be corrected according to Bonferroni, and therefore, the study might be underpowered in some subgroup analyses. At the final follow-up examination, the X-rays of only 7/230, respectively, 3/230 patients showed an unacceptable palmar tilt or radial inclination. Due to the small sample size a comparison between an acceptable and unacceptable radiological result depending on functional outcome was not possible.

The minimum follow-up interval of this study was one year, with a mean of 20 months. Therefore, not all complications that typically occur later, for example, tendon rupture, are covered in this study.

Conclusion

The majority of surgically treated distal radius fractures using palmar locking plates, result in a good clinical and radiological outcome without complications. A positive ulnar variance showed a significant correlation to a decreased grip strength and worse *Quick*DASH or Mayo score, but an unacceptable ulnar variance (> 2 mm) is not associated with a significant or clinical important worse functional outcome. Age (< 65/> 65 years), gender, type of immobilization and fracture of the ulnar styloid showed no significant correlation to a higher risk for complications, loss of reduction or impaired functional outcome.

A total of 30 complications occurred in 230 patients (13%), most common being CTS, intra-articular screws and CRPS. It is debatable whether CTS and CRPS are direct complications due to palmar plating, thus 16/230 (7%) were procedure specific and only 14/230 (6%) were plate related.

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Compliance with ethical standards

Conflict of interest The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Ethical review committee
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References

1. MacIntyre NJ, Dewan N (2016) Epidemiology of distal radius fractures and factors predicting risk and prognosis. J Hand Ther 29:136–145. https://doi.org/10.1016/j.jht.2016.03.003
2. Figl M, Weninger P, Liska M et al (2009) Volar fixed-angle plate osteosynthesis of unstable distal radius fractures: 12 months results. Arch Orthop Trauma Surg 129:661–669. https://doi.org/10.1007/s00402-009-0830-z
3. Figl M, Weninger P, Jurkowitsch J et al (2010) Unstable distal radius fractures in the elderly patient-volar fixed-angle plate osteosynthesis prevents secondary loss of reduction. J Trauma Inj Infect Crit Care 68:992–998. https://doi.org/10.1097/TA.0b013e3181b99f71
4. Gologan RE, Koeck M, Suda AJ, Obertacke U (2019) %3e 10-year outcome of dislocated radial fractures with concomitant intracarpal lesions as proven by MRI and CT. Arch Orthop Trauma Surg 139:877–881. https://doi.org/10.1007/s00402-019-03186-8
5. Esenwein P, Sonderegger J, Gruenert J et al (2013) Complications following palmar plate fixation of distal radius fractures: a review of 665 cases. Arch Orthop Trauma Surg 133:1155–1162
6. Le ZS, Kan SL, Su LX, Wang B (2015) Meta-analysis for dorsally displaced distal radius fracture fixation: volar locking plate versus percutaneous Kirschner wires. J Orthop Surg Res. https://doi.org/10.1186/s13018-015-0252-2
7. Wei DH, Raizman NM, Bottino CJ et al (2009) Unstable distal radial fractures treated with external fixation, a radial column plate, or a volar plate: prospective randomized trial. J Bone Jt Surg Ser A 91:1568–1577. https://doi.org/10.2106/JBJS.H.00722
8. Quadlbauer S, Pezzei C, Jurkowitsch J et al (2018) Early complications and radiological outcome after distal radius fractures stabilized by volar angular stable locking plate. Arch Orthop Trauma Surg 138:1773–1782. https://doi.org/10.1007/s00402-018-3051-5
9. Oka K, Kataoka T, Tanaka H et al (2018) A comparison of corrective osteotomies using dorsal and volar fixation for malunited distal radius fractures. Int Orthop 42:2873–2879. https://doi.org/10.1007/s00264-018-3972-1
10. Martinez-Mendez D, Lizaur-Utrilla A, de Juan-Herrero J (2018) Prospective study of comminuted articular distal radius fractures stabilized by volar plating in the elderly. Int Orthop 42:2243–2248. https://doi.org/10.1007/s00264-018-3903-1
11. Twigt B, Bemelman M, Lansink K, Leenen L (2013) Type C distal radial fractures treated with conventional AO plates: an easy and cost-saving solution in a locking plate era. Int Orthop 37:483–488. https://doi.org/10.1007/s00264-012-1761-9
12. Leixnering M, Rosenauer R, Pezzei C et al (2020) Indications, surgical approach, reduction and stabilization techniques of distal radius fractures. Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-020-03365-y
13. Quadlbauer S, Pezzei C, Jurkowitsch J et al (2016) Early rehabilitation of distal radius fractures stabilized by volar locking plate: a prospective randomized pilot study. J Wrist Surg 06:102–112. https://doi.org/10.1055/s-0036-1587317
14. Lozano-Calderón SA, Souer S, Mudgal C et al (2008) Wrist mobilization following volar plate fixation of fractures of the distal part of the radius. J Bone Jt Surg Ser A 90:1297–1304. https://doi.org/10.2106/JBJS.G.01368
15. Osada D, Kamei S, Masuzaki K et al (2008) Prospective study of distal radius fractures treated with a volar locking plate system. J Hand Surg Am 33:691–700. https://doi.org/10.1016/j.jhsa.2008.01.024
16. Lameijer CM, ten Duis HJ, van Dusseldorp I et al (2017) Prevalence of posttraumatic arthritis and the association with outcome measures following distal radius fractures in non-osteoporotic patients: a systematic review. Arch Orthop Trauma Surg 137:1499–1513. https://doi.org/10.1007/s00402-017-2765-0
17. Arora R, Lutz M, Deml C et al (2011) A Prospective randomized trial comparing nonoperative treatment with volar locking plate fixation for displaced and unstable distal radial fractures in patients sixty-five years of age and older. J Bone Jt Surg Am 93:2146–2153. https://doi.org/10.2106/JBJS.J.01597
18. Arora R, Lutz M, Hennerbichler A et al (2007) Complications following internal fixation of unstable distal radius fracture with

a palmar locking-plate. J Orthop Trauma 21:316–322. https://doi.org/10.1097/BOT.0b013e318059b993
19. Haug LCP, Deml C, Blauth M, Arora R (2011) Dorsal screw penetration following implant removal after volar locked plating of distal radius fracture. Arch Orthop Trauma Surg 131:1279–1282. https://doi.org/10.1007/s00402-011-1300-y
20. Erhart S, Toth S, Kaiser P et al (2018) Comparison of volarly and dorsally displaced distal radius fracture treated by volar locking plate fixation. Arch Orthop Trauma Surg 138:879–885. https://doi.org/10.1007/s00402-018-2925-x
21. Quadlbauer S, Pezzei C, Jurkowitsch J et al (2017) Spontaneous radioscapholunate fusion after septic arthritis of the wrist: a case report. Arch Orthop Trauma Surg 137:579–584. https://doi.org/10.1007/s00402-017-2659-1
22. Hardman J, Al-Hadithy N, Hester T, Anakwe R (2015) Systematic review of outcomes following fixed angle intramedullary fixation of distal radius fractures. Int Orthop 39:2381–2387. https://doi.org/10.1007/s00264-015-2763-1
23. Hohendorff B, Knappwerth C, Franke J et al (2018) Pronator quadratus repair with a part of the brachioradialis muscle insertion in volar plate fixation of distal radius fractures: a prospective randomised trial. Arch Orthop Trauma Surg 138:1479–1485. https://doi.org/10.1007/s00402-018-2999-5
24. Hohendorff B, Unglaub F, Spies CK et al (2019) Repair of the pronator quadratus muscle with a part of the brachioradialis muscle insertion in volar plate fixation of a distal radius fracture. Oper Orthop Traumatol. https://doi.org/10.1007/s00064-019-0601-0
25. Kim JK, Park MG, Shin SJ (2014) What is the minimum clinically important difference in grip strength? Clin Orthop Relat Res 472:2536–2541. https://doi.org/10.1007/s11999-014-3666-y
26. World Health Organization (1972) Psychogeriatrics. Report of a WHO scientific group. World Health Organ Tech Rep Ser 507:1–48
27. Chaudhry H, Kleinlugtenbelt YV, Mundi R et al (2015) Are volar locking plates superior to percutaneous K-wires for distal radius fractures? A meta-analysis. Clin Orthop Relat Res 473:3017–3027
28. Beaton DE, Wright JG, Katz JN et al (2005) Development of the QuickDASH: comparison of three item-reduction approaches. J Bone Jt Surg Ser A 87:1038–1046. https://doi.org/10.2106/JBJS.D.02060
29. Walenkamp MMJ, de Muinck Keizer R-J, Goslings JC et al (2015) The minimum clinically important difference of the patient-rated wrist evaluation score for patients with distal radius fractures. Clin Orthop Relat Res 473:3235–3241. https://doi.org/10.1007/s11999-015-4376-9
30. Hemelaers L, Angst F, Drerup S et al (2008) Reliability and validity of the german version of "the patient-rated wrist evaluation (PRWE)" as an outcome measure of wrist pain and disability in patients with acute distal radius fractures. J Hand Ther 21:366–376. https://doi.org/10.1197/j.jht.2008.03.002
31. Cooney WP, Bussey R, Dobyns JH, Linscheid RL (1987) Difficult wrist fractures. Perilunate fracture-dislocations of the wrist. Clin Orthop Relat Res 214:136–147
32. Veldman PH, Reynen HM, Arntz IE, Goris RJ (1993) Signs and symptoms of reflex sympathetic dystrophy: prospective study of 829 patients. Lancet (London, England) 342:1012–1016
33. Crijns TJ, van der Gronde BATD, Ring D, Leung N (2018) Complex regional pain syndrome after distal radius fracture is uncommon and is often associated with fibromyalgia. Clin Orthop Relat Res 476:744–750. https://doi.org/10.1007/s11999.0000000000000070
34. Müller ME, Koch P, Nazarian S, Schatzker J (1990) Tibia/Fibula=4. The comprehensive classification of fractures of long bones. Springer, Berlin, pp 148–191
35. Ng CY, McQueen MM (2011) What are the radiological predictors of functional outcome following fractures of the distal radius? J Bone Joint Surg Br 93(B):145–150. https://doi.org/10.1302/0301-620X.93B2.25631
36. Schmitt R, Pommersberger K (2014) Karpale Funktion und Morphometerie. In: Schmitt R, Lanz U (eds) Bildgebende Diagnostik der Hand, 3rd edn. Thieme, Germany, pp 184–197
37. Soong M, Earp BE, Bishop G et al (2011) Volar locking plate implant prominence and flexor tendon rupture. J Bone Jt Surg Ser A 93:328–335. https://doi.org/10.2106/JBJS.J.00193
38. Schlickum L, Quadlbauer S, Pezzei C et al (2018) Three-dimensional kinematics of the flexor pollicis longus tendon in relation to the position of the FPL plate and distal radius width. Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-018-3081-z
39. Cohen J (1988) Differences between correlation coefficients. In: Cohen J (ed) Statistical power analysis for the behavioral sciences, 2nd edn. Lawrence Erlbaum Associates, New Jersey, pp 109–145
40. Weil NL, El Moumni M, Rubinstein SM et al (2017) Routine follow-up radiographs for distal radius fractures are seldom clinically substantiated. Arch Orthop Trauma Surg 137:1187–1191. https://doi.org/10.1007/s00402-017-2743-6
41. Weschenfelder W, Friedel R, Hofmann GO, Lenz M (2019) Acute atraumatic carpal tunnel syndrome due to flexor tendon rupture following palmar plate osteosynthesis in a patient taking rivaroxaban. Arch Orthop Trauma Surg 139:435–438. https://doi.org/10.1007/s00402-019-03116-8
42. Janssen SJ, Teunis T, Guitton TG et al (2015) Do surgeons treat their patients like they would treat themselves? Clin Orthop Relat Res 473:3564–3572. https://doi.org/10.1007/s11999-015-4304-z
43. Fok MWM, Fang CX, Lau TW et al (2018) The status of triangular fibrocartilage complex after the union of distal radius fractures with internal plate fixation. Int Orthop 42:1917–1922. https://doi.org/10.1007/s00264-018-3793-2
44. Diwersi N, Babst R, Link B-C (2016) Miniplates as augmentation implants in osteosynthesis of complex distal radial fractures. Oper Orthop Traumatol 28:402–406. https://doi.org/10.1007/s00064-016-0469-1
45. Pillukat T, Fuhrmann R, Windolf J, van Schoonhoven J (2016) Die palmare winkelstabile Plattenosteosynthese bei Extensionsfrakturen des distalen Radius. Oper Orthop Traumatol 28:47–64. https://doi.org/10.1007/s00064-015-0433-5
46. Babikir EME, Al-Maqdassy ED, Hasan K et al (2017) Efficiency of fragment specific fixation plates in the treatment of comminuted distal radial fractures. Int Orthop 41:1763–1769. https://doi.org/10.1007/s00264-017-3516-0
47. Gamba C, Fernandez FAM, Llavall MC et al (2017) Which immobilization is better for distal radius fracture? A prospective randomized trial. Int Orthop 41:1723–1727. https://doi.org/10.1007/s00264-017-3518-y
48. Zhang B, Chang H, Yu K et al (2017) Intramedullary nail versus volar locking plate fixation for the treatment of extra-articular or simple intra-articular distal radius fractures: systematic review and meta-analysis. Int Orthop 41:2161–2169. https://doi.org/10.1007/s00264-017-3460-z
49. Quadlbauer S, Pezzei C, Jurkowitsch J et al (2020) Rehabilitation after distal radius fractures - is there a need for immobilization and physiotherapy? Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-020-03367-w
50. Alter TH, Sandrowski K, Gallant G et al (2019) Complications of volar plating of distal radius fractures: a systematic review. J Wrist Surg 08:255–262. https://doi.org/10.1055/s-0038-1667304
51. Vannabouathong C, Hussain N, Guerra-Farfan E, Bhandari M (2019) Interventions for distal radius fractures. J Am Acad Orthop Surg 27:e596–e605. https://doi.org/10.5435/JAAOS-D-18-00424
52. Reynolds PJ (2014) The correlation of radiographic outcome to functional outcome following fracture of the distal radius in elderly patients: a literature review. Hand Ther 19:31–39. https://doi.org/10.1177/1758998314527069

53. Mulders MAM, Detering R, Rikli DA et al (2018) Association between radiological and patient-reported outcome in adults with a displaced distal radius fracture: a systematic review and meta-analysis. J Hand Surg Am 43:710–719.e5. https://doi.org/10.1016/j.jhsa.2018.05.003
54. Brogren E, Hofer M, Petranek M et al (2011) Relationship between distal radius fracture malunion and arm-related disability: a prospective population-based cohort study with 1-year follow-up. BMC Musculoskelet Disord 12:9. https://doi.org/10.1186/1471-2474-12-9
55. Grewal R, MacDermid JC (2007) The risk of adverse outcomes in extra-articular distal radius fractures is increased with malalignment in patients of all ages but mitigated in older patients. J Hand Surg Am 32:962–970. https://doi.org/10.1016/j.jhsa.2007.05.009
56. Orbay JL, Fernandez DL (2002) Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report. J Hand Surg Am 27:205–215. https://doi.org/10.1053/jhsu.2002.32081
57. Orbay JL, Fernandez DL (2004) Volar fixed-angle plate fixation for unstable distal radius fractures in the elderly patient. J Hand Surg Am 29:96–102
58. Quadlbauer S, Leixnering M, Jurkowitsch J et al (2017) Volar radioscapholunate arthrodesis and distal scaphoidectomy after malunited distal radius fractures. J Hand Surg Am 42:754.e1–754.e8. https://doi.org/10.1016/j.jhsa.2017.05.031
59. Arora R, Gschwentner M, Krappinger D et al (2007) Fixation of nondisplaced scaphoid fractures: making treatment cost effective. Prospective controlled trial. Arch Orthop Trauma Surg 127:39–46. https://doi.org/10.1007/s00402-006-0229-z
60. Rosenauer R, Pezzei C, Quadlbauer S et al (2020) Complications after operatively treated distal radius fractures. Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-020-03372-z
61. Keuchel T, Quadlbauer S, Jurkowitsch J et al (2020) Salvage procedure after malunited distal radius fractures and management of pain and stiffness. Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-020-03369-8
62. Soong M, Van Leerdam R, Guitton TG et al (2011) Fracture of the distal radius: risk factors for complications after locked volar plate fixation. J Hand Surg Am 36:3–9. https://doi.org/10.1016/j.jhsa.2010.09.033
63. Protopsaltis TS, Ruch DS (2008) Volar approach to distal radius fractures. J Hand Surg Am 33:958–965. https://doi.org/10.1016/j.jhsa.2008.04.018
64. Rampoldi M, Marsico S (2007) Complications of volar plating of distal radius fractures. Acta Orthop Belg 73:714–719. https://doi.org/10.1016/j.jhsa.2014.03.038
65. Quadlbauer S, Leixnering M, Rosenauer R et al (2020) Palmar radioscapholunate arthrodesis with distal scaphoidectomy. Oper Orthop Traumatol. https://doi.org/10.1007/s00064-020-00651-1
66. Bentohami A, De Burlet K, De Korte N et al (2014) Complications following volar locking plate fixation for distal radial fractures: a systematic review. J Hand Surg Eur 39:745–754. https://doi.org/10.1177/1753193413511936
67. Roh YH, Lee BK, Noh JH et al (2014) Factors associated with complex regional pain syndrome type I in patients with surgically treated distal radius fracture. Arch Orthop Trauma Surg 134:1775–1781. https://doi.org/10.1007/s00402-014-2094-5
68. Üçeyler N, Eberle T, Rolke R et al (2007) Differential expression patterns of cytokines in complex regional pain syndrome. Pain 132:195–205. https://doi.org/10.1016/j.pain.2007.07.031
69. Nickel FT, Maihöfner C (2010) Aktuelle Erkenntnisse zur Pathophysiologie des CRPS I. Handchirurgie Mikrochirurgie Plast Chir 42:8–14. https://doi.org/10.1055/s-0029-1246211
70. Tanl ECT, Janssenl AJM, Roestenbergl P et al (2011) Mitochondrial dysfunction in muscle tissue of complex regional pain syndrome type I patients. Eur J Pain 15:708–715. https://doi.org/10.1016/j.ejpain.2010.12.003