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Comparison of the Results after Arthroscopically Assisted Surgeries of the Articular Distal Radius Fractures with Internal and External Fixation Methods

Summary of the Doctoral Thesis for obtaining
a doctoral degree (*Ph.D.*)

Sector – Clinical Medicine
Sub-Sector – Orthopaedics

Riga, 2021

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Abbreviations

AO	<i>Arbeitsgemeinschaft für Osteosynthesefragen</i>
APL	<i>m. abductor pollicis longus</i>
CRPS	Complex Regional Pain Syndrome
DDRU	dorsal distal radio-ulnar portal
DIC	dorsal intercarpal ligament
DOA	deformative osteoarthritis
DRCL	dorsal radio-carpal ligament
DRF	distal radius fracture
DRT	dorsal radio-triquetral ligament
DRUJ	distal radio-ulnar joint
ECRB	<i>m. extensor carpi radialis brevis</i>
ECRL	<i>m. extensor carpi radialis longus</i> ,
ECU	<i>m. extensor carpi ulnaris</i>
EDC	<i>m. extensor digitorum communis</i>
EDM	<i>m. extensor digiti minimi</i>
EF	external fixator
EPL	<i>m. extensor pollicis longus</i>
FCR	<i>m. flexor carpi radialis</i>
LRL	long radio-lunate ligament
LTIL	luno-triquetral interosseus ligament
MASS07	Modern Activity Subjective Survey of 2007 score
MC	metacarpal bone
MCID	minimal clinically important difference
MCR	midcarpal radial portal
MCU	midcarpal ulnar portal
MRI	magnetic resonance imaging

N	newton (unit)
ORIF	Open Reduction and Internal Fixation
PDRU	proximal distal radio-ulnar portal
PRUJ	proximal radio-ulnar joint
PRWE	Patient Related Wrist Evaluation score
PQ	<i>m. pronator quadratus</i>
RAKUS	Riga East Clinical University hospital
ROM	range of motion
RSC	radio–scapho–capitate ligament
RSL	radio-scapho-lunate ligament
RTG	X-ray
RVP	radial volar portal
SLAC	scapho-lunate advanced collapse
SLIL	scapho-lunate interosseus ligament
STT	scaphotrapezium-trapezoideum (joint and portal)
TFCC	triangular fibrocartilage complex
UVP	ulnar volar portal
VLP	volar locking plate

Introduction

Fractures of the distal end of the radius are the most common skeletal injuries recorded in emergency rooms. The incidence is from 20 to 30% of all fractures (Ilyas and Jupiter, 2007; MacIntyre and Dewan, 2016). These fractures have bimodal age and gender distribution – complicated high energy distal radius fractures are more common in younger males, but in older population, even if the fractures are less complicated, they mostly are experienced in older females (Court-Brown and Caesar, 2006). According to published data of medical statistics, the incidence of all types of distal radius fractures per 10.000 inhabitants in different countries shows one particular trend: women, for various reasons, are more likely to experience injuries. For example, the women – men ratio in Australia is 17 : 4 (Sanders et al., 1999), South Korea 66.1 : 16.4 (Park et al., 2011), Netherlands 45.8 : 10 (de Putter et al., 2013), Canada 49 : 14 (Jaglal et al., 2005), United Kingdom 36.8 : 9 (O'Neill et al., 2001), Norway 75.1 : 18.9 (Diamantopoulos et al., 2012), Switzerland 63.2 : 17 (Lippuner, 2009). Overall, 15% of women and up to 2% of men are at risk for the distal radius fracture during the lifetime. (Ruch and Papadonikolakis, 2006).

Until now, any statistical studies of this kind have not been carried out in Latvia. Assuming that the incidence of articular DRFs is 20% of all DRFs treated in emergency departments, then roughly calculating the statistical data for 2017 available from the Centre for Disease Prevention and Control, and considering the global calculated percentage trend that AO-C3 fractures constitute approximately 32% of all DRFs, theoretically there could be around 265 AO-C3 type DRF patients per year in Latvia.

The increasing incidence of these injuries may be attributed to an aging population (osteoporotic fractures) and the growing participation in outdoor pursuits (higher energy fractures) (Shukla et al., 2014). Nowadays the incidence of articular distal radius fractures is from 32% (Koo et al., 2013) to 43.3% (Sander et al., 2018) of all distal radius fractures. Activity of the surgical treatment is obviously increasing as a result of evolution of the implants and technical possibilities.

AO (*Arbeitsgemeinschaft für Osteosynthesefragen*) fracture classification system, which is used in Latvia since 1998, has also undergone a number of reviews of treatment criteria and changes of standards (Walenkamp et al., 2015). Nowadays, the traditional treatment of distal radius fractures includes 3 or 4 different fixation methods – K-wires and external fixator (EF), micronails, volar compression plates (VLP), fragment specific plates and spanning plates. Volar locking plates (VLP) and EF + K-wires have been generally used in the Microsurgery Centre of Latvia for several years. Both of these two methods are controversial in the technical meaning (surgical approach and extra traumatization of soft tissues) as well as in different post-operative rehabilitation protocols. Despite the numerous comparative studies on the application of both treatment methods and their results, as well as the evidence of possibilities of better joint surface reconstruction possibilities in arthroscopic assisted surgeries, until now, two diametrically opposed surgical treatment methods have not been compared to arthroscopically assisted study groups. This study was motivated by H. J. Kreder's acknowledgment: "It is neither the fixation nor the implant which dictates the outcome but the ability of the surgeon to meet the goal of satisfactory reduction and vascular preservation with the least invasive procedure possible."

During the course of the study, surgical technique was improved, reducing the timing of surgeries, as well as lessons have been learned about the benefits of one or other of the surgical method, depending on the type and configuration of the articular DRF. During this study, different associated soft tissue injuries were recognized and immediately treated, which would not have been possible without the arthroscopic assistance. Collection of post-operative subjective and objective data was performed using PRWE score (*Patient Related Wrist Evaluation*), MASSH07 score (*Modern Activity Subjective Survey of 2007*) and Gartland & Werley score, which are adapted for interpretation and applied in international publications (Alexander et al., 2008; Changulani et al., 2008; MacDermid et al., 2003). An assessment of surgical notes, post-operative rehabilitation protocols as well as records of subjective and objective outcomes, justifies the use of both arthroscopic assisted articular DRF which would not have been possible without treatment methods, evaluating the capabilities of technical application, equipment as well as the knowledge and skills of the surgeon for the specific manipulation.

Aim of the study

To compare two arthroscopically assisted surgical treatment methods of the articular DRFs, according to their early and late clinical, radiological and functional results, timing of surgery and potential complications. To develop indications for the application of one or other treatment method depending of the specific fracture, for a particular group of patients, forecasting potential results and reducing the risk of potential complications in the future.

Tasks of the study

1. To perform a scheduled assessment of post-operative radiological and functional results of the randomized groups based on assessment of the patients' health condition and life quality (*Gartland and Werley, PRWE and MASS07* scores), as well as X-ray controls 1, 3, 6 and 12 months after surgery.
2. To perform a monitoring of post-operative complications and analysis of compared data in both randomized groups.
3. To determine the usefulness of the arthroscopic part of the surgery in the treatment of the articular DRFs.
4. To create an algorithm for the uniform selection of the treatment methods of the articular DRFs in any hospital in Latvia.
5. To create a systematized protocol of post-operative monitoring after DRFs suitable to further academic studies in Latvia.

Scientific assumptions

Open reduction and internal fixation with plate and screws is mostly recommended for younger patients with better bone structure, active life patterns and longer life experience. Gentler fixation with K-wires in addition with joint distraction in external fixator is recommended in elderly people with a weaker bone structure with potentially possible migration of implants and lower life activity. It is considered that arthroscopic assisted surgical treatment of articular fractures in any localization, provides more accurate reposition of articular fragments and does not create additional soft tissue injuries resulting from visualization of joint surfaces by conventional surgical methods.

It could be possible, that arthroscopic assisted, less invasive method of fracture fixation, in patients of any age, may lead to better conditions for restoring the life quality of patients and wrist functions than open osteosynthesis with plate, avoiding additional soft tissue injuries during the surgery.

Place of the study

Riga Stradiņš University, Riga Eastern Clinical University Hospital “Gaiļezers”, Plastic, Reconstructive and Microsurgery centre of Latvia.

Scientific novelty

For the first time a study has been conducted with systemized monitoring of patients, records of objective and subjective data (*Gartland and Werley*, *PRWE* and *MASS07* scores) and resulting analysis of obtained data after arthroscopic assisted surgical treatment of articular DRFs. Two technically controversial surgical techniques were compared – minimally invasive arthroscopic assisted fracture fixation with K-wires and EF as well as standard open reduction and arthroscopic assisted fixation with VLP.

The monitoring and evaluation system of outcomes used during this study, is intended to be recommended for more extensive use, and processing large amounts of data, it can be used not only for scientific publications, but also for statistical and economic calculations.

Practical value of this study

1. The prototype of the surgical instrument “The device for determination of the exact direction and depth of the K-wire in arthroscopically assisted surgeries of the articular distal radius fractures” has been designed and patented.
2. The necessity of the arthroscopic assistance for the exact reposition of articular DRFs and for the diagnosis of associated soft tissue lesions as well as for treatment of them has been proved.
3. A practical algorithm for the uniform selection of treatment methods for articular DRFs has been created to be applied in any trauma and orthopaedic department or hospital.
4. An algorithm for patient post-operative observation, as well as for the recording of objective and subjective outcomes, has been introduced, to be applied in any trauma and orthopaedics department or hospital.

1 Research section

1.1 Structure of the research

This is a prospective randomized trial where patients are divided into two groups using the method of alternative allocation. Target population – persons of both genders, at least 15 years old with articular distal radius fractures (AO C1,C2 or C3 type) of the one wrist (the healthy wrist is necessary for functional comparison). Fractures were classified according the AO classification according to the primary X-rays, changing the group of classification if different type of fracture was recognized during the surgery.

The number of participants required for the study and the statistical capacity of the study was calculated on the basis of the data available in the literature on hand force measurements (grip strength as the main outcome measure) and the minimal clinically important difference (MCID) in PRWE values. MCID for grip strength is 6.5 kg, or 19.5% for percentage grip strength (Kim et al., 2014). According to these data, only 10 patients in each group would constitute 80% of the capacity. More meaningful calculation on sample size is based on the available data on PRWE, where MCID is 11 points and standard deviation is 14 points (Walenkamp et al., 2015). In capacity calculation it was determined that required total sample size is 50 patients (25 per group) to confirm or reject the hypothesis. Assuming the drop-out rate of 30%, at least 71 patients should be enrolled. Unfortunately no MCID have been established for wrist ROM as well as for MASS07 and modified Gartland and Werley scores. The sample size was calculated on the basis of 80% research capacity by the formulas as follows (Fig. 1.1):

$$k = \frac{n_2}{n_1} = 1$$

$$n_1 = \frac{(\sigma_1^2 + \sigma_2^2/K)(z_{1-\alpha/2} + z_{1-\beta})^2}{\Delta^2}$$

$$n_1 = \frac{(10^2 + 10^2/1)(1.96 + 0.84)^2}{10^2}$$

$$n_1 = 16$$

$$n_2 = K * n_1 = 16$$

$\Delta = |\mu_2 - \mu_1|$ = absolute difference between two means
 σ_1, σ_2 = variance of mean #1 and #2
 n_1 = sample size for group #1
 n_2 = sample size for group #2
 α = probability of type I error (usually 0.05)
 β = probability of type II error (usually 0.2)
 z = critical Z value for a given α or β
 k = ratio of sample size for group #2 to group #1

Fig. 1.1 The sample size was calculated on 80% capacity

Patients were divided in two groups – VLP group and EF group according to preferred method of randomization. They were treated surgically with open reduction and fixation with VLP or minimally invasive fixation with K-wires and EF from dorsal aspect of the wrist. All surgeries were done under axillary block or general anaesthesia (choice of the anaesthesiologist and / or technical possibilities). Both methods of fracture fixation were carried out under arthroscopic guidance, to visualize the congruity of fragments, reduce the formation of post-operative adhesions and visualize associated soft tissue injuries – TFCC or intercarpal ligament injuries. The level of intercarpal ligament injuries, during the arthroscopy, was evaluated according Geissler's classification (Table 1.1) and TFCC tears according Palmer's classification (Table 1.2, Fig. 1.2).

Table 1.1

Geissler W.B. arthroscopic classification of SLIL tears

Grade	Radiocarpal joint	Midcarpal findings	Step-off
1	Haemorrhage of SLIL, no attenuation	None	None
2	Incomplete partial or full SLIL tear, no attenuation	Slight gap (< 3 mm)	Midcarpal only
3	Ligament attenuation, incomplete partial or full tear	Probe can be passed between carpal bones	Midcarpal and radiocarpal
4	Full tear	Gross instability, 2.7 mm scope can be passed between carpal bones (<i>drive-through sign</i>)	Midcarpal and radiocarpal

Table 1.2

Palmer classification of traumatic TFCC injuries

A	Central perforation
B	Peripheral avulsion from the ulna (with or without styloid fracture)
C	Distal avulsion from the carpus (detachment from DUC ligament or volar capsule)
D	Radial avulsion (with or without sigmoid notch fracture)

Fig. 1.2 TFCC injuries according to **Palmer** (author's drawing)

The permissible deviations were determined before the initiation of the study – gap between fragments – less than 1 mm, shortening of the radius – less than 5 mm in comparison with the healthy hand, radial inclination angle $> 15^\circ$, volar tilt $< -10^\circ$. As far as possible, all steps were taken to restore the anatomy of the distal radius to the highest possible accuracy.

1.2 Surgical protocol for patients treated with VLP

Surgeries were performed under axillary block or general anaesthesia and with the tourniquet inflated to between 280 and 320 mmHg. The volar locking plate group (Group VLP) surgeries were performed using the flexor carpi radialis approach and pronator quadratus muscle elevation. Fracture fixation was achieved with two different plates: Synthes 2.4 mm LCP distal radius system or Stryker VariAx plate. Once the fracture was preliminarily fixed with the plate, the wrist joint was assessed arthroscopically using the 3–4 and 4–5 portals. In several cases additional portals, 6U and 1–2, were used to remove blood clots and small articular fragments. If articular step-offs or gaps were present, additional reposition and fixation with K-wires were performed. Distal screws were inserted only after arthroscopic inspection of the radiocarpal joint and a fluoroscopic confirmation of the correct position for the screws. If dorsal, ulnar or radial fragments, uncontrolled by the plate, were detected, additional K-wires were inserted. These were cut under the skin and remained indwelling after the procedure. Associated soft tissue injuries, such as triangular fibrocartilage complex (TFCC) tear, damage of scapholunate or lunotriquetral ligaments, were assessed after the fracture had been stabilized. In several cases, debridement of the injured ligaments or TFCC was performed, as well as trans-articular fixation of the scapholunate and / or lunotriquetral joints with K-wires, or application of peripheral sutures for TFCC tears. Bone-grafting was not performed.

Fig. 1.3 Standard volar approach, preliminary fixation of VLP with wires after the primary reposition

Fig. 1.4 Fixation of the wrist in the arthroscopic tower and the arthroscopic stage of the surgery

If the required position of fracture fragments is achieved and position of implants is optimal, wound is closed starting with suturing of the pronator quadratus muscle and other soft tissues layer by layer. Active aspiration drainage was used as well as short arm cast for two weeks after surgery.

1.3 Surgical protocol for patients treated with EF and K-wires

Surgeries were performed under axillary block or general anaesthesia and with the tourniquet inflated to between 280 and 320 mmHg. The external fixator and K-wire group (Group EF) surgeries commenced with a primary closed reduction and fixation with several K-wires, under fluoroscopic guidance. Following fixation in a traction tower, the articular surfaces were assessed using the same arthroscopic technique as for Group VLP. Further fragment reductions were performed, if required, using a probe or K-wires as joysticks through elongated 3–4, 4–5, 1–2 and in some cases, volar portals. Additional K-wire fixation was used as required. At this point, associated soft tissue injuries were assessed and additional procedures were performed as for Group VLP, when necessary. Once satisfactory reposition was achieved, the bridging external fixator was applied. Both Synthes Small External Fixator and Stryker Hoffmann II Compact External Fixator were used. For this purpose, two threaded pins were inserted in the dorso-radial aspect of the 2nd MC bone and two additional threaded pins in the dorso-radial aspect of the radius, proximally from fracture site. These wires were fixated together with connecting rods. The wrist was only then released from the traction, K-wires were cut under the skin and the wounds were closed with simple interrupted sutures.

All arthroscopically assisted surgeries were performed using the dry arthroscopy technique recommended by Francisco del Piñal (Del Piñal, 2011).

Fig. 1.5 EF application after arthroscopic fracture fixation with wires

1.4 Post-operative protocols

For patients treated with VLP:

- 1 Next day after surgery – removal of the active aspiration drainage and change of the wound dressing, discharge from the hospital on the same or following day.
- 2 Change of the wound dressing in 3 to 4 days.
- 3 Removal of sutures in 12 to 14 days after surgery.

- 4 Immobilization until removal of sutures.
- 5 Active movements of shoulder, elbow and finger joints according to standardized protocol starting the next day after surgery.
- 6 Workout of the wrist joint active and passive movements under the guidance of the hand therapist, starting the 3rd week after surgery.
- 7 X-ray control 4 weeks after the surgery.
- 8 Scheduled visits 1, 3, 6 and 12 months after surgery.

For patients treated with EF and K-wires:

- 1 Change of the wound dressing and discharge from the hospital at the same or following day
- 2 Change of the wound dressing in 3 to 4 days.
- 3 Active movements in shoulder, elbow and finger joints according to standardized protocol starting the next day after surgery.
- 4 Removal of the sutures in 12 to 14 days after the surgery.
- 5 X-ray control 4 weeks after the surgery.
- 6 Removal of the EF and K-wires 4 to 6 weeks after the surgery.
- 7 Workout of the wrist joint active and passive movements under the guidance of the hand therapist, after the removal of the implants.
- 8 Scheduled visits 1, 3, 6 and 12 months after surgery.

1.5 Primary acquisition methods and secondary data sources

The results of treatment were assessed with X ray examinations postero-anterior position in a 10° tilted-view and lateral position in a 20° tilted-view, subjective evaluation using the Patient-Rated Wrist Evaluation (PRWE) score (rating from 0 to 140, with a lower score representing a better result), Modern Activity Subjective Survey of 2007 (MASS07) score (rating from 0 to 100, with a lower score representing a better result), and subjective and objective

evaluation using the Gartland and Werley score (rating from 17.5 to 100, with a higher score representing a better result). X-ray assessment was performed by an independent radiologist as the Gartland and Werley score includes a radiological assessment of fracture consolidation and ulnar variance. The results of the treatment were recorded at every visit:

- 1 Visual evaluation, assessment of the objective data – Grip / pinch / tripod-pinch strength and range of motion (ROM) were measured. Wrist mobility was tested using a goniometer, grip strength with Jamar dynamometer, and pinch and three-point strength with a pinch gauge as well as X ray examinations postero-anterior position in a 10° tilted-view and lateral position in a 20° tilted-view were evaluated by independent radiologist.
- 2 Subjective / objective evaluation using the Patient-Rated Wrist Evaluation (PRWE) score (rating from 0 to 140, with a lower score representing a better result), Modern Activity Subjective Survey of 2007 (MASS07) score (rating from 0 to 100, with a lower score representing a better result), and subjective and objective evaluation using the Gartland and Werley score (rating from 17.5 to 100, with a higher score representing a better result) was also performed.

2 Results

2.1 General data

Consequently 64 patients were included in the final data assessment – 40 females with mean age 55.5 years and 24 males with mean age 43.3 years (Fig. 2.1.1). After dividing patients in research groups, VLP Group consisting of 34 patients with mean age of 52.4 years and EF Group, consisting of 30 patients with mean age of 49.2 years were developed (Fig. 2.2).

Fig. 2.1 Diagram of the gender distribution in research groups

Fig. 2.2 Age distribution in research groups

The age distribution in both groups according to Shapiro-Wilk test is parametric (VLP Group $p = 0.013$ and EF group $p = 0.048$). The age differences between groups ($p = 0.355$), which means – the groups do not statistically differ by the mean age and are equal, were controlled with Independent sample T test. The majority of patients in both groups had AO-C3 type fractures. Distribution of gender, age, fracture classification and other parameters is presented in Table 2.1.

Table 2.1

Description of the groups under study

	VLP group	EF group	P-value
Number of patients	34	30	–
Males / Females	11 / 23	13 / 17	0.365
Age (years)	52.4 ± 14.7	49.2 ± 13.0	0.355
Fractured side right / left	9 / 25	12 / 18	0.250
Dominant / not dominant wrist	10 / 24	10 / 20	–
AO – C1	11.8%	6.7%	–
AO – C2	26.5%	20.0%	–
AO – C3	58.8%	73.3%	–
High energy trauma	3	5	0.334
<i>Proc. styloideus ulnae</i> fracture	41.1%	56.7%	0.443
Associated soft tissue injuries recorded	61.8%	66.7%	0.683

2.2 Statistical processing of study data

Patient population data of both study groups, as well as data derived from study measurements were classified in Microsoft Excel data processing program. Statistical processing of clinical data has been carried out using the SPSS 20 (Statistical Package for the Social Sciences) program – forecasting analytic and statistical analysis software package. Interconnection of data searched with non-parametric tests and correlation analysis methods. In all cases, a relevance level has been used to assess statistical hypotheses ($p \leq 0,05$ to approve, $p > 0,05$ to decline).

2.3 Results of objective measurements

All wrist ROM and grip force measurements show the volume of force or movements (%) compared to the healthy wrist in 1, 3, 6 and 12 months after surgery. Since it was impossible to prove that results obtained correspond to normal distribution (which can also be seen from histograms), only non-

parametric tests were used to compile and evaluate the results (Mann-Whitney and Kolmogorov-Smirnov tests to analyse differences in measurements between control groups and Wilcoxon Signed Ranks and Sign tests, to show changes in measurement results depending on the time after the surgery).

2.3.1 Wrist flexion

Using the standard statistical methodology to assess the average values of wrist flexion, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.2).

Table 2.2

Average values of wrist flexion

	Month 1	Month 3	Month 6	Month 12
Group VLP %	40.7 ± 5.6	62.3 ± 4.9	77.3 ± 5.3	84.7 ± 4.6
Group EF %	32.9 ± 4.3	63.6 ± 6.7	77.1 ± 5.0	81.3 ± 5.5

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.3 Value of the wrist flexion according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist flexion measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist flexion parameter depending on a type of manipulation have been found only at month 1 ($p < 0.05$) after surgery (See Table 2.3).

Table 2.3

**Differences in the values of wrist flexion parameter depending
on a type of manipulation**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	No	No	No
p-value (Mann-Whitney test)	0.048	0.731	0.819	0.325
p-value (Kolmogorov-Smirnov test)	0.303	0.995	0.999	0.717

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist flexion measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of the wrist flexion over the time after the surgery in both research groups ($p < 0.01$) (See Table 2.4).

Table 2.4

Wrist flexion measurements using Wilcoxon Signed Ranks and Sign tests

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.000
p-value (Sign test) Group VLP	0.000	0.000	0.001
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.001
p-value (Sign test) Group EF	0.000	0.000	0.003

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.3.2 Wrist extension

Using the standard statistical methodology to assess the average values of wrist extension, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.5):

Table 2.5

Average values of wrist extension

	Month 1	Month 3	Month 6	Month 12
Group VLP %	46.2 ± 6.7	72.9 ± 5.5	87.6 ± 4.0	91.9 ± 3.7
Group EF %	20.1 ± 6.1	72.8 ± 7.5	80.9 ± 5.6	88.9 ± 4.4

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.4 Value of the wrist extension according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist extension measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist extension parameter depending on a type of manipulation have been found only at month 1 ($p < 0.05$) after surgery (See Table 2.6).

Table 2.6

**Wrist extension measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	No	No	No
p-value (Mann-Whitney test)	0.000	0.995	0.056	0.324
p-value (Kolmogorov-Smirnov test)	0.000	0.472	0.181	0.403

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist extension measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist extension over the time after the surgery in both research groups ($p < 0.01$) (See Table 2.7).

Table 2.7

**Wrist extension measurements using Wilcoxon Signed Ranks
and Sign tests**

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.003
p-value (Sign test) Group VLP	0.000	0.000	0.089
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.005	0.000
p-value (Sign test) Group EF	0.000	0.007	0.000

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.3.3 Wrist radial deviation

Using the standard statistical methodology to assess the average values of wrist radial deviation, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.8).

Table 2.8

Average values of wrist radial deviation

	Month 1	Month 3	Month 6	Month 12
Group VLP %	41.5 ± 8.3	74.5 ± 5.6	84.3 ± 5.6	89.9 ± 3.7
Group EF %	26.0 ± 7.9	61.7 ± 8.9	72.9 ± 5.5	80.6 ± 6.3

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.5 Value of the wrist radial deviation according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist radial deviation measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist radial deviation parameter depending on a type of manipulation have been found in all measurements ($p < 0.05$) after surgery (See Table 2.9).

Table 2.9

**Wrist radial deviation measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	Yes	Yes	Yes
p-value (Mann-Whitney test)	0.003	0.014	0.009	0.036
p-value (Kolmogorov-Smirnov test)	0.012	0.071	0.012	0.098

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist radial deviation measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist radial deviation over the time after the surgery in both research groups ($p < 0.01$) (See Table 2.10).

Table 2.10

**Wrist radial deviation measurements using
Wilcoxon Signed Ranks and Sign tests**

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.001	0.058

Table 2.10 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.001	0.043
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.003	0.038
p-value (Sign test) Group EF	0.000	0.011	0.021

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.3.4 Wrist ulnar deviation

Using the standard statistical methodology to assess the average values of wrist ulnar deviation, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.11).

Table 2.11

Average values of wrist ulnar deviation

	Month 1	Month 3	Month 6	Month 12
Group VLP %	41.8 ± 8.9	70.1 ± 6.3	79.9 ± 5.5	87.8 ± 3.7
Group EF %	38.5 ± 8.7	64.9 ± 8.1	78.3 ± 6.4	88.0 ± 5.0

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.6 Value of the wrist ulnar deviation according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist ulnar deviation measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist radial deviation parameter depending on a type of manipulation have not been found in any measurements ($p < 0.05$) after surgery (See Table 2.12).

Table 2.12

**Wrist ulnar deviation measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	No	No	No	No
p-value (Mann-Whitney test)	0.536	0.284	0.655	0.686
p-value (Kolmogorov-Smirnov test)	0.828	0.252	0.946	0.980

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist ulnar deviation measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist ulnar deviation over the time after the surgery in both research groups ($p < 0.01$) (See Table 2.13).

Table 2.13

**Wrist ulnar deviation measurements using Wilcoxon Signed Ranks
and Sign tests**

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.009	0.006

Table 2.13 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.072	0.045
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.003	0.000
p-value (Sign test) Group EF	0.001	0.063	0.000

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.3.5. Wrist pronation

Using the standard statistical methodology to assess the average values of wrist pronation, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.14).

Table 2.14

Average values of wrist pronation

	Month 1	Month 3	Month 6	Month 12
Group VLP %	69.8 ± 7.0	92 ± 3.5	99.2 ± 1.0	99.5 ± 1.1
Group EF %	63.1 ± 7.5	91.1 ± 4.6	97.8 ± 1.6	99.3 ± 1.0

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig.2.7 Value of the wrist pronation according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist pronation measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist pronation parameter depending on a type of manipulation have not been found in any measurements ($p < 0.05$) after surgery (See Table 2.15).

Table 2.15

**Wrist pronation measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	No	No	No	No
p-value (Mann-Whitney test)	0.214	0.955	0.117	0.509
p-value (Kolmogorov-Smirnov test)	0.768	1.000	0.890	1.000

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist pronation measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist pronation over the time after the surgery in both research groups ($p < 0.01$), but in Group VLP the patients’ improvement between month 6 and month 12 is no longer statistically significant ($p > 0.05$) (See Table 2.16).

Table 2.16

**Wrist pronation measurements using Wilcoxon Signed Ranks
and Sign tests**

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	No
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.713

Table 2.16 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.000	0.625
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.002	0.038
p-value (Sign test) Group EF	0.000	0.007	0.063

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.3.6. Wrist supination

Using the standard statistical methodology to assess the average values of wrist supination, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.17):

Table 2.17

Average values of wrist supination

	Month 1	Month 3	Month 6	Month 12
Group VLP %	57.9 ± 8.4	87.4 ± 4.3	93.9 ± 3.0	96.6 ± 2.3
Group EF %	41.0 ± 7.8	78.2 ± 7.0	88.7 ± 3.6	90.7 ± 3.8

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.8 Value of the wrist supination according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist supination measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist supination parameter depending on a type of manipulation have been found in all measurements ($p < 0.05$) after surgery (See Table 2.18).

Table 2.18

**Wrist supination measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	Yes	Yes	Yes
p-value (Mann-Whitney test)	0.004	0.046	0.019	0.008
p-value (Kolmogorov-Smirnov test)	0.023	0.017	0.024	0.035

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist supination measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist supination over the time after the surgery in both research groups ($p < 0.01$), but in Group EF the patient’s improvement between month 6 and month 12 is no longer statistically significant ($p > 0.05$) (See Table 2.19).

Table 2.19

**Wrist supination measurements using Wilcoxon Signed Ranks
and Sign tests**

	Month 3 vs month 1.	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	No
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.048

Table 2.19 continued

	Month 3 vs month 1.	Month 6 vs. Month 3	Month 12 vs. Month 6
p-Value (Sign test) Group VLP	0.000	0.001	0.180
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.000	0.191
p-value (Sign test) Group EF	0.000	0.002	0.115

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.3.7. Grip force

Using the standard statistical methodology to assess the average values of wrist grip force, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.20):

Table 2.20

Average values of wrist grip force

	Month 1	Month 3	Month 6	Month 12
Group VLP %	27.7 ± 5.9	60.9 ± 5.2	80.4 ± 5.3	86.6 ± 4.0
Group EF %	11.6 ± 3.5	53.8 ± 5.8	71.1 ± 5.9	85.7 ± 4.8

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.9 Value of the wrist grip force according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist grip force measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist grip force parameter depending on a type of manipulation have been found in month 1 and month 6 ($p < 0.05$) after surgery, but have not been found in month 3 and month 12 ($p > 0.05$) (See Table 2.21).

Table 2.21

**Wrist grip force measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	No	Yes	No
p-value (Mann-Whitney test)	0.000	0.081	0.009	0.870
p-value (Kolmogorov-Smirnov test)	0.000	0.351	0.039	0.994

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist grip force measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist grip force over the time after the surgery in both research groups ($p < 0.01$) (See Table 2.22).

Table 2.22

**Wrist grip force measurements using Wilcoxon Signed Ranks
and Sign tests**

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.017

Table 2.22 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.000	0.026
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.000	0.000
p-value (Sign test) Group EF	0.000	0.000	0.000

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”

2.3.8 Key pinch force

Using the standard statistical methodology to assess the average values of key pinch force, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.23).

Table 2.23

Average values of key pinch force

	Month 1	Month 3	Month 6	Month 12
Group VLP %	44.0 ± 8.0	77.9 ± 5.3	86.6 ± 4.4	91.9 ± 2.7
Group EF %	29.4 ± 6.4	75.8 ± 6.8	89.2 ± 4.0	90.7 ± 3.9

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.10 Value of the wrist key pinch force according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist key pinch force measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist key pinch force parameter depending on a type of manipulation have been found only in month 1 ($p < 0.05$) after surgery (See Table 2.24).

Table 2.24

**Wrist key pinch force measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	No	No	No
p-value (Mann-Whitney test)	0.007	0.594	0.519	0.826
p-value (Kolmogorov-Smirnov test)	0.003	0.816	0.909	0.958

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist key pinch force measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist key pinch force over the time after the surgery in both research groups ($p < 0.01$), but in Group EF the patients’ improvement between month 6 and month 12 is no longer statistically significant ($p > 0.05$) (See Table 2.25).

Table 2.25

**Wrist key pinch force measurements using Wilcoxon Signed Ranks
and Sign tests**

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	No
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.002	0.019

Table 2.25 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.018	0.063
p-Value (Wilcoxon Signed Ranks test) Group EF	0.000	0.000	0.262
p-value (Sign test) Group EF	0.000	0.000	0.115

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.3.9. Tripod pinch force

Using the standard statistical methodology to assess the average values of tripod pinch force, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.26).

Table 2.26

Average values of tripod pinch force

	Month 1	Month 3	Month 6	Month 12
Group VLP %	39.7 ± 8.0	74.6 ± 5.3	86.6 ± 4.4	92.1 ± 2.7
Group EF %	26.2 ± 6.4	70.4 ± 6.8	86.7 ± 4.0	92.9 ± 3.9

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.11 Value of the wrist tripod pinch force according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether wrist tripod pinch force measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist tripod pinch force parameter depending on a type of manipulation have been found only in month 1 ($p < 0.05$) after surgery (See Table 2.27).

Table 2.27

**Wrist tripod pinch force measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	No	No	No
p-value (Mann-Whitney test)	0.031	0.306	0.790	0.711
p-value (Kolmogorov-Smirnov test)	0.027	0.946	0.993	0.995

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist tripod pinch force measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement of wrist tripod pinch force over the time after the surgery in both research groups ($p < 0.05$) (See Table 2.28).

Table 2.28

**Wrist tripod pinch force measurements Wilcoxon Signed Ranks
and Sign tests**

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.005

Table 2.28 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.000	0.108
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.000	0.006
p-value (Sign test) Group EF	0.000	0.000	0.017

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.4. Subjective scales:

2.4.1 PRWE

Using the standard statistical methodology to assess the average values of PRWE scale, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.29).

Table 2.29

Average values of PRWE scale

	Month 1	Month 3	Month 6	Month 12
Group VLP %	50.6 ± 8.0	13.5 ± 5.3	7.2 ± 4.4	2.1 ± 2.7
Group EF %	77.8 ± 6.4	21.2 ± 6.8	9.4 ± 4.0	3.9 ± 3.9

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.12 Value of the PRWE scale according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether PRWE measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of wrist PRWE parameter depending on a type of manipulation have been found only in month 1 ($p < 0.01$) after surgery (See Table 2.30).

Table 2.30

**PRWE measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	No	No	No
p-value (Mann-Whitney test)	0.000	0.249	0.490	0.320
p-value (Kolmogorov-Smirnov test)	0.000	0.717	0.717	0.816

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist PRWE measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement (reduction) of wrist PRWE over the time after the surgery in both research groups ($p < 0.05$) (See Table 2.31).

Table 2.31

PRWE measurements using Wilcoxon Signed Ranks and Sign tests

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.009	0.000
p-value (Sign test) Group VLP	0.000	0.012	0.000
p-value (Wilcoxon Signed Ranks tests Group EF	0.000	0.001	0.003
p-value (Sign test) Group EF	0.000	0.009	0.001

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Considering the fact that patients of different ages were presented in both research groups and the PRWE questionnaire included a subjective assessment of the degree of restriction of multiple activities as well as of pain, it was established whether there was a correlation between patient's age and subjective assessment (Fig. 2.4.1.2). The standard correlation does not show a statistically significant dependency of the total PRWE values on patients' age at any time ($p > 0,05$).

Fig. 2.13 Correlation between PRWE values and patient age

2.4.2 MASS07

Using the standard statistical methodology to assess the average values of MASS07 scale, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.32).

Table 2.32

Average values of MASS07 scale

	Month 1	Month 3	Month 6	Month 12
Group VLP %	27.9 ± 9.1	5.1 ± 2.8	1.4 ± 1.4	0.3 ± 0.3
Group EF %	58.1 ± 11.4	8.8 ± 6.6	2.1 ± 1.8	0.9 ± 0.9

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$

Visualization of measurement results:

Fig. 2.14 Value of the MASS07 scale according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether MASS07 measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of

wrist MASS07 parameter depending on a type of manipulation have been found only in month 1 ($p < 0.01$) after surgery (See Table 2.33).

Table 2.33

**MASS07 measurements using Mann-Whitney
and Kolmogorov-Smirnov tests**

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	No	No	No
p-value (Mann-Whitney test)	0.000	0.887	0.376	0.967
p-value (Kolmogorov-Smirnov test)	0.000	0.997	0.993	1.000

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether wrist MASS07 measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement (reduction) of wrist MASS07 over the time after the surgery in both research groups ($p < 0.05$), but in Group EF the patients’ improvement between month 6 and month 12 is no longer statistically significant ($p > 0.05$) (See Table 2.34).

Table 2.34

MASS07 measurements using Wilcoxon Signed Ranks and Sign tests

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	No
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.003	0.031

Table 2.34 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.007	0.227
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.004	0.106
p-values (Sign test) Group EF	0.000	0.007	0.146

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

2.4.3 Modified Gartland and Werley scale

Using the standard statistical methodology to assess the average values of modified Gartland and Werley scale, depending on the type of manipulation and the interval of the time after surgery, we obtained the following average values (95% confidence interval) (See Table 2.35):

Table 2.35

Average values of modified Gartland and Werley scale

	Month 1	Month 3	Month 6	Month 12
Group VLP %	58.9 ± 3.9	78.1 ± 2.9	85.3 ± 2.9	91.8 ± 2.9
Group EF %	47.9 ± 3.0	72.8 ± 3.6	82.8 ± 3.2	88.5 ± 3.8

Calculated by formula: $Mean \pm (Mean\ Upper\ Bound - Mean\ Lower\ Bound) / 2$.

Visualization of measurement results:

Fig. 2.15 Value of the modified Gartland & Werley scale according to type of manipulation and time interval after the surgery

Mann-Whitney and Kolmogorov-Smirnov tests were used to analyse whether modified Gartland & Werley score measurements have statistically significant differences between control groups depending on the time after surgery. The following results were obtained – the statistically significant differences in the values of modified Gartland & Werley score parameter depending on a type of manipulation have been found in month 1 and month 3 ($p < 0.05$) after surgery (See Table 2.36).

Table 2.36

Modified Gartland & Werley score measurements using Mann-Whitney and Kolmogorov-Smirnov tests

	Month 1	Month 3	Month 6	Month 12
There are statistically significant differences between Group VLP and Group EF	Yes	Yes	No	No
p-value (Mann-Whitney test)	0.000	0.023	0.195	0.189
p-value (Kolmogorov-Smirnov test)	0.000	0.035	0.425	0.392

P-value match with Asymp. Sig. (2-tailed) in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

Wilcoxon Signed Ranks and Sign tests were used to determine whether modified Gartland & Werley score measurements are statistically significantly improving over the time after the surgery. The following results were obtained – both tests show statistically significant, monotonous improvement (reduction) of modified Gartland & Werley score over the time after the surgery in both research groups ($p < 0.01$) (See Table 2.37).

Table 2.37

Modified Gartland & Werley score measurements using Wilcoxon Signed Ranks and Sign tests

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
Statistically significant improvement (Group VLP)	Yes	Yes	Yes
Statistically significant improvement (Group EF)	Yes	Yes	Yes
p-value (Wilcoxon Signed Ranks test) Group VLP	0.000	0.000	0.000

Table 2.37 continued

	Month 3 vs. Month 1	Month 6 vs. Month 3	Month 12 vs. Month 6
p-value (Sign test) Group VLP	0.000	0.000	0.000
p-value (Wilcoxon Signed Ranks test) Group EF	0.000	0.000	0.001
p-value (Sign test) Group EF	0.000	0.000	0.000

P-value match with Asymp. Sig. (2-tailed) / 2 in calculation materials. If a single p-value in a column is less than 0.05, write “Yes”, otherwise write “No”.

The modified Gartland and Werley score consists of subjective and objective components. The correlation between the components of objective and subjective parts was evaluated in order to determine whether there was a difference between the patient’s subjective assessment of his or her ability and pain, as well as the objective, value-defined measurements (Fig. 2.16. A, B, C, D).

A

B

C

Fig. 2.16. A, B, C, D Correlation between subjective and objective components of the modified Gartland & Werley score

The standard correlation analysis shows a statistically significant correlation between the objective and subjective components at month 1, month 3 and month 12 ($p < 0.01$).

The standard correlation analysis does not show a statistically significant correlation between these components at month 6 ($p > 0.05$).

Evaluating the data from modified Gartland & Werley score for patients in different age groups, the standard correlation does not show a statistically significant dependency of the values on patient age at any time of data registration ($p > 0.05$) (Fig. 2.17).

Fig. 2.17 Correlation between the modified Gartland & Werley score components depending on patients' age

The clinical parameters (ROM and strengths) as well as subjective scores (PRWE, MASS07 and Gartland and Werley) improved evenly during the 12 months following surgery, showing a small superiority in figures for the patients of Group VLP. There were statistically significant differences in a number of goniometric and dynamometric measurements at particular times during the period of observation. However, other than the results at 1 month, these differences were not found to be consistent at each review time. There were no statistically significant differences in Gartland and Werley scores and MASS07 scores between the groups ($p = > 0.05$). The PRWE pain and function score showed statistically significant differences only at 1 month, 52 points in Group VLP and 74 points in Group EF ($p = 0.001$). The MASS07 and PRWE scores showed better results for patients with a non-dominant hand injury compared with the patients with a dominant hand injury

2.5 Associated injuries

The frequency of ligament co-injury did not statistically significantly differ between the two groups ($p = 0.22$). Sixteen patients had scapholunate ligament tears (Geissler grade II–IV), 11 patients had TFCC tears and eight patients had both. Scapholunate joint trans-fixation with K-wires with additional scaphocapitate joint fixation was performed in nine patients with acute Geissler grade IV scapholunate ligament tears. Seven patients from both groups underwent ulnar styloid fracture fixation with K-wires and tension bands due to TFCC and distal radioulnar joint instability. Additional reduction of fracture fragments at arthroscopy was necessary in 46 cases, 20 patients (59%) in Group VLP and 26 patients (90%) in Group EF ($p = 0.006$).

2.6 Complications

There were several complications recorded during the study (See Table 2.38).

Table 2.38

Rate of complications between research groups

Complication	VLP group (n = 34)	EF group (n = 30)	All patients (n = 64)
CRPS	1 (2.9%)		1.6%
Iatrogenic nerve damage	–	2 (6.6%)	3.1%
Secondary deformation of the joint surface after K-wire removal	–	2 (6.6%)	3.1%
Migration of K-wires	3 (8.8%)		4.7%
All	4 (11.8%)	4 (13.3%)	8 (12.5%)

CRPS – Complex Regional Pain Syndrome; VLP – volar locking plate; EF – external fixator.

All recorded complications, with the exception of secondary deformation of the joint surface following the evacuation of K-wires and the prognostically likely development of osteoarthritis in two Group EF patients, should be considered as minor (Fig. 2.6.1.a and Fig. 2.6.1.b), Patient with CRPS in Group VLP has successfully treated conservatively with physical therapy and appeared symptom-free within 6 months. The disruption caused by migrated K-wires in the Group VLP patients disappeared in a short period after the evacuation of K-wires. Wire-induced damages of the dorsal radial sensory nerve were treated surgically – one patient require the neurolysis surgery while the other patient underwent neurinoma resection surgery and microsurgical reconstruction of the damaged nerve. Neurological symptoms gradually regressed within 6 to 8 months after the secondary surgeries in both patients.

**Fig. 2.18. A X-ray immediately after the surgery and at Month 12 –
loss of the radial length**

Fig. 2.18. B Fluoroscopy during the surgery and at Month 12 – secondary dislocation of the lunate facet

3 Discussion

More than 200 years ago Abraham Colles (1773–1843) described the “typical” fracture of the distal radius and its treatment (Colles, 1970), concluding that despite the relatively simple method of closed reduction “the distortion of the limb instantly returns on the extension being removed” and “... by such mistakes the patient is doomed to endure for many months considerable lameness and stiffness of the limb, accompanied by severe pains on attempting to bend the hand and fingers”.

Discussion on treatment methods and comparison of them have not subsided during these 200 years. Particularly rapidly, treatment options and methods have changed since 1929, when Lorenz Böhler introduced the technique of the closed manual longitudinal forearm traction and elbow contra-traction. J. J. Gartland & C. W. Werley in 1951 in several sequential trials concluded and described that good clinical results could be achieved only in cases when normal anatomy of the wrist has been restored. Authors devised a demerit point system to score subjective and objective function that continues to be used today as well as defined the anatomic indices of normal volar tilt, radial length, and radial inclination to link restoration of anatomy to restoration of function, a principle that is the basis of modern fracture treatment.

G. Frykman in 1967, in the series of 413 DRFs found that osteoarthritic changes occurred not only in the radiocarpal joint, but also in the DRUJ (Frykman, 1967), drawing attention to the fact that in the cases of articular DRFs, the restoration of the DRUJ surface is also essential for the achievement of the good late functional results.

In 1986, J. L. Knirk and J. B. Jupiter presented results of their study, which concluded that 91% of DRFs with intraarticular step-off more than 1 mm and 100% DRFs with intraarticular step-off exceeding 2 mm are complicated by deforming osteoarthritis (Knirk and Jupiter, 1986).

H. J. Kreder with co-authors in 2005 published results of a study which included calculations of the relative risk size (with a confidential interval 95%) in cases of articular step-off and gap deformations. The results obtained were as follows – when the step deformity was greater than 2 mm the risk of developing arthritis was 10.4 times (95% CI 4.1 to 26.6) greater than when it was less than 2 mm. A gap greater than 2 mm was associated with a risk of arthritis which was eight times (95% CI 2.6 to 24.7) higher than that for patients with a gap less than 2 mm (Kreder et al., 2005).

Surgical treatment methods of DRFs are different, starting from closed reduction under the fluoroscope control and transcutaneous fixation with K-wires with or without application of the external fixator and ending with ORIF of all 3 columns as well as fixation with fragment specific plates from both sides.

Given that in this study only two of the possible DRF treatment methods were used – arthroscopic assisted ORIF and fixation with VLP and arthroscopic assisted fixation with K-wires and externa fixator, there will be no further discussion on other methods.

3.1 About external fixator

The use of different external fixation devices started from 40-ties of the previous century. The popularity of external fixation for the treatment of wrist fractures was catapulted forward by the concept of “ligamentotaxis” by Jacques Vidal in 1979, who advocated its use for comminuted articular fractures, including those of the hip, knee, ankle, spine, and wrist. The principle of

ligamentotaxis involved the application of tension “by means of distraction forces working through capsule-ligamentous structures” to obtain reduction (Vidal, 1979). Author described the use of this principle for highly comminuted DRFs that were otherwise suitable for the ORIF. In 80-ties and 90-ties huge amount of different external fixators and modifications were designed and this method was widely used especially in the treatment of the articular DRFs. Approximately 10 years after J. Vidal’s publication different studies started to report about complications associated with this technique. The most common complications related to the overdistracted articular injuries were stiffness of the fingers, reflex sympathetic dystrophy (CRPS), nerve dysfunction as well as different technical problems – inability to maintain reduction of articular fragments, radial length with traction alone (Kaempffe et al., 1993; McQueen et al., 1992; Weber and Szabo, 1986).

Nowadays the technique of external fixation includes “augmentation” of fixation with supplemental Kirschner wires, mini-open or arthroscopic reduction (or both), and bone grafting, with a concomitant reduction in traction-related complications. Setting of the EF in neutral traction allows to start immediate finger movements, while using additional stabilizing K-wires, removal of the EF can be carried out within 4 to 6 weeks, leaving the wires into the bone, if necessary, and allowing to start controlled workout of the wrist movements (Wolfe, 2017).

3.2 About VLP

Historically open reduction of articular fractures of the distal radius was indicated in young and active patients with good bone quality. ORIF can be used in cases when restoration of the joint surface cannot be achieved by closed manipulation, ligamentotaxis, or percutaneous reduction manoeuvres. It can be

used also as an alternative to percutaneous fixation at the preference of the patient or surgeon.

In 2002, the first results of the application of the volar locking plate in 29 patients and 31 fractures were published (Orbay and Fernandez, 2002). Report highlighted the positioning of the plate between the PQ muscle and bone which significantly reduces the risk of the irritation of flexor tendons. It was concluded that combination of stable internal fixation with the preservation of the dorsal soft tissues resulted in rapid fracture healing, reduced need for bone grafting, and low incidence of tendon problems. The greatest benefits of the VLP implant are that it is strong and it permits stable fixation even in the most comminuted unstable fractures, therefore immediate wrist ROM is possible with minimal use of external support (removal wrist splint) (Wright et al., 2005). Osada and co-authors in the biomechanical model assessed and demonstrated that only the volarly placed SCS / V plated specimens resisted deformation of 5 degrees or more at loads up to 250 N, which compares with the physiologic loads expected with active finger motion, and was significantly stronger and more rigid than the other plate groups.(Osada et al., 2003).

The management of unstable DRFs with open surgical methods in elderly, less active patients with osteoporosis traditionally was considered as contraindicated. The rate of complications in this group always was higher, including loss of stability of the fixation, non-union or malunion of the fracture as well as the risk of the CRPS. The treatment of unstable distal radius fractures in the elderly patient with a volar fixed-angle plate provided stable internal fixation and allowed early function. This technique minimized morbidity in the elderly population by successfully handling osteopenic bone, allowed early return to function, provided good final results, and was associated with a low complication rate (Orbay and Fernandez, 2004).

Assessing the information provided above, it is logical that there has always been a desire to compare these different methods of treatment – their advantages and flaws, and especially the possible outcomes.

3.3 Comparison of both methods

In the next part of the discussion I will present several examples of the benefits of the VLP or EF method compared to the other method of surgical treatment. I selected only results of the prospective randomized trials because in the most of retrospective studies randomisation has not been observed. Only studies with displaced articular DRFs treated surgically are presented in further discussion.

In 2000, H. Kapoor et al. reported on study including 90 adult patients with mean age 39. Patients were randomized in 3 groups – each consisted of 30 patients. First group was treated with closed reduction and plaster immobilisation. Treatment results of this group were the worst ones and should not be presented for further analysis. The follow-up period was 1 year. Results of the treatment were assessed based on the Sarniento functional score, because, according to the authors – the DASH score had not yet been introduced when the study was carried out. Results in the EF group – 80% good and excellent, 20% average and poor results, results in ORIF group – 63% good and excellent, 26% average, 11% poor (Kapoor et al., 2000).

In 2005, H. J. Kreder et al. published results of the prospective randomized trial, including 179 skeletally-mature patients between the ages of 16 and 75 years with displaced intra-articular fractures of the distal radius. The follow-up period was 2 years. EF group consisted of 88 patients, and ORIF group – of 91 patients. It should be noted that dorsal or radial column plates also were also used in ORIF group, making this group heterogeneous. Conclusions

made by authors are as follows: Grip and pinch force was better in EF group within first 6 months. During a two-year observation period patients from the EF group recovered functionally more rapidly and achieved better overall results compared to ORIF group patients (Kreder et al., 2005).

In 2014, R. Shukla et al. published results of a study including 110 patients with mean age 39 ± 13 , treated surgically because of the articular DRFs – 68 patients treated with EF and 42 patients treated with VLP. The assessment of pain, range of motion, grip strength and activity were assessed at each follow-up visit and scored according to the Green and O'Brien scoring system. One year after the surgery, 85.5% of EF group patients had good and excellent results, but only 73.3% of patients had good and excellent results in VLP group. As additional conclusion on the use of EF in treatment of the articular DRFs authors mentioned that patients aged < 50 years treated with external fixation had a better outcome than patients aged > 50 years in all parameters studied at the end of 1 year. (Shukla et al., 2014).

This conclusion lines with a part of hypothesis of my study – fixation with EF can be successfully applied in young patients, not only in elderly ones with osteoporotic bone changes.

In 2016, Chuang Ma et al. presented randomised study with 123 patients older than 65. EF group enrolled 58 patients and VLP group – 65 patients. Clinical findings – ROM, Grip, pinch improved evenly in both groups with a slight majority in favour of the EF group. Both groups significantly differ in complication rates – 14 different complications were recorded in EF group with 1 patient who required second surgery because of the complication, however VLP group had 31 different complications with 6 secondary surgeries (Ma et al., 2016).

In 2011, M. K. T. Wilcke et al. presented results of the prospective randomized trial including 63 patients under 70 years of age, with an unstable extra-articular or non-comminuted intra-articular dorsally displaced distal radius fracture. 33 patients were randomized in the VLP group and EF group consisted of 30 patients. The results identified that the VLP group had better ROM, grip DASH and PRWE scores in first 6 months, but differences diminished and were small in 12 months after the surgery. Conclusion of the authors: the volar plate fixation is more advantageous than the external fixation, in the early rehabilitation period (Wilcke et al., 2011).

In 2013, J. H. Williksen et al. published results of the prospective randomized trial of 111 patients with age distribution from 20 to 84. EF group after randomization consisted of 59 patients, but VLP group of 52 patients. The follow-up period after the surgery was 5 years. The conclusion of the authors – in a long-term follow-up, the VLP group patients have better forearm pronation / supination, less radial shortening, less ulnar shortening and better grip force. At 52 weeks, there were 18 (30%) complications in the EF group and 15 (29%) in the VLP group. Eight plates (8 / 52, 15%) were removed due to complications during the first year. Six were related to surgical errors.

Authors have mentioned, but have not stressed and evaluated the fact, that surgeries were performed by 11 surgeons, obviously – experience, surgical technique, the accuracy of the positioning of the implant have certainly not been identical in all cases (Williksen et al., 2013).

Identification of the results of the surgical treatment of the articular DRFs has become the subject of several systematic meta-analyses. Almost all authors have concluded that the heterogeneity of fractures, differences in fracture fixation methods, differences in the surgical techniques and patient populations, have created huge difficulties in the adoption of precise and acceptable conclusions for everybody.

M.M.J. Wallenkamp et al. in such a meta-analysis study found that patients treated with a volar locking plate showed significantly better functional outcome throughout the entire follow-up. However, this difference was only clinically relevant during the early postoperative period (Walenkamp et al., 2013).

In 2013, Chinese authors led by Xuetao Xie published the result of the meta-analyses study where they concluded that for surgical treatment of distal radius fractures, internal fixation yields better functional outcomes, forearm supination, restoration of anatomic volar tilt and radial inclination, and fewer minor complications. The patients who received ORIF using volar locking plates for the treatment of distal radius recovered more quickly than did patients who received EF (Xie et al., 2013).

Meta-analyses study published in 2018 by C. J. C. Gouk et al. concluded, that the majority of the objective and subjective parameters do not differ clinically and statistically within 12 months after the treatment of articular DRFs with VLP or EF. Ulnar variance was better restored by volar locking plates. The volar locking plates group was associated with higher re-operation rate, and the external fixation group had a higher infection rate. Current literature suggests that volar locking plates can provide better subjective scores and radiographic parameters, especially in the first 3 months, but may be associated with a higher re-operation rate (Gouk et al., 2018).

The most frequent conclusions are as follows – despite many advantages, such as stable fixation of fragments or possibility of early active workout of ROM, there are no evidence of statistically significant advantages for VLP compared to EF in the treatment of articular DRFs in long time period (Costa et al., 2014; Roh et al., 2015).

It is proved that VLP allows the rigid fixation of the fracture fragments, but the previous studies do not verify if the fragments fixed by the plate are in the exact anatomical position. Most of the articles mention different step-off and gap deformities of the articular surfaces, remained after the surgeries where fragment visualization and fixation were made only under the control of fluoroscope. Proceeding fixation with EF and K-wires the anatomical fixation of the fracture fragments is much more complicated and stability of the fixation is lesser, resulting in possible secondary dislocations. In both cases, unless the arthrotomy of the joint for the proper reposition of the articular fragments is carried out, which causes additional soft tissue injuries and secondary contractures, precise reposition of AO C2 and C3 fractures is technically complicated.

3.4 Arthroscopy and distal radius fractures

An arthroscopic assisted method of fracture treatment is proposed to minimise risks of inaccurate repositioning and for better visualization of the fracture site.

The place of arthroscopy in this trial deserves a little further consideration. Our results using wrist arthroscopy to visualize fragment positioning following preliminary reduction confirm the worth of this method in the treatment of these fractures.

Over the last two decades, the hand surgeons have been increasingly using both – diagnostical and therapeutical wrist arthroscopies. Arthroscopic assisted fixation of DRFs also is becoming more popular. One of the first descriptions about arthroscopy in the treatment of DRF was published by *H.J. Levy et al.* in 1993. They were placing the arthroscope in the joint using the open volar approach for fracture fixation without opening the joint capsule. This technique

facilitated visualization of the radiocarpal joint while preserving the ligaments which could be injured using the open approach (Levy and Glickel, 1993).

T.L. Whipple in 1995. wrote that, for the distal radius, visual inspection and lavage, reduction of fracture fragments, and pin fixation conducted under arthroscopic control more accurately restore the smooth articular surfaces than is possible using traditional closed manipulation and ligamentotaxis (Whipple, 1995).

In 1995 and 1999, W. B. Geissler et al. published descriptions of arthroscopic assisted percutaneous or limited open techniques of DRF fixation, and indicated the probability and necessity of prevention of the associated soft tissue lesions (Geissler, 1995; Geissler and Freeland, 1999; Geissler et al., 1996).

In 1999, Group of Japanese hand surgeons led by Kazuteru Doi published results of the prospective randomized trial where 34 patients, where treated using arthroscopic assisted DRF fixation with K-wires and EF. The control group consisted of 48 patients who were treated traditionally with ORIF method or K-wires plus EF. The mean follow-up time was 31 months. As a result of the treatment of the patients, the authors found, that Gartland & Werley as well as Green and O'Brien scores demonstrated that the group that had had an arthroscopically assisted procedure had better outcomes than the group that had had conventional open reduction and internal fixation. The group that had had an arthroscopically assisted procedure also had significantly better ranges of flexion-extension and radial-ulnar deviation of the wrist and grip strength ($p < 0.05$). The radiographic results showed that the patients who had had an arthroscopically assisted procedure had better reduction of volar tilt, ulnar variance, and articular (gap) displacement than did those who had been managed with conventional open reduction and internal fixation ($p < 0.05$ for each comparison). The authors concluded, that an arthroscopically guided operation achieved an accurate reduction of intra-articular fractures of the distal aspect of

the radius. Minimum capsular and adjacent soft-tissue scarring reduced postoperative contracture, which improved the overall functional results. They recommended arthroscopically guided reduction and internal fixation not only for young adults but for all patients who are less than seventy years old and have an intra-articular fracture of the distal part of the radius with more than one millimetre of displacement on plain radiographs. (Doi et al., 1999)

The most important advantage of the arthroscopy is the possibility of visualization of the joint on the screen, in real time, in immersive magnification and in natural colours that no auxiliary diagnostic methods can provide. Fluoroscopy alone provides an image that has poorer resolution than that of the magnified camera used for direct arthroscopic visualization, whereas even a small degree of displacement is obvious arthroscopically (Lutsky et al., 2008).

In 2001, C. C. Edwards et al. published an article about the study where articular DRFs after the fluoroscopic guided, “satisfactory” reposition and fixation with K-wires were examined arthroscopically. Authors discovered that the optimal reduction obtained using C-arm was found to have an articular displacement of $> 1\text{mm}$ by adjunctive arthroscopy. (Edwards et al., 2001). In 2008, in a similar study K. Lutsky et al. identified that 36% of surgeries required additional arthroscopic guided fracture repositions.

More severely comminuted and higher energy injuries are more likely to require readjustment. In AO-C3 fractures the necessity of arthroscopic assisted additional fracture reposition after initial treatment by indirect reduction techniques should be necessary up to 71% of patients (Auge and Velazquez, 2000). Necessity for additional fragment reposition during the arthroscopy in my study was more common than in previously published studies. Despite the large number of additional arthroscopic manipulations in Group EF patients, the group VLP patients also needed more additional manipulations in the arthroscopic stage of the surgery as it was described in the previous studies (Abe and Fujii,

2017; Burnier et al., 2018; Khanchandani and Badia, 2013; Ono et al., 2010; Ono et al., 2012).

In the ensuing part of the discussion I will address to the associated soft tissue lesions, incidence of them and the recommended treatment methods. It is possible that in previous comparative trials the unrecognized and misdiagnosed associated soft tissue lesions did not allow to achieve better long-term functional results. It is hoped that overall outcomes will be improved once patient-related and treatment-related factors have been evaluated and previously undetected associated ligament injuries have been found and treated (Lindau, 2017).

There are three intracarpal soft tissues of particular importance: the triangular fibrocartilage complex (TFCC), the scapholunate interosseous ligament (SLIL), and the lunotriquetral interosseous ligament (LTIL). These structures are invisible on the plain radiograms and intra-operative fluoroscopies, but nowadays, if there are technical possibilities and an experienced surgical staff, visualization and prevention of these injuries should be desired. In cases of the SLIL or LTIL injuries most commonly the *Geissler* arthroscopic classification is used, but in cases of TFCC injuries – the *Palmer* classification is advised.

In 2013, T. Ogawa et al. described group of 89 patients with arthroscopic assisted treatment of DRF. They ranged in age from 17 to 92 years (mean, 62.2 years). TFCC injury was present in 59% of cases, SLIL injury in 54.5% of cases, and LTIL injury in 34.5% of cases. Only 17.1% of patients (14 / 82 patients) were negative for all three types of injury. In 81% of cases (72 / 89 patients), some intracarpal soft tissue injury was present in association with the fracture (Ogawa et al., 2013).

In 2020, S. Roulet et al. in 2020 published study in which the cases of arthroscopic findings of associated soft tissue lesions in patients with DRF have been evaluated. The study population consisted of 57 consecutive patients, with

mean age 43 years (range, 18–64 years). Among 57 intraarticular radius fractures, 25 (44%) were associated with arthroscopic SL laxity, 3 (5%) with arthroscopic LT laxity, and 16 (28%) with traumatic TFCC injury (Roulet et al., 2020).

The incidence of the interosseus ligament and TFCC injuries varies in different studies, but on average it ranges at around 50% for TFCC injuries and 30% for SLIL injuries (Ardouin et al., 2018). More detailed analysis of associated soft tissue injuries could be found in the recent publications, but these findings do not correlate with clinical findings and long-term functional results. Clinically it is important to determine the degree of the damage of the stabilizing structures, in order to avoid the formation of the secondary carpal instability. This instability can eventually lead to SLAC (*Scapho-lunate advance collapse*) deformation and osteoarthritis of the wrist joint.

W. B. Geissler, who introduced the arthroscopic classification of SLIL and LTIL injuries, recommended to use wrist immobilization in grade I injuries, arthroscopic reduction and pinning in grade II injuries, arthroscopic or open reconstruction with additional pinning in grade III injuries and open reduction and ligament reconstruction with or without tendon graft in grade IV injuries (Geissler, 2013; Peicha et al., 1999). Such an aggressive surgical approach did not seem acceptable for many hand surgeons, as well as other studies have been previously performed, in which more lenient surgical approach also yielded in good and satisfactory results. In 2007, D. P. Forward et al. published results of the prospective randomized study where they concluded that grade I and II SLIL tears treated only with immobilization, are asymptomatic within 1 year after the surgery (Forward et al., 2007). It is desirable to adjust the immobilization protocol after the DRF fixation with VLP to the degree of the SLIL injury detected during the surgery (Ono et al., 2012). Fixation methods and treatment options of the Geissler III SLIL injuries are still controversial. Several authors

agree with the W. B. Geissler's recommended transfixation in an anatomical position with K-wires (Kasapinova and Kamiloski, 2015; Khanchandani and Badia, 2013). On the other hand, in 2015, A. Mrkonjic et al. published long-term results (13 to 15 years after the primary surgery), where they did not find statistically significant differences in clinical, subjective, objective and radiological results between grade I-II and grade III SLIL injuries. (Mrkonjic et al., 2015). Authors consider that such results could be explained because of the secondary wrist stabilizers (volarly – RSL, RSC and LRL ligaments, dorsally – DRT and DIC ligaments) and they recommended to perform further clinical studies to explain and understand the role of these stabilizers.

Grade IV complete intercarpal injuries can be treated with arthroscopic reduction and percutaneous Kirschner wire (K-wire) pinning provided there are no radiological signs of dissociation because this implies that the secondary stabilizers have been injured as well (Lindau, 2017). In cases of arthroscopic SL joint transfixation with K-wires, an arthroscopic dorsal SL capsulodesis is also recommended, which creates additional stability of the joint (DelPinal F, 2010)

Stability of the DRUJ also is one of the key factors of the successful treatment of the DRFs. The TFCC in combination with a distal part of the interosseous membrane is the major soft tissue stabilizer of the DRUJ, which provides unobstructed movements of the forearm. Interaction of the TFCC with the distal part of the interosseous membrane provides stability of the DRUJ in any phase of movement (Haugstvedt et al., 2017; Moritomo, 2015).

In 2000, T. Lindau et al. published results of the study with 51 patients (aged 20 to 57) with results of the treatment of the articular DRFs, highlighting the functional results of the treatment of the associated TFCC lesions within 1 year after the surgery. Arthroscopy at the time of fracture showed complete or partial TFCC tears in 43 patients. Ten patients with complete peripheral tear and 7 patients with partial peripheral TFCC tear (totally 39.5%) had instability of the

DRUJ 1 year after the DRF showing worse functional and clinical results comparing to other patients (Lindau et al., 2000). These authors published repeated results of the same group of patients after 15 years and they found that only 1 of 17 patients (5.9%) with previously diagnosed DRUJ instability later was treated surgically. The obtained information leads to the conclusion, that peripheral TFCC tears less clinical problems as expected (Lindau, 2017).

Discussion about the type of the ulnar styloid fracture and its association with TFCC tear and instability of the DRUJ is still actual. There is a presumption, that complete fractures of the ulnar styloid are related to the potential separation of the proximal part of the TFCC from the head of ulna, causing DRUJ instability. In 2003, D. S. Ruch et al. describe the results of prevention of 13 symptomatic TFCC tears in a group of 57 DRF fracture patients, treated with arthroscopic assisted surgeries. Two years after the surgery 12 of 13 patients had stable DRUJ. This study documented the efficacy and safety of arthroscopically assisted TFCC repair in conjunction with distal radius fracture fixation. (Ruch et al., 2003).

In 2018, M. W. M. Fok et al. conducted a study where the occurrence and nature of the TFCC injuries associated with the surgical treatment of the DRFs with VLP were analysed. This study enrolled 43 patients with mean age 54 (17 to 75 y.o.) scheduled for implant removal after DRF union, for different reason except septic complications. Concomitant wrist arthroscopy to assess the condition of TFCC at the time of plate removal was routinely offered. Instability of the DRUJ in combination with ulnar wrist pain DRUJ which is statistically likely attributed to the TFCC tear, was found in 8 patients (18.6 %) with a total proximal avulsion the TFCC from the ulnar head. Authors concluded that a large majority of TFCC tears remained unhealed after the union of distal radius fractures. However, not all patients with tear were symptomatic (Fok et al., 2018).

In 2018, A. C-Y. Chen et al. published results of the long-lasting study where early performed surgery Chen outcomes (1 to 3 months after the accident) and delayed surgery results (more than 12 months after the accident) of the ulnar styloid base fracture fixation were compared. The authors concluded that the fractures of the ulnar styloid base are usually associated with TFCC tears and creating secondary DRUJ instability. Early detection and surgical repair yielded better outcomes. Higher complication rates in late-treated fractures show that surgeons should select surgical candidates and modalities properly (Chen et al., 2018).

Various associated soft tissue lesions were identified during my study, and the prevention procedures carried out, when such manipulations were necessary to reduce the risk of instability of joints and subsequent osteoarthritis. The frequency of ligament co-injury did not statistically significantly differ between the two groups ($p = 0.22$). Sixteen patients (25% of all) had scapholunate ligament tears (Geissler grade II–IV), 11 patients had TFCC tears and eight patients had both. Scapholunate joint trans-fixation with K-wires with additional scaphocapitate joint fixation was performed in nine patients (14% of all) with acute Geissler grade IV scapholunate ligament tears. LTIL Geissler grade II tears were found in 6 patients, which coincides with the frequency and severity of LTIL injuries reported above and described in the literature. In cases of the acute SLIL grade IV injuries, the fixation of the joint was performed with K-wires, but in Group EF patients required administration of additional wires and possibly increased the risk of soft tissue complications. Different isolated TFCC tears were found in 11 patients (17.1% of all), but 8 patients (12.5%) had combined TFCC and SLIL injuries. Surgical repair of the TFCC radial tears was not performed because it is known that if the proper anatomic reposition of the ulnar fragments of the DRF is performed, the radial tears of the TFCC cannot create instability in the DRUJ (Fok et al

., 2018). Central TFCC tears, which could theoretically also be degenerative in nature, especially in the elder patients, only debridement of the damaged part was performed. Surgical stabilization of the TFCC was performed only in patients with DRUJ instability if it remained after the fixation of the DRF. Three patients (4.7% of all) had arthroscopic dorsal TFCC fixation with absorbable sutures and 7 patients (10.9% of all) underwent ulnar styloid fracture fixation with K-wires and tension bands due to TFCC and distal radioulnar joint instability

3.5 Evaluation of the results

Traditionally functional outcomes of the wrist after the surgical manipulations are measured by ROM and the grip / pinch force. Both of these measurements provide good and objective representation of the results; however, these methods have drawbacks – they do not provide information on other aspects of the treatment – the patient’s pain, ability to carry out various daily activities or ability to return to the work, etc. Various functional scales have been introduced over time to capture and analyse such data.

Several common and proven data recording methods were used to record and subsequently evaluate the results of this study. Considering the fact that a unified data recording system for the assessment of distal radius fractures has not yet been introduced in hand surgery, I selected the most popular and recommended data recording methods for the assessment of hand injuries – Gartland & Werley modified score and PRWE score, which include both subjective assessments of pain and function, as well as the recording of certain objective variables. In addition, I chose to use the MASS07 scale, which includes functional indicators of the use of modern technological devices, such as computer keyboards, smart phones, electrical appliances, etc. This short 10-item scale is also recommended by M. Alexander et al., who showed that its statistical performance is comparable to the DASH and PRWE scales and is therefore recommended for functional assessment of the wrist joint after the wrist injuries (Alexander et al., 2008).

S. Gupta et al. published an article comparing the DASH and PRWE scales, the most commonly used in research. The authors concluded that statistical analysis of the results of the two scales did not show differences. In view of the above, and the fact that the PRWE scale is specific to wrist function, unlike the DASH, which is more focused on shoulder and elbow function, the authors recommend the PRWE scale as the method of choice for recording of functional outcomes of the wrist (Gupta et al., 2014).

In 2016, J. F. Waljee et al. published an analytic article on the wrist treatment outcomes represented of in the medical literature, and recommended a summary with a preferred minimum of data that could be used in unified data analysis and meta-analysis studies. This recommended standard includes measurements of the symmetrical range of motion of both hands, the grip strength of the hand and fingers (Grip, Pinch, Tripod pinch), visualization of the subjective pain and function (PRWE, MHQ – Michigan Hand Questionnaire,

PROMIS – Patient-Reported Outcomes Measurement Information System scales), recording of specific complications and the manipulations carried out to treat them, as well as radiological data – signs of bone healing, characteristics of joint surfaces, types and sizes of deformities, localisation of metal construction and possible positional or dimensional errors, standard parameters, i.e. volar tilt, radial height, radial incline, relationship of the distal ends of forearm bones (ulna + / –) (Waljee et al., 2016)

Radiological findings in this study were recorded according to the radiological section of Garland & Werley score, as well as position of the plate was evaluated according to Soong criteria.

During the follow-up of the patients in this study, statistically significant differences were found in several objective and subjective parameters, but the results obtained by comparing the two surgical treatments did not show significant differences in clinical terms. The Group VLP showed better short-term functional results, but by 12 months the differences between the two groups had evened out and there were no longer any clinical differences. The significant difference in the measurement results 1 month after surgery is explained by the use of diametrically opposed treatment methods. The Group VLP patients started rehabilitation in the third post-operative week, which naturally allowed them to return to normal daily activities much sooner. In the Group EF, the fixation was removed 4 weeks after surgery or, in some cases, the wires were left in the bone for a longer period of time. When we look at patients' emotional-subjective scores, the short-term scores were significantly better in the group VLP, because they resumed the activities of the injured arm sooner, but no clinically or subjectively significant differences were found between the groups over the 12-month period.

Subsequent alternating statistically significant differences in some aspects of the ROM values could be the result of the inconsistency of measurements performed by three different people. Regardless of these statistically significant differences, the clinical relevance of these differences is questionable (e.g. 90% against 97% of normal supination at 12 months). Our conclusion is that we were unable to demonstrate any clinically relevant differences in any measured parameter between the two groups, except at 1 month. This refutes the hypothesis that minimally invasive treatment could lead to better functional outcomes.

The next important topic for discussion is the analysis of complications. The most common complications of fractures of the distal end of the radius and their treatment are as follows: contracture or restriction of movements, secondary dislocation of the fracture and malunion, migration of the implants, irritation or ruptures of tendons, nerve compressions or injuries, pain or CRPS, as well as infection.

The overall complication rate for distal end fractures of the radius ranges from 6% to 80%, with a note - which conditions are defined as complications (McKay et al., 2001). Fixation of fractures with any metal construction significantly reduces the chances of secondary dislocation and improper fracture healing. In general, most of the presented complications can be prevented from developing after surgery with careful attention to detail during surgery and modification of surgical techniques on an individualized basis (Rhee et al., 2012).

Performing DRF fixation with VLP and screws, one of the most important things is to avoid placing the plate too distally, i.e. it is preferable to follow the Soong criteria and to position the distal edge of the plate so that it does not irritate the flexor tendons (*Soong 0* position).

In 2018, C. A. Selles et al. published the results of a study evaluating the need for plate evacuation in a cohort of 323 patients. Evacuation of the implants was required in 17% of patients. This group consisted mainly of patients with a higher Soong classification (I or II). In the cases of Soong II plate position, evacuation was 6 times more frequent than in the cases of Soong 0 position. These results suggest that accurate positioning of the plate reduces the incidence of tendon damage and hardware removal (Selles et al., 2018). Other authors also note an association of higher grades of Soong classification of plate position with the risk of flexor tendon complications and the need for plate evacuation (Lutsky et al., 2015; Soong et al., 2011)

Another major iatrogenic complication is irritation or damage of the extensor tendons with too long screws, especially in the distal metaphysis. Such lesions occur in 3% to 5% of patients undergoing osteosynthesis of the DRF (Soong et al., 2011). Various injuries of the extensor tendons can account up to 57% of all complications (Arora et al., 2007).

In my study, no patient in the Group VLP developed complications related to tendon irritation or damage, and no plate evacuation was performed. All plates were placed in Soong 0 or I position – 10 patients (29.4%) in Soong I and 24 patients (70.6%) in Soong 0. K-wires, inserted for additional fragment fixation, later were removed under local anaesthesia with or without fluoroscope guidance if the wires were detectable under the skin. No tendon complications related to wire insertion were recorded.

Three out of 34 patients (9 %) in the Group VLP experienced minimal migration of K-wires and skin irritation. This minor complication was attributed to the activation of the patients from the 3rd post-operative week onwards, resulting in loss of primary stability of some wires. Dislocation of the wires did not cause the secondary displacement of the fracture fragments, but only irritated

surrounding soft tissues, causing discomfort or moderate pain in the patients. After the evacuation of the wires, all related complaints disappeared.

F. Schuind in clinical trial where EF was used in the treatment of the articular DRFs described the following complications and their incidence: Fracture of the 2nd MC bone at the site of the implantation of the threaded rod – 1.6%, carpal tunnel syndrome – 2.6%, neurinoma of the sensory branch of the radial nerve – 2.1%, secondary dislocation of the fragments from previously achieved position – 2.1%, pin track infection – 12.8% and CRPS – 0.8% (Schuind et al., 1989). The possible cause of damage to the dorsal radial nerve in my study was the extensive use of K-wires during the primary surgery or application of several K-wires via the 1–2 portal during the arthroscopic assisted manipulation, reposition and fixation of fragments. This suggests that the more extensive use of K-wires in reduction and / or fixation during external fixation and K-wire fixation is more likely to result in nerve damage. In my study, 2 patients (3.1% of all) in the Group EF had secondary bone fragment dislocation after removal of fixation and initiation of the workout of ROM. This complication is due to the possible development of incomplete consolidation between multiple articular fragments, which could be prevented by leaving the wires in the subchondral bone or between the fragments for a longer period of time. Unfortunately, follow-up radiographs 4 to 6 weeks after surgery only visually assess the quality of the callus, which in some cases can be misleading and lead to deformation of the fracture site later in the period of rehabilitation. It should be noted that this particular complication was found in patients with AO – C3 fractures consisting of four or more articular fragments. This leads to the conclusion that, in cases of especially comminuted DRFs, despite the relatively accurate arthroscopic assisted repositioning and fixation, secondary displacement of some fragments is possible during the period of patient's activation.

Both methods of fixation were relatively easy to apply for AO Type C1 fractures. However, surgeries or the more complex AO Type C3 fractures was much more difficult, regardless of the method of reduction and fixation. The higher rate of reposition of fragments at arthroscopy suggests that it is more difficult to obtain optimal reduction in complex fractures with four or more articular fragments when they are treated with external fixation and K-wires. Also, primary reduction and fixation with several K-wires does not guarantee the stability of the extra-articular alignment of the fragments to the same extent as a volar locking plate. Furthermore, the complication of subsequent loss of position of fragments also occurred in two of the Group EF patients.

Another possible complication of peripheral nerve involvement in DRFs is an acute carpal tunnel syndrome, which results from compression caused by contusion of the median nerve or post-traumatic oedema. In patients with symptoms of an acute lesion of the median nerve, the dissection of carpal ligament and neurolysis is recommended if symptoms persist after primary reposition and fixation of the fracture with a plaster cast or EF. In my study, no patient showed symptoms of compression or contusion of the median nerve after the primary repositioning, so routine dissections of the carpal tunnel and visualisation of the nerve were not performed during surgeries. According to the literature, the results of prophylactic carpal tunnel release manipulation are inconsistent – there are authors who argue that this manipulation may increase the risk of unnecessary complications (Lattmann et al., 2008; Odumala et al., 2001). The opposite view can be found in publications in which authors describe a series of operations with standardised carpal ligament dissection in all patients without complications (Gwathmey et al., 2010; Khanchandani and Badia, 2013). In the absence of randomised trials of carpal tunnel ligament repair in asymptomatic patients, undergoing plate fixation of the DRFs, the performance

of this manipulation or its abstention is recommended at the discretion of the surgeon (Seigerman et al., 2019).

One of the most severe and difficult complications is Complex Regional Pain Syndrome (CRPS). It can develop as a result of both conservative and surgical treatment. Clinical manifestations of this syndrome include pain and objective dysfunction of the sympathetic nervous system – oedema, joint stiffness, discolouration of the involved limb and vasomotor disorders such as hyperhidrosis and allodynia. The incidence of CRPS ranges from 1 to 37 % in patients with DRF and it is more common in multifragmentary or high-energy trauma fractures (Dijkstra et al., 2003; Jellad et al., 2014), and the incidence in older women is 3 to 4 times higher than in men (Patterson et al., 2011). Complex therapy is recommended for the treatment of CRPS, including painkillers, intensive occupational therapy, intravenous steroid injections, antidepressants, in some cases ganglion stellatum blockades, and psychological and / or psychiatric help, if necessary. In my study, CRPS was detected in 1 patient (1.6% of all) in the age group over 60 y.o., who already showed initial signs of CRPS before surgery – too tight immobilisation, psychological predisposition and relatively long time (2 weeks after primary injury) to surgery. Following the treatment algorithm recommended in the literature for CRPS, remission of symptoms was achieved within 6 months after surgery. The result is in line with the results published in the medical literature for CRPS, the patient was able to return to her previous activity level, although she was unable to regain full ROM and grip strength.

Given that wrist arthroscopy is the main component of this study, in the next section of the discussion I will focus on the potential complications of this minimally invasive surgical technique. In 2016, C. Leclercq et al. published a summary of complications of wrist arthroscopies at 36 hand surgery centres, including the results of 10107 arthroscopic surgeries. A total of 605 different

surgical complications were recorded (5.98%). The most frequent ones were failure to perform the planned procedure arthroscopically (1.16%), and nerve lesions (1.17%). Cartilage lesions and complex regional pain syndrome each occurred in 0.50% cases. Other complications (wrist stiffness, loose bodies, hematomas, tendon lacerations) were less frequent. Breaking down of the data according to each surgeon's experience of the technique showed a significant relationship with the rate of complications, the threshold for a lower complication rate being approximately 25 arthroscopies a year and / or greater than 5 years of experience (Leclercq et al., 2016). In my study, no complications were found due to the arthroscopic technique. No patients in the study groups developed complications due to infection, which may be associated with standard perioperative antimicrobial prophylaxis with 2 g of Cefazolin administered intravenously in the operating theatre just before the surgery.

This study has a number of limitations. Alternate allocation was chosen as a method of randomization in order to achieve a similar number of patients in both groups as soon as possible. In some cases, this method of allocation made it difficult to fix the fragments optimally. It is possible, that the failure to choose the best treatment method for the fracture configuration or the most convenient for the surgeon, created additional technical difficulties and adversely affected the final outcome of the treatment. Unfortunately, it was not possible to prove this claim with statistical analysis methods in the context of this study. In some Group VLP patients, additional K-wire fixation for free fragments was necessary, although this instability could not be verified fluoroscopically. This specific information reaffirms the necessity of the arthroscopy in the treatment of DRF.

During the 2-year study period, 74 surgeries were performed (38 VLP and 36 Group EF). Four patients in Group VLP and seven patients in Group EF did not return for the follow-up and thus were excluded from the analysis. Consequently, only 34 patients from Group VLP and 29 patients from Group EF were included in the final data assessment. Of the 63 patients, there were 23 males, mean age 43 year (range 19–66) and 40 females, mean age 56 years (range 29–73). The demographic and clinical data were comparable between the groups. In several cases, the follow-up of patients was carried out by the same surgeon who had performed the surgeries, because of the workload of the hand therapist.

Performing surgeries on a common framework, prescribing rehabilitation with the same occupational therapist, equal treatment conditions were provided to all patients. Both groups were demographically well balanced. We excluded the possibility of choosing the method of fixation based on patient age or the comminution of the fracture, so we assessed a mixture of both young and old patients with a mixture of fracture types, treated with external fixation or VLP fixation.

The use of EF and K-wires resulted in a higher complication rate than treatment of fractures with a VLP and required secondary surgical treatment (nerve damage). The Group EF patients also achieved secondary deformities of the fracture fragments, which may lead to the post-traumatic osteoarthritis in the future. The outcomes do not establish absolute evidence for preference of one fixation method over the other, but confirms that both methods are applicable to patients of different ages. The hypothesis that EF and wire fixation in combination with wrist arthroscopy in the treatment of DRF is superior to fixation with arthroscopic assisted fixation with VLP unfortunately was not confirmed. The choice in favour of any of these methods must be made

considering the geometry of the fracture, the experience of the doctor and the technical possibilities.

It is possible that statistically significant differences between the two groups could be obtained by increasing the size of the research groups.

Conclusions

1 Evaluating the postoperative radiological and functional outcomes of the randomised groups, based on the assessment of patients' quality of life and health (Gartland & Werley, PRWE and MASS07 scales), ROM and strength measurements, as well as X-ray follow-up at 1, 3, 6 and 12 months after surgery, the following results were established – at the beginning of the follow-up period, patients in the Group VLP showed better functional results in several parameters. At the 12-month follow-up period, no relevant and statistically significant differences were found between the groups, indicating that both methods are applicable to the DRF treatment. Less invasive arthroscopic assisted treatment with EF and K-wires has not demonstrated the predicted superiority over the arthroscopic assisted ORIF with VLP.

2 Analysis of complications in both groups showed 4 complications in the Group VLP (11.8% of the group) and 4 complications in the Group EF (13.3% of the group).

The number of complications was small in both groups and all of them were resolved during the follow-up period, but complications in the Group EF were considered to be more significant. Complication related to the surgical technique were observed only in Group EF patients. The possible cause of damage to the dorsal radial nerve was the extensive use of K-wires during the primary surgery or application of several K-wires via the 1–2 portal during the arthroscopically assisted manipulation, reposition and fixation of fragments. This suggests that the more extensive use of K-wires in reduction and / or fixation during external fixation and K-wire fixation is more likely to result in nerve damage.

In the EF group, 2 patients demonstrated secondary dislocation of articular fragments after the evacuation of K-wires, suggesting that in some cases prolonged retention of implants (VLP) in bone is essential to ensure stability even in cases of slower consolidation. Migration of the additional K-wires used in Group VLP patients has been attributed to the early workout of the ROM. This minor complication has not caused secondary dislocation of bone fragments or damage to any soft tissue structures in any patient.

3 The place of arthroscopy in this trial deserves a little further consideration. Our results using arthroscopy to visualize fragment position following preliminary reduction confirm the worth of this method in the treatment of these fractures. Additional fragment reposition was required in 46 cases – for 20 patients (59%) in Group VLP and 26 patients (87%) in Group EF, indicating that without arthroscopy, intra-articular dislocation would not have been prevented, making it absolutely necessary for such complex fractures.

Several intra-articular soft tissue lesions were also detected during the arthroscopic stage – injuries of the SLIL, LTIL and TFCC, which were prevented by various additional manipulations. Without arthroscopy, these lesions would remain undiagnosed and potentially worsen both objective and subjective long-term outcomes.

4 The algorithm for the selection of the treatment methods of articular DRF created during this study, will help the orthopaedic surgeons to choose the necessity of the use of arthroscopy in the treatment of certain DRFs and to organise the flow of patients who need this arthroscopically assisted surgical treatment.

5 The study also resulted in an algorithm for the recommended monitoring of post-operative follow-up and outcomes, which can be used not only for assessment of the results of DRF treatment, but also for different wrist

injuries or orthopaedic conditions. The recommended package of measures can be applied in any traumatology and orthopaedics hospital in Latvia without the use of additional special equipment. The obtained data could be used for unified clinical and academic studies in the future.

Publications

1. Funkcionālo rezultātu salīdzinājums pēc tradicionālās un artroskopiski asistētās spieķkaula distālā gala artikulārā lūzuma osteosintēzes; Uldis Krustiņš, Andris Jumtiņš, Diāna Bringina, Kristīne Šitca. <https://www.rsu.lv/zinatniskie-raksti/funkcionalo-rezultati-pec-spiekkaula-distala-gala-artikulara-luzuma-osteosintezes>
2. Krustins U, Krustins J, Bringina D, Laurane K, Jumtins A. Comparison of volar locking plates with external fixation and k-wires in arthroscopically assisted intra-articular distal radial fracture fixation. *J Hand Surg Eur Vol.* 2020, Vol. 45(4) 333-338. DOI: 10.1177/1753193419879567.
3. Comparison of fluoroscopically and arthroscopically assisted volar plating of articular distal radius fractures. Uldis Krustins, Vadims Nefjodovs, Diana Bringina, Aija Jaudzema, Andris Jumtins; PROCEEDINGS OF THE LATVIAN ACADEMY OF SCIENCES. Section B, Vol. 75 (2021), No. 1 (730), pp. 20–30. DOI: 10.2478/prolas-2021-00XX

Presentations on topic

1. ILTOK 2011, Rīga, Latvija – “Plaukstas artroskopija – pirmo 25 gadījumu analīze”.
2. ILTOK 2012, Rīga, Latvija – “Spieķkaula distālo artikulāro lūzumu ārstēšanas iespējas izmantojot plaukstas artroskopiju”.
3. 2nd Baltic hand Surgery Meeting 2012 Riga, Latvia – “Arthroscopically assisted treatment of the distal radius fractures”
4. Joint Singapore – Malaysia – Finland – Estonia – Latvia Hand Surgery Societies Meeting (incorporating the 22nd Comprehensive Hand Review Course), Singapore, 2013, “Arthroscopically Assisted Treatment of Mutilated Distal Radius Fractures”.
5. Joint Singapore – Malaysia – Finland – Estonia – Latvia Hand Surgery Societies Meeting (incorporating the 22nd Comprehensive Hand Review Course), Singapore, 2013, “Arthroscopical Debridement of Stiff Joints after Distal Radius Fractures”.
6. AOTrauma seminar, faculty national, 2013, Riga, Latvia “Technical Principles of the Arthroscopic Treatment of the Distal Radius Fractures”.
7. 5th Baltic Congress of Traumatology and Orthopaedics, 2013, Riga, Latvia – “The Role of Arthroscopic Debridement as a Second Stage Procedure after Articular Distal Radius Fractures”.
8. 10th Congress of APFSSH, 2014, Kuala Lumpur, Malaysia poster presentation – “5-Year Follow-up After Bilateral Articular Distal Radius Fractures”

9. 26th SSSH Congress, 2016, Levi, Finland – “Functional Outcomes After Arthroscopically Assisted and Traditional Surgical Treatment of Displaced Articular Distal Radius Fractures”.
10. EWAS wrist arthroscopy course, 2017, St. Petersburg, Russia – “Wrist from Inside – Basic Principles of the Wrist Arthroscopy”.
11. 11th APFSSH Congress, 2017, Cebu, Phillippines “Arthroscopic vs. Nonarthroscopic Treatment of Distal Radius Fractures – Evaluation of Outcomes”.
12. 11th APFSSH Congress, 2017, Cebu, Phillippines poster presentations – “Arthroscopically Assisted Intra-Articular Distal Radius Fracture Surgery with Volar Locking Plates or External Fixator and K-Wires. Early Results of Ongoing Study”, “Krukenberg Procedure Completed by Two Microvascular Flaps to Save Functionality and Length of the Amputation Stem. A Case Report”.
13. Wrist. Practical Arthroscopy course, 2018, St. Petersburg, Russia – “Wrist Central Column Pathology”.
14. Riga Stradins University International Conference, 2019, “Arthroscopic Treatment and Bone Grafting of Scaphoid Nonunions”.
15. EWAS wrist arthroscopy course with training on anatomical specimen, 2019, St.Petersburg, Russia – “Clinical Evaluation of TFCC Injuries”.
16. EWAS wrist arthroscopy course with training on anatomical specimen, 2019, St.Petersburg, Russia “Ulnocarpal Impingement and TFCC Tears”.
17. EWAS wrist arthroscopy course with training on anatomical specimen , 2019, St.Petersburg, Russia “SLIL Normal Function, Physiology and Dysfunction”.
18. 27th SSSH Congress , 2019, Tallinn, Estonia “Arthroscopy in Distal Radius Fractures”.
19. 12th APFSSH Congress, 2020, Melbourne, Australia “Comparison of Functional Outcomes in Limited Carpal Fusions and Proximal Row Carpectomy”.
20. 12th APFSSH Congress, Melbourne, Australia, 2020, “Comparison of Volar Locking Plates with External Fixation and K-Wires in Arthroscopically Assisted Intra-Articular Distal Radial Fracture Fixation.”, poster presentation “Long Term Follow-up after Microsurgical Reconstruction of the Humerus with Two Vascularized Bone Grafts”.
21. Arthrex Online Webinar, 2020, “Why Is It Important to Eliminate Intra-Articular Displacement? How Do I Do this with an Acute and Incorrectly Fused Distal Radius Fracture”.
22. EOF Online Club Webinar, 2021, “Acute scaphoid fractures”
23. 10th Congress of BAS, 2021, Riga, Online, “Arthroscopically Assisted Treatment of Distal Radius Fractures: 10-Year Experience of the Single Centre”.

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