## Outcomes and challenges in ulnar-sided wrist surgery

Verhiel, Svenna Helena Wilhelmus Lucia

2021

# Outcomes and Challenges in Ulnar-sided Wrist Surgery

Svenna H.W.L. Verhiel

ISBN: 978-94-6361-595-2

Layout and printing: Optima Grafische Communicatie, Rotterdam, the Netherlands



This thesis was embedded in Amsterdam Movement Sciences Research Institute, at the department of Plastic, Reconstructive and Hand Surgery, Amsterdam UMC, Vrije Universiteit Amsterdam, the Netherlands.

Printing of this thesis was financially supported by: the Department of Plastic, Reconstructive and Hand Surgery of the Amsterdam UMC, location VUmc, Nederlandse Vereniging voor Plastische Chirurgie (NVPC), Junior Vereniging voor Plastische Chirurgie (JVPC), Amsterdam Movement Sciences (AMS).

VRIJE UNIVERSITEIT

# *Outcomes and Challenges in Ulnar-sided Wrist Surgery*

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
prof.dr. V. Subramaniam,
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de Faculteit der Geneeskunde
op vrijdag 12 november 2021 om 13.45 uur
in de aula van de universiteit,
De Boelelaan 1105

door

Svenna Helena Wilhelmus Lucia Verhiel

geboren te Geleen

Promotor: Prof. dr. M.J.P.F. Ritt

Copromotor: Dr. N.C. Chen

Leescommissie: Dr. C.M. Lameijer
Dr. M.M. Hoogbergen
Dr. S.D. Strackee
Prof. dr. J.H. Coert
Prof. dr. M. Maas

# Table of contents

# PART I

## General introduction

# LIST OF ABBREVIATIONS

| | |
|---|---|
| CI | confidence interval |
| CMC | carpometacarpal |
| CPT | current procedural terminology |
| CT | computed tomography |
| DRUJ | distal radioulnar joint |
| ECU | extensor carpi ulnaris |
| EXFIX | external fixation |
| FCU | flexor carpi ulnaris |
| HIT | hemiresection interposition technique |
| HR | hazard ratio |
| IQR | interquartile range |
| IRB | institutional review board |
| LC-DCP | limited contact dynamic compression plate |
| LCP | locking compression plate |
| LT | lunotriquetral |
| MRI | magnetic resonance imaging |
| N | number |
| NA | not applicable |
| NRS | numeric rating scale |
| ORIF | open reduction internal fixation |
| PIN | posterior interosseous nerve |
| PROM | patient-reported outcomes measures |
| PROMIS UE-PF | patient-reported outcomes measurement information system upper extremity- physical function |
| PT | pisotriquetral |
| QuickDASH | quick disability of arm, shoulder and hand |
| RPDR | research patient data registry |
| SD | standard deviation |
| SL | scapholunate |
| TFCC | triangular fibrocartilage complex |
| USO | ulnar shortening osteotomy |

# Chapter 1

## General introduction and thesis outline

# GENERAL INTRODUCTION

Ulnar-sided wrist pain is a common cause of upper extremity disability. The ulnar side of the wrist consists of several important and intricate anatomic structures that contribute to stability, yet allow for considerable motion based on complex biomechanics.[1–4] Ulnar-sided wrist pain encompasses a variety of pathologies including arthritis, tendinopathy, ligament injuries, fractures and instability. Due to overlapping anatomy, extensive differential diagnosis, frequently only subtle imaging findings and varied treatment outcomes, the ulnar side of the wrist has been referred to as the 'black box' of the wrist.[1–4]

Several causes of ulnar-sided wrist pain can be found based on the anatomy of the ulnar wrist;

- DRUJ arthritis (degenerative or inflammatory), incongruity or instability
- TFCC lesions
- Ulnar abutment and/or degenerative TFCC lesions, ulnar impaction syndrome (chondromalacia of the ulnar head and lunate, LT instability)
- Traumatic LT instability
- ECU subluxation or stenosing tenosynovitis, posttraumatic injury
- FCU tendinitis
- PT joint dysfunction, e.g. by trauma, instability, arthritis or FCU tendinopathy
- Hamate fracture, either hook of hamate or body, sometimes coexisting with CMC dislocation
- Ulnar nerve entrapment

Treatment strategies for these various pathologies should be evaluated continuously to improve patient care.[5] There has been a recent shift from a volume-based to a value-based healthcare system, with value defined as patient-relevant outcomes relative to costs of medical care.[6,7] As a consequence, there has also been a shift from physician-reported outcome measures to PROMs, in order to determine quality from the patient's perspective.[8–11] PROMs consist of reports coming directly from patients about their functionality, pain-level, satisfaction or other feelings in relation to their health condition and therapy, without judgement by their doctor. PROMs can be used to inform clinical decision-making, helping both patients and clinicians to make more informed decisions about a specific treatment.[8–11]

There is growing evidence that the magnitude of disability has more correlation with subjective, psychosocial aspects of illness and pain (such as emotional distress and coping mechanisms) than with objective measures of impairment and pathophysiology.[12–15] Adequate coping mechanisms play an important role in both the experience of pain and the perception of disability.[12–15]

## Outline of this thesis

The general aim of this thesis is to improve care for patients suffering from ulnar-sided wrist pain. First, by giving insight into the complexity of the differential diagnosis and coherence between pathologies. Second, by identifying characteristics associated with complications and other adverse outcomes of treatment modalities that are used in ulnar-sided wrist surgery. Third, by evaluating patient-reported outcomes after different interventions and the influence of psychological aspects on these outcomes.

In **Chapter 2** we focus on patients who underwent arthroscopic TFCC debridement. We assess the rate and type of complications and reoperations after arthroscopic TFCC debridement. Furthermore, we investigate which factors are associated with reoperation and specifically USO after this procedure.

USO is performed to address ulnar impaction syndrome, and to treat pain and instability after injury to the TFCC. The goal of USO is to decrease the mechanical pressure of the ulnar head on the carpus, to correct subtle DRUJ instability and to correct LT instability in patients with higher grades of ulnar impaction syndrome. In **Chapter 3** we investigate the rate and type of reoperation procedures after USO. Furthermore, we study factors associated with reoperation after USO.

**Chapter 4** portrays the various pathologies that often coexist in ulnar-sided wrist pain. Causes of ulnar-sided wrist pain, other than TFCC tears, include PT joint arthritis, hamate fracture, LT instability, DRUJ dysfunction (arthrosis or instability), ulnar impaction, and tendinopathy of ECU or FCU. In this chapter we investigate and compare the prevalence of potential causes of ulnar-sided wrist pain on MRI in patients who underwent TFCC repair to control subjects. Furthermore we evaluate whether inferior clinical results after TFCC repair show an association with specific patient characteristics or other potential causes of ulnar-sided wrist pain.

There is a plethora of treatments for DRUJ dysfunction, ranging from simple (arthroscopic) debridement to complete joint replacement using an implant. Two well-known procedures are the so-called Darrach procedure and the Sauvé-Kapandji procedure. In a Darrach procedure, the entire ulnar head is resected. A Sauvé-Kapandji procedure consists of fusion of the DRUJ combined with a segmental resection of the ulna just proximal to the DRUJ. **Chapter 5** focuses on patients with post-traumatic DRUJ dysfunction. We assess differences in long-term patient-reported outcomes on physical function, pain and satisfaction, between the Darrach and Sauvé-Kapandji procedure. Furthermore, we describe the radiographic outcomes and assess the difference in rate and type of complications and reoperations between these two procedures.

Another treatment available for DRUJ dysfunction is a (Bowers) HIT arthroplasty. The theoretical advantage of HIT arthroplasty, using an oblique distal ulnar resection, compared with procedures such as the Darrach and Sauvé-Kapandji is the preservation of the attachment of the TFCC to the ulnar styloid process. In **Chapter 6** we investigate factors associated with long-term patient-reported functional, pain, and satisfaction scores (PROMs) in patients who underwent (Bowers) HIT arthroplasty of the DRUJ. Furthermore, we determine the complication and reoperation rates after this procedure.

Symptomatic ECU tendon subluxation is often treated conservatively. Operative treatment is an option when this approach is not successful. Operative techniques include direct repair of the subsheath, repair of the subsheath with the use of a graft, reattachment of the subsheath using transosseous sutures or suture anchors, or reconstruction of the sheath with the creation of a sling. In **Chapter 7** we explore the long-term outcomes and complications of patients that underwent operative treatment specifically using a retinacular sling reconstruction.

Patients with PT arthritis often present with pain localized to the ulnar side of the wrist and aggravated by contraction of the FCU. Symptoms of ulnar nerve paraesthesia may be present. Excision of the pisiform is an infrequently used option when nonoperative treatment is ineffective. **Chapter 8** reviews the patient-reported outcomes of patients treated with pisiformectomy and furthermore focuses on the complications and the need for and time to revision procedure.

Hamate fractures represent only 2 to 4% of all carpal fractures, with injuries to the hamate body being the most rare variant. Coexistence with CMC dislocation accounts for less than 1% of all hand trauma. In **Chapter 9** we present a series of patients who underwent surgical treatment for this injury, assess the fracture morphology and describe the surgical technique that was used. Furthermore, we report on complications and outcomes after surgical treatment.

Knowledge about variations in arborization patterns of the ulnar nerve and communicating branches between the ulnar and median nerves in the palm optimizes diagnoses and minimizes specific surgical risks in hand surgery. In **Chapter 10** we examine variations and frequencies of the arborization patterns and communicating branches, review existing literature, and relate these findings to nerve decompression near the wrist.

In our last chapter we explore the influence of psychology on pain and physical limitations in patients with ulnar-sided wrist pain, and patients with an upper extremity disorder in general. Emotional distress (such as symptoms of depression and anxiety) and maladaptive coping strategies (like catastrophic thinking in response to nociception) are consistently associated with increased pain and physical limitations in patients with upper extremity disorders. Positive-psychology is a field that is not concerned merely with the absence of distress or maladaptive coping, but rather focuses on individual's strengths and qualities of personal growth and flourishing. In **Chapter 11** we investigate the relationship between positive psychology (constructs that enable individuals to thrive and adapt to challenges) and pain and physical limitations.

# REFERENCES

1. Dasilva MF, Goodman AD, Gil JA, Akelman E. Evaluation of ulnar-sided wrist pain. J Am Acad Orthop Surg. 2017;25(8):e150-e156
2. Vezeridis PS, Yoshioka H, Han R, Blazar P. Ulnar-sided wrist pain. Part I: Anatomy and physical examination. Skeletal Radiol. 2010;39(8):733-745
3. Sachar K. Ulnar-sided wrist pain: Evaluation and treatment of triangular fibrocartilage complex tears, ulnocarpal impaction syndrome, and lunotriquetral ligament tears. J Hand Surg Am. 2012;37(7):1489-1500
4. Watanabe A, Souza F, Vezeridis PS, Blazar P, Yoshioka H. Ulnar-sided wrist pain. II. Clinical imaging and treatment. Skeletal Radiol. 2010;39(9):837-857
5. Fleurence RL, Beal AC, Sheridan SE, Johnson LB, Selby J V. Patient-powered research networks aim to improve patient care and health research. Health Aff. 2014;33(7):1212-1219
6. Church J. Quality of life and patient-reported outcomes. Br J Surg. 2018;105(3):157-158. doi:10.1002/bjs.10824
7. Michael E. Porter P. Perspective - What Is Value in Health Care? N Engl J Med. 2010;363(1):1-3
8. Brodke DJ, Saltzman CL, Brodke DS. PROMIS for Orthopaedic Outcomes Measurement. J Am Acad Orthop Surg. 2016;24(11):744-749
9. Weldring T, Smith SMS. Article Commentary: Patient-Reported Outcomes (PROs) and Patient-Reported Outcome Measures (PROMs). Heal Serv Insights. 2013;6:61-68
10. Cheung EC, Moore LK, Flores SE, Lansdown DA, Feeley BT, Zhang AL. Correlation of PROMIS with orthopaedic patient-reported outcome measures. JBJS Rev. 2019;7(8):1-13.
11. Gagnier JJ. Patient reported outcomes in orthopaedics. J Orthop Res. 2017;35(10):2098-2108
12. Talaei-Khoei M, Fischerauer SF, Lee S-G, Ring D, Vranceanu A-M. Pain Catastrophizing Mediates the Effect of Psychological Inflexibility on Pain Intensity and Upper Extremity Physical Function in Patients with Upper Extremity Illness. Pain Pract. 2016;17(1):129-140
13. Dimitriadis Z, Kapreli E, Strimpakos N, Oldham J. Do psychological states associate with pain and disability in chronic neck pain patients? J Back Musculoskelet Rehabil. 2015;28(4):797-802
14. Scheier MF, Carver CS. Optimism, coping, and health: assessment and implications of generalized outcome expectancies. Health Psychol. 1985;4(3):219-247
15. Ring D, Kadzielski J, Fabian L, Zurakowski D, Malhotra LR, Jupiter JB. Self-Reported Upper Extremity Health Status. 2006:1983-1988

# PART II

## Thesis

# Chapter 2

## Predictors of secondary ulnar shortening and reoperation after arthroscopic TFCC debridement

***Verhiel SHWL***, *Ritt MJPF, Chen NC*

*Hand (N Y). 2021 Feb 3; Online ahead of print*

# ABSTRACT

**Purpose** Predicting which patients will do well with arthroscopic TFCC debridement alone or which patients may benefit from simultaneous USO can be challenging. In this retrospective cohort study, we aimed to assess the rate and type of complications and reoperations after arthroscopic TFCC debridement. Furthermore, we aimed to identify factors associated with reoperation and specifically USO after this procedure.

**Methods** We included 163 patients who underwent arthroscopic TFCC debridement as a first surgery for treatment of their ulnar-sided wrist pain. Patient charts were manually reviewed and ulnar variance was measured on pre-operative posteroanterior radiographs of the wrist. Bivariate analysis and a multivariable logistic regression analysis were performed to identify factors associated with reoperation. Additional subgroup analyses looking at USO after TFCC debridement were performed with Kaplan-Meier analysis and Cox regression survival analysis.

**Results** We found a complication rate of 14% and a reoperation rate of 19% (most common USO with 10%). Chondromalacia was independently associated with reoperation. Forty percent of patients with a positive ulnar variance later proceeded to USO. A hazard ratio of 1.8 per millimeter of ulnar variance was found.

**Conclusion** Our data suggest that patients with a positive ulnar variance with frank chondral loss at the time of arthroscopic TFCC debridement may benefit from simultaneous USO.

# INTRODUCTION

One challenge in the treatment of TFCC tears is predicting which patients will do well with arthroscopic debridement alone or which patients will have a better outcome with arthroscopic debridement and USO the same time.[1–4] Most series describe satisfactory outcomes and low complication rates after TFCC debridement.[2,4–11] However, a small percentage of patients continue to complain of chronic ulnar-sided wrist pain and may undergo additional surgery.[12–16]

Large-scale studies investigating predictive factors for reoperation after TFCC debridement are lacking, and findings are often inconsistent.[7,11–13] Positive ulnar variance and existence of concomitant LT ligament tears are most often studied as potential predictive factors. Some studies suggest that the presence of these factors lead to worse clinical outcome and more reoperations,[7,13] but other studies have not found similar associations.[11,12]

We sought to examine our institutional cohort of TFCC debridement to analyze the rate and type of complications and reoperations after arthroscopic TFCC debridement. Furthermore, we aimed to identify factors associated with reoperation and specifically USO after arthroscopic TFCC debridement.

# METHODS

This retrospective study was approved by our IRB. We used CPT code 29846 (Arthroscopy, wrist, surgical; excision and/or repair of triangular fibrocartilage and/or joint debridement) to identify patients by searching our multi-institutional database covering all relevant orthopedic encounters at three regional hospitals: two level I trauma centers and one associated community hospital between January 2003 and December 2016. In addition, we manually reviewed charts of patients with a CPT code for an arthroscopic wrist procedure (29844, 29845, 29840) to identify patients who underwent wrist arthroscopy to capture any miscoded patients.

We only included patients if the arthroscopic TFCC debridement was the first surgery for treatment of their ulnar-sided wrist pain. We excluded patients if they previously or concomitantly underwent ulnar-sided wrist surgery. Furthermore, we excluded patients when younger than 18 years at date of surgery or diagnosed with inflammatory arthritis. Our final cohort consisted of 163 patients. The median time from surgery to the database query was 8.9 years (5.4-13 years).

We then reviewed medical records of these patients and collected data on age at surgery, sex, reported alcohol or tobacco abuse, diagnosis of diabetes, occupation, general laxity, hand dominance, affected side, prior trauma ipsilateral wrist, prior surgery ipsilateral wrist (defined as non-ulnar-sided wrist surgery), duration of symptoms, DRUJ instability, pre-operative ulnar variance, prior conservative treatment, Palmer classification, related pathology found intra-operatively, concomitant procedures, complications and reoperations. The ulnar variance was measured on pre-operative posteroanterior radiographs (n=135) of the wrist, according the method of perpendiculars (Appendix 1; Steyers and Blair, 1989).[17]

## Statistical analysis

We described discrete data using frequencies and percentages, normally distributed continuous data through means and standard deviations, and non-normally distributed continuous data through medians and interquartile ranges.

Bivariate analysis was performed using the two-sided Fisher Exact test for dichotomous and categorical variables, and an unpaired Mann-Whitney U Test for continuous variables.

Factors that were considered to be clinically relevant and had a *P*-value of less than 0.10 in bivariate analysis were entered into a multivariable logistic regression analysis to assess if they were independently associated with reoperation after arthroscopic TFCC debridement.

Additional subgroup analyses were performed, looking at USO after TFCC debridement. A Kaplan-Meier curve was used to estimate and describe the probability of USO over time. To allow comparison based on ulnar variance using a Kaplan-Meier analysis, patients were categorized into 3 groups: ulnar negative (-0.5mm or less), ulnar neutral (-0,5 to 0.5mm) and ulnar positive (0.5mm or more). Cox regression survival analysis was performed to investigate the effect of ulnar variance on the occurrence of USO. HR with 95% CI were reported. A *P*-value of less than 0.05 was considered statistically significant.

# RESULTS

## Patient characteristics

The study cohort consisted of 82 men (50%) and 81 women (50%) (Table 1). The median age was 43 years (IQR 32-53 years). Eighty-six patients (53%) had a traumatic TFCC tear and

**Table 1.** Demographic factors associated with reoperation after arthroscopic TFCC debridement

| Explanatory variable | Reoperation | | | |
|---|---|---|---|---|
| | **All (n=163)** | **No (n=132)** | **Yes (n=31)** | ***P* value** |
| Age in years, median (IQR) | 43 (32-53) | 42 (32-53) | 48 (36-54) | 0.20[1] |
| Sex, n (%) | | | | 0.17[2] |
| Female | 81 (50) | 62 (47) | 19 (61) | |
| Male | 82 (50) | 70 (53) | 12 (39) | |
| Alcohol abuse reported in chart, n (%) | 10 (6.1) | 8 (6.1) | 2 (6.5) | > 0.99[2] |
| Tobacco abuse reported in chart, n (%) | 24 (15) | 17 (13) | 7 (23) | 0.17[2] |
| Diabetes, n (%) | 12 (7.4) | 7 (5.3) | 5 (16) | 0.053[2] |
| Labourer, n (%) | 76 (47) | 62 (47) | 14 (45) | > 0.99[2] |

[1]*Mann-Whitney U Test,* [2]*Fisher's exact test*

76 patients (47%) a degenerative TFCC tear (Table 2). The most common trauma was a fall onto an outstretched hand (n=37; 23%), followed by a twisting movement (n=32; 20%) and a direct trauma to the wrist (n=19; 12%). The median duration of symptoms before proceeding to surgery was 8 months (IQR 5-15 months) (Table 2). Sixty-five patients (40%) underwent another procedure at the time of the TFCC debridement, ranging from intercarpal ligament procedures to carpal tunnel release (Table 3).

**Table 2.** Condition-related factors associated with reoperation after arthroscopic TFCC debridement

| Explanatory variable | Reoperation | | | |
|---|---|---|---|---|
| | **All (n=163)** | **No (n=132)** | **Yes (n=31)** | ***P* value** |
| General laxity, n (%) | 7 (4.3) | 4 (3.0) | 3 (9.7) | 0.13[1] |
| Dominant side affected, n (%) | 93 (64) | 72 (62) | 21 (70) | 0.53[1] |
| Prior trauma ipsilateral wrist, n (%) | 19 (12) | 10 (7.6) | 9 (29) | ***0.003[1]*** |
| Prior surgery ipsilateral wrist, n (%) | 17 (10) | 9 (6.8) | 8 (26) | ***0.005[1]*** |
| Duration symptoms in months, median (IQR) | 8 (5-15) | 8 (5-13) | 12 (6-24) | ***0.015[2]*** |
| DRUJ instability, n (%) | 20 (12) | 15 (11) | 5 (16) | 0.54[1] |
| Ulnar variance in mm, median (IQR) | 0 (0-2) | 0 (0-1.8) | 1.8 (0-3.1) | ***0.011[2]*** |
| Prior conservative treatment, n (%) | 112 (69) | 92 (70) | 20 (65) | 0.67[1] |
| Palmer classification, n (%) | | | | ***0.005[1]*** |
| Class 1 -traumatic | | | | |
| a or d | 86 (53) | 75 (57) | 11 (35) | |
| Class 2 -degenerative | | | | |
| a (without chondromalacia) | 36 (22) | 31 (24) | 5 (16) | |
| b-e (with chondromalacia) | 40 (25) | 25 (19) | 15 (48) | |
| ***Related pathology*** | | | | |
| Chondromalacia, n (%) | 47 (29) | 29 (22) | 18 (58) | ***< 0.001[1]*** |
| Arthrosis, n (%) | 3 (1.8) | 2 (1.5) | 1 (3.2) | 0.47[1] |
| LT ligament tear, n (%) | 16 (9.8) | 11 (8.3) | 5 (16) | 0.19[1] |
| SL ligament tear, n (%) | 33 (20) | 28 (21) | 5 (16) | 0.63[1] |
| Dorsal ganglion, n (%) | 5 (3.1) | 4 (3.0) | 1 (3.2) | > 0.99[1] |
| ECU pathology, n (%) | 13 (8.0) | 13 (9.9) | 0 (0) | 0.13[1] |

*[1]Fisher's exact test, [2]Mann-Whitney U Test*
** Radiograph inaccessible for 28 patients*

## Complications and reoperations

Twenty-three patients (14%) reported a complication during their post-operative course (Table 4). ECU tendinitis/tenosynovitis was the most common complication (n=9; 5.5%). Seventeen patients (10%) received a corticosteroid injection post-operatively because of persistent complaints of ulnar-sided wrist pain. At last clinical follow-up, fifteen patients (9.2%) reported that their pain had not improved compared to pre-surgery level.

**Table 3.** Procedure-related factors associated with reoperation after arthroscopic TFCC debridement

| Explanatory variable | Reoperation | | | |
|---|---|---|---|---|
| | All (n=163) | No (n=132) | Yes (n=31) | *P* value |
| ***Concomitant procedure performed*** | | | | |
| LT ligament debridement/repair, n (%) | 14 (8.6) | 9 (6.8) | 5 (16) | 0.15[1] |
| SL ligament debridement/repair, n (%) | 30 (18) | 25 (19) | 5 (16) | 0.80[1] |
| Excision dorsal ganglion, n (%) | 5 (3.1) | 4 (3.0) | 1 (3.2) | > 0.99[1] |
| ECU surgery, n (%) | 12 (7.4) | 12 (9.1) | 0 (0) | 0.13[1] |
| Carpal tunnel release, n (%) | 4 (2.5) | 4 (3.0) | 0 (0) | > 0.99[1] |

[1]*Fisher's exact test*

**Table 4.** Complications after arthroscopic TFCC debridement (n=23)

| Type complication | n (%) |
|---|---|
| ECU tendinitis/tenosynovitis | 9 (5.5) |
| Symptoms dorsal sensory branch of the ulnar nerve | 5 (3.1) |
| Wound infection/dehiscence | 4 (2.5) |
| Painful scar | 2 (1.2) |
| Fistula formation wrist joint | 1 (0.6) |
| Hypertrophic scar | 1 (0.6) |
| Hypersensitivity sensory branch of radial nerve (radial portal) | 1 (0.6) |

A total of 31 out of 163 (19%) underwent a reoperation (Table 5). The median time from the arthroscopic TFCC debridement to the reoperation was 7.5 months (IQR 3.4-17 months). The most common indication for reoperation was ulnar impaction (n=22; 13%), with an USO performed in 17 patients (10%). Seven patients (4.3%) underwent another TFCC debridement after their index surgery. Seven patients (4.3%) had more than one reoperation; six patients underwent two reoperations and one patient underwent three reoperations (Appendix 2).

In bivariate analysis, no demographic factors were associated with reoperation (Table 1). Multiple condition-related factors had an association with reoperation (Table 2). Prior trauma to the ipsilateral wrist ($P$=0.003), prior surgery to the ipsilateral wrist ($P$=0.005), duration of symptoms ($P$=0.015), ulnar variance ($P$=0.011), Palmer classification of degenerative tear ($P$=0.005), and evidence of chondromalacia ($P$<0.001) were condition-related factors associated with reoperation (Table 2). In a multivariable logistic regression analysis chondromalacia was independently associated with reoperation after arthroscopic TFCC debridement ($P$=0.002; Table 6).

**Table 5.** Reoperation after arthroscopic TFCC debridement (n=31)

| ***Indication reoperation*** | **n (%)** |
|---|---|
| Ulnar impaction | 22 (13) |
| DRUJ disruption | 2 (1.2) |
| DRUJ arthrosis | 2 (1.2) |
| ECU subluxation | 1 (0.6) |
| Intercarpal arthritis | 1 (0.6) |
| Symptoms dorsal sensory branch of the ulnar nerve | 1 (0.6) |
| SL instability | 1 (0.6) |
| Neuroma | 1 (0.6) |
| ***Type reoperation*** | **n (%)** |
| Ulnar shortening osteotomy | 16 (9.8) |
| with concomitant TFCC debridement | 1 (0.6) |
| TFCC debridement | 5 (3.1) |
| with concomitant radial nerve decompression | 1 (0.6) |
| with concomitant ulnar styloid excision | 1 (0.6) |
| ECU subsheath reconstruction | 1 (0.6) |
| Sauvé-Kapandji | 2 (1.2) |
| Excision neuroma radial sensory nerve | 1 (0.6) |
| Neurolysis dorsal sensory branch of the ulnar nerve | 1 (0.6) |
| Scaphocapitate fusion | 1 (0.6) |
| Total wrist arthrodesis | 1 (0.6) |

**Table 6.** Multivariable Analysis - factors independently associated with reoperation after arthroscopic TFCC debridement

| **Explanatory variable** | | | **95% CI** | | |
|---|---|---|---|---|---|
| | **Odds Ratio** | **Standard Error** | **Lower** | **Upper** | ***P* value** |
| Duration symptoms (per month increase) | 1.0 | 0.0084 | 0.99 | 1.0 | 0.48 |
| Chondromalacia (ref=no chondromalacia) | 4.5 | 2.1 | 1.8 | 11 | ***0.002*** |
| Ulnar variance (per mm increase) | 1.1 | 0.13 | 0.89 | 1.4 | 0.35 |

## Ulnar shortening osteotomy and ulnar variance

A total of 18 patients later proceeded to an USO: 17 patients as a first reoperation and 1 patient as a second reoperation (Table 5 and Appendix 2). The median time from the arthroscopic TFCC debridement to the USO was 3.6 months (IQR 2.4-9.1 months). In bivariate analysis the same factors were associated with USO as with reoperation in general, except for duration of symptoms (Appendices 3, 4, 5). To investigate the effect of ulnar variance on the occurrence of USO, we first categorized the measured ulnar variance into 3 groups (negative, neutral and positive). Thirty patients (22%) were categorized as ulnar negative, 55 patients (41%) ulnar neutral and 30 patients (22%) ulnar positive. The Kaplan-Meier curve demonstrates the

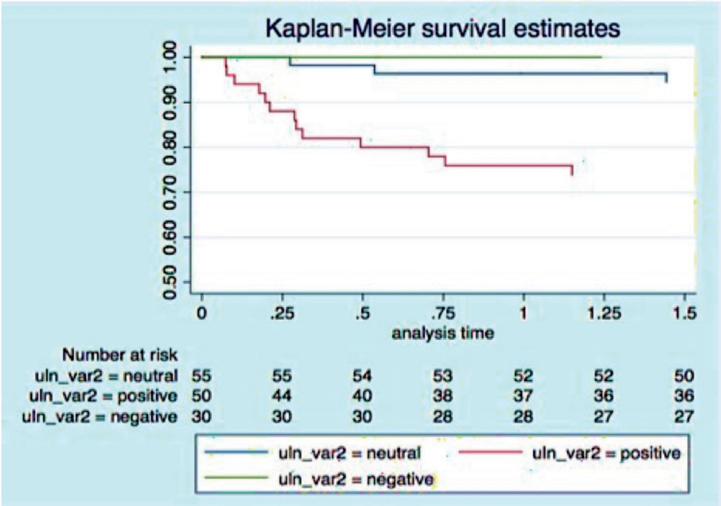


**Figure 1.** Kaplan-Meier survival estimate. *Note.* Kaplan-Meier failure plot demonstrating the probability of USO (1 – probability of survival) among all patients who had a TFCC debridement, categorized by ulnar variance.

relationship of ulnar variance on occurrence of USO over time (Figure 1). In a Cox regression survival analysis, we found a hazard ratio of 1.8 for each millimeter of ulnar variance (95% CI, 1.4-2.4; *P*<0.001).

# DISCUSSION

In our cohort of 163 arthroscopic TFCC debridement procedures, we found a complication rate of 14% (most common ECU tendinitis/tenosynovitis with 5.5%) and a reoperation rate of 19% (more than half of these were USO, n=18). Prior trauma to the ipsilateral wrist, prior surgery to the ipsilateral wrist, a longer duration of symptoms, a positive ulnar variance, a degenerative tear, and evidence of chondromalacia were associated with reoperation in bivariate analyses. In a multivariable logistic regression analysis chondromalacia was independently associated with reoperation.

The median time from arthroscopic TFCC debridement to USO was 3.6 months (IQR 2.4-9.1 months). We performed a cox regression survival analysis to investigate the effect of ulnar variance on the occurrence of USO, and found a HR of 1.8 for measured ulnar variance in mm (95% CI, 1.4-2.4; *P* <0.001).

The findings of the present study should be examined in light of its limitations, which are primarily related to the retrospective design of the study. First, radiographs were missing for 17% (n=28) of the patients. Some patients had radiographs obtained outside of our institution and were not accessible through our institutional database. Second, in 40% (n=65) of cases additional procedures were performed at the time of the index surgery. Complications associated with these procedures also were counted, but some complications may not be directly attributable to the TFCC debridement. It is important to recognize that ulnar-sided wrist pain was the primary indication for the wrist arthroscopy, and that additional procedures were performed for other complaints diagnosed before arthroscopy (e.g. carpal tunnel syndrome) or for incidental findings diagnosed during arthroscopy (e.g. SL ligament tear). Third, differentiating between traumatic and degenerative TFCC lesions during arthroscopy is challenging due to the difference between patient perception of trauma, variation of interpretation between observers, and the retrospective nature of the study.[18,19] These limitations are counterbalanced by the relatively large number of patients (n=163) observed during a 13-year time frame across 3 hospitals.

We found a complication rate of 14%. Other studies report complication rates between 0% and 13%, with symptoms of the dorsal sensory branch of the ulnar nerve reported most commonly.[5–7,9,11,18,20,21] In our study, ECU tendinitis/tenosynovitis was slightly more common than symptoms of the dorsal sensory branch of the ulnar nerve (5,5% versus 3,1%). The rather high complication rate in our study might be explained by the fact that we also reported on minor complications such as scar problems.

Our reoperation rate of 19% is in accordance with other studies (between 0% and 50%).[5,6,18,20] Four studies reported a reoperation rate of 0%.[5,6,18,20] The 50% reoperation rate found by one study was among adolescent patients, which might not allow direct comparison to our study cohort.[22] A total of 18 patients (11%) eventually proceeded to USO in our study. This rate is slightly lower than reported by other studies, ranging from 13% to 25%.[7,11,12,22,23]

Prior trauma and prior wrist surgery were both associated with reoperation in our study. Prior trauma included mainly distal radius fractures (58%) and prior procedures included fixation of these distal radius fractures (29%). Positive ulnar variance secondary to distal radius malunion may result in symptomatic ulnar impaction. A distal radius corrective osteotomy is an effective treatment modality for management of deformity. However, several studies indicate that an isolated USO can be a reasonable and safe alternative to the use of distal radius corrective osteotomy in the management of extra-articular distal radius malunions.[24–26] A longer duration of symptoms was associated with a higher risk of reoperation in our study cohort. A longer duration of symptoms may reflect that those patients had more substantial ulnar-sided pathology. In our study, patients with a positive ulnar variance had a higher risk of reoperation, as well as a higher risk of USO, specifically. Eleven percent of the entire cohort versus 40% of the patients with a positive ulnar variance eventually underwent USO. Previous literature is not consistent about the influence of ulnar variance. Some studies report a significant association between positive ulnar variance and worse clinical outcome,[7,13,27] while other studies do not observe an association.[11,12,18] It is possible that duration of symptoms and ulnar positivity are related or co-vary, but we did not have a cohort large enough to clarify this association.

Degenerative tears were associated with more reoperations in our study cohort, which is in accordance with findings of prior research.[7,14,18,27] Arthroscopic debridement generally consists of shaving of unstable TFCC flaps, TFCC fibrillation, and redundant synovium.[14] Several studies show that wearing-type tears are less responsive to arthroscopic debridement.[4,7,14,18,27] However, we observed that chondromalacia was associated with reoperation, independent of ulnar variance or symptom duration. Ulnar impaction is commonly described as a progression from degenerative TFCC tear to ulno-carpal chondromalacia, LT ligament tears and ulno-carpal osteoarthritis.[20,28] Arthroscopic debridement may be sufficient to resolve mild ulnar impaction in patients with only degenerative tears; however, chondromalacia likely represents a more substantial ulnar impaction where TFCC debridement is unlikely to alter the natural history of the impaction.[14,20]

Forty percent of patients with a positive ulnar variance later proceeded to USO. This data is important to consider for surgical decision-making. Arthroscopic TFCC debridement is less invasive than USO, and non-union is a substantial concern. The overall reoperation rate after USO ranges between 25% and 59%, and the reoperation rate for non-union is 18%.[29] When considering a simultaneous USO with arthroscopy, the morbidity of USO should be taken into account and weighed against the possibility and chance of a late USO.

Overall, we observed that about 1 in 5 patients will undergo reoperation after arthroscopic TFCC debridement, and about 1 in 10 patients will undergo USO. Our data suggest that patients who are ulna positive with frank chondral loss at the time of arthroscopic debridement may benefit from simultaneous USO.

# REFERENCES


1. Palmer AK. Triangular fibrocartilage complex lesions: A classification. J Hand Surg Am 1989;14(4):594-606
2. Osterman AL, Terrill RG. Arthroscopic treatment of TFCC lesions. Hand Clin 1991;7(2):277-281
3. Sachar K. Ulnar-sided wrist pain: Evaluation and treatment of triangular fibrocartilage complex tears, ulnocarpal impaction syndrome, and lunotriquetral ligament tears. J Hand Surg Am 2012;37(7):1489-1500
4. Westkaemper JG, Mitsionis G, Giannakopoulos PN, et al. Wrist arthroscopy for the treatment of ligament and triangular fibrocartilage complex injuries. Arthroscopy 1998;14(5):479-483
5. Miwa H, Hashizume H, Fujiwara K, et al. Arthroscopic surgery for traumatic triangular fibrocartilage complex injury. J Orthop Sci 2004;9(4):354-359
6. Husby T, Haugstvedt JR. Long-term results after arthroscopic resection of lesions of the triangular fibrocartilage complex. Scand J Plast Reconstr Surg Hand Surg 2001;35(1):79-83
7. Minami A, Ishikawa JI, Suenaga N, et al. Clinical results of treatment of triangular fibrocartilage complex tears by arthroscopic debridement. J Hand Surg Am 1996;21(3):406-411
8. Saito T, Malay S, Chung KC. A systematic review of outcomes after arthroscopic débridement for triangular fibrocartilage complex tear. Plast Reconstr Surg 2017;140(5):697e-708e
9. McAdams TR, Swan J, Yao J. Arthroscopic treatment of triangular fibrocartilage wrist injuries in the athlete. Am J Sports Med 2009;37(2):291-297
10. Cardenas-Montemayor E, Hartl JF, Wolf MB, et al. Subjective and objective results of arthroscopic debridement of ulnar-sided TFCC (Palmer type 1B) lesions with stable distal radio-ulnar joint. Arch Orthop Trauma Surg 2013;133(2):287-293
11. Möldner M, Unglaub F, Hahn P, et al. Functionality after arthroscopic debridement of central triangular fibrocartilage tears with central perforations. J Hand Surg Am 2015;40(2):252-258
12. Hulsizer D, Weiss APC, Akelman E. Ulna-shortening osteotomy after failed arthroscopic debridement of the triangular fibrocartilage complex. J Hand Surg Am 1997;22(4):694-698
13. Van Sanden S, De Smet L. Ulnar shortening after failed arthroscopic treatment of triangular fibrocartilage complex tears. Chir Main 2001;Oct;20(5):332-336.
14. Nishizuka T, Tatebe M, Hirata H, et al. Simple debridement has little useful value on the clinical course of recalcitrant ulnar wrist pain. Bone Joint J 2013;95-B(12):1687-1696
15. Löw S, Spies CK, Unglaub F, et al. Preventable repeat wrist arthroscopies: analysis of the indications for 133 cases. J Wrist Surg 2017;6(1):33-38
16. Jang E, Danoff JR, Rajfer R, et al. Revision wrist arthroscopy after failed primary arthroscopic treatment. J Wrist Surg 2011;27(5):e54-e55
17. Steyers CM, Blair WF. Measuring ulnar variance: a comparison of techniques. J Hand Surg Am 1989;14(4):607-612
18. Arsalan-Werner A, Grüter L, Mehling IM, et al. Results after arthroscopic treatment of central traumatic lesions of the triangular fibrocartilage complex. Arch Orthop Trauma Surg 2018;138(5):731-737
19. Löw S, Prommersberger K, Pillukat T, et al. Intra- and interobserver reliability of digitally photodocumented findings in wrist arthroscopy. Handchir Mikrochir Plast Chir 2010;42(5):287-292
20. Darlis NA, Weiser RW, Sotereanos DG. Arthroscopic triangular fibrocartilage complex debridement using radiofrequency probes. J Hand Surg Br 2005;30(6):638-642
21. Blackwell RE, Jemison DM, Foy BD. The holmium:yttrium-aluminum-garnet laser in wrist arthroscopy: a five-year experience in the treatment of central triangular fibrocartilage complex tears by partial excision. J Hand Surg Am 2001;26(1):77-84

22. Farr S, Schüller M, Ganger R, et al. Outcomes after arthroscopic debridement of the triangular fibrocartilage complex in adolescents. J Wrist Surg 2018;7(1):43-50
23. Löw S, Herold A, Unglaub F, et al. Treatment of ulnar impaction syndrome with and without central TFC lesion. J Wrist Surg 2018;7(2):133-140
24. Aibinder WR, Izadpanah A, Elhassan BT. Ulnar shortening versus distal radius corrective osteotomy in the management of ulnar impaction after distal radius malunion. Hand (N Y) 2018;13(2):194-201
25. Terzis A, Koehler S, Sebald J, et al. Ulnar shortening osteotomy as a treatment of symptomatic ulnar impaction syndrome after malunited distal radius fractures. Arch Orthop Trauma Surg 2020;140(5):681-695.
26. Srinivasan RC, Jain D, Richard MJ, et al. Isolated ulnar shortening osteotomy for the treatment of extra-articular distal radius malunion. J Hand Surg Am 2013;38(6):1106-1110
27. Roh YH, Hong SW, Gong HS, et al. Prognostic factors of arthroscopic debridement for central triangular fibrocartilage complex tears in adults younger than 45 years: a retrospective case series analysis. Arthroscopy. 2018;34(11):2994-2998
28. Chan SKL, Singh T, Pinder R, et al. Ulnar shortening osteotomy: are complications under reported? J Hand Microsurg 2015 Dec;7(2):276-82
29. Verhiel SHWL, Özkan S, Eberlin KR, et al. Nonunion and reoperation after ulna shortening osteotomy. Hand (N Y) 2019;Mar 8

# APPENDICES


**Appendix 1.** Measurement of ulnar variance according to the method of perpendiculars

**Appendix 2.** Types of reoperation in patients with multiple reoperations

| Patient | Reoperation | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| 1 | TFCC debridement | TFCC debridement and excision dorsal ganglion | |
| 2 | TFCC debridement | TFCC debridement and open CTR | |
| 3 | TFCC debridement | ulna shortening osteotomy | |
| 4 | TFCC debridement | DRUJ arthroplasty (Aptis) | |
| 5 | ulna shortening osteotomy | neuroplasty  dorsal sensory branch of the ulnar nerve | |
| 6 | ulna shortening osteotomy | wrist fusion and EIP to EPL transfer | |
| 7 | ulna shortening osteotomy | Darrach | DRUJ arthroplasty (Aptis) |

*CTR= Carpal Tunnel Release, EIP= Extensor Indicus Proprius, EPL= Extensor*

**Appendix 3.** Demographic factors associated with USO after arthroscopic TFCC debridement

| Explanatory variable | All (n=163) | USO | | P value |
|---|---|---|---|---|
| | | No (n=145) | Yes (n=18) | |
| Age in years, median (IQR) | 43 (32-53) | 43 (32-52) | 50 (39-55) | 0.059[1] |
| Sex, n (%) | | | | 0.33[2] |
| Female | 81 (50) | 70 (48) | 11 (61) | |
| Male | 82 (50) | 75 (52) | 7 (39) | |
| Alcohol abuse reported in chart, n (%) | 10 (6.1) | 9 (6.2) | 1 (5.6) | >0.99[2] |
| Tobacco abuse reported in chart, n (%) | 24 (15) | 20 (14) | 4 (22) | 0.31[2] |
| Diabetes, n (%) | 12 (7.4) | 10 (6.9) | 2 (11) | 0.63[2] |
| Labouror, n (%) | 76 (47) | 70 (48) | 6 (33) | 0.32[2] |

[1]*Mann-Whitney U Test,* [2]*Fisher's exact test*

**Appendix 4.** Condition-related factors associated with USO after arthroscopic TFCC debridement

| Explanatory variable | All (n=163) | USO | | P value |
|---|---|---|---|---|
| | | No (n=145) | Yes (n=18) | |
| General laxity, n (%) | 7 (4.3) | 6 (4.1) | 1 (5.6) | 0.57[1] |
| Dominant side affected, n (%) | 93 (64) | 81 (63) | 12 (67) | >0.99[1] |
| Prior trauma ipsilateral wrist, n (%) | 19 (12) | 12 (8.3) | 7 (39) | 0.001[1] |
| Prior surgery ipsilateral wrist, n (%) | 17 (10) | 12 (8.3) | 5 (28) | 0.025[1] |
| Duration symptoms in months, median (IQR) | 8 (5-15) | 12.5 (5-24) | 8 (5-14) | 0.18[2] |
| DRUJ instability, n (%) | 20 (12) | 20 (14) | 0 (0) | 0.13[1] |
| Ulnar variance in mm, median (IQR) | 0 (0-2) | 2.4 (1.7-3.6) | 0 (-0.5-1.8) | <0.001[2] |
| Prior conservative treatment, n (%) | 112 (69) | 102 (70) | 10 (56) | 0.28[1] |
| Palmer classification, n (%) | | | | <0.001[1] |
| Class 1 -traumatic | | | | |
| a or d | 86 (53) | 82 (57) | 4 (22) | |
| Class 2 -degenerative | | | | |
| a (without chondromalacia) | 36 (22) | 34 (24) | 2 (11) | |
| b-e (with chondromalacia) | 40 (25) | 28 (19) | 12 (67) | |
| Related pathology | | | | |
| Chondromalacia, n (%) | 47 (29) | 34 (23) | 13 (72) | <0.001[1] |
| Arthrosis, n (%) | 3 (1.8) | 2 (1.4) | 1 (5.6) | 0.30[1] |
| Lunotriquetral ligament tear, n (%) | 16 (9.8) | 13 (9.0) | 3 (9.8) | 0.39[1] |
| Scapholunate ligament tear, n (%) | 33 (20) | 31 (21) | 2 (11) | 0.53[1] |

[1]*Fisher's exact test,* [2]*Mann-Whitney U Test*

**Appendix 5.** Procedure-related factors associated with USO after arthroscopic TFCC debridement

| Explanatory variable | All (n=163) | USO | | *P* value |
|---|---|---|---|---|
| | | No (n=145) | Yes (n=18) | |
| ***Concomitant procedure performed*** | | | | |
| Lunotriquetral ligament debridement/repair, n (%) | 14 (8.6) | 11 (7.6) | 3 (17) | 0.19[1] |
| Scapholunate ligament debridement/repair, n (%) | 30 (18) | 28 (19) | 2 (11) | 0.53[1] |
| Excision dorsal ganglion, n (%) | 5 (3.1) | 5 (3.5) | 0 (0) | >0.99[1] |
| ECU surgery, n (%) | 12 (7.4) | 12 (8.3) | 0 (0) | 0.37[1] |
| Carpal tunnel release, n (%) | 4 (2.5) | 4 (2.8) | 0 (0) | >0.99[1] |

[1] *Fisher's exact test*

# Chapter 3

## Non-union and reoperation after ulnar shortening osteotomy

***Verhiel SHWL***, *Özkan S, Eberlin KR, Chen NC*

*Hand (N Y). 2020 Sep;15(5):638-646*

# ABSTRACT

**Background** The primary purpose of our study was to identify factors associated with reoperation after USO. Our secondary aims were to determine the rate and type of reoperation procedures.

**Methods** In this retrospective study, we included patients older than 18 years of age who underwent an USO between January 2003 and December 2015. Medical records of patients were assessed for our explanatory variables, reoperations and reporting of symptoms. We used bivariate and multivariable analyses to identify factors associated with reoperation after USO.

**Results** Among 94 patients who underwent 98 USO procedures, there were 34 reoperations (35%). Nineteen patients underwent removal of hardware (19%), 6 had a non-union (6.1%) and 9 patients (9.2%) underwent additional surgeries. Surgery on their dominant limb, trauma and prior surgery to the ipsilateral wrist were associated with reoperation. In multivariable analysis, factors independently associated with reoperation were the dominant side being affected (odds ratio 3.9; 95% CI 1.36-11) and traumatic origin (odds ratio 3.4; 95% CI 1.1-11). Bivariate analysis identified younger age and prior surgery of the affected wrist as factors associated with hardware removal. More operations for re-fixation due to non-union of the osteotomy were performed in patients with a transverse osteotomy compared to patients with an oblique osteotomy.

**Conclusions** One in 3 patients will undergo a reoperation after USO, most often due to hardware irritation or non-union of the osteotomy. Awareness of these rates and predictive factors may be helpful for pre-operative discussions and surgical decision-making.

# INTRODUCTION

USO is performed to address ulnar impaction syndrome, and to treat pain and instability after injury to the TFCC or the LT ligament. The goal of USO is to decrease the mechanical pressure of the ulnar head on the carpus, to correct subtle DRUJ instability and to correct LT instability in patients with higher grades of ulnar impaction syndrome.[1–4] Many types of diaphyseal USO and fixation techniques are available, ranging from freehand transverse osteotomies and fixation with a dynamic compression plate to the use of advanced jigs and compression devices to achieve more precise oblique osteotomies and compression at the osteotomy site.[5–13] The plate can be positioned on either the dorsal, volar or ulnar aspect of the ulna.[9,14–18]

The most common complications resulting from USO are tendon irritation due to plate positioning and non-union of the ulna. Hardware irritation occurs in up to 55% of cases and non-union occurs in up to 18% of cases.[9,17,19–22] Prior series suggest that tendon irritation may be associated with position and type of the plate.[13,17,18,23] Known risk factors for non-union include higher age, poor nutrition, alcohol abuse, tobacco smoking, and diabetes.[9,24–28]

Most published data on USO are limited to relatively small retrospective series.[9,11,18,29–31] Few studies report on predictors of reoperation.[21,24,28] We studied the null hypothesis that there are no factors associated with reoperation after USO. Our secondary aims were to determine the rate and type of reoperation procedures.

# METHODS

This retrospective study was approved by our IRB. We used CPT codes 25390 and 25360 to identify 102 adult patients who had a total of 106 USO procedures by searching our multi-institutional database covering all relevant orthopedic encounters at three regional hospitals: two level I trauma centers and one associated community hospital between January 2003 and December 2015. Indications for USO in our hospitals include ulnar impaction syndrome, irreparable tears of the TFCC, previous radial head excision and associated Essex-Lopresti lesions that result in ulnar-positive variance, attritional LT ligament tears, ulnar non-unions, radial malunions resulting in ulnar-positive variance and early post traumatic DRUJ arthritis.

We then reviewed medical records and collected data on age at surgery, sex, body mass index, reported alcohol or tobacco abuse, diagnosis of diabetes, occupation, workers' compensation status, hand dominance, affected side, perception of traumatic or non-traumatic origin, prior surgery, prior non-surgical treatment, MRI evidence of TFCC tear, arthroscopy prior to surgery, osteotomy type, reduction, plate type, plate position, concomitant wrist procedure, and reoperations.

Eight patients were excluded: 4 due to inaccessible radiographs, 2 had inaccessible operative notes, and 2 had insufficient post-operative follow-up. This resulted in a final cohort of

**Table 1.** Demographic factors associated with reoperation after ulnar shortening osteotomy

| Explanatory variable | Reoperation | | | |
|---|---|---|---|---|
| | **All (n=94)** | **No (n=60)** | **Yes (n=34)** | ***P* value** |
| Age in years, mean ± SD | 46 ± 13 | 47 ± 13 | 44 ± 13 | 0.21[1] |
| Sex, n (%) | | | | 0.83[2] |
| Male | 38 (40) | 25 (42) | 13 (38) | |
| Female | 56 (60) | 35 (58) | 21 (62) | |
| BMI in kg/m2, mean ± SD* | 27 ± 4.7 | 27 ± 5.0 | 27 ± 4.3 | 0.81[1] |
| Alcohol abuse reported in chart, n (%) | 6 (6.4) | 3 (5.0) | 3 (8.8) | 0.66[2] |
| Tobacco abuse reported in chart, n (%) | 13 (14) | 9 (15) | 4 (12) | 0.76[2] |
| Diabetes, n (%)** | 6 (7.0) | 4 (7.1) | 2 (6.7) | > 0.99[2] |
| Occupation, n (%)** | | | | > 0.99[2] |
| Heavy manual labor | 5 (5.9) | 3 (5.6) | 2 (6.5) | |
| Other | 80 (94) | 51 (94) | 29 (94) | |
| Workers compensation, n (%)** | 7 (7.6) | 3 (5.1) | 4 (12) | 0.25[2] |

*[1]Student t-test with equal variances; [2]Fisher's exact test*
** Not reported in 13 patients; **= not extractable from all medical charts*

94 patients who underwent 98 USO procedures. In terms of follow-up, the median time from operation to the last clinical note was 13 months (IQR 6.6 – 24 months). The median time from surgery to the database query was 61 months (IQR 43 – 117 months).

Our final cohort consisted of 38 men (40%) and 56 women (60%; Table 1). Nearly half of the patients (n=48; 49%) could recall a specific trauma as beginning of their symptoms (Table 2). The osteotomies were exclusively diaphyseal, either transverse or oblique using a freehand technique or a dynamic compression system (Table 2). The post-treatment protocol varied per the surgeon's discretion.

## Statistical analysis

We described discrete data using frequencies and percentages, normally distributed continuous data through means and SD, and non-normally distributed continuous data through medians and IQR.

Bivariate analysis was performed using the two-sided Fisher Exact test for dichotomous and categorical variables, and an unpaired Student *t*-test for continuous variables.

Factors with a *P*-value of less than 0.10 in bivariate analysis were entered into a multivariable logistic regression analysis to assess if they were independently associated with reoperation after USO. A *P*-value of less than 0.05 was considered statistically significant.

**Table 2.** Condition- and treatment related factors associated with reoperation after ulnar shortening osteotomy

| Explanatory variable | Reoperation | | | |
|---|---|---|---|---|
| | All (n=98) | No (n=64) | Yes (n=34) | *P* value |
| ***Condition related*** | | | | |
| Dominant side affected, n (%)* | 46 (52) | 24 (41) | 22 (73) | ***0.007***[1] |
| Origin, n (%) | | | | ***0.003***[1] |
| Non-traumatic | 50 (51) | 40 (63) | 10 (29) | |
| Traumatic | 48 (49) | 24 (38) | 24 (71) | |
| Prior surgery ipsilateral wrist, n (%) | 36 (37) | 17 (27) | 19 (56) | ***0.008***[1] |
| Radiographic signs TFCC tear, n (%) | 42 (43) | 29 (45) | 13 (38) | 0.53[1] |
| ***Treatment related*** | | | | |
| Prior non-surgical treatment, n (%) | 59 (60) | 40 (63) | 19 (56) | 0.67 |
| Arthroscopy prior to surgery, n (%) | | | | 0.91[1] |
| Therapeutic arthroscopy | 26 (27) | 17 (27) | 9 (26) | |
| Diagnostic arthroscopy | 2 (2.0) | 2 (3.1) | 0 (0) | |
| Osteotomy type, n (%) | | | | > 0.99[1] |
| Oblique | 77 (79) | 50 (78) | 27 (79) | |
| Transverse | 21 (21) | 14 (22) | 7 (21) | |
| Reduction in mm, mean ± SD** | 4.1 ± 1.8 | 4.3 ± 2.0 | 3.7 ± 1.2 | 0.12[2] |
| Plate type, n (%) | | | | 0.44[1] |
| TriMed Ulnar Osteotomy Compression Plate | 52 (53) | 35 (55) | 17 (50) | |
| Synthes LC-DCP | 22 (22) | 12 (19) | 10 (29) | |
| Rayhack Ulnar Shortening Plate | 11 (11) | 6 (9.4) | 5 (15) | |
| Synthes LCP | 8 (8.2) | 7 (11) | 1 (2.9) | |
| AcuMed Ulnar Shortening Plate | 5 (5.1) | 4 (6.3) | 1 (2.9) | |
| Plate position, n (%) | | | | 0.89[1] |
| Volar | 71 (72) | 47 (73) | 24 (71) | |
| Dorsal | 15 (15) | 10 (16) | 5 (15) | |
| Ulnar | 12 (12) | 7 (11) | 5 (15) | |
| Concomitant wrist procedure, n (%) | | | | 0.42[1] |
| None | 52 (53) | 35 (55) | 17 (50) | |
| Arthroscopy | 19 (19) | 14 (22) | 5 (15) | |
| Other procedure | 27 (28) | 15 (23) | 12 (35) | |

*[1]Fisher's exact test; [2]Student t-test with equal variances*
** Not extractable from all medical charts, ** not reported in 2 patients*

# RESULTS

A total of 34 out of 94 patients (36%) underwent a reoperation. The median time from the USO to the reoperation was 11 months (IQR 9.0-17 months) after the USO. Most reoperations were removal of hardware (n=19, 19%), followed by refixation due to non-union of osteotomy (n=6, 6.1%), and other surgeries (n=9, 9.2%; Table 3). Three patients who underwent removal of hardware also underwent a concurrent procedure because of other complaints besides hardware irritation. Of the patients who underwent "other" surgeries, 8 were performed for persistent pain on the ulnar side of the wrist. Three patients underwent an arthroscopy with synovectomy, 2 patients underwent exploration and neurolysis of the dorsal ulnar sensory nerve branch, 2 patients underwent an arthroscopic TFCC debridement, 2 patients underwent a Darrach procedure, and 1 patient underwent a prosthetic DRUJ arthroplasty (Scheker distal radioulnar joint prosthesis, Aptis Medical). Six of the 34 patients (6.4%) required more than 1 reoperation; 3 patients underwent 2 reoperations, 2 underwent 3 reoperations, and 1 patient underwent 4 reoperations (Appendix 1).

In bivariate analysis, surgery on the dominant side ($P$=0.007), perceived traumatic origin ($P$=0.003) and prior surgery to the affected wrist ($P$=0.008) were associated with reoperation (Table 2 and Appendix 2). A total of 24 patients who underwent reoperation recalled a traumatic origin. Pre-operatively, 8 (33%) of these patients had radiographic evidence of

**Table 3.** Types of reoperation after ulnar shortening osteotomy (n=34)

| Reoperation procedure | n (%) |
|---|---|
| ***Removal of hardware*** | 16 (16) |
| With concurrent: | |
| Arthroscopy with complete synovectomy, TFCC debridement and cubital tunnel release | 1 (1.0) |
| Arthroscopy with complete synovectomy and TFCC debridement | 1 (1.0) |
| Diagnostic arthroscopy, neurolysis of dorsal ulnar sensory nerve, tenosynovectomy of the ECU | 1 (1.0) |
| ***Refixation due to non-union of osteotomy*** | |
| No graft | 3 (3.1) |
| Iliac crest bone graft | 2 (2.0) |
| Local bone graft | 1 (1.0) |
| ***Other*** | |
| Arthroscopy with synovectomy | 3 (3.1) |
| Exploration right ulnar wrist and neurolysis dorsal ulnar sensory nerve branch | 1 (1.0) |
| Arthroplasty DRUJ | 1 (1.0) |
| Removal of broken DRUJ pin | 1 (1.0) |
| Radial head excision, Darrach procedure with ECU tenodesis | 1 (1.0) |
| Darrach procedure with ECU tenodesis | 1 (1.0) |
| Ulnar nerve decompression elbow, screw removal with inability to remove cold welded plate | 1 (1.0) |

**Table 4.** Multivariable Analysis* - factors independently associated with reoperation after ulnar shortening osteotomy

| Explanatory variable | | | 95% CI | | |
|---|---|---|---|---|---|
| | Odds Ratio | Standard Error | Lower | Upper | *P* value |
| Dominant side affected (ref = dominant side not affected) | 3.9 | 2.1 | 1.36 | 11 | ***0.011*** |
| Traumatic origin (ref = non-traumatic) | 3.4 | 2 | 1.1 | 11 | ***0.039*** |
| Prior surgery wrist (ref = no prior surgery wrist) | 2.5 | 1.4 | 0.82 | 7.4 | 0.11 |

**Area under the receiver operating characteristic curve = 0.78; Pseudo R2, 0.19; P value for Hosmer–Lemeshow test, 0.96*



a TFCC tear and 3 (13%) patients had radiographic evidence of traumatic DRUJ arthritis. Multivariable logistic regression analysis revealed that dominant side being affected (odds ratio 3.9; *P*=0.011) and perceived traumatic origin (odds ratio 3.4; *P*=0.039) were independently associated with reoperation after USO (Table 4).

Because most of the reoperations were performed for hardware removal or refixation due to non-union of the osteotomy, we performed an additional analysis to identify factors that were associated specifically with these procedures. Bivariate analysis identified younger age (*P*=0.0039) and prior surgery of the affected wrist (*P*=0.015) as factors associated with hardware removal (Table 5 and 6). More operations for refixation due to non-union of the osteotomy were performed in patients with a transverse osteotomy compared to patients with an oblique osteotomy (*P*=0.018) (Table 7, Appendices 3 and 4).

At the final clinical note at median 13 months (IQR 6.6 – 24 months), 21 of 94 patients (22%) reported persistent ulnar-sided wrist pain, regardless of reoperation. The suspected

**Table 5.** Demographic factors associated with hardware removal after ulnar shortening osteotomy

| Explanatory variable | | Hardware removal | | |
|---|---|---|---|---|
| | All (n=94) | No (n=75) | Yes (n=19) | *P* value |
| Age in years, mean ± SD | 46 ± 13 | 48 ± 12 | 38 ± 13 | ***0.0039***[1] |
| Sex, n (%) | | | | 0.80[2] |
| Male | 38 (40) | 31 (41) | 7 (37) | |
| Female | 56 (60) | 44 (59) | 12 (63) | |
| BMI in kg/m2, mean ± SD* | 27 ± 4.7 | 27 ± 4.7 | 27 ± 4.9 | 0.90[1] |
| Alcohol abuse reported in chart, n (%) | 6 (6.4) | 4 (5.3) | 2 (11) | 0.60[2] |
| Tobacco abuse reported in chart, n (%) | 13 (14) | 11 (15) | 2 (11) | > 0.99[2] |
| Diabetes, n (%)** | 6 (7.0) | 4 (5.7) | 2 (13) | 0.31[2] |
| Occupation, n (%)** | | | | 0.58[2] |
| Heavy manual labor | 5 (5.9) | 5 (7.3) | 0 (0) | |
| Other | 80 (94) | 64 (93) | 16 (100) | |
| Workers compensation, n (%)** | 7 (7.6) | 6 (8.1) | 1 (5.6) | > 0.99[2] |

** Not reported in 13 patients; **= not extractable from all medical charts*
*[1]Student t-test with equal variances; [2]Fisher's exact test*

**Table 6.** Condition- and treatment related factors associated with hardware removal after ulnar shortening osteotomy

| **Explanatory variable** | **Hardware removal** | | | |
|---|---|---|---|---|
| | **All (n=98)** | **No (n=79)** | **Yes (n=19)** | ***P* value** |
| ***Condition related*** | | | | |
| Dominant side affected, n (%)* | 46 (52) | 36 (49) | 10 (67) | 0.27[1] |
| Origin, n (%) | | | | 0.075[1] |
| Non-traumatic | 50 (51) | 44 (56) | 6 (32) | |
| Traumatic | 48 (49) | 35 (44) | 13 (68) | |
| Prior surgery ipsilateral wrist, n (%) | 36 (37) | 24 (30) | 12 (63) | ***0.015[1]*** |
| Radiographic signs TFCC tear, n (%) | 42 (43) | 35 (44) | 7 (37) | 0.61[1] |
| ***Treatment related*** | | | | |
| Prior non-surgical treatment, n (%) | 59 (60) | 47 (59) | 12 (63) | >0.99[1] |
| Arthroscopy prior to surgery, n (%) | | | | 0.73[1] |
| Therapeutic arthroscopy | 26 (27) | 22 (28) | 4 (21) | |
| Diagnostic arthroscopy | 2 (2.0) | 2 (2.5) | 0 (0) | |
| Osteotomy type, n (%) | | | | 0.35[1] |
| Oblique | 77 (79) | 60 (76) | 17 (89) | |
| Transverse | 21 (21) | 19 (24) | 2 (11) | |
| Reduction in mm, mean ± SD** | 4.1 ± 1.8 | 4.3 ± 1.9 | 3.4 ± 1.1 | 0.067[2] |
| Plate type, n (%) | | | | 0.87[1] |
| TriMed Ulnar Osteotomy Compression Plate | 52 (53) | 43 (54) | 9 (47) | |
| Synthes LC-DCP | 22 (22) | 17 (22) | 5 (26) | |
| Rayhack Ulnar Shortening Plate | 11 (11) | 8 (10) | 3 (16) | |
| Synthes LCP | 8 (8.2) | 7 (8.9) | 1 (5.3) | |
| AcuMed Ulnar Shortening Plate | 5 (5.1) | 4 (5.1) | 1 (5.3) | |
| Plate position, n (%) | | | | 0.20[1] |
| Volar | 71 (72) | 60 (76) | 11 (58) | |
| Dorsal | 15 (15) | 10 (13) | 5 (26) | |
| Ulnar | 12 (12) | 9 (11) | 3 (16) | |
| Concomitant wrist procedure, n (%) | | | | 0.52[1] |
| None | 52 (53) | 44 (56) | 8 (42) | |
| Arthroscopy | 19 (19) | 15 (19) | 4 (21) | |
| Other procedure | 27 (28) | 20 (25) | 7 (37) | |

*[1]Fisher's exact test; [2]Student t-test with equal variances*
** Not extractable from all medical charts, ** not reported in 2 patients*

underlying cause for this pain was TFCC pathology in 6 patients, tendon irritation by the plate in 4 patients, ECU tendinitis in 1 patient, and unknown in the others. Six patients received either splinting or corticosteroid injection at their last clinical follow-up.

Of the patients who had undergone hardware removal (n=19), 3 patients still had tenderness at the prior plate location. Four of the 6 patients who had undergone a reoperation for

**Table 7.** Characteristics of patients with refixation due to non-union of osteotomy

| Patient | Sex | Age | Comor-bidities | Domi-nant side affected | Origin | Prior surgery | Prior non-surgical treatment | TFCC tear | Prior arthroscopy | Osteotomy type | Plate type | Plate position | mm reduc-tion | Unplanned reoperation (indication) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F | 58 | obese, alcohol and tobacco abuse | yes | non-traumatic | no | splint, NSAID, steroid injection | yes | yes, with TFCC debridement | transverse | 6 hole LC-DCP | volar | 3.5 | 1. ORIF with 8 hole LC-DCP (non-union) |
| 2 | F | 41 | none | no | traumatic | no | none | yes | yes, with synovectomy | transverse | 5 hole LC-DCP | volar | 3 | 1. ORIF with local bone graft (non-union) |
| 3 | M | 43 | obese | yes | traumatic | yes; arthroscopy with TFCC debridement | none | no | no | oblique | Rayhack USO plate | ulnar | 2.5 | 1. ORIF with iliac crest bone graft (non-union)<br>2. ORIF with iliac crest bone graft (infection non-union)<br>3. Removal of hardware (hardware irritation) |
| 4 | F | 55 | none | yes | traumatic | no | splint | no | no | oblique | TriMed USO plate | volar | 6 | 1. ORIF with iliac crest bone graft (non-union) |
| 5 | F | 66 | none | yes | traumatic | yes; arthroscopy with extensive debridement | splint, NSAID, steroid injection | yes | yes, with TFCC debridement | transverse | 6 hole LC-DCP | volar | 6 | 1. ORIF with 8 hole LC-DCP (non-union)<br>2. Removal of hardware (hardware irritation)<br>3. Darrach resection and ECU-FCU transfer (DRUJ incongruity)<br>4. DRUJ arthroplasty (DRUJ incongruity) |
| 6 | F | 47 | none | yes | traumatic | no | no | yes | yes, with TFCC debridement | transverse | 6 hole LC-DCP | volar | 3 | 1. ORIF with 7 hole LC-DCP (non-union) |

non-union of the osteotomy had radiographic evidence of osteotomy union at last follow-up; the other 2 had a complex post-operative course with multiple reoperations (Appendix 1).

# DISCUSSION

In our cohort of 98 USO procedures, we found that nearly 1 in 5 patients underwent reoperation for hardware irritation and 1 of 20 patients underwent reoperation for refixation due to non-union. Involvement of the dominant limb and prior surgery were associated with reoperation.

There are some limitations to our study. Due to its retrospective nature, erroneous documentation may affect the results. We considered two forms of follow-up: time from surgery to last clinical note and time from surgery to database query. Defining follow-up as time from surgery to query assumes that the majority of patients would return to the original surgeon. It is possible that secondary surgeries occurred at a different institution. Based on our experience with referral patterns within our institutions, this is not likely. We found that 4 of our included patients switched care from one institution to another institution within our system. Non-union of the osteotomy was defined by the treating surgeon, and the threshold for reoperation varies. There is no clear consensus among surgeons regarding the definitions of union, delayed union, or non-union of long-bone fractures, and the ulna is notoriously slow to heal.[32–34] Although we found a significant association between transverse osteotomy and reoperation for non-union, there were a small number of non-unions. This result may not be accurate if there was sampling error and these 6 non-union cases do not parallel the actual non-union population.

These limitations are counterbalanced by the large number of patients accrued during a 13-year time frame across three hospitals among 13 surgeons. There was variety of osteotomy types and fixation techniques which make this data more generalizable to usual practice than a single surgeon case series.

We found an overall reoperation rate of 35%. Other studies quote reoperation rates between 25% to 59%: Gaspar et al found a reoperation rate of 25% among 69 USO procedures, while Chan et al reported a rate of 48% in 63 patients.[6,8,9,13,17,20,22,28–30]

Nineteen patients (19% of total) underwent removal of hardware, which is similar to prior research.[9,17–21,30,35] Prior studies report conflicting results on the relation between hardware removal and the position and type of the plate. [9,13–18,23] Some authors have suggested ulnar or volar placement to be superior to dorsal placement because of better coverage by the forearm muscles, whereas others promote dorsal placement.[16,18,24] In our study, plate location did not appear to be associated with hardware removal. Significantly more reoperations for removal of hardware were found in patients who had a prior surgery of the affected wrist. Hardware removal is a discretionary surgery, and this finding may reflect a preference of these patients towards surgical intervention to address symptoms.

Six patients (6.1% of total) had a reoperation because of non-union of the osteotomy. Prior studies report inconsistent rates for reoperation for non-union of osteotomy: ranging from 1.9% to 7.7% in transverse osteotomies,[6,12,21,24] and from 0% to 18% in oblique osteotomies.[8,9,30,12,13,16–18,22,28,29] A greater surface area of contact in oblique osteotomies compared to transverse osteotomies would facilitate bone healing and lead to lower rates of non-union in the former group.[7,12,29,35,36] This is consistent with our finding that more operations for non-union of osteotomies were performed in patients with a transverse osteotomy compared to oblique osteotomy.

Other studies report that delayed union or non-union are associated with diabetes, poor bone mineral density, decreased wrist range of motion, and smoking. We did not have evidence for either association or absence of association between non-union of osteotomy and age, poor nutrition, alcohol consumption, smoking or diabetes. [9,24–28] It is important to recognize that we identified non-unions that underwent reoperation and did not identify all radiographic non-unions. This may explain some of the differences in our findings compared to prior studies. It may be argued that these are clinically important non-unions and not stable, fibrous unions.

We also found that at last follow-up, 1 in 5 patients reported persistent ulnar-sided wrist pain after USO. Prior studies report persistent ulnar-sided wrist pain ranging from 5.2% to 23% [5,8,12,15,18,20,28,29]. In a study by Loh et al, 5 of 22 patients reported no pain relief after the procedure.[19] Ahsan et al found persistent ulnar-sided wrist pain in 2 of 38 patients, one case involved pain at the ulnocarpal joint with twisting, the other patient had dorsal ulnar sensory neuropathic pain.[13]

In conclusion, 1 in 3 patients will undergo an reoperation after USO, most often due to hardware irritation. Hardware removal tends to occur in younger patients who had another surgery pre-dating the USO.  Reoperation for non-union occurs in about 1 in 20 patients and has a relationship to osteotomy technique. Persistent ulnar-sided wrist pain occurs in about 1 in 5 of patients, regardless of reoperation. Both surgeons and patients should be aware of these rates and incorporate this in the surgical decision making when considering USO.

# REFERENCES

1. Palmer a K, Werner FW. Biomechanics of the distal radioulnar joint. Clin Orthop Relat Res. 1984;(187):26-35
2. Werner FW, Palmer AK, Fortino MD, Short WH. Force transmission through the distal ulna: Effect of ulnar variance, lunate fossa angulation, and radial and palmar tilt of the distal radius. J Hand Surg Am. 1992;17(3):423-428
3. Baek GH, Lee HJ, Gong HS, et al. Long-term outcomes of ulnar shortening osteotomy for idiopathic ulnar impaction syndrome: At least 5-years follow-up. Clin Orthop Surg. 2011;3(4):295-301
4. Sachar K. Ulnar-sided wrist pain: Evaluation and treatment of triangular fibrocartilage complex tears, ulnocarpal impaction syndrome, and lunotriquetral ligament tears. J Hand Surg Am. 2012;37(7):1489-1500
5. Darrow JCJ, Linscheid RL, Dobyns JH, Mann JM 3rd, Wood MB, Beckenbaugh RD. Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg Am. 1985;10(4):482-491
6. Hulsizer D, Weiss APC, Akelman E. Ulna-shortening osteotomy after failed arthroscopic debridement of the triangular fibrocartilage complex. J Hand Surg Am. 1997;22(4):694-698
7. Rayhack JM, Gasser SI, Latta LL, Anne Ouellette E, Milne EL. Precision oblique osteotomy for shortening of the ulna. J Hand Surg Am. 1993;18(5):908-918
8. Mizuseki T, Tsuge K, Ikuta Y. Precise ulna-shortening osteotomy with a new device. J Hand Surg Am. 2001;26(5):931-939
9. Chen NC, Wolfe SW. Ulna shortening osteotomy using a compression device. J Hand Surg Am. 2003;28(1):88-93
10. Chennagiri R, Burge P. Pre-osteotomy plate application technique for ulnar shortening. J Hand Surg Am. 2004;29(5):453-457
11. Darlis NA, Ferraz IC, Kaufmann RW, Sotereanos DG. Step-cut distal ulnar-shortening osteotomy. J Hand Surg Am. 2005;30(5):943-948
12. Sunil TM, Wolff TW, Scheker LR, McCabe SJ, Gupta A. A comparative study of ulnar-shortening osteotomy by the freehand technique versus the Rayhack technique. J Hand Surg Am. 2006;31(2):252-257
13. Ahsan ZS, Song Y, Yao J. Outcomes of ulnar shortening osteotomy fixed with a dynamic compression system. J Hand Surg Am. 2013;38(8):1520-1523
14. Chun S, Palmer AK. The ulnar impaction syndrome: Follow-up of ulnar shortening osteotomy. J Hand Surg Am. 1993;18(1):46-53
15. Baek GH, Chung MS, Lee YH, Gong HS, Lee S, Kim HH. Ulnar Shortening Osteotomy in Idiopathic Ulnar Impaction Syndrome: Surgical Technique. JBJS Essent Surg Tech. 2006;os-88(1_suppl_2):212-220
16. Van Sanden S, De Smet L. Ulnar shortening after failed arthroscopic treatment of triangular fibrocartilage complex tears. Chir Main. 2001;20(5):332-336
17. Pomerance J. Plate removal after ulnar-shortening osteotomy. J Hand Surg Am. 2005;30(5):949-
18. Das De S, Johnsen PH, Wolfe SW. Soft tissue complications of dorsal versus volar plating for ulnar shortening osteotomy. J Hand Surg Am. 2015;40(5):928-933
19. Loh YC, Van Den Abbeele K, Stanley JK, Trail I a. The results of ulnar shortening for ulnar impaction syndrome. J Hand Surg Br. 1999;24B(3):316-320. doi:10.1054/JHSB.1999.0062
20. Rajgopal R, Roth J, King G, Faber K, Grewal R. Outcomes and complications of ulnar shortening osteotomy:an institutional review. Hand. 2014;10(3):535-540
21. Iwasaki N, Ishikawa J, Kato H, Minami M, Minami A. Factors affecting results of ulnar shortening for ulnar impaction syndrome. Clin Orthop Relat Res. 2007;465(465):215-219

22. Fulton C, Grewal R, Faber KJ, Roth J, Gan BS. Outcome analysis of ulnar shortening osteotomy for ulnar impaction syndrome. Can J Plast Surg. 2012;20(1)
23. Jungwirth-Weinberger A, Borbas P, Schweizer A, Nagy L. Influence of Plate Size and Design upon Healing of Ulna-Shortening Osteotomies. J Wrist Surg. 2016;5(4):284-289
24. Cha SM, Shin HD, Ahn KJ. Prognostic Factors Affecting Union After Ulnar Shortening Osteotomy in Ulnar Impaction Syndrome: A Retrospective Case-Control Study. J Bone Joint Surg Am. 2017;99(8):638-647
25. Ding L, He Z, Xiao H, Chai L, Xue F. Factors affecting the incidence of aseptic nonunion after surgical fixation of humeral diaphyseal fracture. J Orthop Sci. 2014;19(6):973-977
26. Dodson NB, Ross AJ, Mendicino RW, Catanzariti AR. Factors Affecting Healing of Ankle Fractures. J Foot Ankle Surg. 2013;52(1):2-5
27. Jiao H, Xiao E, Graves DT. Diabetes and Its Effect on Bone and Fracture Healing. Curr Osteoporos Rep. 2015;13(5):327-335
28. Gaspar MP, Kane PM, Zohn RC, Buckley T, Jacoby SM, Shin EK. Variables Prognostic for Delayed Union and Nonunion Following Ulnar Shortening Fixed with a Dedicated Osteotomy Plate. J Hand Surg Am. 2016;41(2):237-243e2
29. Chan SKL, Singh T, Pinder R, Tan S, Craigen MA. Chan. Ulnar shortening osteotomy: are complications underreported? J Hand Microsurg. 2015;7(2):276-282.
30. Fufa DT, Carlson MG, Calfee RP, Sriram N, Gelberman RH, Weiland AJ. Mid-Term Results Following Ulna Shortening Osteotomy. HSS J. 2014;10(1):13-17.
31. Megerle K, Hellmich S, Germann G, Sauerbier M. Hardware location and clinical outcome in ulna shortening osteotomy. Plast Reconstr Surg Glob Open. 2015;3(10):1-6.
32. Marsh D. Concepts of fracture union, delayed union, and nonunion. Clin Orthop Relat Res. 1998;(355 Suppl):S22-S30.
33. Bhandari M, Fong K, Sprague S, Williams D, Petrisor B. Variability in the Definition and Perceived Causes of Delayed Unions and Nonunions. J Bone Jt Surgery-American Vol. 2012;94(15):e109-1-6
34. Bhandari M, Guyatt GH, Swiontkowski MF, Tornetta 3rd P, Sprague S, Schemitsch EH. A lack of consensus in the assessment of fracture healing among orthopaedic surgeons. J Orthop Trauma. 2002;16(8):562-566
35. Papatheodorou LK, Baratz ME, Bougioukli S, Ruby T, Weiser RW, Sotereanos DG. Long-Term Outcome of Step-Cut Ulnar Shortening Osteotomy for Ulnar Impaction Syndrome. J Bone Joint Surg Am. 2016;98(21):1814-1820
36. Tatebe M, Nishizuka T, Hirata H, Nakamura R. Ulnar shortening osteotomy for ulnar-sided wrist pain. J Wrist Surg. 2014;3(2):77-84

# APPENDICES

**Appendix 1.** Types of reoperation in patients with multiple reoperations

| Patient | Reoperation | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | Hardware removal | DRUJ arthroplasty (Aptis) | | |
| 2 | Arthroscopy with synovectomy | Proximal row carpectomy | | |
| 3 | Darrach procedure | Hardware removal | | |
| 4 | Refixation due to non-union | Infection non-union | Hardware removal | |
| 5 | Arthroscopy with synovectomy | Hardware removal | Arthroscopy with synovectomy | |
| 6 | Refixation due to non-union | Hardware removal | Darrach procedure | DRUJ arthroplasty (Aptis) |

**Appendix 2.** Characteristics of prior surgery to ipsilateral wrist (n=36)

| Types surgery by indication | n (%) |
|---|---|
| **Ulna** | |
| *Ulnar impaction* | |
| Burring ulnar head | 2 (5.6) |
| Wafer ulnar resection | 2 (5.6) |
| **Radius** | |
| *Post distal radius fracture* | |
| Corrective osteotomy | 4 (11) |
| ORIF distal radius fracture | 3 (8.3) |
| External fixation distal radius | 3 (8.3) |
| *Madelung deformity* | |
| Radial shortening osteotomy | 1 (2.8) |
| **Other** | |
| *TFCC tear* | |
| TFCC debridement/repair (arthroscopic) | 17 (47) |
| TFCC repair (open) | 1 (2.8) |
| *Scaphoid fracture* | |
| Fixation scaphoid fracture | 1 (2.8) |
| *Tendon* | |
| ECU stabilization procedure | 1 (2.8) |
| *Neuroma* | |
| Translocation of palmar neuromas into palmar musculature | 1 (2.8) |

**Appendix 3.** Demographic factors associated with refixation due to non-union after ulna shortening osteotomy

| Explanatory variable | All (n=94) | Refixation due to non-union | | *P* value |
|---|---|---|---|---|
| | | No (n=88) | Yes (n=6) | |
| Age in years, mean ± SD | 46 ± 13 | 46 ± 13 | 50 ± 7.0 | 0.40[1] |
| Sex, n (%) | | | | 0.40[2] |
| Male | 38 (40) | 37 (42) | 1 (17) | |
| Female | 56 (60) | 51 (58) | 5 (83) | |
| BMI in kg/m2, mean ± SD* | 27 ± 4.7 | 27 ± 4.7 | 28 ± 5.3 | 0.67[1] |
| Alcohol abuse reported in chart, n (%) | 6 (6.4) | 5 (5.7) | 1 (17) | 0.33[2] |
| Tobacco abuse reported in chart, n (%) | 13 (14) | 12 (14) | 1 (17) | > 0.99[2] |
| Diabetes, n (%)** | 6 (7.0) | 6 (7.5) | 0 (0) | > 0.99[2] |
| Occupation, n (%)** | | | | > 0.99[2] |
| Heavy manual labor | 5 (5.9) | 5 (6.3) | 0 (0) | |
| Other | 80 (94) | 74 (94) | 6 (100) | |
| Workers compensation, n (%)** | 7 (7.6) | 7 (8.1) | 0 (0) | > 0.99[2] |

**not reported in 13 patients; **= not extractable from all medical charts*
*[1]Student t-test with equal variances; [2]Fisher's exact test*

**Appendix 4.** Condition- and treatment related factors associated with refixation due to non-union after ulna shortening osteotomy

| Explanatory variable | All (n=98) | Refixation due to non-union | | *P* value |
|---|---|---|---|---|
| | | No (n=92) | Yes (n=6) | |
| ***Condition related*** | | | | |
| Dominant side affected, n (%)* | 46 (52) | 41 (50) | 5 (83) | 0.21[1] |
| Origin, n (%) | | | | 0.11[1] |
| Non-traumatic | 50 (51) | 49 (53) | 1 (17) | |
| Traumatic | 48 (49) | 43 (47) | 5 (83) | |
| Prior surgery ipsilateral wrist, n (%) | 36 (37) | 34 (37) | 2 (33) | > 0.99[1] |
| Radiographic signs TFCC tear, n (%) | 42 (43) | 38 (41) | 4 (67) | 0.40[1] |
| ***Treatment related*** | | | | |
| Prior non-surgical treatment, n (%) | 59 (60) | 56 (61) | 3 (50) | 0.68[1] |
| Arthroscopy prior to surgery, n (%) | | | | 0.11[1] |
| Therapeutic arthroscopy | 26 (27) | 22 (24) | 4 (67) | |
| Diagnostic arthroscopy | 2 (2.0) | 2 (2.2) | 0 (0) | |
| Osteotomy type, n (%) | | | | 0.018[1] |
| Oblique | 77 (79) | 75 (82) | 2 (33) | |
| Transverse | 21 (21) | 17 (18) | 4 (67) | |
| Reduction in mm, mean ± SD** | 4.1 ± 1.8 | 4.1 ± 1.8 | 4.0 ± 1.6 | 0.90[2] |
| Plate type, n (%) | | | | 0.093[1] |
| TriMed Ulnar Osteotomy Compression Plate | 52 (53) | 51 (55) | 1 (17) | |
| Synthes LC-DCP | 22 (22) | 18 (20) | 4 (67) | |
| Rayhack Ulnar Shortening Plate | 11 (11) | 10 (11) | 1 (17) | |
| Synthes LCP | 8 (8.2) | 8 (8.7) | 0 (0)) | |
| AcuMed Ulnar Shortening Plate | 5 (5.1) | 5 (5.4) | 0 (0) | |
| Plate position, n (%) | | | | 0.65[1] |
| Volar | 71 (72) | 66 (72) | 5 (83) | |
| Dorsal | 15 (15) | 15 (16) | 0 (0) | |
| Ulnar | 12 (12) | 11 (12) | 1 (17)) | |
| Concomitant wrist procedure, n (%) | | | | 0.076[1] |
| None | 52 (53) | 46 (50) | 6 (100) | |
| Arthroscopy | 19 (19) | 19 (21) | 0 (0) | |
| Other procedure | 27 (28) | 27 (29) | 0 (0) | |

** = not extractable from all medical charts, ** not reported in 2 patients*
*[1]Fisher's exact test; [2]Student t-test with equal variances*

# Chapter 4

## MRI findings in patients undergoing triangular fibrocartilage complex repairs versus patients without ulnar-sided wrist pain

***Verhiel SHWL****, Blackburn J, Ritt MJPF, Simeone FJ, Chen NC*

*Hand (N Y). 2020 Jul 19; Online ahead of print*

# ABSTRACT

**Background** The clinical picture of ulnar-sided wrist pain is oftentimes confusing, because various pathologies may be co-existent. In this study, we aimed 1) to compare the prevalence of potential causes of ulnar-sided wrist pain on MRI in patients who underwent TFCC repair to control subjects, 2) to evaluate whether inferior clinical results were associated with specific patient characteristics or other potential causes of ulnar-sided wrist pain.

**Methods** We included 67 patients who underwent a TFCC repair and 67 control subjects. MRI scans were examined for sources of ulnar-sided wrist pain. Fourty-two patients after TFCC repair (63%) completed surveys, including QuickDASH and pain scores. Bivariate analysis was performed to compare our groups and to identify factors associated with our outcomes.

**Results** We found significantly higher rates of DRUJ arthritis (p=0.033), ECU pathology (p=0.028) and ulnar styloid fractures (p=0.028) in patients with TFCC repairs. With increasing age, increasing pathology in the PT joint (p=0.040), more ulnocarpal abutment (p=0.0081) and more degenerative tears (p<0.001) were seen in both groups. No demographic characteristics or MRI findings were significantly associated with our outcomes.

**Conclusions** We observed higher rates of DRUJ arthritis and ECU pathology in patients with TFCC tears undergoing repair compared to age- and sex-matched controls. This may be due to damage to the TFCC itself altering relationships of the DRUJ and the ECU subsheath, or it may reflect various pathologies that cause ulnar-sided wrist pain and drive patients towards surgery.

# INTRODUCTION

There are many causes of ulnar-sided wrist pain, and it can be difficult to diagnose and treat.[1] Causes of ulnar-sided wrist pain include, amongst others, a tear of the TFCC, PT joint arthritis, hamate facet arthrosis, LT instability, DRUJ arthrosis, DRUJ instability, ulnar impaction, and tendinopathy of ECU or FCU. Understanding which of these pathologies contributes to ulnar-sided wrist pain is important for clinical decision-making. Often, the clinical picture is confusing because these pathologies are co-existent.



The TFCC has a close relation to its surrounding structures and consists of 1) the triangular fibrocartilage disc proper, 2) the ulnar extrinsic ligaments, 3) the ECU subsheath, 4) the meniscal homologue and 5) the volar and dorsal DRUJ ligaments.[2] TFCC tears are generally conceptualized as traumatic tears or degenerative tears. The majority of TFCC tears, whether traumatic or degenerative are managed non-operatively.[2] Patients with a traumatic tear are generally younger, and the tear occurs in the periphery, rather than centrally. Degenerative tears are usually the result of attritional wear over time and may be accompanied by impaction of the ulna upon the ulnar carpus.

The primary aim of our study was to compare the prevalence of potential causes of ulnar-sided wrist pain on MRI in patients who underwent TFCC repair to control subjects without ulnar-sided wrist pain. Our null hypothesis was that there would be no difference in the rates of these diagnoses between the two groups. Secondary aims of our study were to evaluate whether patients with inferior clinical results and ongoing ulnar-sided wrist pain after TFCC repair had greater rates of specific patient characteristics or other potential causes of ulnar-sided wrist pain.

# METHODS

Our study was approved by our IRB (#1999P008705). A RPDR was used to identify all adult patients who underwent TFCC repair at two institutions between the beginning of January 2003 and the end of December 2017. We used CPT codes for TFCC repair (codes: 29844, 25320, 25107, 25337, 25676, 25830). We excluded patients if TFCC repair was not the primary surgery (for instance patients who had a DRUJ reconstruction or fixation of a distal radius fracture), as well as patients with inflammatory arthritis or previous wrist surgery and patients who had no pre-operative MRI available. A total of 67 patients were included.

We examined medical records for demographic data including age, gender, hand dominance and a history of a manual labor profession. A clinical history of anxiety or depression was noted. For patients who underwent TFCC repair, the medical records were examined for whether the repair was performed via an open or arthroscopic approach and we noted the Palmer classification for traumatic TFCC tears.[2]

Patients who underwent TFCC repair were contacted via telephone and asked if they had ulnar-sided wrist pain at rest or during forceful forearm rotation in the last month. The patient rated functional outcome was measured by the QuickDASH questionnaire. The QuickDASH consists of 11 questions about daily activities and symptoms, each scored on a scale of 1 (no disability) to 5 (severe disability). These scores are transformed to a scale of 0 to 100, reflecting patients' perception of physical arm function and symptoms. A higher score indicates more arm related disabilities experienced by the patient. Patients were also asked to rate their pain in rest and during rotation on a Numerical Rating Scale from 0 to 10, where 10 represents the worst pain.

Preoperative plain radiographs of the wrist of all patients who underwent TFCC repair, were examined for measurement of ulnar variance using the method of perpendiculars.[3]

A list of all MRIs of the wrist and hand performed over the same period of time was generated. Control subjects were identified from this list as those with MRI scans performed for radial-sided or dorsal wrist pain that were age- and sex-matched to the patients who underwent TFCC repair. The list of MRIs was then randomly sorted before the scans were reviewed by a fellow-ship-trained musculoskeletal radiologist to obscure whether the MRI was from a control or a TFCC repair patient. All included MRI scans were examined for sources of ulnar-sided wrist pain, including 1) TFCC tear, 2) PT joint pathology, 3) hamate fracture, 4) DRUJ degenerative disease, 5) ECU pathology, 6) FCU pathology, 7) ulnocarpal abutment and 8) ulnar styloid fracture.

As our institutions receive referrals from a number of local hospitals as well as outside institutions, the MRI techniques were heterogeneous. The pulse sequences obtained for each MRI varied from institution to institution but all studies contained axial, sagittal, and coronal images of the wrist. All scans included fluid sensitive sequences such as a T2, T2 fat-saturated, STIR, or proton-density fat-saturated image for review. In addition to the fluid sensitive sequences, anatomic sequences such as T1 or proton density weighted images were utilized for further evaluation of the wrist. Image quality was adequate on all studies and often was good or excellent. No studies were deemed uninterpretable secondary to missing sequences or imaging artefacts.

## Statistical analysis

We described discrete data using frequencies and percentages, normally distributed continuous data through means and SD, and non-normally distributed continuous data through medians and IQR.

For the bivariate analyses between the two groups, the two-sided Fisher Exact test was used. To identify an association between our MRI findings and age, an unpaired Mann-Whitney U Test was used. To identify factors associated with our outcomes QuickDASH, pain in rest and pain during rotation, a Spearman's rank correlation coefficient was used for continuous explanatory variables, an unpaired Mann-Whitney U Test for dichotomous explanatory variables, and Kruskal-Wallis test for categorical explanatory variables. A p-value of less than 0.05 was considered statistically significant.

A post-hoc power calculation was performed, using the study sample size and observed effect size.

# RESULTS



In the TFCC repair group there were 44 female and 23 male patients, with a median age of 36 years at time of surgery (IQR 29-48). The dominant hand was affected in 52% of cases and most (94%) were classified as a peripheral TFCC defect on the ulnar side (Palmer 1B). The repair was performed via an arthroscopic (assisted) approach in 58% of cases. A previous or current diagnosis of depression was documented in 22 patients (33%), while a previous or current diagnosis of anxiety was documented in 25 patients (37%). Of these patients, 18 (27%) had a previous or current diagnosis of both depression and anxiety. The demographic and clinical characteristics of the cases are presented in Table 1.

There were more TFCC tears, specifically traumatic tears, in the TFCC repair group than in the control group (both $p<0.001$; Table 2). The rates of PT joint pathology between patients with TFCC repair and control subjects appeared similar (39% versus 37%; $p>0.99$; Figure 1).

**Table 1.** Characteristics of cases (n=67)

| **Explanatory variable** | |
|---|---|
| Age, median (IQR) | 36 (29-48) |
| Sex, n (%) | |
| Male | 23 (34) |
| Female | 44 (66) |
| Manual labour, n (%) | 39 (58) |
| Previous history of anxiety, n (%) | 25 (37) |
| Previous history of depression, n (%) | 22 (33) |
| Dominant side affected, n (%) | 35 (52) |
| Ulnar variance in mm, median (IQR) | 0 (-0.8-1.8) |
| Prior conservative treatment, n (%) | 53 (79) |
| Palmer classification, n (%) | |
| 1B | 63 (94) |
| 1C | 2 (3.0) |
| 1D | 2 (3.0) |
| Type repair, n (%) | |
| Open | 28 (42) |
| Arthroscopic | 39 (58) |

**Table 2.** MRI findings

| | All (n=134) | Cases (n=67) | Controls (n=67) | *P* value |
|---|---|---|---|---|
| Triangular fibrocartilage complex tear | 68 (51) | 54 (81) | 14 (21) | ***<0.001*** [1] |
| Traumatic | 34 (25) | 32 (48) | 2 (3.0) | ***<0.001*** [1] |
| Degenerative | 34 (25) | 22 (33) | 12 (18) | 0.073[1] |
| Pisotriquetral joint pathology, n (%) | 51 (38) | 26 (39) | 25 (37) | >0.99[1] |
| Pisotriquetral joint space narrowing, n (%) | 0 (0) | 0 (0) | 0 (0) | NA |
| Pisotriquetral misalignment, n (%) | 17 (13) | 8 (12) | 9 (13) | >0.99[1] |
| Pisotriquetral bony proliferation, n (%) | 3 (2.2) | 3 (4.5) | 0 (0) | 0.24[1] |
| Pisiform bone marrow edema, n (%) | 5 (3.7) | 5 (7.5) | 0 (0) | 0.058[1] |
| Triquetral bone marrow edema, n (%) | 12 (9.0) | 8 (12) | 4 (6.0) | 0.37[1] |
| Pisiform subchondral cyst, n (%) | 1 (0.75) | 1 (1.5) | 0 (0) | >0.99[1] |
| Triquetral subchondral cyst, n (%) | 10 (7.5) | 7 (10) | 3 (4.5) | 0.33[1] |
| Pisotriquetral joint ganglion, n (%) | 19 (14) | 8 (12) | 11 (16) | 0.62[1] |
| Pisiform fracture, n (%) | 0 (0) | 0 (0) | 0 (0) | NA |
| Hamate fracture, n (%) | 0 (0) | 0 (0) | 0 (0) | NA |
| Distal radioulnar joint degenerative disease, n (%) | 9 (6.7) | 8 (12) | 1 (1.5) | ***0.033*** [1] |
| Extensor carpi ulnaris pathology, n (%) | 34 (25) | 23 (34) | 11 (16) | ***0.028*** [1] |
| Extensor carpi ulnaris tendinopathy, n (%) | 24 (18) | 16 (24) | 8 (12) | 0.12[1] |
| Extensor carpi ulnaris tear, n (%) | 10 (7.5) | 9 (13) | 1 (1.5) | ***0.017*** [1] |
| Extensor carpi ulnaris tenosynovitis, n (%) | 5 (3.7) | 4 (6.0) | 1 (1.5) | 0.37[1] |
| Extensor carpi ulnaris subluxation, n (%) | 5 (3.7) | 4 (6.0) | 1 (1.5) | 0.37[1] |
| Flexor carpi ulnaris pathology, n (%) | 0 (0) | 0 (0) | 0 (0) | NA |
| Flexor carpi ulnaris tendinopathy, n (%) | 0 (0) | 0 (0) | 0 (0) | NA |
| Flexor carpi ulnaris tear, n (%) | 0 (0) | 0 (0) | 0 (0) | NA |
| Flexor carpi ulnaris tenosynovitis, n (%) | 0 (0) | 0 (0) | 0 (0) | NA |
| Ulnocarpal abutment, n (%) | 6 (4.5) | 5 (7.5) | 1 (1.5) | 0.21[1] |
| Ulnar styloid fracture, n (%) | 6 (4.5) | 6 (9.0) | 0 (0) | ***0.028*** [1] |

[1]*Fisher's exact test*

There were significantly more patients with degenerative disease of the DRUJ in the repair group than in the control group (12% versus 1.5%; p=0.033) (Figure 2). There was also significantly more overall ECU pathology (34% versus 16%; p=0.028) including ECU tears in patients with TFCC repair (13% versus 1.5%; p=0.017) (Figure 3). There were also significantly more ulnar styloid fractures in the repair group (9.0% versus 0%; p=0.028) (Figure 4).

Bivariate analysis showed that with increasing age, increasing pathology was seen in the PT joint (p=0.040), greater prevalence of ulnocarpal abutment (p=0.0081) and more degenerative tears (p<0.001) were seen in patients of the TFCC repair group and control subjects (Appendix 1).

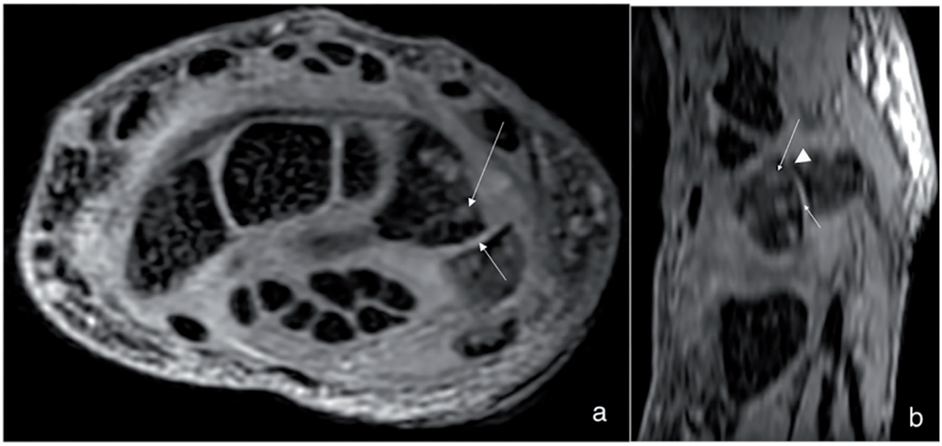


**Figure 1.** In a 52-year-old woman with ulnar-sided wrist pain, 3-dimensional gradient echo axial and reformatted sagittal images show pisotriquetral degenerative changes, including (a + b) subchondral cyst formation (long arrow), loss of joint space (short arrow), (b) osteophyte formation (arrowhead), and (b) bone marrow edema (increased signal of both pisiform and triquetrum compared with other visible carpus).

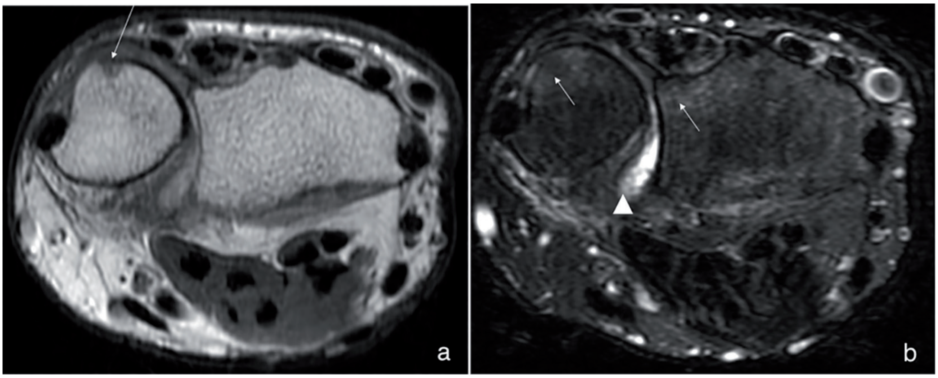


**Figure 2.** A 56-year-old woman with ulnar-sided wrist pain demonstrates DRUJ degenerative changes, including (a) subchondral cystic change (long arrow), (b) subchondral bone marrow edema (short arrows), and (b) DRUJ effusion with synovitis (arrowhead).

We were able to contact 42 of the 67 patients who underwent TFCC repair to ascertain their current function and pain. After a median follow-up duration of 6.7 years (IQR 3.0-9.1) we found a median QuickDASH score of 4.5 (IQR 0-15.9), a median score for pain in rest of 0 (0-2) and a median score for pain during rotation of 1 (0-3). No demographic characteristics or MRI findings were significantly associated with QuickDASH scores or patient-reported pain (Table 3).

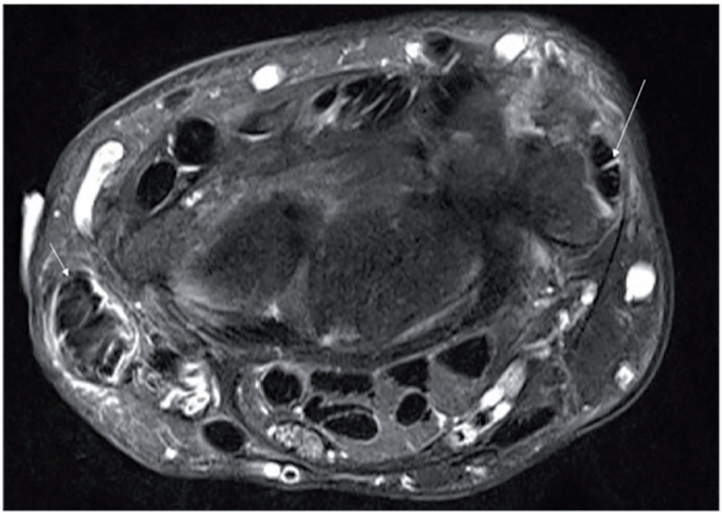

**Figure 3.** In a 52-year-old woman with radial-sided wrist pain, longitudinal split tear of the ECU tendon (long arrow) is noted in addition to De Quervain tenosynovitis (short arrow).

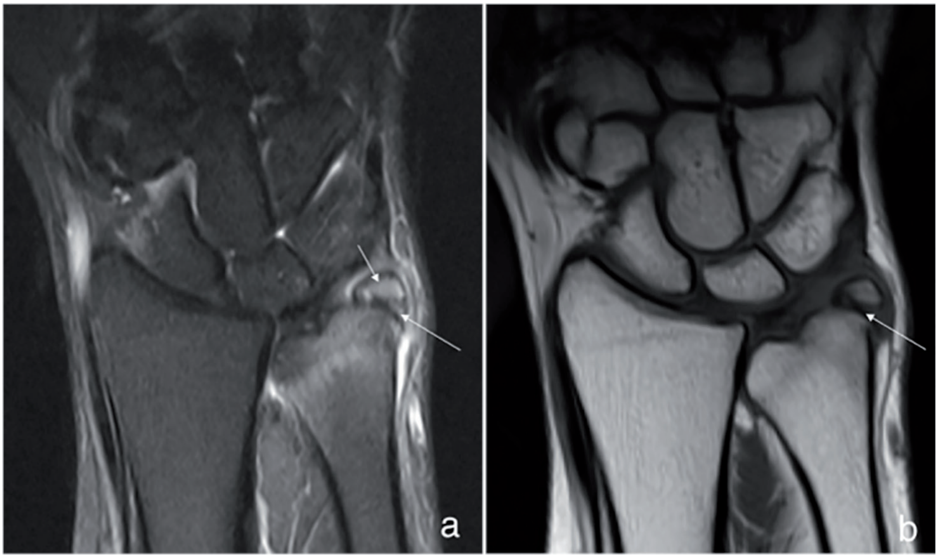


**Figure 4.** A 38-year-old woman with ulnar-sided wrist pain demonstrates (a + b) chronic ulnar styloid fracture with nonunion (long arrows) and (a) resultant degenerative pseudarthrosis and bone marrow edema (short arrow).

**Table 3.** Factors associated with outcomes after TFCC repair (n=42)

| | QuickDASH | Pain rest | Pain rotation |
|---|---|---|---|
| **Patient characteristics** | | | |
| Age | 0.95[1] | 0.93[1] | 0.86[1] |
| Sex | 0.24[2] | 0.48[2] | 0.67[2] |
| Manual labour | 0.82[2] | 0.32[2] | 0.57[2] |
| Previous history of anxiety | 0.30[2] | 0.57[2] | 0.64[2] |
| Previous history of depression | 0.17[2] | 0.68[2] | 0.16[2] |
| Dominant side affected | 0.092[2] | 0.66[2] | 0.14[2] |
| Ulnar variance | 0.43[1] | 0.39[1] | 0.25[1] |
| Prior conservative treatment | 0.88[2] | 0.46[2] | 0.81[2] |
| Palmer classification | 0.23[3] | 0.28[3] | 0.30[3] |
| **Radiographic characteristics** | | | |
| Triangular fibrocartilage complex tear | 0.78[2] | 0.55[2] | 0.60[2] |
| Traumatic | 0.44[2] | 0.82[2] | 0.54[2] |
| Degenerative | 0.30[2] | 0.77[2] | 0.86[2] |
| Pisotriquetral joint pathology | 0.89[2] | 0.44[2] | 0.70[2] |
| Pisotriquetral joint space narrowing | NA | NA | NA |
| Pisotriquetral misalignment | 0.27[2] | 0.084[2] | 0.11[2] |
| Pisotriquetral proliferation | 0.26[2] | 0.39[2] | 0.30[2] |
| Pisiform bone marrow edema | 0.63[2] | 0.85[2] | 0.82[2] |
| Triquetral bone marrow edema | 0.40[2] | 0.53[2] | 0.93[2] |
| Pisiform subchondral cyst | 0.20[2] | 0.37[2] | 0.27[2] |
| Triquetral subchondral cyst | 0.13[2] | 0.88[2] | 0.23[2] |
| Pisotriquetral joint ganglion | 0.24[2] | 0.062[2] | 0.069[2] |
| Pisiform fracture | NA | NA | NA |
| Hamate fracture | NA | NA | NA |
| Distal radioulnar joint degenerative disease | 0.77[2] | 0.35[2] | 0.98[2] |
| Extensor carpi ulnaris pathology | 0.76[2] | 0.57[2] | 0.96[2] |
| Extensor carpi ulnaris tendinopathy | 0.48[2] | 0.23[2] | 0.54[2] |
| Extensor carpi ulnaris tear | 0.74[2] | 0.24[2] | 0.48[2] |
| Extensor carpi ulnaris tenosynovitis | 0.20[2] | 0.28[2] | 0.64[2] |
| Extensor carpi ulnaris subluxation | >0.99[2] | 0.61[2] | 0.76[2] |
| Flexor carpi ulnaris pathology | NA | NA | NA |
| Flexor carpi ulnaris tendinopathy | NA | NA | NA |
| Flexor carpi ulnaris tear | NA | NA | NA |
| Flexor carpi ulnaris tenosynovitis | NA | NA | NA |
| Ulnocarpal abutment | 0.19[2] | 0.57[2] | 0.22[2] |
| Ulnar styloid fracture | 0.82[2] | 0.52[2] | 0.88[2] |

*[1]Spearman's rank correlation coefficient, [2]Mann-Whitney U Test, [3]Kruskal-Wallis test NA= not applicable*

# DISCUSSION

We found significantly higher rates of TFCC tears, DRUJ arthritis, ECU pathology and ulnar styloid fractures on MRI scans in patients who underwent TFCC repair compared to controls with radial-sided symptoms. We found no significant difference in the prevalence of PT joint pathology between patients of the TFCC repair group and patients undergoing MRI for radial-sided symptoms, although the prevalence was unexpectedly high in both groups. This might be explained by the fact that we also considered minor abnormalities of the PT joint as PT joint pathology. To illustrate, PT misalignment accounted for 33% (17/51) of the total PT joint pathology. Overall, our findings suggest that patients who undergo TFCC surgery tend to have other co-existing pathologies with the TFCC tear that could result in ulnar-sided wrist pain, but the presence of these other pathologies was not associated with inferior post-operative patient-rated outcomes.

The prevalence of TFCC tears was significantly higher in the repair group than in the control group, as one would expect based on the study group selection. MRI did not identify all tears in the TFCC repair group. The sensitivity of MRI in our study was found to be 81% (54/67). In literature the reported sensitivity varies widely, between 65% and 94%.[4,5,6,7] Wide variations in practice, such as the resolution of the scanner, the thickness of the sections and the inter-rater variability among radiologists may be the reason for the variation. In 21% of our control group a TFCC tear was found. This reflects the finding that TFCC abnormalities have been found to be common in both symptomatic and asymptomatic individuals.[8] Our study shows that degenerative tears are more common with increasing age ($p<0.001$), which is also in line with previous studies.[8,9]

Determining DRUJ degenerative disease can be difficult on MRI. The presence of osteophytes is a reliable indicator for degenerative joint disease, but determining cartilage thickness and joint asymmetry can be confounded by the position of the wrist and elbow.[10,11,12] Optimal visualisation of cartilage thickness in all parts of the ulnar articular facet is best done in at least 2 of 3 positions including neutral, maximal pronation or maximal supination.[10] As the MRI scans in our study were performed at a number of centres, the position of the patients' wrists was heterogeneous.

In our study cohort, the prevalence of degenerative disease of the DRUJ was significantly higher in patients with TFCC repair than in control subjects. This could reflect consequences after damage to the TFCC itself. Most of our patients with TFCC tears (94%) had Type 1B traumatic ulnar avulsions. Severe tears of the ulnar attachments of the TFCC can cause DRUJ instability, leading to progressive arthritis and dysfunction. A study of MRI scans in patients with foveal tears of the TFCC found an association with subluxation of the ulnar head in pronation.[13,14] A further study found a higher incidence of DRUJ fluid collections in MRI scans of patients with TFCC tears compared to MRI scans of patients without ulnar-sided wrist pain.[15] In that study, a DRUJ fluid collection was presumed to reflect degenerative joint disease but was not correlated with clinical symptoms. They postulated that the mechanism of DRUJ arthritis might be due to concentration of stress in the disc following TFCC tear.[15]

The prevalence of overall ECU pathology, including ECU tears, was significantly greater in patients with TFCC tears. The ECU may be affected by the initial injury causing the TFCC tear. However, ECU tendinopathy has also been reported to have a prevalence of between 4% and 85% in asymptomatic volunteers.[16,17] A study found rates of tendinopathy of 41% in patients with MRIs performed for ulnar-sided wrist pain compared to 10% in MRIs performed for other causes.[18] As one would expect in traumatic TFCC tears, we did not observe a higher rate of findings consistent with ulnocarpal abutment. This would probably be different if we also included patients with degenerative TFCC tears. However, we chose to focus on the group with a traumatic TFCC tear and a subsequent repair procedure, as this ulnocarpal abutment is often conceptualized differently.

The rates of PT joint pathology between patients with TFCC repair and controls were similar. A study of 24 patients with scapho-lunate advanced collapse (SLAC) also found no significant difference in PT joint pathology compared to control MRIs.[19] In keeping with other published studies, we found that increasing age was significantly associated with increased pathology of the PT joint. Cadaveric studies found rates of PT arthritis in 65% of wrists with an average age of 73 years and 91% of wrists with an average age of 75 years, but none in those under 40 years.[20,21]

The limitations of our study are that 1) it is performed retrospectively, 2) the MRI scans were heterogeneous as they were performed at a number of centres with different protocols, 3) we were only able to follow up 63% of the patients who underwent TFCC repair and 4) we did not perform a clinical examination on follow up. However, for patients with ongoing ulnar-sided wrist pain following TFCC repair, further clinical assessment will be needed to see if their pain correlates with clinical examination findings. We had a sample of convenience and did not have adequate power to demonstrate "no difference"; overall, we had (48%) power to establish no difference between a history of anxiety and QuickDASH and between PT ganglion and pain at rest.

In conclusion, we observed higher rates of DRUJ arthritis and ECU pathology in patients with TFCC tears undergoing repair compared to age- and sex-matched controls. This may be due the damage to the TFCC itself altering relationships of the DRUJ and the ECU subsheath, or it may reflect various pathologies that cause ulnar-sided wrist pain and drive patients towards surgery.

# REFERENCES

1. Watanabe A, Souza F, Vezeridis PS, et al. Ulnar-sided wrist pain. II. Clinical imaging and treatment. Skeletal Radiol 2010;39(9):837-857
2. Palmer AK. Triangular fibrocartilage complex lesions: a classification. J Hand Surg Am 1989;14(4):594-606
3. Steyers C, Blair W. Measuring ulnar variance: a comparison of techniques. J Hand Surg Am 1989;14(4):607-612
4. Petsatodis E, Pilavaki M, Kalogera A, et al. Comparison between conventional MRI and MR arthrography in the diagnosis of triangular fibrocartilage tears and correlation with arthroscopic findings. Injury 2019;50(8):1464-1469
5. Boer BC, Vestering M, van Raak SM, et al. MR arthrography is slightly more accurate than conventional MRI in detecting TFCC lesions of the wrist. Eur J Orthop Surg Traumatol 2018;28(8):1549-1553
6. Smith TO, Drew B, Toms AP, et al. Diagnostic accuracy of magnetic resonance imaging and magnetic resonance arthrography for triangular fibrocartilaginous complex injury: a systematic review and meta-analysis. J Bone Joint Surg Am 2012;94(9):824-832
7. Cherian BS, Bhat AK, Rajagopal KV, et al. Comparison of MRI & direct MR arthrography with arthroscopy in diagnosing ligament injuries of wrist. J Orthop 2019;19:203-207
8. Bendre HH, Oflazoglu K, van Leeuwen WF, et al. The prevalence of triangular fibrocartilage complex signal abnormalities on magnetic resonance imaging relative to clinical suspicion of pathology. J Hand Surg Am 2018; 43(9):819-826
9. Chan JJ, Teunis T, Ring D. Prevalence of triangular fibrocartilage complex abnormalities regardless of symptoms rise with age: systematic review and pooled analysis. Clin Orthop Relat Res 2014;472(12):3987-3994
10. Buck FM, Nico MA, Gheno R, et al. Morphology of the distal radioulnar joint: cadaveric study with MRI and MR arthrography with the forearm in neutral position, pronation, and supination. AJR Am J Roentgenol 2010;194(2):W202-207
11. Gulati A, Wadhwa V, Ashikyan O, et al. Current perspectives in conventional and advanced imaging of the distal radioulnar joint dysfunction: review for the musculoskeletal radiologist. Skeletal Radiol 2019;48(3):331-348
12. Fu E, Li G, Souer JS, et al. Elbow position affects distal radioulnar joint kinematics. J Hand Surg Am 2009;34(7):1261-1268
13. Amrami KK, Moran SL, Berger RA, et al. Imaging the distal radioulnar joint. Hand Clin 2010;26(4):467-475
14. Ehman EC, Hayes ML, Berger RA, Felmlee JP, Amrami KK. Subluxation of the distal radioulnar joint as a predictor of foveal triangular fibrocartilage complex tears. J Hand Surg Am 2011;36(11):1780-1784
15. Santo S, Omokawa S, Iida A, et al. Magnetic resonance imaging analysis of the extensor carpi ulnaris tendon and distal radioulnar joint in triangular fibrocartilage complex tears. J Orthop Sci 2018;23(6):953-958
16. Parodi M, Silverstri E, Garlaschi G, et al. How normal are the hands of normal controls? A study with dedicated magnetic resonance imaging. Clin Exp Rheumatol 2006;24(2):134-141
17. Timins ME, O'Connell SE, Erickson SJ, et al. MR imaging of the wrist: normal findings that may simulate disease. Radiographics 1996;16:987-995
18. Kuntz MT, Janssen SJ, Ring D. Incidental signal changes in the extensor carpi ulnaris on MRI. Hand (N Y) 2015;10(4):750-755

19. Rancy SK, Trehan SK, Li AE, et al. The prevalence of pisotriquetral arthritis in the setting of scapholunate advanced collapse. J Wrist Surg 2016 ;5(4):261-264
20. Yamaguchi S, Viegas SF, Patterson RM. Anatomic study of the pisotriquetral joint: ligament anatomy and cartilagenous change. J Hand Surg Am 1998;23(4):600-606
21. Theumann NH, Pfirrmann CW, Chung CB, et al. Pisotriquetral joint: assessment with MR imaging and MR arthrography. Radiology 2002;222(3):763-770

# APPENDICES

**Appendix 1.** Association between age and MRI findings

| | Age |
|---|---|
| Triangular fibrocartilage complex tear | 0.093[1] |
| Traumatic | 0.15[1] |
| Degenerative | <0.001[1] |
| Pisotriquetral joint pathology | 0.040[1] |
| Pisotriquetral joint space narrowing | NA |
| Pisotriquetral misalignment | 0.30[1] |
| Pisotriquetral proliferation | 0.017[1] |
| Pisiform bone marrow edema | 0.039[1] |
| Triquetral bone marrow edema | 0.075[1] |
| Pisiform subchondral cyst | 0.24[1] |
| Triquetral subchondral cyst | 0.039[1] |
| Pisotriquetral joint ganglion | 0.78[1] |
| Pisiform fracture | NA |
| Hamate fracture | NA |
| Distal radioulnar joint degenerative disease | 0.93[1] |
| Extensor carpi ulnaris pathology | 0.38[1] |
| Extensor carpi ulnaris tendinopathy | 0.77[1] |
| Extensor carpi ulnaris tear | 0.25[1] |
| Extensor carpi ulnaris tenosynovitis | 0.70[1] |
| Extensor carpi ulnaris subluxation | 0.56[1] |
| Flexor carpi ulnaris pathology | NA |
| Flexor carpi ulnaris tendinopathy | NA |
| Flexor carpi ulnaris tear | NA |
| Flexor carpi ulnaris tenosynovitis | NA |
| Ulnocarpal abutment | 0.0081[1] |
| Ulnar styloid fracture | 0.25[1] |

[1]*Mann-Whitney U Test*

# Chapter 5

## A comparative study between Darrach and Sauvé-Kapandji procedures for post-traumatic distal radioulnar joint dysfunction

***Verhiel SHWL**, Özkan S, Ritt MJPF, Chen NC, Eberlin KR*

*Hand (N Y). 2019 Jun 27; Online ahead of print*

# ABSTRACT

**Background** There are various treatments for post-traumatic DRUJ dysfunction. The present study aimed to assess differences in long-term patient-reported outcomes on physical function, pain and satisfaction, between the Darrach and Sauvé-Kapandji procedure. Secondary aims were to describe the radiographic outcomes and to assess the difference in rate and type of complications and reoperations between these two procedures.

**Methods** We retrospectively analyzed 85 patients who had a post-traumatic DRUJ derangement.and had been treated by either a Darrach (n=57) or Sauvé-Kapandji procedure (n=28). Fifty-two patients (61%) completed patient rated outcomes surveys at a median of 8.4 years after their procedure. Radiographic measurements consisted of ulnar distance, radioulnar distance and ulnar gap (only in Sauvé-Kapandji group).

**Results** There were no significant differences in PROMIS UE-PF score, pain score, satisfaction score, complications and reoperations between patients who had a Darrach procedure or a Sauvé-Kapandji procedure. Seventeen patients (30%) in the Darrach group experienced a complication and 14 patients (50%) in the Sauvé-Kapandji group experienced a complication ($P$=0.09). The most common complication was instability of the ulnar stump (n=10), followed by symptoms of the dorsal sensory branch of the ulnar nerve (n=8). Patients who underwent a Sauvé-Kapandji procedure had more reoperations for excision of heterotopic ossification.

**Conclusions** Darrach and Sauvé-Kapandji procedure show comparable long-term patient reported outcomes in treatment of post-traumatic DRUJ dysfunction. Complication and reoperation rate are relatively high, with non-significant differences between the two procedures.

# INTRODUCTION

Salvage surgery for disorders of the DRUJ varies widely, with a number of procedures available to the reconstructive surgeon.[1,2] Resection of the ulnar head was first described by Malgaine in 1855[3] and later popularized by Darrach in 1912,[4–6] for whom this procedure has received its eponymous name. However, long-term complications include instability of the proximal ulna and loss of grip strength.[7,8]

The Sauvé-Kapandji procedure consists of fusion across the distal radioulnar joint and excision of a segment of the distal ulna, which theoretically preserves ulnar support of the carpus, the distal radioulnar ligaments and ulnocarpal ligaments.[9,10] Retaining the ulnar head may allow for more normal transmission of force through the wrist, which may make this procedure preferable in patients with 'high-demand' wrists and specifically after post-traumatic DRUJ derangements.

Comparative studies with large sample sizes between these different techniques are lacking and confounded by heterogeneous cohorts that include patients with both osteoarthritis and inflammatory arthritis.[8,11,12] The aim of the present study is to assess differences in long-term patient-reported outcomes on physical function, pain, and satisfaction between the Darrach and Sauvé-Kapandji procedures for post-traumatic indications. Our secondary aims are to describe the radiographic outcomes and to assess the difference in rate and type of complications and reoperations between these two procedures.

# METHODS

Patients were identified by searching our multi-institutional database using the following CPT codes: 25240, 25830, 25337, 25150, 25676, 25360, 25332. All patients were treated at one of our three regional hospitals: two level I trauma centers and one associated community hospital between January 2003 and December 2015.

The medical records of 567 patients aged 18 or older were assessed for inclusion. Patients were first categorized based on their diagnosis (post-traumatic, degenerative, inflammatory or other) and type of procedure (eg. Darrach, Sauvé-Kapandji or Bower's hemi-resection arthroplasty). After review of CPT codes and operative notes, our initial study cohort consisted of 106 patients who had undergone either a Darrach or a Sauvé-Kapandji procedure and had a post-traumatic DRUJ derangement (We did not include the 9 patients who underwent a Bower's procedure for a post-traumatic DRUJ derangement.) We excluded seven patients who passed away, five who moved away, two who had their initial surgery elsewhere, and seven who did not have any follow-up at our institutions after their surgery. Our final cohort consisted of 85 patients.

Patients underwent operation in cases of an unsalvageable DRUJ after trauma. Specific indications to undergo surgery were non- or malunion of the radius or ulna, DRUJ osteoarthritis, DRUJ incongruity without signs of osteoarthritis and DRUJ instability. The selection of a specific procedure was at the surgeon's discretion.

## Outcome measurements

Patients were invited by letter to participate in this study. Two patients (2.4%) refused to participate, and 31 (36%) did not respond. A total of 34 Darrach and 18 Sauvé-Kapandji patients (61%) completed patient-rated outcomes surveys online or over the phone. The median follow-up was 8.4 years after the index procedure (IQR 3.4-12 years).

The patients' disability in activities of daily living was assessed using the PROMIS UE-PF questionnaire. Higher scores on the PROMIS UE-PF represent greater levels of upper extremity function; a T-score of 50 represents the norm in the United States population, and each difference of 10 points from this norm represents a standard deviation from the norm.[13]

Subjective outcomes were assessed using the NRS. Patients rated their average pain during the last month and overall satisfaction with the outcome of the procedure. For pain-assessment, the scale ranged from '0' representing "no pain" to '10' representing "worst pain imaginable". For assessment of satisfaction, the scale ranged from '0' representing "not satisfied at all" to '10' representing "couldn't be more satisfied".

Radiographic assessment was based on the last available post-operative wrist radiographs. In case of reoperation, the last radiograph before reoperation was selected. A total of 78 radiographs were available for review, they were obtained at an average of 14 ± 3.2 months after the procedure. The ulnar distance (distance from the articular surface of the radius to the proximal stump of the ulna) and radioulnar distance (width of interosseous space between the radius and the ulna at the proximal stump of the ulna) were measured. The ulnar gap (the gap in the ulna at the pseudoarthrosis) was measured for the patients in the Sauvé-Kapandji group (Figure 1).[16]

Medical records of patients were reviewed and assessed for complications, rate of unplanned reoperations and type of reoperations.

## Statistical analysis

We described discrete data using frequencies and percentages, normally distributed continuous data through means and SD, and non-normally distributed continuous data through medians and IQR.

Bivariate analysis was performed using the Fisher Exact test for dichotomous and categorical variables, and a Student *t*-test for continuous variables. In case of non-normal distribution of continuous variables, we used the Mann-Whitney U test. A *P*-value of less than 0.05 was considered statistically significant.

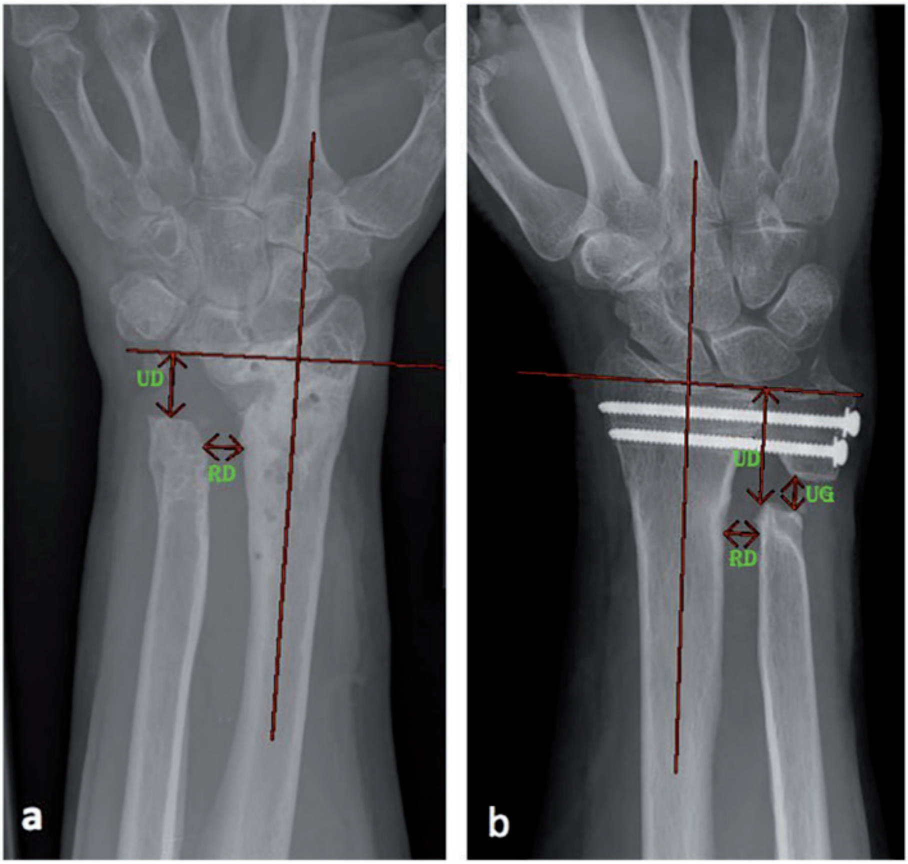


**Figure 1.** Measurement on postero-anterior radiograph in (a) Darrach and (b) Sauvé-Kapandji.
Note. UD = ulnar distance; RD = radioulnar distance; UG = ulnar gap.

Post-hoc power analysis showed that the study has sufficient power (80%) to demonstrate a difference of at least 7.3 between the mean PROMIS UE-PF scores, with an effect size of 0.83 in a cohort of 34 in one group and 18 in the other group.

# RESULTS

## Patient characteristics

Fifty-seven patients (67%) underwent a Darrach procedure and 28 patients (33%) underwent a Sauvé-Kapandji procedure performed for a post-traumatic indication (Table 1). The majority of the patients were female (n=52; 61%) and the median age was 52 years (IQR 40-61 years).

Sixty-seven patients (79%) of the 85 patients sustained a previous distal radius fracture. Of these 67 patients, 13 (19%) had concomitant fractures in the ipsilateral extremity. Other

**Table 1.** Patient characteristics

| Patient characteristics | All (n=85) | Procedure: Darrach (n=57) | Procedure: Sauvé-Kapandji (n=28) | *P* value |
|---|---|---|---|---|
| **Demographics** | | | | |
| Age in years, median (IQR) | 52 (40-61) | 53 (46-61) | 48 (27-59) | 0.055[1] |
| Sex, n (%) | | | | ***0.005[2]*** |
| Male | 33 (39) | 16 (28) | 17 (61) | |
| Female | 52 (61) | 41 (72) | 11 (39) | |
| BMI in kg/m², mean ± SD* | 30 ± 6.9 | 29 ± 6.3 | 32 ± 7.8 | 0.074[3] |
| Diabetes, n(%)** | 9 (12) | 5 (9.6) | 4 (16) | 0.46[2] |
| Tobacco abuse reported in chart, n (%)** | 10 (13) | 7 (13) | 3 (12) | >0.99[2] |
| Occupation, n (%)** | | | | 0.14[2] |
| Heavy manual laborer | 6 (7.1) | 2 (3.5) | 4 (14) | |
| Other | 72 (85) | 51 (89) | 21 (75) | |
| **Condition related** | | | | |
| Dominant side affected, n (%)** | 40 (53) | 24 (50) | 16 (59) | 0.48[2] |
| Type trauma, n (%) | | | | ***0.027[2]*** |
| Distal radius fracture | 67 (79) | 49 (86) | 18 (64) | |
| Other | 18 (21) | 8 (14) | 10 (36) | |
| Indication surgery, n (%) | | | | ***0.005[2]*** |
| Non- or malunion of radius or ulna | 27 (32) | 23 (40) | 4 (14) | |
| DRUJ osteoarthritis | 29 (34) | 13 (23) | 16 (57) | |
| DRUJ incongruity without signs of osteoarthritis | 23 (27) | 18 (32) | 5 (18) | |
| DRUJ instability | 6 (7.0) | 3 (5.3) | 3 (11) | |
| **Treatment related** | | | | |
| Previous surgeries, n (%) | 61 (72) | 40 (70) | 21 (75) | 0.80[2] |
| Tenodesis stabilization during index procedure, n (%) | 29 (34) | 13 (23) | 16 (57) | ***0.003[2]*** |
| Additional procedure during index procedure ipsilateral wrist, n (%) | | | | 0.51[2] |
| Wrist fusion | 7 (8.2) | 5 (8.8) | 2 (7.1) | |
| Corrective osteotomy radius | 5 (5.9) | 5 (8.8) | 0 (0) | |
| Other | 3 (3.5) | 2 (3.5) | 1 (3.6) | |

*[1]Mann-Whitney U Test, [2]Fisher's exact test, [3]Student t-test with equal variances*
**Not reported in 22 patients, **= not reported in all medical charts*

injuries that led to a subsequent Darrach or Sauvé-Kapandji procedure included ulnar fracture (n=7), radial head/shaft fracture (n=4), DRUJ dislocation (n=4), perilunate dislocation (n=1) or TFCC tear (n=5). Sixty-one of the 85 patients had undergone a previous operation (72%): 25 patients had one previous operation and 36 had two or more operations. Prior surgery included ORIF (n=30), EXFIX (n=9), USO (n=5) and corrective osteotomy (n=4). The Darrach procedure was performed more commonly in patients who had a prior distal radius fracture

(49 out of 67 vs 8 out of 18) and were undergoing surgery for a nonunion or malunion of the radius or ulna (23 out of 27 patients vs. 34 out of 58 patients). Patients underwent their Darrach or Sauvé-Kapandji procedure at a median of 14 months (IQR 6.8-29 months) after their initial injury.

Eleven out of 57 (19%) patients in the Darrach group concomitantly underwent a stabilization of the ulnar stump with an ECU tendon slip, one with a FCU tendon slip, and one with a combined ECU/FCU tendon slip. Thirteen out of 28 patients (46%) in the Sauvé-Kapandji group concomitantly underwent stabilization of the ulnar stump with an ECU tendon slip, two with a FCU tendon slip, and one with a combined ECU/FCU tendon slip. Seven patients underwent concomitant wrist fusions to treat a painful or unstable wrist joint with advanced destruction due to osteoarthritis, rheumatoid arthritis or post-traumatic arthritis. Four patients underwent a total wrist arthrodesis, the other 3 underwent a radioscapholunate arthrodesis. One patient underwent a Darrach procedure with simultaneous arthroscopic debridement in the ulnocarpal joint, one patient underwent a Darrach procedure with simultaneous proximal row carpectomy and one patient underwent a Sauvé-Kapandji procedure with simultaneous LT fusion.



## Outcomes

At final follow-up, there were no significant differences in PROMIS UE-PF scores, pain, or satisfaction between patients who had a Darrach procedure or a Sauvé-Kapandji procedure. The PROMIS UE-PF score was 39 for both groups (P=0.91). The median score for pain was 2.5 for both groups (P=0.76), and the satisfaction score that patients assigned to the overall outcome after their surgery had a median of 9.5 (IQR 8-10) for both groups (P=0. 89).

The mean post-operative ulnar distance was 18 ± 7.3mm after a Darrach procedure and 33 ± 6.3mm after a Sauvé-Kapandji procedure. The median radioulnar distance was 5.5 mm (IQR 2.6-8.7 mm) in the Darrach group and 8 (IQR 7.2-11 mm) in the Sauvé-Kapandji group. The mean ulnar gap after a Sauvé-Kapandji procedure was 10 ± 3.5 mm.

A total of 38 complications occurred among the 85 patients (44.7%; Table 2). Seventeen patients (30%) in the Darrach group experienced a complication and 14 patients (50%) in the Sauvé-Kapandji group experienced a complication (P=0.09). The most common complication was instability of the ulnar stump (14% in Darrach group vs 7.1% in Sauvé-Kapandji group). Instability of the ulnar stump was defined as instability reported by the patient and confirmed by clinical assessment. Heterotopic ossification, which was symptomatic and radiographically confirmed, was more common after a Sauvé-Kapandji procedure (P=0.014).

Twenty patients (24%) underwent an unplanned reoperation (Table 3); the rate of reoperation did not differ significantly between the two groups (18% in Darrach group vs 36% in Sauvé-Kapandji group; P=0.10). The median time from either Darrach or Sauvé-Kapandji procedure to the first unplanned operation was 9.1 months (IQR 4.8-20 months). Most of the procedures performed were hardware removal (n=4). For hardware removal, we considered

**Table 2.** Complications

| Type complication, n (%) | All (n=85) | Procedure | | *P* value |
|---|---|---|---|---|
| | | Darrach (n=57) | Sauvé-Kapandji (n=28) | |
| Instability | 10 (12) | 8 (14) | 2 (7.1) | 0.49[1] |
| Symptoms dorsal sensory branch of the ulnar nerve | 8 (9.4) | 5 (8.8) | 3 (11) | >0.99[1] |
| Heterotopic ossification | 6 (7.1) | 1 (1.8) | 5 (18) | ***0.014[1]*** |
| Hardware irritation | 4 (4.7) | n.a. | 4 (14) | n.a. |
| Radioulnar convergence | 4 (4.7) | 4 (7.0) | 0 (0) | 0.30[1] |
| Extensor tendon rupture/adhesion | 3 (3.5) | 3 (5.3) | 0 (0) | 0.55[1] |
| Non-union pseudarthrosis | 2 (2.4) | n.a. | 2 (7.1) | n.a. |
| Wrist infection | 1 (1.2) | 1 (1.8) | 0 (0) | >0.99[1] |

*[1] Fisher's exact test, n.a.= not applicable*

**Table 3.** Types of unplanned reoperations

| Reoperation procedure, n (%) | All (n=85) | Procedure | | *P* value |
|---|---|---|---|---|
| | | Darrach (n=57) | Sauvé-Kapandji (n=28) | |
| Hardware removal | 4 (4.7) | n.a. | 4 (14) | n.a. |
| Excision heterotopic ossification | 3 (3.5) | 0 (0) | 3 (11) | ***0.033*** |
| Total radioulnar arthroplasty (Aptis Prosthesis) | 3 (3.5) | 3 (5.3) | 0 (0) | 0.55 |
| Revision Darrach/ Sauvé-Kapandji | 2 (2.4) | 1 (1.8) | 1 (3.6) | >0.99[1] |
| Radiolunate- and radioscaphoid fusion | 2 (2.4) | 1 (1.8) | 1 (3.6) | >0.99[1] |
| Total wrist arthrodesis | 2 (2.4) | 1 (1.8) | 1 (3.6) | >0.99[1] |
| Other | | | | |
| Wrist irrigation | 1 (1.2) | 1 (1.8) | 0 (0) | >0.99[1] |
| Tendon repair | 1 (1.2) | 1 (1.8) | 0 (0) | >0.99[1] |
| Corrective osteotomy of radius | 1. (1.2) | 1 (1.8) | 0 (0) | >0.99[1] |
| Darrach | 1 (1.2) | n.a. | 1 (3.6) | n.a. |

*[1] Fisher's exact test, n.a.= not applicable*

only removal of DRUJ screws after Sauvé-Kapandji procedure, not removal of wrist arthrodesis plate (n=1) or radioscapholunate arthrodesis hardware (n=3). Five percent of the reoperations in the Darrach group (n=3) later underwent a radioulnar arthroplasty, no patients in the Sauvé-Kapandji group later underwent a radioulnar arthroplasty. Three patients underwent excision of heterotopic ossification after a Sauvé-Kapandji procedure (Figure 2). Two patients underwent a total wrist arthrodesis: one patient after a Darrach procedure and one after a Sauvé-Kapandji procedure (Figure 3).

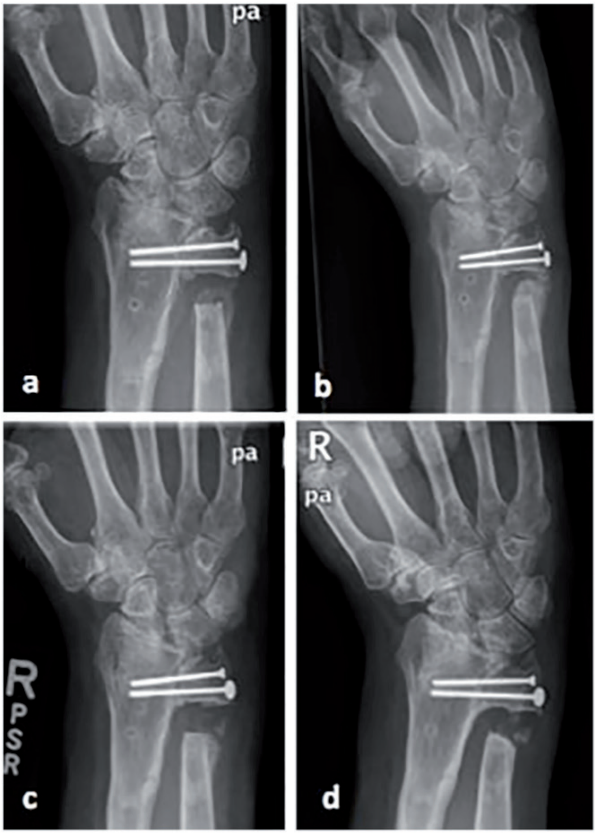


**Figure 2.** Radiographs of a patient who underwent excision of heterotopic ossification as a reoperation after a Sauvé-Kapandji procedure.

Note. (a) One month after index procedure (Sauvé-Kapandji), (b) 3 months after index procedure and 1 month prior to excision heterotopic ossification, (c) 1 month after excision heterotopic ossification, and (d) last follow-up, 16 months after excision heterotopic ossification.

Four patients (4.7%) underwent multiple subsequent operations; two patients (2.4%) underwent two reoperations, one patient (1.2%) underwent three reoperations, and one patient (1.2%) underwent six reoperations (Appendix 1; Figure 4).

# DISCUSSION

In this study, we compared long-term patient-reported outcomes and the rate of complications and unplanned reoperations between patients who underwent a Darrach or Sauvé-Kapandji procedure for post-traumatic dysfunction of the DRUJ. We also described radiographic outcomes after each of these procedures. We found similar patient-rated outcomes and comparable, but high rates for reoperation and complications for these two procedures. Patients who

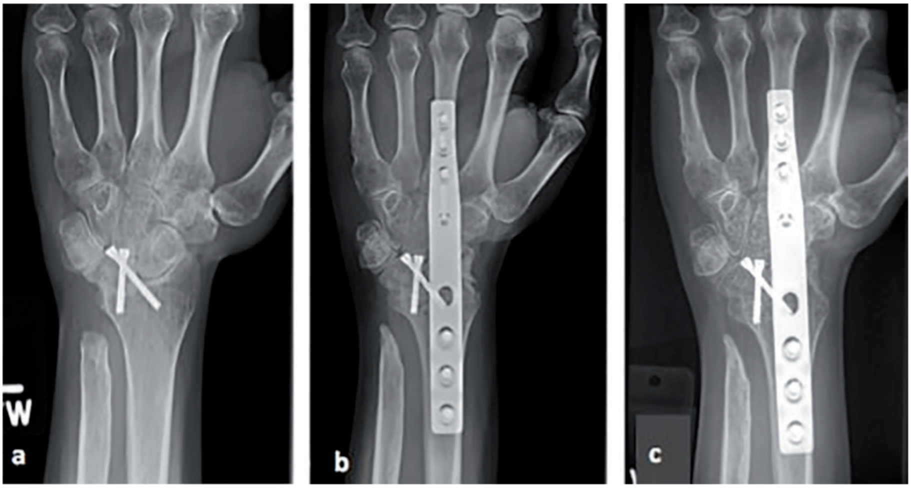


**Figure 3.** Radiographs of a patient who underwent a total wrist arthrodesis as a reoperation after a Darrach procedure.
Note. (a) Three months after index procedure (Darrach), (b) 2 weeks after total wrist arthrodesis, and (c) last follow-up, 1 year after total wrist arthrodesis.

undergo a Sauvé-Kapandji procedure have a higher risk of heterotopic ossification, which may lead to reoperation with removal of the ossification.

There are limitations to interpretation of our data. First, we used CPT codes to identify patients who underwent these procedures. There is no specific CPT code for either of these two procedures; however, we believe that we captured the majority of the patients by using seven different CPT codes and reviewing each chart manually.  Second, complications may be under-reported in retrospective studies as patients could have been treated for complications in a different hospital not used in our database search. We found that 14 of our included patients switched care from one institution to another institution within our system (and therefore are captured by our data). Third, radiographs were not standardized, and there was variation with radiographic technique that may affect measurements. In this setting, the best possible view was utilized for radiographic evaluation. Most patients had radiographs in a resting position and we were not able to evaluate for dynamic convergence.

This study includes a follow-up of 8.4 years, which is one of its strengths. Only one study comparing the Darrach to the Sauvé-Kapandji procedure had longer follow-up (mean 10 years).[8] However, their study population was different, including patients with primary and secondary DRUJ osteoarthritis.[8] We studied a relatively large cohort of patients that underwent these two procedures. In addition, these 85 procedures were performed among 10 surgeons, which makes this data more generalizable than a case series performed by one or two surgeons. Eight surgeons performed both procedures in an equal proportion, one surgeon performed more Darrach than Sauvé-Kapandji procedures (n=30 vs n=4) and one surgeon only performed the Sauvé-Kapandji procedure (n=5). Furthermore, we only included patients

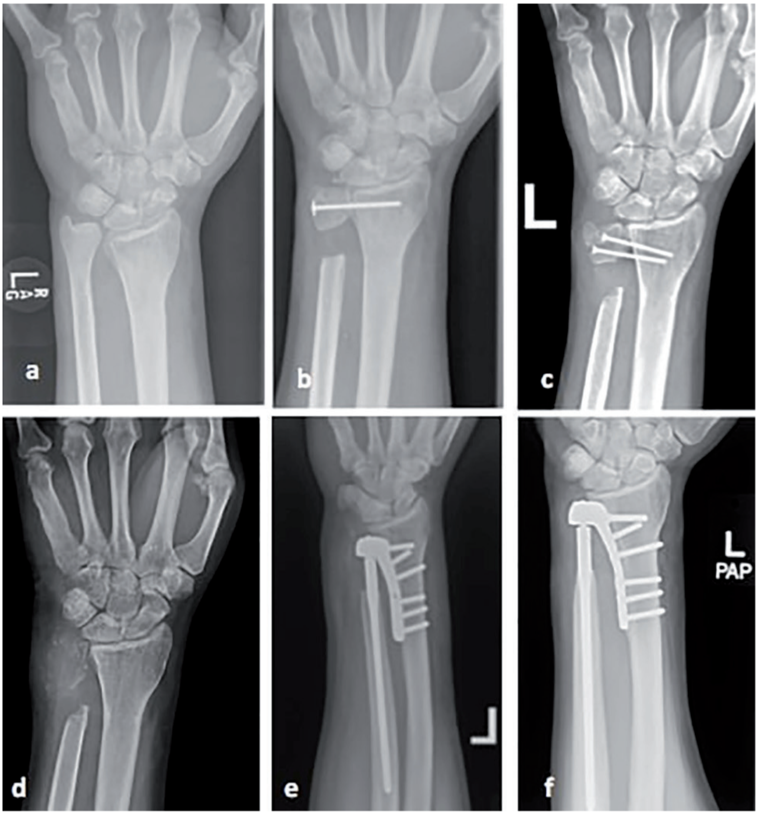


**Figure 4.** Radiographs of patient who underwent 6 reoperations.

Note. (a) Pre-operative status, (b) 4 months after index procedure (Sauvé-Kapandji), (c) 1 month after third reoperation (refusion DRUJ), (d) 10 days after fifth reoperation (Darrach procedure), (e) 10 days after sixth reoperation (DRUJ arthroplasty), and (f) last follow-up, 5 years after DRUJ arthroplasty.

with a post-traumatic DRUJ derangement (either non- or malunion of radius or ulna, DRUJ osteoarthritis, DRUJ incongruity without signs of osteoarthritis or DRUJ instability), as we believe that patients who undergo these procedures for other indications are more heterogeneous and may have different post-operative courses. We believe that this helps make our data more homogeneous compared to prior studies that included indications for inflammatory arthritis or osteoarthritis;[8,14–17] however, our findings are only applicable to these procedures in a post-traumatic setting.

In this study, we found comparable long-term patient-reported outcomes of patients who underwent a Darrach or Sauvé-Kapandji procedure. For both groups, we found a mean PROMIS UE-PF score of 39, a median score for pain of 2.5, and a median score for satisfaction of 9.5. However, it is important to recognize that these scores reflect the entire post-traumatic injury course. The majority of original injuries in the Darrach cohort were distal radius fractures. Of these, 15 were malunions and 7 patients previously underwent a corrective osteotomy of the radius. Five patients underwent simultaneous corrective osteotomy with the Darrach procedure. Conversely, the Sauvé-Kapandji group consisted of more patients with DRUJ arthritis; 16 out of 28 patients (57%) versus 13 out of 57 patients (23%). The groups are otherwise similar: there were 5 wrist fusions in the Darrach cohort (8.8%) and 2 fusions in the Sauvé-Kapandji cohort (7.1%).

The Darrach procedure has traditionally been recommended for older patients and discouraged in younger, more active patients.[2,8,12,18–20] Additionally, some surgeons caution that the Sauvé-Kapandji procedure may be problematic in older patients because of difficulty in achieving union and potential soft tissue problems.[2,11,21] In our study, patients who underwent a Sauvé-Kapandji procedure were slightly younger (mean of 48 years) than patients who underwent a Darrach procedure (mean of 53 years), ($P$ =0.055). It is likely that our Sauvé-Kapandji cohort was younger than seen in other reports because of our focus on post-traumatic conditions.

Five previous studies compared the Darrach to the Sauvé-Kapandji procedure in variable study populations.[8,12,14,15,17] Two of these studies focused on patients with post-traumatic DRUJ dysfunction.[8,12] Minami et al. looked at patients with osteoarthritis, of whom 23 had secondary osteoarthritis as a result of distal radius fracture malunions.[8] After an average follow-up of 10 years the authors found the Darrach procedure to be inferior to the Sauvé-Kapandji procedure in terms of grip strength and return to their original job. More complications occurred after the Darrach procedure. They concluded that the Darrach procedure is better indicated for severe osteoarthritic changes of the DRUJ in elderly patients.[8] George et al. evaluated the two procedures after distal radius fractures in 48 patients less than 50 years old.[12] The Darrach and the Sauvé-Kapandji procedure yielded comparable and unpredictable results with respect to both subjective and objective parameters.[12] The mean DASH scores were 23 in the Darrach group (range, 4-61) and 23 in the Sauvé-Kapandji group (range 0-60).[12]

We found a complication rate of 30% after the Darrach procedure and a rate of 50% after the Sauvé-Kapandji procedure ($P$=0.09). Prior studies report varying complication rates.[8,12,14,16,20] George et al. reported relatively frequent complications after both the Darrach (33%) and the Sauvé-Kapandji (50%) including hardware irritation and symptoms of the dorsal sensory branch of the ulnar nerve,[12] which is similar to our study. On the contrary, Nakamura et al. reported an uneventful post-operative course for all 15 patients after a Sauvé-Kapandji procedure.[16] In our study, symptomatic ulnar stump instability was the most common complication and occurred in 14% of the patients after the Darrach and in 7.1% of the patients after the Sauvé-Kapandji procedure. These rates are lower than previously reported by other studies, which show rates of instability up to 60% after Darrach and up to 40% after Sauvé-Kapandji procedures.[8,12,20] We believe that these differences are best explained because the ulnar stump was frequently stabilized in our study cohort: 19% patients in the Darrach group and 46% in the Sauvé-Kapandji group tendon stabilization of the distal ulna with the ECU, FCU, or both.

The reoperation rate in our study was 18% after the Darrach and 36% after the Sauvé-Kapandji procedures. In prior studies, reoperation rates after the Darrach procedure range from 0% to 22%;[12,22–24] Hernekamp et al. reported a 3% (n=1) reoperation rate among 37 patients with chronic degenerative or post-traumatic osteoarthritis, the patient underwent revision surgery on the ulnar stump due to persistent pain.[24] Grawe et al. reported a 22% (n=6) reoperation rate among 27 patients with post-traumatic DRUJ dysfunction.[23] Five patients underwent a radiocarpal arthrodesis and 1 underwent a DRUJ arthroplasty for continued symptoms of pain with activity. For the Sauvé-Kapandji procedure, George et al. reported a reoperation rate of 17% (n=2) in patients less than 50 years old.[12] One of the patients underwent screw removal; the other experienced a painful click and was revised with a Darrach procedure. Of our Sauvé-Kapandji patients, four (14%) underwent screw removal and three patients (11%) underwent excision of heterotopic ossification. Prior studies rarely report heterotopic ossification after Sauvé-Kapandji procedure.[14,20] In our cohort, heterotopic ossification occurred in 18% of the patients after the Sauvé-Kapandji compared to 1.8% of the patients after the Darrach procedure ($P$= 0.014). As one attempts to fuse the ulnar head to the distal radius, prior trauma and preparation of the DRUJ for fusion may create local stimulus for heterotopic ossification. Furthermore, ossification may be more likely to occur if the periosteum of the ulna is not completely removed together with the ulnar fragment.

Nakamura et al. reported that the post-operative radioulnar distance after their Sauvé-Kapandji procedures averaged 53% of the pre-operative radioulnar distance at rest, with an average post-operative distance of 8 ± 3mm.[16] This is slightly more than the 5.5 mm (IQR 2.6-8.7 mm) that we found in our study. Previous studies suggest that ulnar impingement is not associated with clinical reports of pain, and that the ulnar and radioulnar distance in the Sauvé-Kapandji procedure do not affect functional results significantly.[16,20,23,25]

In a post-traumatic setting, the Darrach and Sauvé-Kapandji procedures appear to yield similar patient-rated outcomes. In both groups, complications are somewhat common; however, patients who undergo Sauvé-Kapandji have a higher risk of heterotopic ossification that may result in reoperation. In our cohort, stabilization appeared to protect patients from reoperation for convergence.

# REFERENCES


1. Bowers WH. Distal radioulnar joint arthroplasty: the hemiresection-interposition technique. J Hand Surg Am. 1985;10(2):169-178.
2. Lichtman DM, Ganocy TK, Kim DC. The indications for and techniques and outcomes of ablative procedures of the distal ulna. The Darrach resection, hemiresection, matched resection, and Sauve-Kapandji procedure. Hand Clin. 1998;14(2):265-277.
3. Malgaine J, Brailliere J. Traité des fractures et des luxations. 2nd Edn. Paris. Chez J.-B. Baillière, 1855.
4. Darrach W. Partial excision of lower shaft of the ulna for deformity following Colles's fracture. Clin Orthop Relat Res. 1992;(275):3-4.
5. Darrach W. Anterior dislocation of the head of the ulna. Ann Surg. 1912;56:802–803.
6. McKee MD, Richards RR. Dynamic radio-ulnar convergence after the Darrach procedure. J Bone Joint Surg Br. 996;78(3):413-418.
7. Field J, Majkowski RJ, Leslie IJ. Poor results of Darrach's procedure after wrist injuries. J Bone Joint Surg Br. 1993;75(1):53-7.
8. Minami A, Iwasaki N, Ishikawa J, et al. Treatments of osteoarthritis of the distal radio-ulnar joint: long-term results of the three procedures. Hand Surg. 2005;10(2-3):243-248.
9. Sauvé L, Kapandji M. Nouvelle technique de traitement chirurgical des luxations récidivantes isolées de l'extrémité inférieure du cubitus. J Chir. 1936,47:589-594.
10. Lluch A. The Sauvé-Kapandji procedure. J Wrist Surg. 2013;2(1):33-40.
11. Zimmerman RM, Kim JM, Jupiter JB. Arthritis of the distal radioulnar joint: from Darrach to total joint arthroplasty. J Am Acad Orthop Surg. 2012;20(10):623-632.
12. George MS, Kiefhaber TR, Stern PJ. The Sauve-Kapandji procedure and the Darrach procedure for distal radio-ulnar joint dysfunction after Colles' fracture. J Hand Surg Br. 2004;29(6):608-613.
13. Tyser AR, Beckmann J, Franklin JD, et al. Evaluation of the PROMIS physical function computer adaptive test in the upper extremity. J Hand Surg Am. 2014;39(10):2047-2051.e4.
14. Hagino H, Teshima R, Naniwa S, et al. Comparative study on Sauvé-Kapandji and Darrach procedures in synovectomy for rheumatoid wrists. Jap J Rheum. 1999,9:365–372.
15. Nakagawa N, Abe S, Kimura H, et al. Comparison of the Sauvé-Kapandji procedure and the Darrach procedure for the treatment of rheumatoid wrists. Mod Rheumatol. 2003;13(3):239-242.
16. Nakamura R, Tsunoda K, Watanabe K, et al. The Sauve-Kapandji procedure for chronic 1992;17(2):127-132.
17. Kobayashi A, Futami T, Tadano I, et al. Radiographic comparative evaluation of the Sauve-Kapandji procedure and the Darrach procedure for rheumatoid wrist reconstruction. Mod Rheumatol. 2005;15(3):187-190.
18. Bell MJ, Hill RJ, McMurtry RY. Ulnar impingement syndrome. J Bone Joint Surg Br. 1985;67(1):126-129.
19. Bieber EJ, Linscheid RL, Dobyns JH, et al. Failed distal ulna resections. J Hand Surg Am.
20. Carter PB, Stuart PR. The Sauve-Kapandji procedure for post-traumatic disorders of the distal radio-ulnar joint. J Bone Joint Surg Br. 2000;82(7):1013-1018.
21. Lluch A. The Sauvé-Kapandji procedure: Indications and tips for surgical success. Hand Clin. 2010;26(4):559-572.
22. De Witte PB, Wijffels M, Jupiter JB, et al. The Darrach procedure for post-traumatic reconstruction. Acta Orthop Belg. 2009;75(3):316-322.
23. Grawe B, Heincelman C, Stern P. Functional results of the Darrach procedure: A long-term outcome study. J Hand Surg Am. 2012;37(12):2475-2480.e1-2.

24. Jochen-Frederick H, Pouyan Y, Khosrow BA, et al. Long-term functional outcome and patient satisfaction after ulnar head resection. J Plast Reconstr Aesthet Surg. 2016;69(10):1417-1423.
25. Papatheodorou LK, Rubright JH, Kokkalis ZT, et al. Resection interposition arthroplasty for failed distal ulna resections. J Wrist Surg. 2013;2(1):13-18.

# APPENDICES

**Appendix 1.** Types of reoperation in patients with multiple reoperations

| Patient | Initial surgery | Reoperation | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** |
| 1 | Darrach | corrective osteotomy radius | corrective osteotomy radius | | | | |
| 2 | Sauvé-Kapandji | excision heterotopic ossification | removal DRUJ screw | | | | |
| 3 | Darrach | wrist irrigation | excision heterotopic ossification | tendon transfer* | | | |
| 4 | Sauvé-Kapandji | removal DRUJ screw | excision nonunion ulnar styloid | refusion DRUJ with bone graft | removal DRUJ screw | Darrach | DRUJ arthroplasty |

** flexor carpi radialis to extensor digitorum communis and extensor pollicis longus*

# Chapter 6

## Hemiresection interposition arthroplasty of the distal radioulnar joint: a long-term outcome study

*Nawijn F, **Verhiel SHWL**, Jupiter JB, Chen NC*

*Hand (N Y). 2019 Sep 13; Online ahead of print*

# ABSTRACT

**Background** The aim of this study is to assess factors associated with long-term patient reported functional, pain and satisfaction scores in patients who underwent (Bower's) HIT arthroplasty of the DRUJ. The secondary aims are to determine complication and reoperation rates.

**Methods** A retrospective study with long-term follow-up of patients undergoing HIT arthroplasty was performed. Demographic, disease and treatment characteristics were collected for the 66 included patients. Thirty-one patients completed all surveys, which were the QuickDASH, our custom-made HIT arthroplasty questionnaire, NRS for pain and NRS for satisfaction. The mean interval between surgery and follow-up by means of questionnaires was 8.6 ± 3.4 years.

**Results** The mean QuickDASH score was 31.0 ± 20.2. The mean score of the HIT arthroplasty questionnaire was 2 ± 2. The median NRS for pain was 1 (IQR 0-3) and the median NRS for satisfaction was 9 (IQR 8 – 10). The complication rate and reoperation rate were 14% and 8%, respectively.

**Conclusions** Overall, patients expressed satisfaction with HIT arthroplasty, despite a mean QuickDASH score of 31.0. In our cohort, patients with inflammatory arthritis had higher satisfaction and lower pain scores. Patients who had prior trauma, prior surgery, or DRUJ subluxation are generally less satisfied. Males, older patients and post-traumatic patients had higher long-term pain scores; however, PIN neurectomy is associated with improved pain scores. Our findings support the use of HIT arthroplasty in patients with inflammatory arthritis.

# INTRODUCTION

Arthritis of the DRUJ is one of the causes of ulnar-sided wrist pain.[1–3] Etiologies include inflammatory arthritis, post-traumatic arthritis and primary osteoarthritis[2,4] Options for treatment of DRUJ arthritis include resection of the entire ulnar head (Darrach resection), fusion of the DRUJ combined with a segmental resection of the ulna just proximal to the DRUJ (Sauvé-Kapandji resection), partial resection of the ulnar joint surface with interposition of soft tissue using tendons or joint capsule ((Bower's) HIT arthroplasty) or DRUJ replacement (e.g. Aptis-Scheker replacement).[2,5–8]

The theoretical advantage of the HIT arthroplasty compared to procedures such as the Darrach and Sauvé-Kapandji is the preservation of the attachment of the TFCC to the ulnar styloid process. By using an oblique distal ulnar resection, the DRUJ remains stable while the arthritic portion of the DRUJ is removed.[6,9,10] However, some warn that this technique should be used with caution in patients with inflammatory or posttraumatic arthritis, because the TFCC may be structurally incompetent. In cases where the TFCC is compromised, stylocarpal impingement is a potential complication.[4,11]

There is a paucity of studies evaluating the overall long-term outcomes of HIT arthroplasty.[3,6,7,11] Therefore, the aim of this study is to assess factors associated with the long-term patient reported functional, pain and satisfaction scores in patients who underwent a HIT arthroplasty of the DRUJ. The secondary aims are to describe our complications and reoperation rates.

# METHODS

A priori, the IRB granted permission for retrospective data collection (#1999P008705). We performed a retrospective multicenter study with long-term follow-up of all patients undergoing HIT arthroplasty for DRUJ arthritis at 1 of 3 large urban area hospitals (two level I trauma centers and one community hospital tied to a level I trauma center) from January 2001 until January 2016. We identified patients from the Institutions' RPDR using multiple CPT codes (25105, 25107, 25119, 25240, 25332, 25337, 25360, 25676, 25830). Patients eligible for inclusion underwent HIT arthroplasty that was either confirmed by operative note or radiographs. The surgeries were performed according to the hemi-resection interposition technique first described by Bowers et al. [4,6]

After exclusion of patients younger than 18 years at time of surgery or patients with DRUJ dysfunction resulting from congenital causes, the cohort consisted of 66 patients. (Fig 1). The mean age of the population at time of the surgery was 58 ± 15 years. The majority were female (n=57, 86%) (Table 1). The most common indication for surgery was inflammatory arthritis (n = 55, 83%), followed by post-traumatic arthritis (n = 9, 14%) (Supplement 1). On

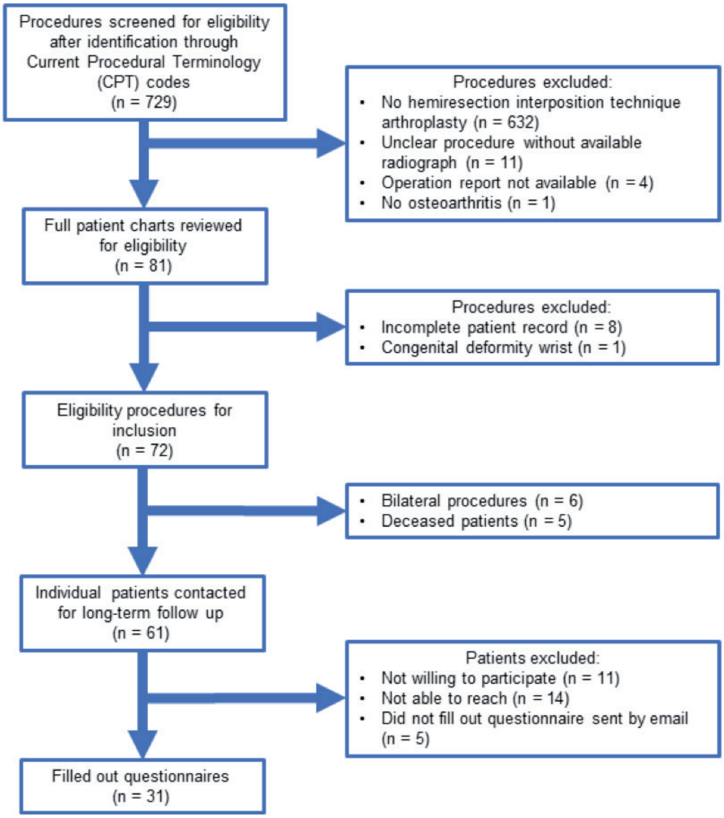


**Figure 1.** Flowchart of inclusion and exclusion of patients with hemiresection interposition arthroplasty.

radiographic evaluation, arthritic change was visible in 42 out of 50 patients with radiographs (84%) and 24 out of 47 patients with radiographs suitable for assessing subluxation (51%) had subluxation prior to surgery (Table 2). There were eight patients (16%) without evident arthritic changes on the radiograph, these patients were diagnosed based on their symptoms and physical examination. Fourteen patients (22%) had prior surgery on the affected wrist and nine patients (14%) had a prior fracture of the affected wrist. Additional procedures in addition to the HIT arthroplasty included: PIN neurectomy (n = 48, 72%), tenosynovectomy (21, 32%), tendon transfer (n = 21, 32%) and DRUJ ligament reconstruction (n = 4, 6%) (Table 2). After the HIT arthroplasty, patients had a median in clinic follow-up of eight months (IQR 4 – 18). See figure 2 and 3 for examples of radiographs prior and after the surgery for this procedure.

## Explanatory variables and outcome measures

For all identified patients, demographic characteristics (age, sex, dominant hand, BMI, diabetes mellitus, smoking status, alcohol dependency, heavy manual labor as occupation), disease characteristics (affected wrist side, type of arthritis, prior ipsilateral wrist surgery or fracture)

**Table 1.** Patients demographics of hemiresection interposition arthroplasty

| | **Total** | **Responder** | **DASH score** | **HIT arthroplasty questionnaire** | **NRS pain** | **NRS satisfaction** |
|---|---|---|---|---|---|---|
| | **n = 66 (100%)** | **n = 31 (51%)** | ***p*-value** | ***p*-value** | ***p*-value** | ***p*-value** |
| Age, mean ± SD | 58 ± 15 | 58 ± 13 | 0.362[a] | 0.802[a] | **0.024**[c] | 0.655[c] |
| Sex, n (%) | | | 0.250[b] | **0.010**[b] | **0.005**[d] | 0.641[d] |
| Male | 9 (14) | 3 (10) | | | | |
| Female | 57 (86) | 28 (90) | | | | |
| Body mass index in kg/m2†, median (IQR) | 26 (23 - 30) | 26 (22 - 30) | 0.123[c] | 0.320[c] | 0.245[c] | 0.733[c] |
| Comorbidities, n (%) | | | | | | |
| Diabetes mellitus^ | 8 (12) | 3 (10) | 0.731[b] | 0.183[b] | 0.272[d] | 0.883[d] |
| Osteoporosis^ | 18 (28) | 6 (20) | 0.352[b] | 0.840[b] | **0.010**[d] | 0.438[d] |
| Tobacco use reported in chart*, n (%) | 5 (8) | 3 (10) | 0.159[b] | 0.619[b] | 0.732[d] | 0.133[d] |
| Alcohol dependency reported in chart~, n (%) | 2 (3) | 0 (0) | NA | NA | NA | NA |
| Heavy manual labor as occupation[×], n (%) | 5 (9) | 2 (8) | 0.322[b] | 0.243[b] | 0.624[d] | 0.149[d] |

*Missing cases: †11 mising; ^1 missing; * 3 missing; ~ 5 missing; [×] 10 missing.*
*Statistical test used: [a] Pearson's correlation coefficient; [b] Independent t-test; [c] Spearman's rank correlation coefficient; [d] Mann-Whitney U test.*

6

**Table 2.** Pre-operative and procedure characteristics of hemiresection interposition arthroplasty

| | Total | Responder | DASH score | HIT arthroplasty questionnaire | NRS pain | NRS satisfaction |
|---|---|---|---|---|---|---|
| | **n = 66 (100%)** | **n = 31 (51%)** | ***p*-value** | ***p*-value** | ***p*-value** | ***p*-value** |
| **Dominant hand affected†, n (%)** | 35 (61) | 13 (48) | 0.671[a] | 0.392[a] | 0.075[c] | 0.397[c] |
| **Prior surgery on ipsilateral wrist^, n (%)** | 14 (22) | 7 (23) | 0.918[a] | 0.616[a] | 0.052[c] | **0.030**[c] |
| **Prior ipsilateral wrist fracture, n (%)** | 9 (14) | 4 (13) | 0.428[a] | 0.361[a] | **0.010**[c] | **0.043**[c] |
| Distal radius fracture | 5 (56) | 3 (75) | | | | |
| Distal radius fracture with DRUJ dislocation | 1 (11) | 0 (0) | | | | |
| Ulnar fracture | 2 (22) | 1 (25) | | | | |
| Unknown | 1 (11) | 0 (0) | | | | |
| **Radiology, n (%)** | | | | | | |
| Visible arthritic changes* | 42 (84) | 20 (80) | 0.877[a] | 0.657[a] | 0.175[c] | 0.417[c] |
| Subluxation~ | 24 (51) | 9 (38) | **0.020**[a] | 0.931[a] | 0.875[c] | **0.010**[c] |
| **Indication for surgery, n (%)** | | | 0.196[b] | 0.283[b] | **0.004**[d] | 0.305[d] |
| Inflammatory arthritis | 55 (83) | 25 (81) | | | | |
| Post-traumatic arthritis | 9 (14) | 5 (16) | | | | |
| Other | 2 (3) | 1 (3) | | | | |
| **Concomitant wrist diagnosis at time of surgery^, n (%)** | 43 (66) | 20 (65) | 0.875[a] | 0.469[a] | 0.878[c] | 0.111[c] |
| Tendon rupture | 23 (35) | 10 (32) | 0.715[a] | 0.564[a] | 0.280[c] | **0.049**[c] |
| Dorsal (teno)synovitis | 19 (29) | 8 (26) | 0.818[a] | **0.041**[a] | 0.211[c] | 0.594[c] |
| Non-/malunion | 2 (3) | 2 (6) | 0.646[a] | 0.857[a] | **0.029**[c] | 0.167[c] |
| Caput ulnae syndrome | 2(3) | 1 (3) | NA | NA | NA | NA |
| DRUJ dislocation | 2 (3) | 1 (3) | NA | NA | NA | NA |
| Other[×] | 10 (15) | 6 (19) | 0.928[a] | 0.557[a] | 0.352[c] | 0.391[c] |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Concomitant procedures performed, n (%)** | 65 (98) | 31 (100) | | | | |
| Total wrist replacement | 6 (9) | 2 (6) | 0.233[a] | 0.827[a] | 0.171[c] | 0.897[c] |
| Wrist arthrodesis | 20 (30) | 12 (39) | 0.322[a] | 0.281[a] | 0.517[c] | 0.572[c] |
| Radiolunate arthrodesis | 4 (6) | 1 (3) | NA | NA | NA | NA |
| Carpectomy | 6 (9) | 4 (13) | 0.973[a] | 0.361[a] | 0.380[c] | 0.569[c] |
| DRUJ reconstruction | 4 (6) | 1 (3) | NA | NA | NA | NA |
| Tendon transfer | 21 (32) | 10 (32) | 0.715[a] | 0.564[a] | 0.280[c] | **0.049**[c] |
| Posterior interosseous neurectomy | 48 (72) | 24 (77) | 0.243[a] | 0.419[a] | **0.007**[c] | 0.224[c] |
| (Teno)synovectomy | 46 (70) | 20 (65) | 0.833[a] | 0.605[a] | 0.210[c] | **0.019**[c] |
| Other[∞] | 15 (25) | 3 (10) | 0.597[a] | 0.577[a] | 0.213 | 0.085[c] |

*Missing cases: † 9 missing; ^ 1 missing; * 16 missing; ~ 19 missing; [×] Bone spicules, carpal tunnel release, dislocation of hand joints other than DRUJ, joint destruction other than DRUJ; [∞] Arthroplasty thumb, bursectomy, carpal tunnel release, capsulodese, intercarpal fusion, open reduction and internal fixation, osteotomy distal radius, plate removal, tendonrelease, ulnar shortening osteotomy.*

*Statistical tests used: [a] Independent-test; [b] ANOVA test; [c] Mann-Whitney U test; [d] Kruskal-Wallis test.*


**Figure 2.** Preoperative and postoperative radiographs of a patient undergoing hemiresection interposition arthroplasty for inflammatory arthritis of the DRUJ. This patient had no complications and did not undergo reoperation.


**Figure 3.** Preoperative and postoperative radiographs of a patient undergoing hemiresection interposition arthroplasty combined with ORIF for post-traumatic arthritis of the DRUJ. This patient had a fracture a year prior to the surgery for which the patient was treated conservatively. This patient had no complications and did not undergo reoperation.

**Table 3.** Results of hemiresection interposition arthroplasty questionnaire

| **Questions** | **n = 31** |
|---|---|
| Do you experience more swelling at the ulnar side of your wrist and/or forearm which was operated on compared to your other wrist and/or forearm? | 6 (19%) |
| Do you experience weakness of the wrist and/or forearm which was operated on (e.g. dropping objects, unable to carry heavy groceries with operated hand)? | 18 (58%) |
| Do you feel an increase in pain located at the ulnar side of your wrist and/or forearm which was operated on during rotation of your forearm (e.g. changing a light bulb, turning a key)? | 11 (35%) |
| Do you feel or hear a ‘click’ over the ulnar side of your wrist or/and forearm which was operated on during rotation of your forearm (e.g. changing a light bulb, turning a key)? | 8 (26%) |
| Do you experience the sensation of instability of the wrist and/or forearm that was operated? | 7 (23%) |
| Does the wrist and forearm you were operated on cause you any limitations in your daily activity (compared to before the surgery or before the onset of your wrist complaints)? | 19 (61%) |
| **Total score of hemiresection interposition arthroplasty questionnaire, mean ± SD** | **2 ± 2** |

and treatment characteristics (concomitant wrist diagnosis at time of surgery, concomitant procedures performed during surgery, follow-up time, complications and unplanned reoperations affecting the ulna) were extracted from the hospital's electronic medical charts. In case of bilateral HIT arthroplasties, only data from the first procedure was analyzed to avoid violating the statistical assumption of independence. Furthermore, two researchers (FN, SV) extracted all radiographs and independently assessed each radiograph on the presence of arthritis and the presence of ulnar subluxation. When no consensus could be reached, the senior author was consulted until consensus was reached.



Five patients passed away during the follow-up period, which resulted in 61 potential subjects available for contact. Patients who responded that they were willing to participate or did not respond within two weeks were contacted by telephone to administer the questionnaires. Multiple attempts were made to reach every patient to obtain the highest possible response rate and reduce selection bias caused by non-response. If preferred, the questionnaires were sent by mail through a secured survey system. Thirty-one patients participated in the study, reflecting a response rate of 51% (Fig. 1). The mean interval between the surgery and the survey was 8.6 ± 3.4 years (range 2.8 – 13.9).

Our primary outcome measure was the QuickDASH questionnaire score and our custom-made HIT arthroplasty questionnaire. Our secondary outcome measures were NRS for pain and NRS for patient's satisfaction. The QuickDASH consists of 11 questions about daily activities and symptoms, each scored on a scale of 1 (no disability) to 5 (severe disability). These scores are transformed to a scale of 0 to 100, reflecting patients' perception of physical arm function and symptoms. A higher score indicates more arm related disabilities experienced by the patient.[12] The HIT arthroplasty questionnaire was developed by our department to assess the common symptoms and complaints related to the DRUJ.[1–3] The full questionnaire is available in Table 3. The score can range between 0 and 6, with a high score indicating that more DRUJ symptoms still present after surgery. The NRS for pain measures the average amount of pain a patient experiences during a regular day on a scale of 0 (no pain) to 10 (worst pain imaginable).[13] The NRS for patient's satisfaction measures satisfaction with the given treatment on a scale 0 (completely unsatisfied) to 10 (very satisfied).

## Statistical analysis

Continuous variables were presented as means and SD if normally distributed or as median with IQR if non-normal distributed. Categorical variables were presented as frequencies and percentages. Missing data were handled using pairwise deletion to reduce information bias. Bivariate analyses were performed to identify associations between our explanatory variables and outcome variables (QuickDASH score, HIT arthroplasty questionnaire, NRS for pain score, NRS for patient's satisfaction score). For bivariate analyses the independent T-test was used for dichotomous explanatory variables, the one-way ANOVA for categorical explanatory variables and the Pearson-correlation coefficient continuous explanatory variables. Based on normality, the non-parametrical equivalent of these tests was used (Mann-Whitney test, Kruskal-Wallis test, Spearman's rank correlation coefficient, respectively). A multivariable linear regression was attempted to identify factors independently associated with a higher QuickDASH score, therefore the most clinically relevant variables with a *p*-value <0.2 were imputed in the model. This was not attempted for the other questionnaires due to the limited and therefore not clinically relevant spread of outcomes on the continuous scales. A *p*-value of <0.05 was considered statistically significant.

# RESULTS

## Clinical outcomes

The complication rate was 14% (n = 9). Complications included stylocarpal impingement (n = 2), wound complications (n= 2), ulnar exostoses (n = 1), ulnar subluxation (n = 1), carpus subluxation (n = 1), tendon rupture (n = 1) and necrotizing fasciitis (n = 1). The reoperation rate was 8% (n = 5). Reoperations included a Darrach resection to treat stylocarpal impingement (n = 2), a Darrach resection and tendon repair to treat persistent complaints and an extensor tendon rupture (n = 1), hemiarthroplasty revision to treat a distal ulnar exostosis (n = 1) and surgical exploration with irrigation and debridement for necrotizing fasciitis (n = 1).

## Patient-reported outcomes

The mean QuickDASH score was 31.0 ± 20.2 (range 0 – 65.9). DRUJ subluxation visible on radiographs prior to surgery was associated with a higher QuickDASH score (41.9 ± 20.0 vs. 24.1 ± 14.6; p-value = 0.020). Imputation of BMI, smoking, post-traumatic arthritis as surgery indication and subluxation on radiographic evaluation in a multivariable linear regression model did not identify a variable independently associated with the QuickDASH score (Supplement 2).

The mean HIT arthroplasty questionnaire score was 2 ± 2 (range 0 - 5). Male sex (2 ± 2 vs, 5 ± 1; p = 0.010) and dorsal tenosynovectomy (1 ± 1 vs. 3 ± 2; p = 0.041) were associated with inferior scores. The most common persistent wrist symptom was the experience of weakness of the wrist after surgery (n = 18, 58%) (Table 3).

The median NRS for pain was 1 (IQR 0 – 3; range 0 - 10). Higher pain scores were associated with older age (p = 0.024), male sex (8 (4 – 10) vs. 0 (IQR 0 – 2); p = 0.005), presence of osteoporosis (1 (IQR 0 – 4) vs. 0 (IQR 0 – 0); p = 0.010), prior ipsilateral wrist fracture (6 (IQR 3 – 9) vs. 0 (0 – 2); p = 0.010), post-traumatic arthritis as indication for surgery (5 (IQR 4 – 8) vs. 0 (IQR 0 – 2); p = 0.004), or non- or malunion as concomitant diagnosis at time of surgery (7 (IQR 4 – 10) vs. 0 (0 – 2); p = 0.029). Patients in whom PIN resection was performed had lower pain scores (0 (IQR 0 – 2) vs. 4 (1 – 8); p = 0.007).

The median NRS for satisfaction was 9 (IQR 8 – 10, range 0 -10). Twenty-nine patients (94%) had a satisfaction score greater than 7. In bivariate analysis, patients who had prior surgery on the ipsilateral wrist (9 (IQR 8 – 10) vs. 10 (IQR 10 – 10); p = 0.030), prior fracture of the ipsilateral wrist (9 (IQR 8 – 10) vs. 10 (IQR 10 – 10); p = 0.043), subluxation visible on radiographic evaluation (9 (IQR 7 – 9) vs. 10 (IQR 9 – 10); p = 0.010), tendon rupture at the time of surgery (9 (IQR 7 – 10) vs. 10 (IQR 9 – 10); p = 0.049), tendon repair as concomitant procedure (9 (IQR 7 – 10) vs. 10 (IQR 9 – 10); p = 0.049) and who did not undergo tenosynovectomy as concomitant procedure (9 (IQR 8 – 10) vs. 10 (IQR 10 – 10); p = 0.019) were less satisfied.(Table 1 and 2).

The occurrence of complications or reoperations did not appear to influence the patient-reported outcomes.



# DISCUSSION

This current study investigated the factors associated with long-term patient-reported functional, pain and satisfaction scores and to determine the rate of complications and reoperations of patients who underwent a HIT arthroplasty. We found a mean QuickDASH of 31.0, a NRS for pain of 1 and a NRS for satisfaction of 9. The complication rate and reoperation rate during the 8.6 years follow-up was respectively 14% and 8%.

This study is limited by its retrospective nature: First, the complications and reoperation rate might be under-reported due to patients seeking care for new or persistent wrist complaints at a hospital outside our records. Based on our experience with referral patterns within our institutions, this is uncommon. We found that two of our included patients switched care from one institution to another institution within our system. Second, CPT codes were used to identify patients, however, no specific CPT codes are available for the HIT arthroplasty. We used nine different CPT codes and manual chart review to try to capture as many cases as possible. Third, our results are likely influenced by selection bias because it is possible that those who chose not to respond had a different outcome than those who chose to participate. However, when evaluating the demographic, pre-operative, and procedure characteristics, the responder cohort appears similar to the initial cohort. Finally, the DASH scores reflect not only the HIT arthroplasty, but also reflect the global problems of the wrist including inflammatory arthritis and post-traumatic sequelae of the radiocarpal joint.

The study also has some strengths: It is a relatively large cohort of patients who underwent HIT arthroplasty with a considerably long follow-up of 8.6 years. There were nine surgeons performing this procedure, all of whom were attending-level surgeons. We used a specific HIT arthroplasty questionnaire to assess symptoms post-operatively. Although this is not validated, we asked reasonable questions that can be applied in practical manner to interpret symptoms that are not captured by other outcome measures.

Schoonhoven et al. found an average DASH score of 35 with an average follow-up of 34 months, which is a similar finding compared to this study.[14] In our study we found that pre-operative subluxation on radiograph was a predictive factor for worse QuickDASH scores, since patients with subluxation had and score of 41.9 compared to 14.6 in patients without pre-operative subluxation. Pre-operative subluxation likely indicates pre-operative joint instability and TFCC incompetence.[15] When comparing to the Darrach or Sauve Kapandji procedures, DASH scores in patients with posttraumatic or degenerative arthritis vary between 17 - 26 and 23 - 28, respectively.[16–19]

The survey specifically made for patients with DRUJ symptoms showed that 58% of the patients still experienced weakness of the wrist. Previous studies showed slight increases in grip strength postoperatively, but this eventually never matches the strength of the contralateral side, possibly explaining why patients still report on experiencing weakness of the wrist.[9,20,21] In our study 23% of the patients reported instability of the wrist, which is in line with previous described rates for the HIT arthroplasty.[20]

We found that the mean NRS for pain was 1 (IQR 0 – 3). This is a very low score compared to the mean DASH score of 31, however, most patients we spoke to were satisfied with the procedure since it reduced the pain. Previous studies report that 54% to 94% of patients described no remaining pain at follow up.[6,7,22–24] Lee et al. reported a NRS for pain of 1.7 in a cohort of only rheumatoid arthritis patients undergoing HIT arthroplasty, while two other studies found pain scores of 3.9 and 5.4 in cohorts only or predominately consisting of patients with post-traumatic arthritis.[11,14,21] In our cohort, patients with post-traumatic arthritis had more frequently a higher NRS for pain (NRS of 5 compared to 0). Patients with post-traumatic arthritis are usually younger (previous described ages between 39 and 53 year), more active and did not have complaints of the wrist prior to the trauma, and also have and different outcome expectations.[6,11,14,23] These findings are similar for patients who underwent a Darrach procedure, where patients with post-traumatic arthritis describe more postoperative pain at long-term follow-up compared to those with inflammatory arthritis.[25]

We found that PIN neurectomy was associated with reduced pain. Patients with PIN neurectomy scored 0 on the NRS for pain compared to a score of 4 by patients who did not undergo PIN neurectomy. It is unclear whether this procedure improves outcomes because of denervation of the radiocarpal joint and helps resolve other pathology, or PIN neurectomy denervates the DRUJ.[26–28] It is also possible the PIN neurectomy is a surrogate for other technical factors that are unable to be captured in the data available.

Ninety-four percent of the patients reported they were satisfied, which is in line with the prior studies of satisfaction (84 - 93%).[11,24] Two previous studies assessing the NRS for satisfaction reported scores of 6.4 and 6.9.[14,21] One of these studies had a relatively high rate of radioulnar impingements (41%), while the other study consisted of mostly relatively young patients with post-traumatic arthritis resulting in a population with different expectations of the surgery.[14,21]

Our complication rate was 14%, which is comparable to the reported historical complication rates that vary between 3% and 44%.[6,7,29] The reoperation rate is also in line with previous described reoperation rates (0% to 13%), with persistent pain and stylocarpal impingement being the primary indications for reoperation.[4,7,21,29] Complications in our cohort were mainly related to persistent pain, joint instability and wound complications. Minami et al. had a complication rate of 44% that they attributed to ECU tendinitis secondary to retinacular reconstruction performed. Complication rates only assessing stylocarpal impingement vary between 8% and 41%.[14,21] In this study, persistent pain due to stylocarpal impingement occurred in two patients (3%), in both cases was a reoperation with the Darrach procedure performed.

Overall, we found that patients expressed satisfaction with HIT arthroplasty, despite a mean QuickDASH score of 31. In our cohort, patients with inflammatory arthritis had higher satisfaction and pain scores. Patients who had prior trauma, prior surgery, or DRUJ subluxation are generally less satisfied. Males, older patients, post-traumatic patients have less pain relief; however, PIN neurectomy is associated with improved pain relief. Overall, the indications for HIT arthroplasty should take into account etiology, age, and TFCC status. In addition, PIN neurectomy may be beneficial in improving clinical outcomes.

# REFERENCES


1. Murray PM. Current concepts in the treatment of rheumatoid arthritis of the distal radioulnar joint. Hand Clin. 2011;27(1):49-55.
2. Glowacki K. Hemiresection arthroplasty of the distal radioulnar joint. Hand Clin. 2005;21(4):591-601.
3. Ahmed SK, Cheung JPY, Fung BK-K, et al. Long Term Results of Matched Hemiresection Interposition Arthroplasty for Druj Arthritis in Rheumatoid Patients. Hand Surg. 2011;16(02):119-125.
4. Bowers W. Distal radioulnar joint arthroplasty: current concepts. Clin Orthop Relat Res. 1992;(275):104-109.
5. Srikanth KN, Shahane SA, Stilwell JH. Modified Matched Ulnar Resection for Arthrosis of Distal Radioulnar Joint in Rheumatoid Arthritis. Hand Surg. 2006;11(01n02):15-19.
6. Bowers WH. Distal radioulnar joint arthroplasty: The hemiresection-interposition technique. J Hand Surg Am. 1985;10(2):169-178.
7. Watson HK, Ryu J, Burgess RC. Matched distal ulnar resection. J Hand Surg Am. 1986;11(6):812-817.
8. Scheker LR. Implant Arthroplasty for the Distal Radioulnar Joint. J Hand Surg Am. 2008;33(9):1639-1644.
9. Rekant M. Distal Ulna Arthroplasties. Hand Clin. 2012;28(4):611-615.
10. Sauerbier M, Fujita M, Hahn M, et al. The dynamic radioulnar convergence of the Darrach procedure and the ulnar head hemiresection interposition arthroplasty: A biomechanical study. J Hand Surg Am. 2002;27 B(4):307-316.
11. Lee CH, Chung US, Lee BG, et al. Long-term results of simple hemiresection arthroplasty in the rheumatoid distal radio-ulnar joint. J Hand Surg Eur Vol. 2013;38(7):719-726.
12. Kenedy C, Beaton D, Smith P, et al. Measurement properties of the QuickDASH (Disabilities of the Arm, Shoulder and Hand) outcome measure and cross-cultural adaptations of the QuickDASH: a systematic review. Qual Life Res. 2013;22:2509-2547.
13. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. J Clin Nurs. 2005;14(7):798-804.
14. van Schoonhoven J, Kall S, Schober F, et al. The hemiresection-interposition arthroplasty as a salvage procedure for the arthrotically destroyed distal radioulnar joint. Handchir Mikrochir Plast Chir. 2003;35(3):175-180.
15. Zimmerman RM, Jupiter JB. Instability of the distal radioulnar joint. J Hand Surg Eur Vol. 2014;39(7):727-738.
16. Zimmermann R, Gschwentner M, Arora R, et al. Treatment of distal radioulnar joint disorders with a modified Sauvé-Kapandji procedure: Long-term outcome with special attention to the DASH questionnaire. Arch Orthop Trauma Surg. 2003;123(6):293-298.
17. Grawe B, Heincelman C, Stern P. Functional results of the Darrach procedure: A long-term outcome study. J Hand SurgAm.2012;37(12):2475-2480. http://dx.doi.org/10.1016/j.jhsa.2012.08.044.
18. Daecke W, Martini AK, Schneider S, et al. Amount of ulnar resection is a predictive factor for ulnar instability problems after the Sauvé-Kapandji procedure: A retrospective study of 44 patients followed for 1-13 years. Acta Orthop. 2006;77(2):290-297.
19. George MS, Kiefhaber TR, Stern PJ. The Sauve-Kapandji procedure and the Darrach procedure for distal radio-ulnar joint dysfunction after Colles' fracture. J Hand Surg Am. 2004;29(6):608-613.
20. Minami A, Iwasaki N, Ishikawa J, et al. Treatments of Osteoarthritis of the Distal Radioulnar Joint: Long-Term Results of Three Procedures. Hand Surg. 2005;10(02n03):243-248..
21. Bain GI, Pugh DMW, MacDermid JC, et al. Matched hemiresection interposition arthroplasty of the distal radioulnar joint. J Hand Surg Am. 1995;20(6):944-950.

22. Imbriglia JE, Matthews D. Treatment of chronic post-traumatic dorsal subluxation of the distal ulna by hemiresection-interposition arthroplasty. J Hand Surg Am. 1993;18(5):899-907.
23. Minami A, Kaneda K, Itoga H. Hemiresection-interposition arthroplasty of the distal radioulnar joint associated with repair of triangular fibrocartilage complex lesions. J Hand Surg Am. 1991;16(6):1120-1125.
24. Faithfull DK, Kwa S. A review of distal ulnar hemi-resection arthroplasty. J Hand Surg Am. 1992;17B:408-410.
25. Fraser KE, Diao E, Peimer CA, et al. Comparative results of resection of the distal ulna in rheumatoid arthritis and post-traumatic conditions. J Hand Surg Am. 1999;24 B(6):667-670.
26. Hohenberger GM, Maier MJ, Dolcet C, et al. Sensory nerve supply of the distal radio-ulnar joint with regard to wrist denervation. J Hand Surg Eur Vol. 2017;42(6):586-591.
27. Grechenig S, Lidder S, Dreu M, et al. Wrist denervation of the posterior interosseous nerve through a volar approach: a new technique with anatomical considerations. Surg Radiol Anat. 2017;39(6):593-599.
28. Vanden Berge DJ, Kusnezov NA, Rubin S, et al. Outcomes Following Isolated Posterior Interosseous Nerve Neurectomy: A Systematic Review. Hand. 2017;12(6):535-540.
29. Minami A, Kaneda K, Itoga H. Hemiresection-interposition arthroplasty of the distal radioulnar joint associated with repair of triangular fibrocartilage complex lesions. J Hand Surg Am. 1991;16(6):1120-1125.

# APPENDICES

**Appendix 1.** Disease related characteristics based on arthritis aetiology of patients undergoing hemiresection interposition arthroplasty

| | | |
|---|---|---|
| **Inflammatory arthritis n = 55** | Type, n (%) | |
| | Rheumatoid arthritis | 47 (85) |
| | Juvenile rheumatoid arthritis | 7 (13) |
| | Systemic lupus erythematosus | 2 (4) |
| | Psoriatic arthritis | 1 (2) |
| | Hidradenitis suppurativa arthritis | 1 (2) |
| | Unknown | 1 (2) |
| | Rheumatoid factor*, n (%) | |
| | Seropositive | 30 (65) |
| | Seronegative | 16 (35) |
| | Arthritis treatment received one year prior to surgery**, n (%) | |
| | Splint | 20 (38) |
| | Daily NSAIDs | 23 (43) |
| | Steroid injection | 6 (11) |
| | Oral steroids | 29 (55) |
| | DMARD | 31 (58) |
| | Methothrexate | 26 (49) |
| | No prior treatment | 5 (9) |
| | Radiographs | |
| | Presence of osteoarthritis*** | 36 (88) |
| | Subluxation of distal radioulnar joint**** | 19 (50) |
| **Non-inflammatory arthritis n = 11** | Type, n (%) | |
| | Post-traumatic arthritis | 9 (82) |
| | Degenerative arthritis | 1 (9) |
| | Unknown | 1 (9) |
| | Arthritis treatment received one year prior to surgery, n (%) | |
| | Splint | 4 (36) |
| | Daily NSAIDs | 1 (9) |
| | Steroid injection | 1 (9) |
| | No prior treatment | 6 (55) |
| | Radiographs | |
| | Presence of osteoarthritis** | 6 (67) |
| | Subluxation of distal radioulnar joint** | 5 (56) |

*DMARD = Disease-Modifying Antirheumatic Drug; NSAID = NonSteroidal Anti-Inflammatory Drug*
**9 missing case; **2 missing cases; *** 14 missing cases; ****17 missing cases;*

**Appendix 2.** Multivariable linear regression of factors associated with QuickDASH

| Independent variables | Coefficient *b* | Standard Error | 95% CI | *p* - value |
|---|---|---|---|---|
| **QuickDASH score ($R^2$ = 32%; Adjusted $R^2$ = 16%; *p*-value = 0.127)** | | | | |
| Body Mass Index | 0.81 | 0.66 | -0.5 - 2.2 | 0.233 |
| Smoking | 12.59 | 12.53 | -13.7 - 38.9 | 0.328 |
| Post-traumatic osteoarthritis | 6.24 | 10.88 | -16,6 - 29.1 | 0.574 |
| Subluxation on radiograph | 5.08 | 9.46 | -14.8 - 25.0 | 0.59 |

6

# Chapter 7

## Long-term outcomes after extensor carpi ulnaris subsheath reconstruction with extensor retinaculum

***Verhiel SHWL**, Özkan S, Chen NC, Jupiter JB*

*Tech Hand Up Extrem Surg. 2020 Mar;24(1):2-6*

# ABSTRACT

This study assessed the long-term outcomes and complications of patients that underwent operative treatment for ECU subluxation. Fifteen patients underwent ECU subsheath reconstruction at a median of 5.9 weeks non-operative treatment interval (IQR 2.4-13). Reconstruction consisted of using the extensor retinaculum as a sling reconstruction. We found that about 1 in 3 patients had a complication or reoperation. At a median of 8 years follow-up, many patients had some residual symptoms, but in general most patients were satisfied.

# INTRODUCTION

Although many patients who experience symptomatic ECU tendon subluxation do well with conservative treatment;[1–4] operative treatment is an option when this approach is not succesful.[5,6] Operative techniques include direct repair of the subsheath,[5–7] repair of the subsheath with the use of a graft,[6–10] reattachment of the subsheath using trans-osseous sutures or suture anchors,[7,11,12] or reconstruction of the sheath with creation of a sling.[1,4,9,13,14] Some investigators believe that flat and convex ECU tendon grooves increase the risk of recurrent subluxation, and advocate for deepening of the ECU groove.[4,11]

Published data concerning operative treatment of ECU tendon subluxation are primarily case report studies with small numbers of patients and often without consistent measures of clinical outcomes.[1,4,6,7,10–12] The purpose of this study was to assess the long-term outcomes and complications of patients that underwent operative treatment for this condition specifically using a retinacular sling reconstruction.



# ANATOMY

The ECU arises from the lateral epicondyle of the distal humerus and inserts at the fifth metacarpal base.[3,11,15] The ECU tendon passes through a fibro-osseous tunnel (the sixth extensor compartment) as it leaves the formearm, lying within an osseous groove on the dorsal surface of the ulna. The ECU is stabilized within its osseous groove by the ECU subsheath, that overlies 1.5 to 2.0 cm of the distal ulna and arcs from the radial to ulnar wall of the ECU osseous groove.[8,11,14–16] The overlying extensor retinaculum courses over the ECU subsheath and distal ulna to attach to the pisiform and triquetrum, it prevents bowstringing of the tendon across the wrist during muscle contraction.[3,5,8,14] The ulnar insertion of the fibro-osseous tunnel is reinforced by the linea jugata, which consists of longitudinal fibers that provide dynamic stability.[11,14,15,17]

In pronation, the ECU adopts a straight course to its insertion and causes minimal force on the subsheath. In supination, the ECU radially translates and subtends an oblique path to its insertion, causing maximal force on the subsheath.[3,8,14,15,17] For this reason, ECU subsheath injuries most commonly result from sudden rotational force against a supinated forearm with the wrist fixed in a position of flexion and ulnar deviation, as occurs following a racquet stroke or swinging a club, bat, or hockey stick.[1–3,5,8]

# INDICATIONS AND CONTRAINDICATIONS

## Indications:

- Symptomatic ECU instability, refractory to non-operative treatment
- Failed prior subsheath repair (either direct repair, use of a graft, or reattachment using trans-osseous sutures or suture anchors)
- Concomitant ECU and ulnocarpal pathologies

## Contraindications:

- Inadequate trial of non-operative treatment
- Prior surgical procedures that lead to violation of the extensor retinaculum

# TECHNIQUE (FIGURE 1)[14]

A dorso-ulnar incision was made along the course of the osseous groove and ECU. Skin was elevated off the underlying extensor retinaculum of the fifth and sixth extensor compartments. Care was being made to identify and protect any crossing sensory branches of the dorsal ulnar nerve.

A radially based extensor retinacular sling was designed. The retinaculum was opened between the fifth and sixth extensor compartment, freeing up the extensor digitorum quinti minimi. Following this, the retinaculum was elevated until the extensor carpi ulnaris was identified and it was freed up from surrounding synovium. Subsequently, the extensor retinaculum was incised transversely in thirds and a sling was constructed from the central portion by releasing it from the volar ulnar insertion. The sling was brought under the ECU, then curved back and reattached to the dorsal DRUJ capsule at the sigmoid notch using #3-0 Tevdek suture. Care was taken to not over tighten the repair, but this was tensioned until there was smooth gliding of the tendon and there was no subluxation with wrist flexion and extension.

Five patients underwent a slightly modified version of this technique. The extensor retinaculum was incised transversely in thirds. The middle third was brought under the ECU and then brought up and curved back dorsally to be secured to the most proximal third, effectively creating a sling.

## Concomitant surgical considerations

The ECU may demonstrate tenosynovitis and/or longitudinal split tears. Treatment of these intrinsic ECU pathologies is facilitated during sling reconstruction. The close relationship between the distal ECU subsheath and the ulnocarpal compartment underlines the importance of recognizing other concomitant causes for ulnar-sided wrist pain. Wrist arthroscopy

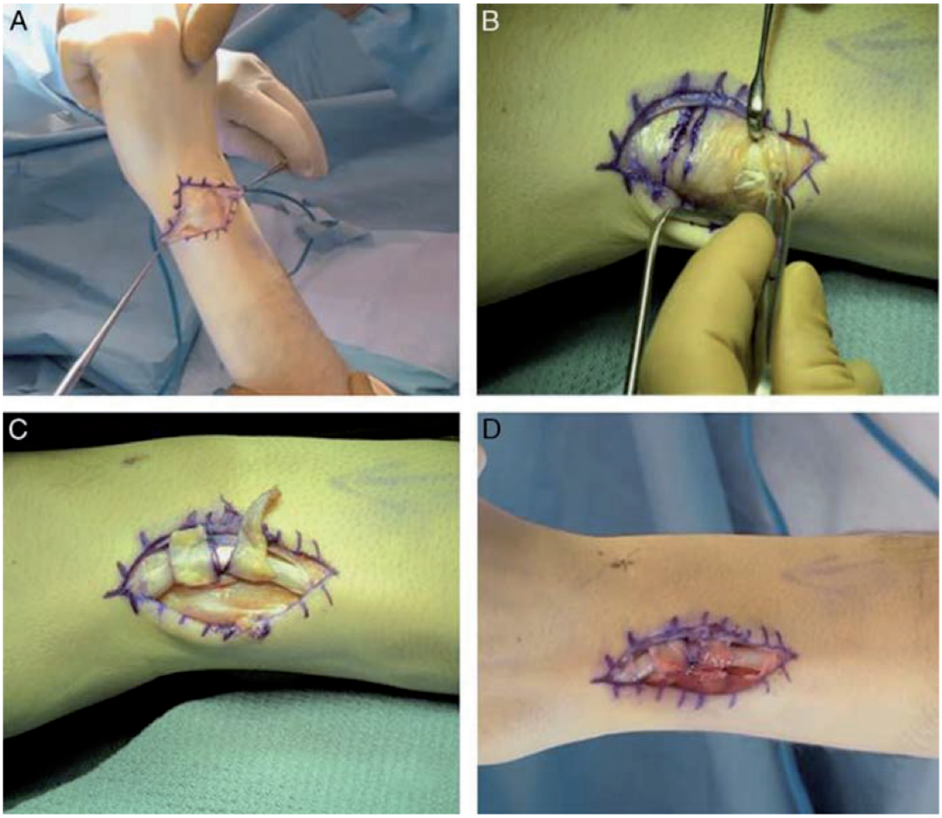


**Figure 1.** Reconstruction technique in detail. (a) A dorsal ulnar incision was made, care being made to identify and protect any crossing sensory branches of the dorsal ulnar nerve. The retinaculum was opened between the fifth and sixth extensor compartment, freeing up the extensor digitorum quinti minimi. Following this, the retinaculum was elevated until the extensor carpi ulnaris was identified and it was freed up from surrounding synovium. (b) Subsequently, a sling was constructed from a central portion of the retinaculum by releasing it from the volar ulnar insertion. (c) and (d) The sling was brought under the extensor carpi ulnaris, then curved back and reattached to the dorsal distal radioulnar joint capsule at the sigmoid notch using #3-0 Tevdek (In this example the extensor retinaculum had a split in the middle and had to be sutured in 2 separate areas).

can be performed prior to ECU stabilization for both diagnostic purposes and also to treat concomitant TFCC lesions.

In our cohort, 4 patients concomitantly underwent a synovectomy of the ECU. In 1 patient, a repair of the TFCC was performed, in another a TFCC debridement. The patient who previously had a primary subsheath repair received a neurolysis of 3 sensory branches of the dorsal ulnar nerve. One patient underwent a concomitant excision of a wrist-ganglion.

## Rehabilitation

After skin closure, a long-arm splint was applied with the elbow flexed to 90° and the wrist in neutral position, worn for 2 weeks to allow for swelling. To achieve a total of 6 weeks of immobilization, a cast or splint in the same position for an additional 4 weeks was applied. Rehabilitation was begun 6 weeks post-operatively consisting of progressive range of motion exercises.

# METHODS

Six male and 9 female patients with a median age of 39 years (IQR 37-53) underwent a retinacular sling reconstruction (Table 1). Two surgeons performed these surgeries.

Eight patients reported an acute onset of their symptoms after a specific injury; 3 of the injuries were sustained during sporting activities (2 playing golf and 1 playing tennis). The median time between the date of injury and the first visit to our institutions was 5.9 months (IQR 1.7-6.9). Seven patients were not able to recall any acute trauma and reported a gradual onset of their symptoms, aggravated by physical activity. Eight patients injured the dominant wrist.

All patients complained about pain over the dorso-ulnar wrist. Eleven patients had a palpable dislocation of the ECU tendon along the ulnar head with active or passive supination and ulnar deviation on examination. Radiographs were unremarkable in 6 patients, while 3 patients had signs of mild soft tissue edema overlying the ulnar styloid process. An additional MRI was obtained in 9 patients. This showed a subluxation of the ECU tendon in 1 patient (Figure 2); an ulnar-sided capsular injury in another patient; tendinopathy of the ECU tendon in 4 patients; a split tear of the ECU tendon in 1 patient (Figure 3); and a peripheral triangular fibrocartilage complex (TFCC) pathology in 3 patients.

Treatment prior to surgery consisted of splint immobilization in 10 patients; non-steroidal anti-inflammatory medication in 5 patients and local steroid injections in 6 patients. One patient underwent a primary subsheath repair by another physician and presented with a recurrent ECU subluxation. The patients proceeded to surgery at a median of 5.9 weeks after an interval of non-operative treatment (IQR 2.4-13).

Questionnaires were completed by 10 patients at a median follow-up of 8.4 years after their procedure (IQR 7.8-11) (Table 2). The median PROMIS UE-PF score was 56 (IQR 41-56), the median score for pain 0.5 (IQR 0-2) and the median score for satisfaction 9.5 (IQR 6-10). Four patients reported persistent symptoms related to their ECU subluxation in rest or during forceful forearm rotation, 1 patient experienced limitations in daily activity, and 4 patients experienced limitations in their sports activity (Table 2).

**Table 1.** Characteristics of study cohort, complications and reoperations

| Patient | Age at surgery | Affected side | Onset of symptoms | Prior wrist surgery | Related pathology | Concomitant procedure | Complications | Reoperations |
|---|---|---|---|---|---|---|---|---|
| *1* | 61 | non-dominant | acute | none | none | tenosynovectomy ECU | none | none |
| *2* | 45 | dominant | acute | none | none | none | none | none |
| *3* | 37 | dominant | acute | none | split tear ECU | none | none | none |
| *4* | 36 | dominant | acute | none | TFCC tear | tenosynovectomy ECU | none | removal stitch |
| *5* | 29 | dominant | acute | ORIF ulna | TFCC tear + ulnar-sided capsular injury | TFCC repair | ECU tendinitis | none |
| *6* | 53 | dominant | graduate | none | none | none | none | none |
| *7* | 46 | non-dominant | acute | none | ECU tendinopathy | tenosynovectomy ECU | none | none |
| *8* | 39 | dominant | acute | none | TFCC tear + ECU tendinopathy | TFCC debridement | none | none |
| *9* | 59 | non-dominant | graduate | TFCC debridement | ECU tendinopathy | neurolysis cutaneous branches ulnar nerve | none | none |
| *10* | 36 | non-dominant | graduate | none | ECU tendinopathy | tenosynovectomy ECU | none | none |
| *11* | 61 | dominant | graduate | none | none | none | none | neurolysis cutaneous branches ulnar nerve x2 and USO |
| *12* | 46 | non-dominant | acute | none | none | none | ECU tendinitis | none |
| *13* | 37 | non-dominant | graduate | TFCC debridement | none | none | none | none |
| *14* | 34 | dominant | graduate | TFCC debridement | none | none | none | none |
| *15* | 34 | non-dominant | graduate | none | none | excision ganglion | none | TFCC debridement |

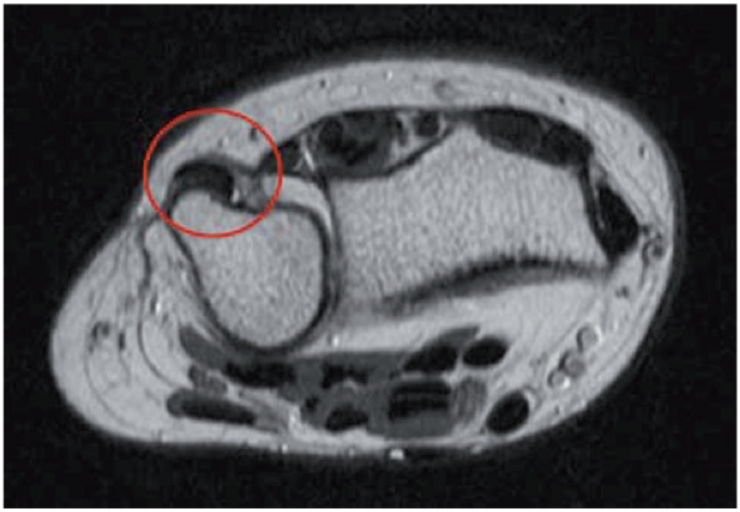

**Figure 2.** Subluxation of the distal extensor carpi ulnaris tendon. Axial T1-weighted image with the forearm neutral showing the distal extensor carpi ulnaris tendon subluxated. Circle indicates the ECU tendon.

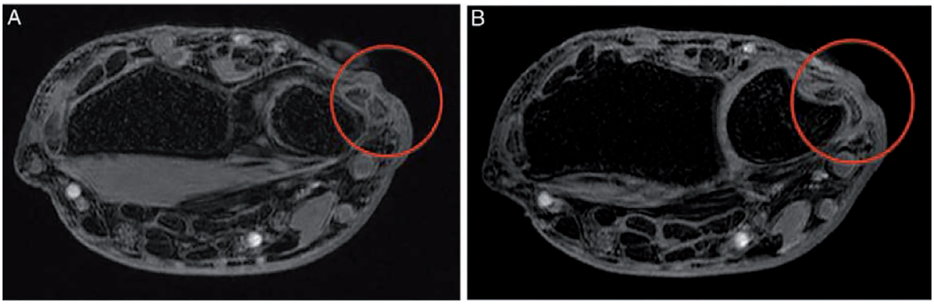


**Figure 3.** Subluxation and split tear of the distal extensor carpi ulnaris tendon. Axial magnetic resonance imaging T1 3D-FSPGR special; a marker was placed over the dorsomedial surface of the distal ulna. (a) There is a split tear of the extensor carpi ulnaris tendon at the level of the skin marker and extending distally. (b) View more distally; the tendon is subluxated. Circles indicate the ECU tendon.

# COMPLICATIONS AND REOPERATIONS

There are several complications to be considered after retinacular sling reconstruction. Injury to the sensory branches of the dorsal ulnar nerve can cause pain and/or paresthesia. Care should be taken to identify and protect any crossing sensory branches intra-operatively. These branches usually cross the axial midline approximately at the midpoint between the ulnar styloid and the fifth metacarpal base, but this course is variable. The ECU tendon can rupture as a result of attrition, weakening from chronic inflammation or iatrogenic manipulation. The same conditions can lead to tendinitis of the ECU. When the repair is too tight, it can cause a stenosing tenosynovitis of the ECU. Intra-operatively, one should check if there is smooth

**Table 2.** Long-term outcomes of study cohort

| Patient | Follow-up (in years) | PROMIS UE-PF | Pain | Satisfaction | Symptoms at rest | Symptoms during forceful forearm rotation | Limitations in daily activity | Limitations in sports activity |
|---|---|---|---|---|---|---|---|---|
| *1* | * | * | * | * | * | * | * | * |
| *2* | 11.4 | 56.4 | 0 | 10 | none | none | none | plays tennis two-handed to spare operated wrist |
| *3* | * | * | * | * | * | * | * | * |
| *4* | 8.4 | 56.4 | 1 | 10 | none | none | none | none (plays hockey and baseball) |
| *5* | 8.4 | 40.5 | 4 | 2 | none | tenderness, sometimes snapping sensation, no palpable dislocation | none | none (does not practice any sports) |
| *6* | 13.6 | 56.4 | 0 | 10 | none | none | none | does push-ups with closed fists |
| *7* | * | * | * | * | * | * | * | * |
| *8* | 10.2 | 56.4 | 0 | 9 | none | none | none | none (plays golf) |
| *9* | 7.8 | 56.4 | 2 | 9 | sometimes swelling and tenderness | none | none | none (does yoga) |
| *10* | 8 | 56.4 | 0 | 10 | none | none | none | none (goes to the gym) |
| *11* | 5.8 | 37.1 | 3 | 3 | swelling | pain, no snapping or dislocation | weakness, sometimes drops things | not able to do yoga or pilates |
| *12* | * | * | * | * | * | * | * | * |
| *13* | 13.8 | 35 | 3 | 6 | tenderness | pain, no snapping or dislocation | none | not able to play tennis |
| *14* | * | * | * | * | * | * | * | * |
| *15* | 7.3 | 47.6 | 0 | 10 | none | none | none | none (does not practice any sports) |

**not available for telephone interview* gliding of the ECU tendon, without any signs of subluxation with wrist flexion and extension. As mentioned previously, it is important to recognize other concomitant causes for ulnar-sided wrist pain. Wrist arthroscopy can be performed prior to ECU stabilization to either rule out or diagnose and treat other causes of ulnar-sided wrist pain (eg TFCC lesions).

In our cohort, no ruptures of the ECU tendon occurred. Two patients developed ECU tendinitis after respectively 5 and 9 months post-operatively. Both patients were injected with 1 ml of dexamethasone and 1 ml of lidocaine. This resolved symptoms in 1 patient; the other patient had continued wrist-pain. One patient experienced ulnar-sided wrist pain after playing tennis 3 months post-operatively. She was placed in a cast for 3 weeks, which completely resolved her complaints. Another patient had ongoing pain during rotation; MRI showed some thickening around the extensor tendon, but no recurrent subluxation or other pathology. This was considered a normal post-operative imaging finding and the patient did not undergo any further treatment despite continued symptoms. Three patients underwent a reoperation. Of these, 1 patient experienced irritation by one of the permanent stitches used in reconstruction and requested removal of this stitch. Another patient had continued ulnar-sided wrist pain and underwent an arthroscopic TFCC debridement 9 months after the ECU subsheath reconstruction. The third patient underwent 3 subsequent operations, at 5 months, 15 months and 24 months after her initial surgery. The patient first underwent neurolysis of 2 sensory branches of the dorsal ulnar nerve and ECU tenolysis that maintained integrity of the reconstruction, then an USO for ulnar impaction, and repeat neurolysis of 2 sensory branches of the dorsal ulnar nerve with release of the ECU tendon sheath. At her last clinical follow-up, the patient still experienced stiffness and pain aggravated by activity.

# DISCUSSION

Inoue and Tamura described 3 types of subluxation of the ECU tendon [6,7] In type A, the fibro-osseous sheath is disrupted at its ulnar side and the tendon may lie beneath the fibro-osseous sheath. In type B, the sheath is disrupted from its radial wall and the tendon may overlie it and prevent healing. In type C, the tendon dislocates into a false pouch formed by stripping of the periosteum from the ulna. Some authors base surgical decision making on this classification: a direct repair is preferred when the site of subsheath disruption is radial, while an extensor retinaculum (ER) graft is preferred in case of an ulnar disruption.[6] In our study, we used a radially based sling of the ER for all patients. We favor this technique over a direct repair because we feel that direct repair has a higher risk of being too tight, resulting in a stenosing tenosynovitis.[14] Furthermore, it allows for concomitant treatment of instrinsic ECU pathologies as opposed to strategies that leave the ECU sheath intact.

Some surgeons theorize that a shallow ECU groove may represent an anatomic variation that predisposes patients to subsequent ECU subluxation, and therefore deepen the groove as a component of ECU stabilization.[4,11] However, this concept continues to be controversial. A recent study on 5 human cadaveric specimens however showed that groove deepening did not improve stability of the ECU tendon, and concluded that subsheath reconstruction alone was equally effective at eliminating dislocation events.[18] We do not deepen the groove as we share concerns of other authors: Overaggressive deepening may weaken the bone and cause rim fractures.[13,18] Furthermore, if the ulnar border of the ECU groove is not re-established in the presence of a deepened sulcus, the tendon actually may have a higher risk of subluxating. Recurrent subluxation in the setting of a deepened groove may lead to more tendon damage than if the groove was shallower and had a smoother transition at its border.[13,18]

## CONCLUSION



In conclusion, ECU sheath reconstruction using a radially based extensor retinacular sling yielded high satisfaction and validated outcomes in most patients, despite some residual symptoms. This technique allows the surgeon to address pathology in the tendon sheath, unlike procedures that rely on preservation of sheath integrity, and appears to have reasonable and durable results.

# REFERENCES


1. Burkhart SS, Wood MB, Linscheid RL. Posttraumatic recurrent subluxation of the extensor carpi ulnaris tendon. J Hand Surg Am. 1982;7(1):1-3
2. Rayan GM. Recurrent dislocation of the extensor carpi ulnaris in athletes. Am J Sports Med. 1983;11(3):183-184
3. Campbell D, Campbell R, O'Connor P, Hawkes R. Sports-related extensor carpi ulnaris pathology:a review of functional anatomy, sports injury and management. Br J Sports Med. 2013;47(17):1105-1111
4. Iorio ML, Huang JI. Extensor carpi ulnaris subluxation. J Hand Surg Am. 2014;39(7):1400-1402
5. Rowland S. Acute traumatic subluxation of the extensor carpi ulnaris tendon at the wrist. J Hand Surg Am. 1986;11A:809-811.
6. Inoue G, Tamura Y. Recurrent dislocation of the extensor carpi ulnaris tendon. Br J Sports Med. 1998;32(3):172-174
7. Inoue G, Tamura Y. Surgical treatment for recurrent dislocation of the extensor carpi ulnaris tendon. J Hand Surg Am. 2001;26(6):556-559
8. Eckhardt WA, Palmer AK. Recurrent dislocation of extensor carpi ulnaris tendon. J Hand Surg Am. 1981;6(6):629-631
9. Adams B. Distal radioulnar joint instability. In: Wolfe SW, Hotchkiss RN, Pederson WC, Kozin SH. In: Green's Operative Hand Surgery. 6th editio. Philadephia: Elsevier; 2011:523-560.
10. Stathopoulos IP, Raptis K, Ballas EG, Spyridonos SPG. Recurrent dislocation of the extensor carpi ulnaris tendon in a water-polo athlete. Trauma Mon. 2016;21(1).
11. MacLennan AJ, Nemechek NM, Waitayawinyu T, Trumble TE. Diagnosis and Anatomic Reconstruction of Extensor Carpi Ulnaris Subluxation. J Hand Surg Am. 2008;33(1):59-64.
12. Allende C, Le Viet D. Extensor carpi ulnaris problems at the wrist-classification, surgical treatment and results. J Hand Surg Am. 2005;30(3):265-272
13. Graham TJ. Pathologies of the Extensor Carpi Ulnaris (ECU) Tendon and its Investments in the Athlete. Hand Clin. 2012;28(3):345-356
14. Ruchelsman DE, Vitale MA. Extensor Carpi Ulnaris Subsheath Reconstruction. J Hand Surg Am. 2016;41(11):e433-e439
15. Spinner M, Kaplan E. Extensor carpi ulnaris. Its relationship to the stability of the distal radio-ulnar joint. Clin Orthop Relat Res. 1970;68:124-129.
16. Iorio ML, Bayomy AF, Huang JI. Morphology of the extensor carpi ulnaris groove and tendon. J Hand Surg Am. 2014;39(12):2412-2416
17. Taleisnik J, Gelberman RH, Miller BW, Szabo RM. The extensor retinaculum of the wrist. J Hand Surg Am. 1984 Jul;9(4):495-501
18. Puri SK, Morse KW, Hearns KA, Carlson MG. A Biomechanical Comparison of Extensor Carpi Ulnaris Subsheath Reconstruction Techniques. J Hand Surg Am. 2017;42(10):837.

# Chapter 8

## Long-term results of pisiformectomy in a cohort of 57 patients

***Verhiel SHWL**, Blackburn J, Ritt MJPF, Chen NC*

*J Wrist Surg. 2020 Dec;9(6):465-469*

# ABSTRACT

**Purpose** Excision of the pisiform is an infrequently used option for pisotriquetral joint dysfunction when nonoperative treatment is ineffective. This study reviews the patient-reported outcomes of patients treated with pisiformectomy, and furthermore focuses on the complications and the need for and time to revision procedure.

**Methods** Medical records of 57 patients were manually reviewed and assessed for complications, rate of unplanned reoperations and type of reoperations. Thirty-seven patients (65%) completed patient-rated outcomes surveys at a median of 10 years after their procedure.

**Results** The complication rate was 13% (n=7). Ulnar nerve symptoms were noted in 3 patients. No reoperations were performed after the pisiform excision. Out of the 16 patients who had pre-operative symptoms of ulnar nerve compression at the wrist, 10 patients reported that their symptoms had completely resolved after the surgery. The median QuickDASH score after surgery was 4.5 (2.3-16), median score for pain 0 (IQR 0-2) and median score for overall satisfaction 10 (IQR 8-10).

**Conclusions** Pisiformectomy is a surgery used sparingly in cases with refractory pain associated with arthrosis of the pisotriquetral joint or enthesopathy of the FCU/pisiform interface. When utilized in this fashion, patients report limited disability on patient-rated outcome measures, low pain scores and high satisfaction at mid- to late- follow-up

# INTRODUCTION

The pisiform contributes indirectly to wrist and hand function through its multiple soft tissue attachments and articulation with the triquetrum.[1–6] The etiologic factors that are believed to contribute to pisotriquetral joint dysfunction are trauma (acute or chronic), instability of (carpal tunnel release, hypermobile joint), ganglion, arthritis, and flexor carpi ulnaris tendinopathy.[3,7]

Clinically, patients with pisotriquetral arthritis often present with pain localized to the ulnar side of the wrist and aggravated by contraction of the FCU. Symptoms of ulnar nerve paraesthesia may be present.[4,8,9] Usually, nonoperative treatment, consisting of splinting or injection, is successful. Excision of the pisiform is an infrequently used option when nonoperative treatment is ineffective.[5,7,8,10–13]

Pisiformectomy relieves pain variably among studies, ranging from 50%[8] to 97% success rates.[5,7,12,14–16] Some authors report a high rate of return to work.[5,14] Similarly, return of range of motion and grip strength are variable. [5,10–14,16] Most of these observational studies consist of small cohorts of up to 30 patients [5,7,8,11,13–16] and generally use patient reported outcome measures. This study reviews the patient-reported outcomes of patients treated with pisiformectomy by 1 of 3 surgeons, and furthermore focuses on the complications and the need for and time to revision procedure.



# METHODS

This study was performed with the approval of our IRB. We performed a retrospective multicenter study with cross-sectional follow-up of patients undergoing a pisiform excision at 1 of 3 large urban area hospitals (2 level I trauma centers and 1 associated community hospital) between January 2002 and December 2017. We identified patients from the Institution's RPDR using CPT code 25210 "Carpectomy; one bone". Of the 358 patients with this code, 73 had a pisiform excision. Thirteen patients were excluded because their pisiform excision was part of a larger procedure (e.g. four corner fusion or pisotriquetral excision) and 3 patients were excluded because of incomplete recordkeeping. Our final cohort consisted of 57 patients.

For all identified patients, demographic characteristics (age, sex, dominant hand, arthritis, diabetes mellitus, smoking status, alcohol dependency, manual labor as occupation), disease characteristics (affected hand, prior ipsilateral wrist trauma or surgery, symptom duration, indication for surgery, neurologic symptoms, radiographic, intra-operative and pathology findings) and treatment characteristics (prior treatment, concomitant procedures performed) were extracted from the hospital's electronic medical charts.

## Patient characteristics

Thirty-nine female (68%) and 18 male patients (32%) with a median age of 52 years (IQR 39-59 years) underwent a pisiform excision (Table 1). The direct indication for their surgery was PT arthrosis in 48, FCU enthesopathy in 5, PT inflammation in 2, pisiform non-union in 1 and pisiform subluxation in 1. Fifteen patients had a history of arthritis (25%), most often osteoarthritis (n=9), followed by rheumatoid arthritis (n=4). Twenty-two patients (39%) had a prior surgery to the ipsilateral hand, of whom 8 patients had a carpal tunnel release and 2 had a Guyon's canal release. Nineteen patients (33%) gave a history of a definite injury proceeding the symptoms, the other patients had an insidious onset of symptoms increasing over a variable period. All patient characteristics can be found in Table 1.

Diagnosis was based on the combination of clinical- and radiographic findings. The primary presenting symptom was pain, varying from mild to severe. The pain was worse with direct pressure to the PT joint. Sixteen patients (28%) had symptoms of ulnar nerve compression at the wrist with paresthesia, numbness or weakness in the appropriate distribution. Standard postero-anterior and lateral radiographs were obtained for all patients, to rule out other causes. Additional imaging (other than radiographs) was obtained for 56% of the patients, most often MRI. This imaging confirmed PT arthrosis in 22 patients, FCU tendinopathy in 2 and PT instability in 1. Additional findings were TFCC tears in 7 patients, a ganglion in the PT joint in 3 and ECU tendinopathy in 2. A nerve conduction study was performed in 9 patients (16%), 1 showed mild ulnar neuropathy at Guyon's canal, 2 showed mild median neuropathy and the others were negative for ulnar or median neuropathy. Prior to operation, patients were treated with non-operative measures, which included local steroid injections (n=32), splints (n=22) and non-steroidal anti-inflammatory drugs (n=3). Patients underwent pisiformectomy after a median duration of symptoms of 13 months (IQR 10-24 months).

## Surgical procedure

Excision of the pisiform was performed through a volar approach. An incision was made over the pisiform and carried down through the skin and subcutaneous tissue. The FCU was identified and followed distally to the pisiform. The FCU fibers were split in the longitudinal direction and then the pisiform was removed, while identifying and protecting the ulnar neurovascular bundle. The FCU was approximated with a suture. Post-operative immobilization was variable, though most patients were placed in a palmar splint for 10 days until suture removal.

## Outcome measurement

Medical records of patients were manually reviewed and assessed for complications, rate of unplanned reoperations and type of reoperations.

Patients were invited by letter to complete patient rated outcomes surveys and over the phone or by email. In addition, they were asked to answer some additional questions regarding potential neurologic symptoms, pain around the incision area and current use of painkillers.[17] Two patients (3.5%) passed away during the follow-up period, three (5.3%) refused to participate, and 16 (28%) could not be reached. The 36 patients willing to participate formed the study's sample size, which reflects a response rate of 63%. The median time from pisiform excision to the follow-up was 10 years (IQR 4.5-14 years).

Patients were asked how their neurologic symptoms changed after the procedure (in case of pre-operative neurologic symptoms), how many months it took before the area around the incision was completely pain-free, and if they currently take any painkillers for pain related to the pisiform excision.

The patient rated functional outcome was measured by the QuickDASH questionnaire.[18] The QuickDASH consists of 11 questions about daily activities and symptoms, each scored on a scale of 1 (no disability) to 5 (severe disability). These scores are transformed to a scale of 0 to 100, reflecting patients' perception of physical arm function and symptoms. A higher score indicates more arm related disabilities experienced by the patient.[18] Patients rated their average pain in rest and during forceful forearm rotation during the last month and overall satisfaction with the outcome of the procedure. For pain-assessment, the scale ranged from '0' representing "no pain" to '10' representing "worst pain imaginable". For assessment of satisfaction, the scale ranged from '0' representing "not satisfied at all" to '10' representing "couldn't be more satisfied".



### Statistical evaluation

We described discrete data using frequencies and percentages, and our non-normally distributed continuous data through medians and IQR. Bivariate analyses were performed to identify factors associated with our outcomes. To identify factors associated with our outcomes complications and reoperations, the two-sided Fisher Exact test was used for dichotomous and categorical explanatory variables, and an unpaired Mann-Whitney U Test for continuous explanatory variables. To identify factors associated with our outcomes QuickDASH, pain in rest, pain during rotation and satisfaction, an unpaired Mann-Whitney U Test was used for dichotomous explanatory variables, a Kruskal-Wallis test for categorical explanatory variables, and Spearman's rank correlation coefficient for continuous explanatory variables.

## RESULTS

At operation, macroscopic osteoarthritis was noted in 39 patients. Reactive effusion was seen in 8 patients, a PT ganglion in 3, FCU tendinitis in 3 and an osteocartilageneous body in the PT joint in 2 others. An abnormally large pisiform was described in 4 patients, and compression in Guyon's canal was seen in 2 others. Thirty-four patients underwent a concomitant procedure. Of these, 10 patients underwent a Guyon's canal release (18%), 4 underwent a carpal tunnel release (7%) and 6 underwent TFCC surgery (11%). Pathological examination was performed

**Table 1.** Patient characteristics and their associations with outcomes

| Patient characteristics | All (n=57) | Complications *P* value | Responders (n=37) | QuickDASH *P* value | Pain rest *P* value | Pain rotation *P* value | Satisfaction *P* value |
|---|---|---|---|---|---|---|---|
| **Demographics** | | | | | | | |
| Age in years, median (IQR) | 52 (39-59) | 0.90[1] | 53 (47-58) | 0.30[3] | 0.52 | 0.21 | 0.61 |
| Sex | | >0.99[2] | | 0.34[1] | 0.64[1] | 0.91[1] | 0.33[1] |
| Male, n (%) | 18 (32) | | 10 (27) | | | | |
| Female, n (%) | 39 (68) | | 27 (73) | | | | |
| Arthritis, n (%) | 15 (26) | >0.99[2] | 12 (32) | 0.26[1] | 0.30[1] | 0.43[1] | 0.85[1] |
| Diabetes, n (%) | 3 (5.3) | >0.99[2] | 2 (5.4) | 0.40[1] | 0.28[1] | 0.19[1] | 0.21[1] |
| Tobacco abuse reported in chart, n (%) | 7 (12) | 0.58[2] | 5 (14) | 0.81[1] | 0.74[1] | 0.72[1] | 0.83[1] |
| Alcohol abuse reported in chart, n(%) | 1 (1.8) | >0.99[2] | 0 (0) | NA | NA | NA | NA |
| Manual labor, n (%) | 23 (40) | >0.99[2] | 14 (38) | ***0.049[1]*** | 0.33[1] | 0.49[1] | 0.74[1] |
| **Condition related** | | | | | | | |
| Dominant side affected, n (%)* | 28 (58) | >0.99[2] | 17 (53) | 0.32[1] | 0.98[1] | 0.61[1] | 0.41[1] |
| Prior trauma ipsilateral hand/wrist, n (%) | 19 (33) | 0.68[2] | 11 (30) | 0.31[1] | 0.29[1] | 0.30[1] | 0.57[1] |
| Symptom duration prior to surgery in months, median (IQR) | 13 (10-24) | 0.86[1] | 13 (10-24) | 0.97[3] | 0.61[3] | 0.59[3] | 0.44[3] |
| Indication for surgery | | 0.40[2] | | 0.21[4] | 0.38[4] | 0.49[4] | 0.25[4] |
| PT arthrosis, n (%) | 48 (84) | | 29 (78) | | | | |
| FCU enthesopathy, n (%) | 5 (8.8) | | 5 (14) | | | | |
| PT inflammation, n (%) | 2 (3.5) | | 2 (5.4) | | | | |
| Pisiform nonunion, n (%) | 1 (1.8) | | 0 (0) | | | | |
| Pisiform subluxation, n (%) | 1 (1.8) | | 1 (2.7) | | | | |
| Symptoms ulnar nerve compression, n (%) | 16 (28) | 0.39[2] | 15 (41) | 0.69[1] | 0.14[1] | 0.29[1] | 0.99[1] |
| Additional imaging, n (%) | 32 (56) | 0.22[2] | 19 (51) | 0.11[1] | 0.12[1] | 0.33[1] | 0.24[1] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Treatment related** | | | | | | | |
| Prior conservative treatment, n (%) | 35 (61) | 0.095[2] | 19 (51) | 0.23[1] | 0.17[1] | 0.064[1] | 0.87[1] |
| Prior surgery ipsilateral hand/wrist, n (%) | 22 (39) | 0.70[2] | 13 (35) | 0.41[1] | 0.19[1] | 0.92[1] | 0.63[1] |
| Concomitant procedure (other than Guyon release), n (%) | 24 (42) | ***0.034[2]*** | 19 (51) | 0.74[1] | 0.73[1] | 0.76[1] | 0.91[1] |
| Concomitant Guyon release, n (%) | 10 (18) | 0.59[2] | 9 (24) | 0.66[1] | 0.78[1] | 0.86[1] | 0.54[1] |

*Mann-Whitney U Test, [2]Fisher's exact test, [3]Spearman's rank correlation coefficient, [4]Kruskal-Wallis test. NA=not applicable* for 42 patients (74%). Pathology reports came back as osteoarthritis in 34 patients (of whom 14 mild and 6 severe).

## Complications and reoperations

The complication rate was 13% (n=7). Ulnar nerve symptoms, with paresthesia and numbness, were noted in 3 patients. Two patients had a local skin infection which was successfully treated with local debridement in 1, and with systemic antibiotics (Amoxicillin/clavulanic acid for 7 days) in the other. A suture granuloma was reported in 2 patients. A concomitant procedure (other than Guyon release) was the only statistically significant factor associated with a higher complication rate (P=0.034; Table 1). No reoperations were performed after the pisiform excision.

## Patient rated outcomes

Out of the 16 patients who had pre-operative symptoms of ulnar nerve compression at the wrist, 10 patients reported that their symptoms had completely resolved after the surgery, 5 patients reported improvement, in 1 patient the symptoms remained equal. The area around the incision was free of pain within 2 months in 69% of the patients.

After a median of 10 years (IQR 4.5-14 years), the median QuickDASH score was 4.5 (2.3-16). Patients reported low scores for pain, with a median of 0 (IQR 0-2) for both pain in rest and pain during forceful forearm rotation. Patients were generally very satisfied, with a median score of 10 (IQR 8-10) for overall satisfaction after the procedure. Manual labour was associated with a higher QuickDASH score (more disability). No other characteristics were associated with QuickDASH, pain and satisfaction (Table 1).

# DISCUSSION

We report on 57 patients who underwent pisiformectomy, predominantly for arthritis of the pisotriquetral joint. Thirty-four of our patients had concomitant surgery, mostly for decompression of the ulnar nerve in Guyon's canal. Our complication rate was 13% but no patients required reoperations. Of the 37 patients who agreed to participate in our outcome surveys, the median satisfaction score was 10/10 (IQR 8-10) and 69% were pain-free within 2 months post-operatively. They also had good patient-reported outcome scores, with NRS of 0 for pain at rest or on forceful forearm rotation (IQR 0-2) and QuickDASH of 4.5 (IQR 2.3-16).

Our findings should be interpreted within the limitations of the study. We successfully contacted 65% of our cohort for information about their current clinical condition. There may be a selection bias in that patients who agreed to participate in our study might have better outcomes than those that declined. Secondly, we did not measure range of motion, grip strength in follow-up because of the logistical difficulties in re-evaluating patients. Third, we did not have preoperative patient-reported outcome measures to allow calculation of improvement in pain and function scores. Finally, it is important to recognize that pisiformectomy is sparingly performed. Among 3 surgeons, there were on average 4 pisiformectomies performed each year over a 16 year span.

The advantage of this study is that we were able to obtain patient-reported outcomes from 37 patients. This compares favorably with other cohorts ranging from 9[8,10] to 30 patients.[5,7,11,13,14,16,19] Carroll & Coyle described outcomes of 76 pisiformectomies but did not report any patient-reported outcomes.[12]

Our patients were broadly similar demographically to patients who underwent pisiformectomy in other studies, as 68% were female with an average age of 52 years. In other studies, the average age of participants was in their late 40s[5,10,12–14] and between 56%[12] and 88% female[7,8,10,16]. In keeping with other studies, all our patients presented with pain.[8,10,11,14] In our study 28% of patients had symptoms of ulnar nerve compression, while in other studies rates ranged from 20%[13] to 91%[8,10–12]. Additional imaging was obtained for 56% of our patients, while in other studies MRI was used in between 14%[7] and 73%[10] of patients.

The indications for surgery in our patients was predominantly arthritis (48/57 patients), and this is similar to other studies where arthritis was the indication for surgery between 71%[7] and 92%[11] of patients. In 5 patients (8.8%) FCU enthesopathy was the indication for surgery, which is lower than the 14% reported by another study.[7] Thirty-four patients underwent concomitant procedures including 10 Guyon's canal release, 4 carpal tunnel release and 6 TFCC surgery. In other studies of pisiformectomy, concomitant ulnar nerve decompression rates are slightly higher at 20%[16] to 25%[8].

Our complication rate was 13%, including 3 with ulnar nerve symptoms, 2 infections requiring either debridement or antibiotic treatment and 2 suture granulomas. Prior studies do not document complications.[7,8,11–13,16,19] However, in these studies some patients went on to have further surgery to the DRUJ[12], resection of the distal ulna1[2] or Darrach procedure[8]. This speaks to the confounding nature of ulnar-sided wrist pain, and caution should be taken before proceeding to pisiform excision.

The median QuickDASH score for our patients at 10 year follow up was 4.5 (2.3-16). In a study from France that included 11 patients, postoperative median QuickDASH score was 27.6 at almost 8 years follow up.[19] In another study of 35 patients, median DASH score after pisiformectomy was 25.3 (12-38).[13]

Furthermore, our patients also reported low scores for pain at 10 year follow up with median NRS of 0 (IQR 0-2) for both pain at rest and during forceful forearm rotation. In a study of 35 patients, NRS scores after pisiformectomy were comparable: 1.3 (0-3).[13] In another study of 11 patients, postoperative NRS scores were also similar at 1.1.[19] The patients that agreed to participate in our study reported a very high satisfaction with the outcome of their pisiformectomy (10/10, IQR 8-10). This is similar to the excellent satisfaction reported in another study of pisiformectomy from the USA.[16]

8

We feel that our data can serve as a reference for decisions prior to electing pisiformectomy in cases with refractory pain associated with arthrosis of the pisotriquetral joint or enthesopathy of the FCU/pisiform interface. It is important to recognize that we advocate for non-operative management as much as possible as evidenced by the relatively small number of surgical procedures over 16 years among 3 hospitals. Using strict indications, complication- and reoperation rates are low. Furthermore, patients report limited disability on patient-rated outcome measures, low pain scores and high satisfaction at mid- to late- follow-up.

# REFERENCES

1. Pevny T, Rayan GM, Egle D. Ligamentous and tendinous support of the pisiform, anatomic and biomechanical study. J Hand Surg Am 1995;20(2):299-304
2. Yamaguchi S, Viegas SF, Patterson RM. Anatomic study of the pisotriquetral joint: Ligament anatomy and cartilagenous change. J Hand Surg Am 1998;23(4):600-606
3. Rayan GM, Jameson BH, Chung KW. The pisotriquetral joint: anatomic, biomechanical, and radiographic analysis. J Hand Surg Am 2005;30(3):596-602
4. Moraux A, Lefebvre G, Pansini V, et al. Pisotriquetral joint disorders: an under-recognized cause of ulnar side wrist pain. Skeletal Radiol 2014;43(6):761-773
5. Lam KS, Woodbridge S, Burke FD. Wrist function after excision of the pisiform. J Hand Surg Br 2003;28(1):69-72
6. Moojen TM, Snel JG, Ritt MJPF, Venema HW, Den Heeten GJ, Bos KE. Pisiform kinematics in vivo. J Hand Surg Am 2001;26(5):901-907
7. Gómez CL, Renart IP, Pujals JI, Palou EC, Busquets RC. Dysfunction of the pisotriquetral joint: degenerative arthritis treated by excision of the pisiform. Orthopedics 2005;28(4):405-408
8. Johnston GH, Tonkin MA. Excision of pisiform in pisotriquetral arthritis. Clin Orthop Relat Res 1986;(210):137-142
9. Kofman KE, Schuurman AH, Mulder MC, et al. The pisotriquetral joint: osteoarthritis and enthesopathy. J Hand Microsurg 2014;6(1):18-25
10. Van Eijzeren J, Karthaus RP. The effect of pisiform excision on wrist function. J Hand Surg Am 2014;39(7):1258-1263
11. Belliappa PP, Burke FD. Excision of the pisiform in piso-triquetral osteoarthritis. J Hand Surg Br 1992;17(2):133-136
12. Carroll RE, Coyle MP. Dysfunction of the pisotriquetral joint: treatment by excision of the pisiform. J Hand Surg Am 1985;10(5):703-707
13. Lautenbach M, Eisenschenk A, Langner I, Arntz U, Millrose M. Comparison of clinical results after pisiformectomy in patients with rheumatic versus posttraumatic osteoarthritis. Orthopedics 2013;36(10):e1239-1243
14. Palmieri TJ. Pisiform area pain treatment by pisiform excision. J Hand Surg Am 1982;7(5):477-480
15. Paley D, McMurtry RY, Cruickshank B. Pathologic conditions of the pisiform and pisotriquetral joint. J Hand Surg Am 1987;12(1):110-119
16. Campion H, Goad A, Rayan G, Porembski M. Pisiform excision for pisotriquetral instability and arthritis. J Hand Surg Am 2014;39(7):1251-1257
17. Bot A, Becker SJE, Mol MF, Ring D, Vranceanu AM. Validation of phone administration of short-form disability and psychology questionnaires. J Hand Surg Am 2013;38(7):1383-1387
18. Kennedy CA, Beaton DE, Smith P, et al. Measurement properties of the QuickDASH (Disabilities of the Arm, Shoulder and Hand) outcome measure and crosscultural adaptations of the QuickDASH: a systematic review. Qual Life Res 2013;22(9):2509-2547
19. De Almeida Y, Piessat C, Athlani L, Dap F, Dautel G. Pisiformectomy in advanced pisotriquetral joint arthritis: a retrospective study of 12 wrists with a mean follow-up of 7.5 years. Hand Surg Rehabil 2019;38(3):165-168

# Chapter 9

## Carpometacarpal 4/5 fracture dislocations: fracture morphology and surgical treatment

***Verhiel SHWL***, *Knaus WJ, Simeone FJ, Mudgal CS*

*J Hand Microsurg. 2020 Oct;12(Suppl 1):S21-S27*

# ABSTRACT

We conducted a retrospective review of 6 patients with CMC 4/5 fracture-dislocations managed with ORIF by a single surgeon between October 2006 and August 2017. An open, dorsal approach to the hamate was utilized with a combination of interfragmentary screw fixation and Kirschner wire reduction of the CMC joints. At a mean of 96 days follow-up (range 31-265), all patients had recovered wrist motion, excellent grip strength and complete resolution of pain. There were no complications or reoperations during the postoperative period. Radiographic review showed restoration of anatomy and well-maintained congruity of the CMC joints. Our study has shown favorable outcomes after open reduction and internal fixation of the hamate body fracture with interfragmentary screws, when combined with stabilization of the CMC dislocation with percutaneous Kirschner wires. Fracture morphology does not appear to guide choice for specific hardware (size screw, headed/headless) or use of a washer.

# INTRODUCTION

Hamate fractures represent only 2-4% of all carpal fractures, with injuries of the hamate body being the most rare variant.[1–3] Coexistence with CMC dislocation accounts for less than 1% of all hand trauma.[1,2,4–6]

A high clinical suspicion and adequate use of radiological tests are required for diagnosing the injury.[1,7] An early diagnosis is essential in order to avoid or minimize the risk for fracture malunion, non-union, posttraumatic arthritis, and chronic pain.[3,7] Plain radiography is not optimal to evaluate this area of the carpal anatomy, due to the irregular topography, small fracture fragments, and complex articulations. CT can be more useful for the diagnosis and for an accurate definition of the fracture pattern.[1,3,7,8]

The original classification system of CMC 4/5 fracture-dislocations was developed by Cain et al. and was based on the orientation of the hamate fracture line.[9] Advances in diagnostic imaging have allowed for more accurate assessment of injury morphology to the hamato-metacarpal complex, which has resulted in the development of novel classification systems. These new classification systems have focused on more specific features, such as the presence of metacarpal base fractures and the size of the intra-articular hamate fracture fragment.[2,6,7,10]



Treatment options for fractures of the hamate range from non-operative immobilization to operative internal fixation with Kirschner wires and/or interfragmentary screws. Displaced hamate fractures, or those with an associated metacarpal fracture and dislocation, are probably better treated with ORIF.[1-6,8,9,11-14]

To date, treatment guidelines have largely been based on individual case reports or small case series without consistent outcome measures.[1–6,8,10,14,15] We therefore aim to present a series of patients who underwent surgical treatment for this injury by a single surgeon at our institution, to assess the fracture morphology and to describe the surgical technique that was used. Furthermore, we aim to report complications and outcomes after surgical treatment.

# METHODS

This study was approved by the hospital's IRB (# 2017P000694). We conducted a retrospective review of patients at a single institution who underwent surgical treatment for CMC 4/5 fracture-dislocations between October 2006 and August 2017, by a single surgeon. We excluded patients younger than 18 years of age and patients who previously underwent other surgical treatment for their injury. All patients were operated on and followed by the senior author (CSM).

The electronic medical records were reviewed for demographic data including age and sex, as well as clinical information such as date of injury, laterality and dominance of injured hand, mechanism of injury and additional imaging that was obtained.

CT scans were reviewed on a picture archiving and communication system (AGFA IMPAX version 6.6, Mortsel, Belgium) to assess the fracture morphology**.** We carried out the following measurements using TeraRecon version 4.4 (Foster City, California): the length of the distal bone surface of the dorsal hamate fragment (in mm), the length of the distal bone surface of the palmar hamate fragment to include the hook of the hamate (in mm), the length of the gap between the fragments at the midpoint in the sagittal plane (in the radio-ulnar direction) (in mm), the distance between the fragments in the axial plane (in the dorsal-palmer direction) on the 4th metacarpal side (in mm), the distance between the fragments in the axial plane (in the dorsal-palmer direction) on the 5th metacarpal side (in mm), the volume of the dorsal fragment (in $cm^2$) and the volume of the volar fragment (in $cm^2$).

Medical records were reviewed for the surgical technique that was used for fixation. The post-operative course was determined by collecting data on complications, need for subsequent procedures, clinical union and outcomes in terms of range of motion and pain resolution.

Surgical technique involved exposure of the injury from a dorsal approach. If the hook of hamate was widely displaced, a volar and dorsal approach was used. A dorsal longitudinal incision is made between the bases of the 4th and 5th metacarpals to expose the CMC between the extensor tendons. The CMC joint is exposed and the capsule is entered longitudinally to expose the fracture segments. Fracture-site hematoma is removed and the hamate is reduced under fluoroscopy. A guide wire for a cannulated screw is placed into the hamate fracture, aiming for the hook of hamate. It is vital that this guidewire is placed incrementally with periodic imaging to avoid cortical penetration volarly thereby reducing the possibility of endangering the ulnar neurovascular bundle. The screw length is then determined and a cannulated screw is placed over the guidewire to fix the fracture. In most circumstances, the screw utilized was a 2.4 mm or 3.0 mm headed / headless cannulated screw (Synthes, Paoli PA). An additional interfragmentary screw would be placed into the body of the hamate if needed for additional stability.

The 4th and 5th metacarpal bases are then reduced to restore the CMC joint under fluoroscopy. Depending on the stability of the affected metacarpals, one or two 0.062 inch Kirschner wires are placed transversely from ulnar to radial along the fifth to fourth metacarpals or alternatively trans articularly into the hamate, if there is concern about hardware purchase in the 4th metacarpal in the presence of its concomitant fracture. The wound is then closed and placed into a forearm based bivalved splint, with the wrist in 20 degrees of extension and the metacarpophalangeal joints in an intrinsic plus position.

The patient is immobilized in a cast for 4 weeks. Metacarpophalangeal and interphalangeal range of motion is initiated at the first post-operative visit, on the 5th post-operative day. The cast and the pins are removed at around 4 weeks. The patient is then placed in a volar forearm based orthoplast resting splint, with the ring and small fingers buddy taped and the splint is weaned over the next 2 to 3 weeks, as strengthening is commenced. Unrestricted use of the hand and contact sports are allowed after 12 weeks.

# RESULTS

A total of 6 patients were identified as having undergone surgical treatment of CMC 4/5 fracture-dislocations using the aforementioned inclusion criteria. All patients were male, with a mean age of 35 years (range, 23-51 years). The dominant hand was most commonly affected (n=4, 67%), mechanism of injury was either punching (n=3), fall from standing position (n=2) or fall from a height (n=1). Two patients had a prior injury to the affected hand or wrist: one patient had a fracture of the ulnar styloid process, the other had a fracture through the midshaft of the fifth metacarpal bone. None of the patients had any previous surgeries performed on their injured hand or wrist. The average time from injury to presentation at our clinic was 12 days (range, 3-30 days).

Recognition of the true nature of the injury and immediate diagnosis by the radiologist based on initial plain radiographs occurred in only 1 case (Figure 1). CT scans were obtained for further evaluation and preoperative planning in all but one patient (n=5). Five patients had an associated fracture of the 4th metacarpal base, 1 patient had a fracture of the capitate. There was dislocation of the 5th CMC joint in 4 patients, dislocation of the 4th CMC joint in one other patient, and dislocation of both 4th and 5th CMC joints in the remaining patient (Table 1).



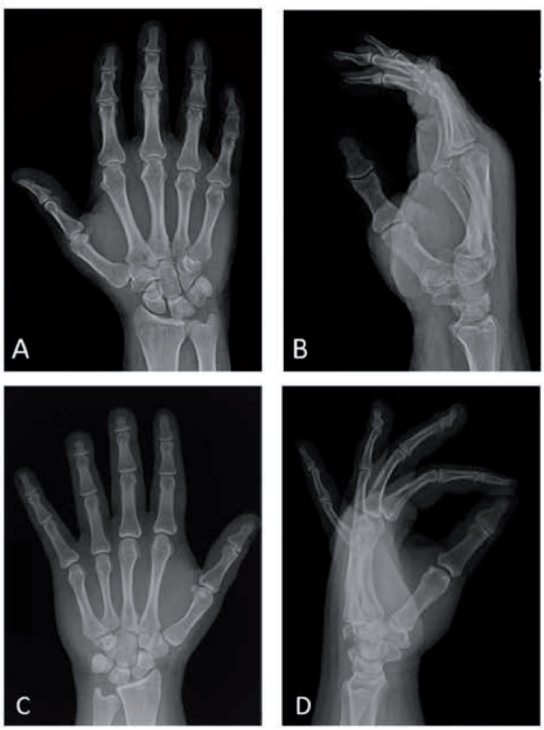


**Figure 1.** Initial radiographs. (a) Postero-anterior view. (b) Lateral view of patient 1 (diagnosis of fracture-dislocation under-diagnosed by radiologist). (c) Posteroanterior view. (d) Lateral view of patient 3 (diagnosis of fracture-dislocation made by radiologist).

**Table 1.** Injury- and surgical characteristics

| Patient | Metacarpal (MC) fracture | CMC dislocation | Time injury to surgery (in days) | Approach | Articular depression hamate | Number of screws | Type screws | Number Kirschner wires | Number washers | Concomitant procedure |
|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 4th MC base | CMC 5 | 14 | dorsal | no | 1 | Headless, cannulated screw (3mm) | 1 (base 5th MC across hamate into capitate) | 0 | none |
| *2* | 4th MC base | CMC 5 | 33 | dorsal + volar | no | 2 | Headed screw, short threaded x 2 (3mm and 2.4mm) | 2 (5th MC to 4th MC) | 1 | ulnar nerve release at Guyon's canal |
| *3* | 4th MC base | CMC 4 | 7 | dorsal | yes | 1 | Headed, cannulated screw (3mm) | 1 (threaded K wire to treat articular depression hamate) | 1 | none |
| *4* | none | CMC 4 + 5 | 12 | dorsal | no | 1 | Headed screw, fully threaded (2.4mm) | 2 (base 5th MC across hamate into capitate) | 0 | none |
| *5* | 4th MC base | CMC 5 | 20 | dorsal | no | 2 | Headed, cannulated screw x 2 (3mm) | 1 (5th MC to 4th MC) | 1 | none |
| *6* | 4th MC base | CMC 5 | 24 | dorsal | no | 1 | Headless, cannulated screw (3mm) | 2 (5th MC to 4th MC and base 5th MC into hamate) | 0 | none |

**Table 2.** Fracture morphology

| Patient | Length of distal bone surface of dorsal hamate fragment (in mm) | Length of distal bone surface of palmar hamate fragment (in mm) | Length of gap between fragments at midpoint (in mm) | Distance between fragments on 4th metacarpal side (in mm) | Distance between fragments on 5th metacarpal side (in mm) | Volume of dorsal fragment (in cm²) | Volume of volar fragment (in cm²) |
|---|---|---|---|---|---|---|---|
| *1* | 5.1 | 13.8 | 6.6 | 7.5 | 4.6 | 0.55 | 2.42 |
| *2* | 7.5 | 11.7 | 9.4 | 11.1 | 5.5 | 1.73 | 0.91 |
| *3* | 3.4 | 14.0 | 8.1 | 8.9 | 5.9 | 0.28 | 2.07 |
| *4** | - | - | - | - | - | - | - |
| *5* | 4.2 | 14.7 | 6.8 | 7.8 | 4.6 | 0.82 | 1.20 |
| *6* | 6.1 | 14.4 | 10.4 | 12.0 | 5.9 | 1.01 | 1.69 |

** no CT available*

CT scans were reviewed to further assess the hamate fracture morphology (Table 2; Figure 2 and 3). The average length of the distal bone surface of the dorsal hamate fragment was 5.3mm, the average length of the distal bone surface of the palmar hamate fragment was 13.7mm, the average length of the gap between the fragments at the midpoint (in the radioulnar direction) was 8.3mm, the average distance between the fragments on the 4th metacarpal

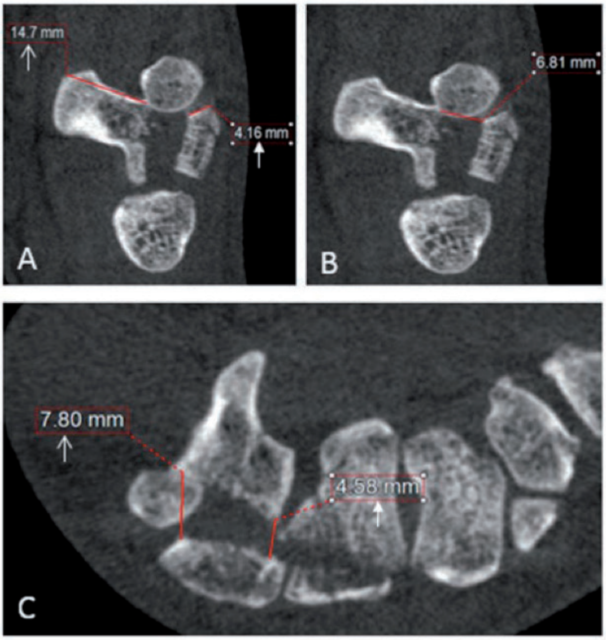


**Figure 2.** Fracture morphology of patient 5. (a) Length of distal bone surface of dorsal hamate fragment (solid arrow) and length of the distal bone surface of the palmar hamate fragment including the hook (open arrow). (b) Length of gap between fragments at the midpoint (in the radioulnar direction). (c) Distance between fragments on fourth metacarpal side (solid arrow) and distance between fragments on fifth metacarpal side (open arrow).

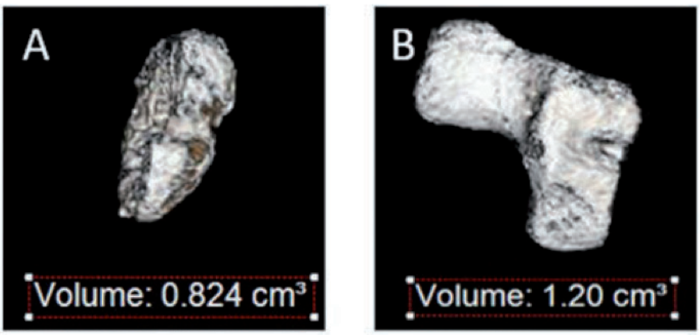


**Figure 3.** Fracture morphology of patient 5. (a) Volume of the dorsal fragment. (b) Volume of the volar fragment.

side was 9.5mm, the average distance between the fragments on the 5th metacarpal side was 5.3mm, the average volume of the dorsal fragment was $0.88 cm^2$ and the average volume of the volar fragment was $1.66 cm^2$.

Surgery was performed in all 6 patients, at an average of 18 days after injury (range 7-33 days; Table 1). All patients were immobilized with either a cast or a splint before surgical intervention. Operative treatment consisted of ORIF of the hamate fracture with interfragmentary screws and reduction of CMC dislocation with Kirschner wires under fluoroscopy. A dorsal approach was used in 5 cases, in 1 case a combined dorsal and volar approach was used. One screw was sufficient for fixation of the hamate in 4 cases, 2 screws were required in the 2 other cases. Two Kirschner wires were used for stabilization of the CMC joints in 3 cases, one wire was used for the same purpose in 1 case. One patient had articular depression of the hamate, which was elevated, bone grafted and fixed with a threaded Kirshner-wire cut flush and buried in an intraosseous manner. A washer was placed in 2 cases. In 1 case a concomitant ulnar nerve release in Guyon's canal was performed because this patient had developed a post-traumatic ulnar neuropathy of the hand in the setting of a delayed presentation. Intraoperative assessment showed stable CMC joints and stable reduction of the hamate fracture in all cases. Patients were placed in a short-arm splint after final radiographic confirmation (Figure 4). The Kirschner wires were removed after an average of 33 days (range, 24-39 days).

9


**Figure 4.** Immediate postoperative radiographs. (a) Posteroanterior view. (b) Lateral view. Radiographs of patient 1 show K-wire fixation of the base of the fifth metacarpal across the hamate into the capitate, in addition to headless screw fixation of the hamate fracture. (c) Posteroanterior view. (d) Lateral view. Radiographs of patient 3 show K-wire fixation after elevating the articular depression of the hamate, in addition to headed screw fixation of the hamate fracture.


**Figure 5.** Radiographs at last follow-up. (a) Posteroanterior view. (b) Lateral view. Radiographs of patient 1 show restoration of anatomy and well-maintained congruity of the carpometacarpal (CMC) joints at 52 days postoperatively. Kirschner wire was removed on day 24 postoperatively. (c) Posteroanterior view. (d) Lateral view. Radiographs of patient 3 show restoration of anatomy and well-maintained congruity of the CMC joints at 265 days postoperatively.

Mean follow-up was 96 days (range, 31-265 days). There were no complications or reoperations during the post-operative period. At the time of last follow-up, all 6 patients had good functional outcomes with full wrist flexion and extension, no distal deficit, no malrotation, excellent grip strength and complete resolution of pain. Review of final radiographic images showed restoration of anatomy and well-maintained congruity of the CMC joints (Figure 5).

# DISCUSSION

The rarity of hamate body fractures with CMC dislocations as well as the difficulty in diagnosing them on plain radiographs supports that they are likely underdiagnosed.[7] Inadequately treated hamate body fractures with CMC dislocations can result in non-union and resultant disability.[16,17] Similar to most displaced articular fractures in other locations, appropriate diagnosis and open reduction and internal fixation of the hamate body fractures involving the CMC articular surface is important in achieving optimal outcomes from this injury. In our series, we present our experience with this injury pattern including the clinical presentation, radiographic analysis, surgical technique, and clinical outcomes in six patients. With our technique, good results have been achieved as has been noted by other authors.[5,18–20]

A high index of suspicion is necessary when assessing patients on initial presentation. In our series, 5 of the 6 patients were under diagnosed on initial plain imaging read by an attending radiologist. CT imaging ultimately confirmed the diagnosis in the remaining patients. In a review of imaging of cadaver hands with hamate fractures, radiographs were noted to be 72.2% sensitive and 88.8% specific and CT scans were 100% sensitive, 94.4% specific.[21] Other authors have reviewed this injury and have noted improved sensitivity and specificity on plain films by measuring an increased index to small metacarpal angle of the CMC joint on lateral radiographs.[22] With displacement of a hamate body fracture, associated posterior dislocation of the ulnar-sided CMC joints has been noted in a previous report on radiographs.[23]

The mechanism of injury is thought to occur from axial loading of the ulnar-sided metacarpals transmitting force across the carpus through the hamate.[7,9,24]

In an effort to better understand the morphology of this fracture pattern, we have reviewed the available CT scans in our series and measured the fracture segments in multiple planes. In our series, the fracture preferentially occurred ulnar to the hook of the hamate. Van Schil et al have also reported a fracture ulnar to the hook of the hamate in their case report.[25] This suggests that the fifth metacarpal impaction may provide a more central dislocating force than the fourth metacarpal. Most commonly, the palmar segment was considerably larger than the dorsal segment as well. Knowledge of the fracture morphology may have implications in the technique of internal fixation. On the basis of our study, we feel that obtaining fixation into the hook of the hamate may not be critical to stable fixation or ultimate outcome. While headless screws were used in the 2 oldest cases, more recently our practice has changed towards the use of headed screws as the amount of bone that can be covered by headed screws is greater. Although the use of a headless screw appears to be independent of fragment size, we speculate that headless screws are best utilized when the dorsal fragment is thick enough to accommodate all the trailing threads of the headless screw. Furthermore, a washer was placed in 3 cases. Fragment size did not dictate the use of a washer either. The use of a washer appears to be more arbitrary and based on surgeon-preference after intra-operative assessment of dorsal fragment thickness as well as size. In the presence of a thinner dorsal fragment, the use of a washer may seem prudent to help dissipate the compressive forces over a larger area of the fragment, thereby reducing the possibility of fragment comminution and loss of fixation. Threaded Kirschner wires can be utilized for extremely small fragments or articular fragments. These can be cut flush with the surface of the bone and appear to provide adequate stability, without the concern for migration. Multiple classification schemes have been reported in the literature. Milch et al initially differentiated fractures of the hamate into those affecting the hook and body.[26] Additional classification schemes have further subdivided hamate body fractures. Cain's review of 17 patients differentiated a progressive pattern of worsening hamate/carpometacarpal joint injuries from isolated CMC dislocations (type IA) to type III with a coronal plane fracture splitting the hamate and CMC dislocation.[9] Ebraheim further distinguished coronal-plane fractures into a central (type A), oblique (type B), and dorsal (type C) pattern along with CMC dislocation.[27] The relative incidence of these types of patterns is currently unknown.

For operative technique, we utilized an open, dorsal approach to the hamate with a combination of interfragmentary screw fixation and Kirschner wire reduction of the CMC joints. Multiple reports in the literature exist including closed reduction and percutaneous pinning[13,18] to open reduction and internal fixation with K wires,[5,9,11,19,28,29] screws,[2,5,24,30] and plates.[11,31] The heterogeneity between different studies highlights the variation seen clinically, and it remains unclear whether different injury patterns are best treated differently.[12,15]

At mean follow up of 96 days, all patients achieved clinical and radiographic healing of the injury. At final clinic follow up, all patients were noted to have no pain, full wrist motion, composite digital flexion, and normal rotation of the digits. We experienced no complications or reoperations in our series. Our findings are similar to others. Hirano and Inoue reported on 5 cases and all achieved bony union. Three out of 5 of their patients reached full range of motion of the wrist and fingers and full grip strength. Two patients had ulnar nerve palsies and reduced grip strength.[18] More recently, Wharton et al reviewed their experience with the operative management of 9 patients treated with a variety of approaches.[5] At an average follow up of 14.8 months, 6/8 patients had excellent DASH scores. Delays in diagnosis have been associated with worse outcomes in other studies.[16,17]

Hamate body fractures represent a spectrum of morphologies which can involve the fourth and fifth carpometacarpal joints. Terminology in the literature aims to be descriptive but can vary widely between reports. A review of the literature reflects multiple names for a similar pattern of injury: coronal hamate fracture,[5,28,32] hamate body fracture,[7,19,25,29] divergent fracture-dislocation of the hamatometacarpal joint,[9,24] hamate fracture,[30,33] intra osseous fifth carpometacarpal dislocation,[2] carpometacarpal fracture-dislocation,[22] and dorsal hamate fracture.[23] We believe that a coronal hamate fracture with CMC dislocation is a specific injury pattern and would benefit from a uniform terminology.

This study has several weaknesses including the retrospective data collection, observer bias, small patient number, and short duration of follow up. However, we feel that our mean follow up time of 96 days was sufficient to assess radiographic union and clinical range of motion. Since all the surgical procedures were performed by a single surgeon, there is a consistency of surgical technique, implant usage as well as surgical decision making and post-operative rehabilitation. This could be considered a strength of our study. Inclusion of standard outcome measurements and longer-term follow up would improve reporting in the future.

In summary, our study has shown favorable outcomes after open reduction and internal fixation of the hamate body fracture with interfragmentary screws, when combined with stabilization of the CMC dislocation with percutaneous Kirschner wires. Fracture morphology does not appear to guide choice for specific hardware (size screw, headed/headless) or use of a washer. However, CT scans should be routinely considered and also possibly routinely acquired for surgical approach planning, to rule out other injuries and to assess for articular depression of the hamate. Further studies should consider if fracture fixation of the hamate near the 5th metacarpal and ulnar to the hook of hamate is sufficient for clinical union and stability.

# REFERENCES


1. Kerr HD. Hamate-metacarpal fracture dislocation. J Emerg Med. 1992;10(5):565-568
2. Austin RE, Pennings AL, ElMaraghy AW. Intraosseous fifth carpometacarpal dislocation associated with a coronal hamate fracture: A case report. 2014;4(3):e76-e4
3. Cano Gala C, Pescador Hernández D, Rendón Díaz DA, López Olmedo J, Blanco Blanco J. Fracture of the body of hamate associated with a fracture of the base of fourth metacarpal: A case report and review of literature of the last 20 years. Int J Surg Case Rep. 2013;4(5):442-445
4. Fakih RR, Fraser AM, Pimpalnerkar AL. Hamate fracture with dislocation of the ring and little finger metacarpals. J Hand Surg Eur Vol. 1998;23(1):96-97
5. Wharton DM, Casaletto JA, Choa R, Brown DJ. Outcome following coronal fractures of the hamate. J Hand Surg Eur Vol. 2010;35(2):146-149
6. Athanasiou V, Iliopoulos ID, Pantazis K, Panagopoulos A. Fracture of the body of the hamate with dorsal dislocation of the 4 and 5 metacarpals: A case report. Open Orthop J. 2017;11(1):447-451
7. Cecava ND, Finn MF, Mansfield LT. Subtle radiographic signs of hamate body fracture: a diagnosis not to miss in the emergency department. Emerg Radiol. 2017;24(6):689-695
8. Uhl RL, Campbell M. Hamate fracture-dislocation: A case report. J Hand Surg Am. 1995;20(4):578-580
9. Cain JE, Shepler TR, Wilson MR. Hamatometacarpal fracture-dislocation: Classification and treatment. J Hand Surg Am. 1987;12(5):762-767
10. Kim JK, Shin SJ. A novel hamatometacarpal fracture-dislocation classification system based on CT scan. Injury. 2012;43(7):1112-1117
11. Bao B, Zhu H, Zheng X. Fourth and fifth carpometacarpal fracture-dislocations is plate or Kirschner wire fixation superior: A retrospective cohort study. Int J Surg. 2018;52: 293-296
12. Büren C, Gehrmann S, Kaufmann R, Windolf J, Lögters T. Management algorithm for index through small finger carpometacarpal fracture dislocations. Eur J Trauma Emerg Surg. 2016;42(1):37-42
13. Brinkman JN, Hartholt KA, De Vries MR. Multiple carpometacarpal dislocations and an associated fracture of the hamate: An uncommon injury. BMJ Case Rep. 2016;15
14. Gil JA, Goodman AD, Starr A. Coronal hamate fracture associated with carpometacarpal dislocations of all of the fingers: review of the literature and case report. Hand. 2017;12(5):NP51-NP54
15. Cobb WA, Dingle L, Adami RZ, Rodrigues J. Management of fracture-dislocations of the little finger carpometacarpal joint : a systematic review. Hand Surg Eur Vol. 2018;43(5):530-538
16. Terrono A, Ferrenz C, Nalebuff E. Delayed diagnosis in non-union of the body of the hamate. J Hand Surg Br. 1989;14(3):329-331
17. Thomas A, Birch R. An unusual hamate fracture. Hand. 1983;15(3):281-286
18. Hirano K, Inoue G. Classification and treatment of hamate fractures. Hand Surg. 2005;10(2-3):151-157
19. Kimura H, Kamura S, Akai M, Ohno T. An unusual coronal fracture of the body of the hamate bone. J Hand Surg Am. 1988;13(5):743-745
20. Loth TS, McMillan MD. Coronal dorsal hamate fractures. J Hand Surg Am. 1988;13:616-618.
21. Andresen R, Radmer S, Sparmann M, Bogusch G, Banzer D. Imaging of hamate bone fractures in conventional X-rays and high- resolution computed tomography: An in vitro study. Invest Radiol. 1999;34:46-50
22. McDonald LS, Shupe PG, Hammel N, Kroonen LT. The intermetacarpal angle screening test for ulnar-sided carpometacarpal fracture-dislocations. J Hand Surg Am. 2012;37: 1839-1844

23. Gillespy T, Stork JJ, Dell PC. Dorsal fracture of the hamate: Distinctive radiographic appearance. Am J Roentgenol. 1988;151:351-353
24. Moriya K, Saito H, Takahashi Y, Ohi H. Divergent fracture-dislocation of the hamatometacarpal joint: Case report. J Hand Surg Am. 2011;36:47-51
25. Van Schil P, De Smet C, Schoofs E. Fracture of the body of the hamate bone. Arch Orthop Trauma Surg. 1988;107:191-192
26. Milch H. Fracture of the hamate bone. J Bone Jt Surg Am. 1934;16:459-462
27. Ebraheim NA, Skie MC, Savolaine ER, Jackson WT. Coronal fracture of the body of the hamate. J Trauma - Inj Infect Crit Care. 1995;38:169-174
28. Takami H, Takahashi S, Hiraki S. Coronal fracture of the body of the hamate: case reports. J Trauma - Inj Infect Crit Care. 1992;Jan;32(1):110-112
29. Ogunro O. Fracture of the body of the hamate bone. J Hand Surg Am. 1983;8:353-355
30. Borse VH, Hahnel J, Faraj A. Lessons to be learned from a missed case of hamate fracture: A case report. J Orthop Surg Res. 2010, 27: 64
31. Snoap T, Habeck J, Ruiter T. Hamate fracture. Eplasty. 2015;June 4(15):ic28
32. Gella S, Borse V, Rutten E. Corotnal fractures of the hamate: are they rare or rarely spotted? J Hand Surg Eur Vol. 2007;32(6):721-722
33. Chalmers R, Kong K. An unusual fracture of the hamate. J Hand Surg Br. 2006;31(5):577-578.

# Chapter 10

## Patterns of ulnar nerve arborization in the palm: clinical implications for nerve decompression in the hand and wrist

***Verhiel SHWL***, *van Hooven D, Garg R, Gottlieb REW, Ritt MJPF, Chen NC, Eberlin KR*

*J Hand Surg GO. 2019: 21-27*

# ABSTRACT

**Purpose** The purposes of this study were to examine variations and frequencies of the arborization patterns and communicating branches of the ulnar nerve in the palm, to review existing literature, and to relate these findings to nerve decompression in the hand and wrist.

**Methods** The arborization pattern of the ulnar nerve near Guyon's canal was examined in eighteen cadaver hands, and described according to the classification of Murata et al. Communicating branches between the ulnar nerve and the median nerve were described according to the classification by Bas & Kleinert. The specific distance from the wrist flexion crease to the origin of the communicating branch and the angle of the communicating branch with the originating nerve were measured.

**Results** In 13 of 18 (72%) hands, a type 1 arborization pattern was found; in 4 (22%) hands, a type 2 was found; and in 1 hand (6%), a branching pattern not previously described was found. In 11 of 18 (61%) hands, a communicating branch between the ulnar and median nerve was observed. The branch ran from the ulnar to the median nerve (type 1) in 10 (56%) hands, the connection was plexiform (type 4) in 1 (5.6%) hand.

**Conclusions** Variations in arborization patterns of the ulnar nerve and existence of communicating branches between the ulnar and median nerve in the palm are common and may lead to atypical distribution of symptoms and unforeseen risks during hand surgery

# INTRODUCTION

The anatomic course of the ulnar nerve distal to the wrist follows a predictable course: it typically bifurcates within Guyon's canal into a deep (motor) branch and a superficial (sensory) branch. Thereafter, the superficial branch divides into the fourth common digital nerve and the ulnar proper digital nerve of the small finger,[1–3] while the motor branch continues into the hand to innervate the intrinsic muscles.

Gross & Gelberman described three distinct zones of the ulnar nerve within Guyon's canal, which can be useful when identifying the site of compression.[4] Zone 1 includes the area proximal to the bifurcation of the ulnar nerve, where compression leads to a combined motor and sensory loss. Zone 2 includes the deep branch after it has bifurcated, and compression results in isolated loss of motor function of the ulnar nerve. Zone 3 involves the superficial (sensory) branch of the ulnar nerve, and compression leads to sensory loss of the hypothenar eminence, small finger, and ulnar side of the ring finger.[1,4] Variations of this classic arborization pattern may occur frequently and the "three-zone" concept may not always be consistent.[2,3,5–8]

Communicating branches between the ulnar nerve and the median nerve in the palm have been called "rami communicans cum nervi ulnari" or "Berrettini branches."[9–11] The prevalence of these branches is unknown, with a wide range between 4% and 100% described in the literature and varying classification within different studies.[3,11–21] Sensory symptoms due to compression neuropathy of the ulnar or median nerve, which do not correspond with the typical innervation pattern, may be explained by the existence of palmar communications between these 2 nerves.[11,14,16,20,22–24].

Understanding the variations in arborization pattern and communicating branches is important for diagnosis and also for surgical planning of carpal tunnel and/or Guyon's canal decompression, as there may be an increased risk to the ulnar and/or median nerve branches if appropriate care is not taken during surgery.[6,11,13–15,19,25] The aims of this cadaver study were to examine variations and frequencies of the arborization patterns and communicating branches, to review existing literature, and to relate these findings to nerve decompression near the wrist.

# METHODS

Eighteen fresh frozen hands from 9 cadavers (4 male and 5 female) with a median age of 72 years (IQR 70-80) were dissected by trained hand surgeons. None of the cadavers showed evidence of previous surgical procedures or traumatic lesions to the wrist or hand.

For exposure, a transverse incision was made on the palmar surface of the distal forearm and the skin and subcutaneous tissue were removed from the wrist flexion crease to the distal interphalangeal (DIP) joints of all fingers and the interphalangeal (IP) joint of the thumb to evaluate the neurovascular structures. Next, a carpal tunnel release was performed by incising

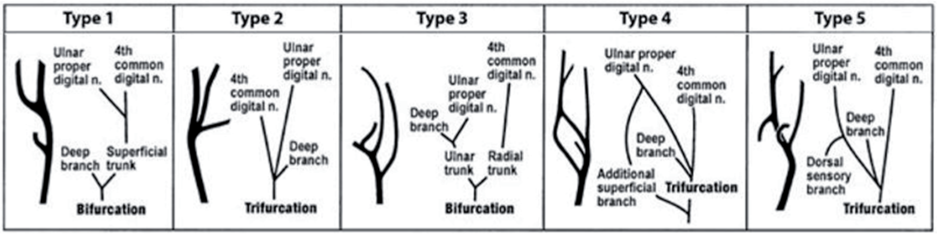


**Figure 1.** Classification of arborization pattern according to Murata et al. Adapted from Murata K, Tamai M, Gupta A. Anatomic study of variations of hypothenar muscles and arborization patterns of the ulnar nerve in the hand. J Hand Surg Am. 2004;29(3):506. Copyright 2004 by the American Society for Surgery of the Hand.

the transverse carpal ligament (TCL) in line with the radial border of the ring finger. Guyon's canal was released by incising the palmaris brevis and the fascia overlying the ulnar nerve. The superficial palmar vascular arch and excess adipose tissue were carefully removed in the palm to visualize the ulnar and median nerves and their branches.

The arborization pattern of the ulnar nerve at the level of Guyon's canal was examined, and described according to the classification of Murata et al. (Figure 1).[6] Distances from the distal wrist flexion crease to the following points were measured with a metric ruler: 1) branching of the deep motor branch from the ulnar nerve, 2) division of the superficial sensory branch of the ulnar nerve into the fourth common digital nerve and the ulnar proper digital nerve of the small finger (Figure 2).

All communicating branches between the ulnar nerve and the median nerve were identified and described according to the classification developed by Meals & Shaner and modified by Bas & Kleinert (Figure 3).[11,20] The specific distance from the wrist flexion crease to the origin of the communicating branch and the angle of the communicating branch with the originating

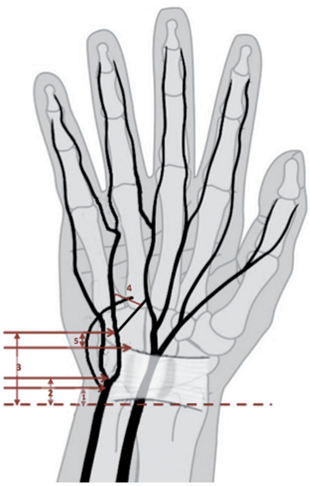

**Figure 2.** Measurements performed in this study: (1) distance between the wrist flexion crease and branching of the deep motor branch from the ulnar nerve, (2) distance between the wrist flexion crease and division of the superficial sensory branch of the ulnar nerve into the fourth common digital nerve and the ulnar proper digital nerve of the little finger, (3) distance between the wrist flexion crease and the origin of the communicating branch, (4) angle of the communicating branch with the originating nerve, (5) and distance from the distal edge of the transverse carpal ligament to the origin of communicating branch.

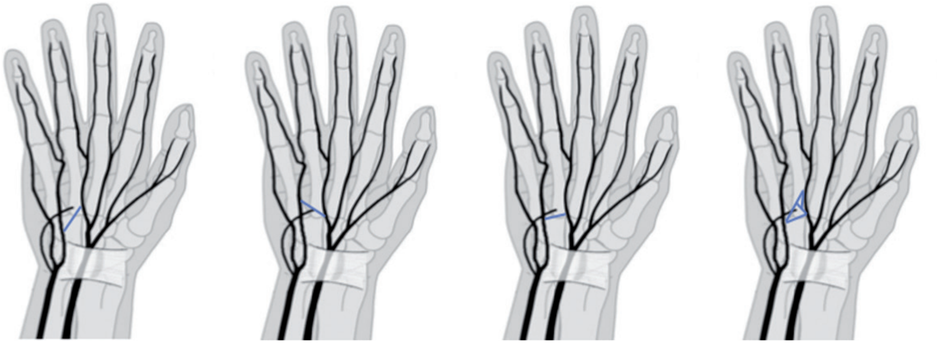

**Figure 3.** Classification of communicating branches according to Meals and Shaner and modified by Bas and Kleinert.

nerve were measured. We also calculated the distance from the distal edge of the transverse carpal ligament to the origin of communicating branch.

All measurements were performed using a metric ruler to the nearest millimeter. Discrete data points were described using frequencies and percentages and non-normally distributed continuous data through medians and IQR.



# RESULTS

## Arborization pattern

In 13 of 18 (72%) hands, a type 1 arborization pattern was found; in 4 (22%) hands, a type 2 was found; and in 1 hand (6%), a branching pattern not previously described was found (Table 1). In this hand, the ulnar nerve had an additional branch proximal to Guyon's canal, which looped back to the fourth common digital nerve and connected to the plexiform communicating branch between the fourth common digital nerve and the third common digital nerve (Figure 4). There was a bilateral type 2 arborization pattern in 1 cadaver, the other type 2 patterns were unilateral.

In 4 of 18 (22%) hands, the deep motor branch emerged from the ulnar nerve proximal to Guyon's canal. The median distance from the wrist flexion crease to the deep motor branch of the ulnar nerve was 12mm (IQR 8-19). Division to the fourth common digital nerve and the ulnar proper digital nerve of the small finger occurred within Guyon's canal in 12 (67%) hands, distal to Guyon's canal in 4 (22%) hands, and proximal to Guyon's canal in 2 (11%) hands. The median distance from the wrist flexion crease to this division was 24mm (IQR 16-28) (Table 1).

**Table 1.** Arborization pattern

| Cadaver ID* | Type** | For type 1 pattern: Distance to deep branch (in mm) *** | For type 1 pattern: Relation to Guyon's canal | For type 1 pattern: Distance to 4th common and the ulnar proper (in mm) *** | For type 1 pattern: Relation to Guyon's canal | For type 2 pattern: Distance to deep branch, 4th common and ulnar proper (in mm) *** | For type 2 pattern: Relation to Guyon's canal |
|---|---|---|---|---|---|---|---|
| **1L** | 1 | -10 | proximal | 8 | proximal | - | - |
| **1R** | 1 | 17 | within | 22 | within | - | - |
| **2L** | 2 | - | - | - | - | 11 | within |
| **2R** | 2 | - | - | - | - | 12 | within |
| **3L** | 1 | 20 | within | 38 | distal | - | - |
| **3R** | 1 | 12 | within | 25 | within | - | - |
| **4L** | 1 | 12 | within | 31 | distal | - | - |
| **4R** | 1 | 19 | within | 25 | within | - | - |
| **5L** | 2 | - | - | - | - | 28 | within |
| **5R** | 1 | 21 | within | 25 | within | - | - |
| **6L** | **** | 25 | within | 27 | within | - | - |
| **6R** | 1 | 0 | proximal | 16 | within | - | - |
| **7L** | 2 | - | - | - | - | -10 | proximal |
| **7R** | 1 | 18 | within | 32 | distal | - | - |
| **8L** | 1 | 8 | proximal | 25 | within | - | - |
| **8R** | 1 | 10 | within | 23 | within | - | - |
| **9L** | 1 | 10 | within | 21 | within | - | - |
| **9R** | 1 | 7 | within | 28 | distal | - | - |

** L= left, R= right*
*** According to classification by Murata et al.*
**** Distance measured from distal wrist flexion crease*
***** Not to be grouped by classification of Murata; additional branch before Guyon's canal, looping back to the fourth common digital nerve and giving off a branch to the communicating branch. Bifurcation into deep and superficial branch.*

## Communicating branches

In 11 of 18 (61%) hands, a communicating branch between the ulnar and median nerve was observed (Table 2). Three cadavers had a communicating branch bilaterally, 5 cadavers unilaterally and only 1 patient had no communicating branch. The branch ran from the ulnar to the median nerve (type 1) in 10 (56%) hands, with multiple distal attachments to the median nerve in 1 hand (Figure 5). More specifically, the branch ran from the fourth common digital nerve of the ulnar nerve to the third common digital nerve of the median nerve in 8 specimens; the branch ran from the superficial branch of the ulnar nerve to the third common digital nerve of the median nerve in 2 specimens. The connection was formed by more than one branch in both directions at the same time (type 4), between the fourth common digital nerve of the ulnar nerve and the third common digital nerve of the median nerve, in 1 (5.6%) hand.

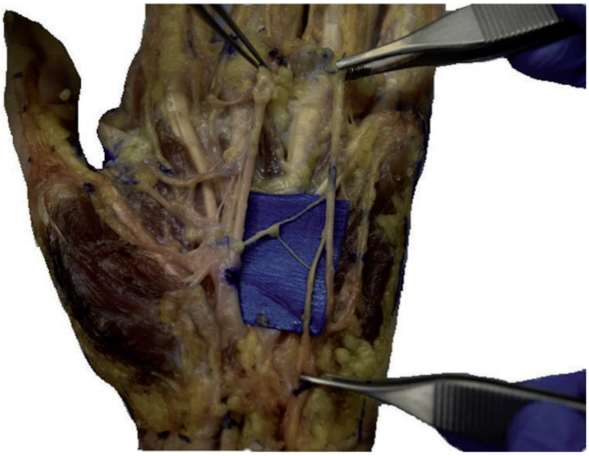

**Figure 4.** Variation in arborization pattern (right lower forceps holding on to additional branch originating from ulnar nerve proximal to Guyon canal, right upper forceps holding on to fourth common digital nerve, and left forceps holding on to third common digital nerve).

**Table 2.** Communicating branches

| Cadaver ID* | Present? | Type** | Degrees *** | Distance TCL (in mm) **** |
|---|---|---|---|---|
| **1L** | No | - | - | - |
| **1R** | Yes | 1 | 50 | 1 |
| **2L** | Yes | 1 | 45 | 3 |
| **2R** | Yes | 1 | 35 | -11 |
| **3L** | No | - | - | - |
| **3R** | No | - | - | - |
| **4L** | Yes | 1 | 40 | 7 |
| **4R** | No | - | - | - |
| **5L** | Yes | 1 | 35 | 1 |
| **5R** | No | - | - | - |
| **6L** | Yes | 4 | ***** | 15 |
| **6R** | No | - | - | - |
| **7L** | Yes | 1 | 50 | 17 |
| **7R** | Yes | 1 | 40 | -7 |
| **8L** | Yes | 1 | 45 | -17 |
| **8R** | Yes | 1 | 40 | -7 |
| **9L** | No | - | - | - |
| **9R** | Yes | 1 | 45 | -2 |

** L= left, R= right*
*** According to classification by Meals & Shaner and modified by Bas & Kleinert*
**** Measured from originating nerve*
***** Distance measured from distal TCL to proximal point communicating branch*
****** Not to be determined because of plexiform pattern*

**Figure 5.** Communicating branch from the ulnar to the median nerve (type 1) with multiple distal attachments to the median nerve.

The communicating branch originated at a median distance of 1mm from the distal edge of the transverse carpal ligament and had a median angle of 42.5 degrees (IQR 40-45) from its originating nerve. In 5 specimens, this branch originated from the ulnar nerve proximal to the distal end of the transverse carpal ligament (Table 2; Figure 6).

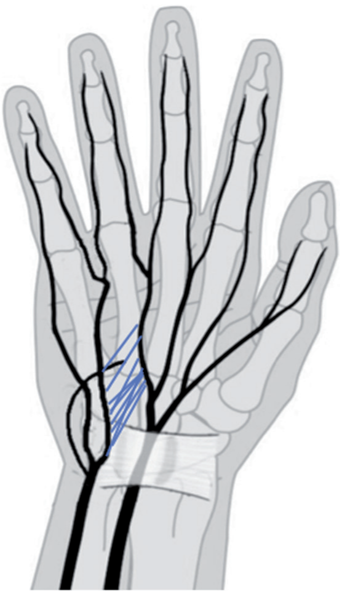

**Figure 6.** Communicating branches from the ulnar to the median nerve and its relation to the transverse carpal ligament.

# DISCUSSION

In this study, we investigated the arborization patterns of the ulnar nerve and communicating branches between the ulnar and median nerve in the palm of cadavers. These branching patterns have implications for nerve decompression at the level of the wrist.

Various and sometimes contradictory information about the prevalence and classification of arborization patterns and communicating branches between the ulnar and median nerves have been described previously.[3,11,20,22,24,26–28,12–19] Our study summarizes the variable and heterogeneous results from prior studies into a more unified manner based on one classification system (Table 3). Previous literature about the arborization patterns of the ulnar nerve and communicating branches is mainly focused on reporting of anatomical findings, without relating these finding to clinical practice. Our study looks in further detail at the communicating branch between the ulnar and median nerve, its distance from various different anatomic landmarks and its orientation. These anatomic details help to correlate these findings to clinical practice, especially nerve decompression in the palm and wrist.

Many studies have classified the arborization pattern of the ulnar nerve in the hand into 3 types: bifurcated, trifurcated and anomalous. The most commonly reported type is a bifurcated



**Table 3.** Prevalence of communicating branches in literature*

| Authors | Sample size (n) | Type 1 | Type 2 | Type 3 | Type 4 | No branch |
|---|---|---|---|---|---|---|
| **Linell (1920)** | 20 | 20% | - | - | - | 80% |
| **Hirasawa (1931)** | 80 | 27.5% | 27.5% | 45% | - | - |
| **Mannerfelt (1966)** | 16 | 100% | - | - | - | - |
| **Meals and Shanner (1983)** | 50 | 76% | 2% | 2% | - | 20% |
| **Bonnell and Vila (1985)** | 50 | 92% | - | 8% | - | - |
| **Ferrari and Gilbert (1991)** | 50 | 86% | 4% | - | - | 10% |
| **Bas and Kleinert (1999)** | 30 | 37% | 13% | - | 17% | 33% |
| **Stancic et al (1999)** | 100 | 65% | - | 16% | - | 19% |
| **Don Griot et al (2000)** | 53 | 83% | 3,8% | 7.5% | - | 5.7% |
| **Olave et al (2001)** | 56 | 80.3% | 14.3% | - | 1.8% | 3.6% |
| **Don Griot et al (2002)** | 26 | 81% | 7.6% | 11.4% | - | - |
| **Kawashima et al (2004)** | 169 | 47.3% | 14.2% | - | 3% | 35.5% |
| **Loukas et al (2007)** | 200 | 71.5% | 6% | 3% | 4.5% | 15% |
| **Tagil et al (2007)** | 30 | 40% | 3.3% | 6.7% | 10% | 40% |
| **Biafora et al (2007)** | 50 | 68% | 6% | - | - | 26% |
| **Zolin et al (2014)** | 30 | 33% | - | 3.3% | 6.7% | 57% |
| **Sulaiman et al (2016)** | 98 | 83% | 5% | 2% | 10% | - |
| ***Mean prevalence*** | | ***64.2%*** | ***6.3%*** | ***6.2%*** | ***3.1%*** | ***20.3%*** |

**According to classification by Meals & Shaner and modified by Bas & Kleinert* ulnar nerve, with an incidence ranging from 66% and 86%.[3,5–7,29] The trifurcated type has been reported to occur with an incidence of 13 to 22%.[3,5–7,29] This is consistent with our finding of a bifurcation in 72% and trifurcation in 22%.

Multiple classification systems of the communicating branches between the ulnar and median nerves have been described. Most often, they are based on the origin of the communicating branch and its relationship to the distal margin of the transverse carpal ligament, the pattern of formation of the communicating branch, and/or the destination of the nerve fibers.[3,5,11–22,24,27,30] Meals & Shaner (1983) were the first to classify the palmar communicating branch into 3 patterns based on its proximal and distal attachment points between the common digital nerves in the palm.[11] Bas & Kleinert (1999) modified this scheme and added a Type 4 (plexiform) pattern.[20]

We categorized data from previous literature about communicating branches according to the classification developed by Meals & Shaner and modified by Bas & Kleinert, to provide a complete overview and to allow comparison with our findings (Table 3). Overall prevalence of communicating branches was 79.8%, with predominantly type 1 branches (64.2%). Type 2 branches accounted for 6.3% of total, type 3 for 6.2% and type 4 for 3.1%. The prevalence of communicating branches in our specimens was slightly lower (61.2%) than the reported literature, with type 1 being the most common.

Compression neuropathies in the upper extremity may present with a classic or an atypical distribution of symptoms. Compression of median nerve in carpal tunnel typically involves radial three and a half digits and compression of ulnar nerve in cubital tunnel involves ulnar one and a half digits.[31,32] However, there is often a wide variation in presentation with symptoms ranging from involvement of all digits, or predominantly ulnar sided fingers in carpal tunnel syndrome and radial sided involvement in cubital tunnel syndrome.[33–35] The communicating nerve branches described above may help explain this diversity in clinical presentation.

The use of topographical information and morphometric data to represent the course of communicating nerve branches in the palm is useful for surgeons. It can help in the recognition and preservation of these branches during surgical procedures on the palmar surface of the hand, such as carpal tunnel release, exploration of Guyon's canal, palmar fasciectomy and flexor tendon release.[15,24,25,36] Various reference points have historically been used to provide topographical information about the presence of critical structures: the transverse carpal ligament, superficial palmar arch, bistyloid line, and metacarpophalangeal joint.[3,12–17,19,24] In this study, the transverse carpal ligament and the distal flexion wrist crease were used as reference points. We found these landmarks to be the most relevant because they are directly identifiable in a clinical or surgical setting.

Carpal tunnel release is one of the most common procedures performed in hand surgery and typically has reliable outcomes.[37–40] Infrequently, there can be complications such as nerve injury, persistent scar hypersensitivity, and complex regional pain syndrome (CRPS).[37–40] Iatrogenic injury to the communicating branches described in this investigation is possible with the commonly used techniques and may contribute to development of CRPS. Neuroma formation from injury to one of these branches may also contribute to scar hypersensitivity.[41,42]

Both endoscopic and open approaches may be utilized for carpal tunnel release.[37–40] The length of the incision varies, but often is <4 cm and limited to the palm. When the incision is limited to the palm, the proximal aspect of transverse carpal ligament is incised in a distal to proximal direction using either a sliding technique or a visualized cut with scissors.[43–45] Communicating branches between ulnar and median nerves as described in this study are at a risk of iatrogenic injury with these techniques, as the entire length of transverse carpal ligament is not incised under direct visualization. Similarly endoscopic carpal tunnel release may be performed using either one-portal or two-portal techniques.[40,46,47] Both methods involve finding a path within the carpal tunnel and incising the ligament under endoscopic visualization. Failure to clear communicating branches off the undersurface of the transverse carpal ligament or cutting distal to the distal edge of the transverse carpal ligament risks injury to these branches. In this study, a median angle of 42.5 degrees (IQR 40-45) between de communicating branch and its originating nerve was found. The angle under which the communicating branch divides is a risk factor, as a perpendicular course of the communicating branch has a theoretical higher risk of surgical damage than a steep angle of origin of this branch.[14,16]



Palmer et al. surveyed members of the American Society for Surgery of the Hand between 1990 and 1995 to characterize complications after endoscopic and open carpal tunnel release.[48] Of all the digital nerve injuries reported in this study, injury to the common digital nerve to the third web space was the most common. The present investigation shows that the communicating branch from the ulnar nerve always joined the common digital nerve to the third web space. Unrecognized damage to this communicating branch may, in part, explain the frequency of injury to the common digital nerve to the third web space in these surveys.

The communicating branches described in this study may also have implications in sensory nerve transfers in the hand. For critical median nerve sensation, transfers have been described using dorsal cutaneous branch of the ulnar nerve in the forearm.[44,49–51] In the palm, the ulnar nerve branch to the fourth web space can be transferred to the median branch to the first web space.[44,49–51] These transfers do come at the cost of loss of sensation in the respective ulnar nerve territories. Utilizing the communicating branch described in this investigation for transfer to the median nerve fascicles supplying the critical first web space could decrease the donor morbidity by avoiding loss of sensation in the donor ulnar nerve distribution. Further research is needed to study feasibility and the number of axons available for transfer.

This study should be interpreted in light of its limitations. First, our study encompasses a sample of 18 hands. Other prior studies have larger sample sizes, and as a result may give a more accurate estimation of the prevalence of the different types of communicating branches. However there is a large variability in the reporting of these branches. Our study summarizes the data from prior studies in a unified manner using one classification system to provide a comprehensive overview. Second, this is a purely anatomic study focused on the arborization pattern, existence of communicating branches, and clinical landmarks of these findings. No histologic examination was performed of these branches, and the functional significance of communicating branches needs to be more comprehensively studied, including the consequences of injury to these structures. Third, we did not investigate the presence of other possible communicating branches in the forearm and palm, like the Martin-Gruber, Marinacci, or Riche-Cannieu anastomoses as our specimens were limited to the distal forearm, wrist, and hand. We used a metric ruler with millimeter precision. Although precision could be improved with a digital caliper, increased precision may not be clinically relevant as structures are displaced with anatomic dissection.

In conclusion, knowledge about variations in arborization patterns of the ulnar nerve and communicating branches between the ulnar and median nerve in the palm optimizes diagnoses and minimizes specific surgical risks in hand surgery. The possibility of utilizing communicating branches for specific applications, like sensory nerve transfers, should be studied in future research.

# REFERENCES


1. Polatsch DB, Melone CP, Beldner S, Incorvaia A. Ulnar Nerve Anatomy. Hand Clin. 2007;23(3):283-289.
2. Earp B, Floyd W, Louie D, Koris M, Protomastro P. Ulnar Nerve Entrapment at the Wrist. Am Acad Orthop Surg. 2014;22(11):699-706.
3. Bonnel F, Vila RM. Anatomical study of the ulnar nerve in the hand. J Hand Surg Am. 1985;10(2):165-168.
4. Gross MS, Gelberman RH. The anatomy of the distal ulnar tunnel. Clin Orthop Relat Res. 1985;(196):238-247.
5. Lindsey JT, Watumull D. Anatomic study of the ulnar nerve and related vascular anatomy at Guyon's canal: A practical classification system. J Hand Surg Am. 1996;21(4):626-633.
6. Murata K, Tamai M, Gupta A. Anatomic study of variations of hypothenar muscles and arborization patterns of the ulnar nerve in the hand. J Hand Surg Am. 2004;29(3):500-509.
7. Depukat P, Henry BM, Popieluszko P, et al. Anatomical variability and histological structure of the ulnar nerve in the Guyon's canal. Arch Orthop Trauma Surg. 2017;137(2):277-283.
8. Konig PSA, Hage J, Bloem JJA, Prose LP. Variations of the Ulnar Nerve and Ulnar Artery in Guyon ' s Canal : A Cadaveric Study. J Hand Surg Am. 1994;19A:617-622.
9. Berrettini P, Petrioli C. Tabulae Anatomicae. Rome Typogr Antonii rubeis. 1741:1-4.
10. Greathouse D, Halle J, Dalley A. Terminologia anatomica: revised anatomical terminology. J Orthop Sport Phys Ther. 2004;34:363-367.
11. Meals RA, Shaner M. Variations in digital sensory patterns: A study of the ulnar nerve—median nerve palmar communicating branch. J Hand Surg Am. 1983;8(4):411-414.
12. Zolin SD, Barros MD, Abdouni YA, Nascimento V das G, da Costa AC, Chakkour I. Anatomical study of sensory anastomoses in the hand. Acta Ortop Bras. 2014;22(1):34-37.
13. Loukas M, Louis RG, Stewart L, et al. The surgical anatomy of ulnar and median nerve communications in the palmar surface of the hand. J Neurosurg. 2007;106(5):887-893.
14. Ferrari GP, Gilbert A. The superficial anastomosis on the palm of the hand between the ulnar and median nerves. J Hand Surg Am. 1991;16(5):511-514.
15. Stančić MF, Mićović V, Potoćnjak M. The anatomy of the Berrettini branch: implications for carpal tunnel release. J Neurosurg. 1999;91(6):1027-1030.
16. Don Griot JPW, Zuidam JM, Van Kooten EO, Prosé LP, Hage JJ. Anatomic study of the ramus communicans between the ulnar and median nerves. J Hand Surg Am. 2000;25(5):948-954.
17. Olave E, Del Sol M, Gabrielli C, Mandiola E, Rodrigues CFS. Biometric study of the relationships between palmar neurovascular structures, the flexor retinaculum and the distal wrist crease. J Anat. 2001;198(6):737-741.
18. Kawashima T, Sato K, Sasaki H. Stratification of the flexor retinaculum and the course and distribution of the ulnar, median, and palmar digital nerves: An anatomical study. Clin Anat. 2004;17(8):643-650.
19. Tagil SM, Bozkurt MC, Özçakar L, Ersoy M, Tekdemir I, Elhan A. Superficial palmar communications between the ulnar and median nerves in Turkish cadavers. Clin Anat. 2007;20(7):795-798.
20. Bas H, Kleinert JM. Anatomic variations in sensory innervation of the hand and digits. J Hand Surg Am. 1999;24(6):1171-1184.
21. Dogan NU, Uysal II, Karabulut AK, Seker M, Ziylan T. Communications between the palmar digital branches of the median and ulnar nerves: A study in human fetuses and a review of the literature. Clin Anat. 2010;23(2):234-241.

22. Griot JPWD, Van Kooten EO, Zuidam JM, Prosé LP, Hage JJ. Internal anatomy of the communicating branch between the ulnar and median nerves in the hand and its relevance to volar digital sensibility. J Hand Surg Am. 2002;27(1):143-146.
23. Hoogbergen MM, Kauer JM. An unusual ulnar nerve-median nerve communicating branch. J Anat. 1992;181 Pt 3:513-516.
24. Sulaiman S, Soames R, Lamb C. An anatomical study of the superficial palmar communicating branch between the median and ulnar nerves. J Hand Surg Eur Vol. 2016;41(2):191-197.
25. Boughton O, Adds PJ, Jayasinghe JAP. The potential complications of open carpal tunnel release surgery to the ulnar neurovascular bundle and its branches: A cadaveric study. Clin Anat. 2010;23(5):545-551.
26. Linell E a. The Distribution of Nerves in the Upper Limb, with reference to Variabilities and their Clinical Significance. J Anat. 1921;55(Pt 2-3):79-112.
27. Mannerfelt L. Studies on the hand in ulnar nerve paralysis. A clinical-experimental investigation in normal and anomalous innervation. Acta Orthop Scand. 1966;37(87):11-176.
28. Biafora SJ, Gonzalez MH. Sensory communication of the median and ulnar nerves in the palm. J Surg Orthop Adv. 2007.
29. Gotani H, Yamano Y, Gilbert A. Anatomy of the ulnar nerve in the hand: study of anomalous sensory branches. J Jpn Soc Surg Hand. 2001;18:670-674.
30. Unver Dogan N, Uysal II, Seker M. The communications between the ulnar and median nerves in upper limb. Neuroanatomy. 2009;8:15-19.
31. Arnold WD, Elsheikh BH. Entrapment neuropathies. Neurol Clin. 2013;31(2):405-424.
32. Toussaint CP, Perry EC, Pisansky MT, Anderson DE. What's new in the diagnosis and treatment of peripheral nerve entrapment neuropathies. Neurol Clin. 2010;28(4):979-1004.
33. Clark D, Amirfeyz R, Leslie I, Bannister G. Often atypical? The distribution of sensory disturbance in carpal tunnel syndrome. Ann R Coll Surg Engl. 2011;93(6):470-473.
34. Saeed WR, Davies DM. Sensory innervation of the little finger by an anomalous branch of the median nerve associated with recurrent, atypical carpal tunnel syndrome. J Hand Surg (British Eur Vol. 1995;20(1):42-43.
35. Chen SH, Tsai TM. Ulnar tunnel syndrome. J Hand Surg Am. 2014;39(3):571-579.
36. Cobb TK, Carmichael SW, Cooney WP. The ulnar neurovascular bundle at the wrist A technical note on endoscopic carpal tunnel release. J Hand Surg Am. 1994;19(1):24-26.
37. Tang CQY, Lai SWH, Tay SC. Long-term outcome of carpal tunnel release surgery in patients with severe carpal tunnel syndrome. Bone Joint J. 2017;99-B(10):1348-1353.
38. Sayegh ET, Strauch RJ. Open versus Endoscopic Carpal Tunnel Release: A Meta-analysis of Randomized Controlled Trials. Clin Orthop Relat Res. 2014;473(3):1120-1132.
39. Calotta NA, Lopez J, Deune EG. Improved Surgical Outcomes With Endoscopic Carpal Tunnel Release in Patients With Severe Median Neuropathy. Hand. 2017;12(3):252-257.
40. Trumble TE, Diao E, Abrams RA, Gilbert-Anderson MM. Single-portal endoscopic carpal tunnel release compared with open release : a prospective, randomized trial. J Bone Joint Surg Am. 2002;84-A(7):1107-1115.
41. Depaoli R, Coscia DR, Alessandrino F. In-continuity neuroma of the median nerve after surgical release for carpal tunnel syndrome: case report. J Ultrasound. 2015;18(1):83-85.
42. Louis DS, Greene TL, Noellert RC. Complications of carpal tunnel surgery. J Neurosurg. 1985;62(3):352-356.
43. Cranford CS, Ho JY, Kalainov DM, Hartigan BJ. Carpal tunnel syndrome. J Am Acad Orthop Surg. 2007;15(9):537-548.

44. Keith MW, Masear V, Amadio PC, et al. Treatment of carpal tunnel syndrome. J Am Acad Orthop Surg. 2009;17(6):397-405.
45. Kim P-T, Lee H-J, Kim T-G, Jeon I-H. Current Approaches for Carpal Tunnel Syndrome. Clin Orthop Surg. 2014;6(3):253.
46. Agee JM, Relton McCarroll H, Francisco S, et al. Endoscopic release of the carpal tunnel: A randomized prospective multicenter study. J Hand Surg Am. 1992;17:987-995.
47. Chow JCY. Endoscopic release of the carpal ligament: A new technique for carpal tunnel syndrome. Arthrosc J Arthrosc Relat Surg. 1989;5(1):19-24.
48. Palmer AK, Toivonen DA. Complications of endoscopic and open carpal tunnel release. J Hand Surg Am. 1999;24(3):561-565.
49. Moore AM, Franco M, Tung TH. Motor and sensory nerve transfers in the forearm and hand. Plast Reconstr Surg. 2014;134(4):721-730.
50. Brunelli GA. Sensory nerves transfers. J Hand Surg Am. 2004;29(6):557-562.
51. Tung TH, Mackinnon SE. Nerve Transfers: Indications, Techniques, and Outcomes. J Hand Surg Am. 2010;35(2):332-341.

# Chapter 11

## What role does positive psychology play in understanding pain intensity and disability among patients with hand and upper extremity conditions?

***Verhiel SHWL***, *Greenberg J, Zale EL, Chen NC, Ring DC, Vranceanu AM*

*Clin Orthop Relat Res. 2019 Aug;477(8):1769-1776*

# ABSTRACT

**Background** A large body of research shows that psychologic distress and ineffective coping strategies substantially contribute to more severe pain and increased physical limitations among patients with orthopaedic disorders. However, little is known about the relationship between positive psychology (constructs that enable individuals to thrive and adapt to challenges) and pain and physical limitations in this population.

**Questions/purposes** (1) Which positive-psychology factors (satisfaction with life, gratitude, coping through humor, resilience, mindfulness, and optimism) are independently associated with fewer upper-extremity physical limitations after controlling for the other clinical and demographic variables? (2) Which positive-psychology factors are independently associated with pain intensity after controlling for relevant clinical and demographic variables?

**Methods** In a cross-sectional study, we recruited patients presenting for a scheduled appointment with an orthopaedic surgeon at a hand and upper-extremity clinic of a major urban academic medical center. Of 125 approached patients, 119 (44% men; mean age, 50 ± 17 years) met screening criteria and agreed to participate. Patients completed a clinical and demographic questionnaire, the Numerical Rating Scale to assess pain intensity, the PROMIS UE-PF CAT to assess physical limitations, and six measures assessing positive-psychology constructs: The Satisfaction with Life Scale, the Gratitude Questionnaire, the Coping Humor Scale, the Brief Resilience Scale, the Cognitive and Affective Mindfulness Scale-Revised, and the Life Orientation Test-Revised. We first examined bivariate associations among physical limitations, pain intensity, and all positive-psychology factors as well as demographic and clinical variables. All variables that demonstrated associations with physical limitations or pain intensity at $p < 0.05$ were included in two-stage multivariable hierarchical regression models.

**Results** After controlling for the potentially confounding effects of prior surgical treatment and duration since pain onset (step1; $R^2$ total = 0.306; F[7,103] = 6.50), the positive-psychology variables together explained an additional 15% ($R^2$ change = 0.145, F change [5, 103] = 4.297, p = 0.001) of the variance in physical limitations. Among the positive-psychology variables tested, mindfulness was the only one associated with fewer physical limitations ($\beta$ = 0.228, t = 2.293, p = 0.024, 4% variance explained). No confounding demographic or clinical variables were found for pain intensity in bivariate analyses. All positive-psychology variables together explained 23% of the variance in pain intensity ($R^2$=0.23; F[5,106] = 6.38, $p < 0.001$). Among the positive-psychology variables, satisfaction with life was the sole factor independently associated with higher intensity ($\beta$ = -0.237, t = -2.16, p = 0.033, 3% variance explained).

**Conclusions** Positive-psychology variables explained 15% of the variance in physical limitations and for 23% of the variance in pain intensity among patients with heterogenous upper extremity disorders within a hand and upper extremity practice. Of all positive-psychology factors, mindfulness and satisfaction with life were most important for physical limitations and pain intensity, respectively. As positive-psychology factors are more easily modifiable through skills-based interventions than pain and physical limitations, results suggest implementation of such interventions to potentially improve outcomes in this population. Skills-based interventions targeting mindfulness and satisfaction with life may be of particular benefit.

# INTRODUCTION

Emotional distress (such as symptoms of depression and anxiety) and maladaptive coping strategies (like catastrophic thinking in response to nociception) are consistently associated with increased pain and physical limitations in heterogeneous patients with upper extremity disorders.[1–6] However, assessing and addressing these factors within the normal flow of orthopaedic care is challenging, primarily as a result of the stigma associated with mental health concerns and surgeons' lack of comfort in discussing these issues with their patients.[7] The positive-psychology framework, which focuses on cultivating individual strengths (versus focusing on deficiencies), may provide novel insight into the development of feasible and acceptable interventions for this population. The field of positive-psychology is not concerned merely with the absence of distress or maladaptive coping. Rather, it focuses on individual's strengths and qualities of personal growth and flourishing. Interventions that follow positive-psychology principles are associated with increased well-being and improved function.[8,9] Such interventions may foster effective communication between surgeons and patients, and may increase the likelihood that patients would participate in psychosocial interventions.[10,11]

Positive-psychology constructs such as satisfaction with life (one's level of individual subjective well-being [12]), gratitude (one's tendency to recognize and respond with grateful emotion to general life events [13]), coping through humor (seeing mirth within stressful experiences [14]), resilience (the ability to bounce back or recover from stress [15]), mindfulness (the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment to moment [16,17]), and optimism (ability to remain positive in the face of stress [18]) have been consistently shown to confer beneficial effects for mental health and in coping with stress and chronic illness [19]. Our team has shown that among patients with upper extremity conditions, greater overall mindfulness is associated with lower pain intensity [20] and that a 60-second mindfulness-based video exercise can be effective in improving momentary pain, anxiety, depression, and anger in this group [21]. We have also shown that satisfaction with life buffers the effect of pain in individuals with upper extremity musculoskeletal disorders.[22] However, no prior studies have comprehensively assessed multiple positive-psychology factors simultaneously in this population. This information is needed to determine the individual and combined role of positive-psychology constructs and thus inform novel interventions.

In the current work, we asked the following research questions: (1) Which positive-psychology factors (satisfaction with life, gratitude, coping through humor, resilience, mindfulness, and optimism) are independently associated with fewer upper-extremity physical limitations after controlling for the other clinical and demographic variables? (2) Which positive-psychology factors are independently associated with pain intensity after controlling for relevant clinical and demographic variables?

# METHODS

After IRB approval, we invited 125 patients presenting for a scheduled appointment with an orthopaedic surgeon at a hand and upper extremity clinic of a major urban academic medical center to participate in this cross-sectional study. Patients were approached regardless of visit type (for example, new patient or followup). Research assistants were on-site 1 day a week between April 2017 and June 2017. We only approached English-speaking patients aged 18 years or older. Exclusion criteria were being pregnant and having self-reported serious mental illness (for example, active substance abuse, untreated bipolar disorder, schizophrenia, or psychotic symptoms) because these populations were precluded by our IRB. After verbal informed consent was provided, patients completed self-report measures on a tablet computer through the sure web-based research platform RedCap.[23]

All participants (n = 125) who were approached and screened met inclusion and exclusion criteria; however, six declined. The main reasons for declining were no time for participation or lack of interest in the research project. Our final sample included the 119 patients who agreed to participate and provided informed consent. A total of 56% of the patients were women (n = 67) and had a mean age of 50 years (SD = 17). Most patients were white (n = 104; 87%) and all (n = 119; 100%) had insurance. Race was self-reported by patients. Eight percent of the patients (n = 10) had less than a high school diploma. Fifty-seven percent of patients (n = 68) were employed (Table 1).



## Measures

### ***PROMIS Upper Extremity Physical Function CAT***

The PROMIS UE-PF CAT is a computerized adaptive test (CAT) that assesses patients' abilities to engage in various activities that involve the hands and upper extremities (for example, tying shoelaces, holding a plate of food, reaching into a high cupboard) using a response scale from 1 ("without any difficulty") to 5 ("unable to do").[24] CATs optimize questionnaire administration by distributing only relevant items based on previous responses. The CAT generates a standardized T-score (mean = 50, SD = 10). Higher scores represent fewer physical limitations. The PROMIS UE-PF CAT has been validated for use in patients with upper extremity disorders by multiple studies.[25,26]

### ***Numerical Pain Rating Scale***

Patients rated their pain intensity on a scale ranging from 0 ("no pain at all") to 10 ("most severe pain").

**Table 1.** Demographic factors and clinical characteristics of the study population (n = 119)

| Parameter | Value |
|---|---|
| Age (years), mean ± SD | 50 ± 17 |
| Gender, number (%) | |
| Women | 67 (56) |
| Men | 52 (44) |
| Race, number (%) | |
| White | 104 (87) |
| Black | 6 (5.0) |
| Latino | 6 (5.0) |
| Asian | 2 (1.7) |
| Other | 1 (0.8) |
| Education level (years), mean ± SD | 15 ± 3 |
| Marital status, number (%) | |
| Married/unmarried couple | 71 (60) |
| Divorced/separated | 7 (5.9) |
| Widowed | 4 (3.4) |
| Never married | 37 (31) |
| Employment status, number (%) | |
| Employed | 68 (57) |
| Unemployed | 51 (43) |
| Insurance status, number (%) | |
| Private | 84 (71) |
| Medicaid | 11 (9.2) |
| Medicare | 23 (19) |
| Workers' compensation | 1 (0.8) |
| Smoking status, number (%) | |
| Smoker | 8 (6.7) |
| Nonsmoker | 111 (93) |
| Type of visit, number (%) | |
| First visit | 61 (51) |
| Followup visit | 58 (49) |
| Side affected, number (%) | |
| Dominant side | 79 (66) |
| Nondominant side | 40 (34) |
| Diagnosis, number (%)* | |
| Traumatic | 63 (53) |
| Nontraumatic | 55 (46) |
| Prior conservative treatment for this condition, number (%) | 58 (49) |
| Prior surgery for this condition, number (%) | 39 (33) |
| Pain duration (days), mean ± SD | 360 (550) |

*One missing value.*

***Satisfaction with Life Scale (SWLS)***

The SWLS is a reliable and valid five-item scale designed to measure the extent to which patients are satisfied with their life on a 7-point Likert scale.[12,27] Items were summed to generate a total score, with higher scores representing higher satisfaction with life. Internal consistency in the current sample was good ($\alpha$ = 0.87).[28]

***Gratitude Questionnaire-Six Item Form (GQ-6)***

The GQ-6 is a reliable and valid six-item measure of the general tendency to experience gratitude. Patients rated the extent to which they agree (1 = "strongly disagree"; 7 = "strongly agree") with six statements about gratitude.[13,29] Negatively worded items were reverse-scored, and all items were then summed to generate a total score, with higher scores representing a greater tendency toward optimism.[29] Internal consistency in the current sample was adequate ($\alpha$ = 0.74).[28]

***Coping Humor Scale (CHS)***

The CHS is a reliable and valid seven-item measure of the extent to which individuals use humor as a means of coping with difficult situations or adversity.[14] Respondents rated the degree to which each agree (1 = "strongly disagree"; 4 = "strongly agree") with each statement. Negatively worded items are reverse-scored, and all items are summed to generate a total score with higher scores representing a higher tendency to use humor for coping. Internal consistency in the current sample was adequate ($\alpha$ = 0.67).[28]

***Brief Resilience Scale (BRS)***

The BRS is a reliable and valid six-item self-report measure that assesses the extent to which individuals recover quickly from stress or adversity.[15] Patients rate how much they agree (1 = "strongly disagree"; 5 = "strongly agree") with each statement. Negatively worded items are reverse-scored, and all items are then summed to generate a total score. Higher scores represent greater resilience.[15] Internal consistency in the current sample was good ($\alpha$ = 0.84).[28]

***Cognitive and Affective Mindfulness Scale-Revised (CAMS-R)***

The 10-item version of the CAMS-R is a reliable and valid self-report measure of the frequency (0 = "rarely/not at all"; 3 = "almost always") with which patients use mindfulness behaviors (for example, noticing thoughts without judgment) in their daily lives.[17] Negatively worded items are reverse-scored, and all items are summed to generate a total score, with higher scores representing greater levels of mindfulness. Internal consistency in the current sample was good ($\alpha$ = 0.86).[28]

### *Life Orientation Test-Revised (LOT-R)*

The LOT-R is a reliable and valid 10-item measure of a general tendency toward optimism or pessimism. Patients rated the extent to which they agree (0 = "strongly disagree"; 4 = "strongly agree") with six statements about optimism or pessimism.[30] There are four filler items that are discarded leaving six items that comprise the scale. Negatively worded items are reverse-scored, and the six scored items are summed to generate a total score. Higher scores represent higher levels of optimism. Internal consistency in the current sample was adequate ($\alpha = 0.74$).[28]

## Demographic and Clinical Variables

Patients self-reported demographics (that is, age, gender, race/ethnicity, education level, marital status, employment status, insurance status, smoking status). Patients also self-reported their visit type (new versus follow-up), whether they were seeking care for a traumatic injury, the duration of their pain, and whether they had received prior surgical treatment for the current chief disorder.

## Statistical Analysis

### *Bivariate tests*

First, we summarized descriptive statistics for demographic and clinical variables. Second, we examined bivariate Pearson correlations among physical limitations, pain intensity, and all positive-psychology factors as well as continuous demographic and clinical variables. For categorical factors (for example, gender, marital status, smoking status), we conducted univariate analyses of variance to assess differences in pain intensity and physical limitations. In bivariate correlations, higher satisfaction with life ($r = 0.272$, $p = 0.003$), gratitude ($r = 0.248$, $p = 0.007$), humor ($r = 0.197$, $p = 0.033$), mindfulness ($r = 0.394$, $p < 0.001$), optimism ($r = 0.224$, $p = 0.017$) and longer duration of pain ($r = 0.233$, $p = 0.011$) were associated with fewer physical limitations. Physical limitations were also lower among patients who had not received prior surgical treatment for their chief complaint ($M = 38.966$, $SD = 8.483$) compared with those who had received surgery ($M = 32.729$, $SD = 7.639$; $F(1,117)=13.87$ $p < 0.001$). Higher satisfaction with life ($r = -0.411$, $p < 0.001$), gratitude ($r = -0.271$, $p = 0.003$), resilience ($r = -0.262$, $p = 0.004$), mindfulness ($r = -330$, $p < 0.000$), and optimism ($r = -0.364$, $p < 0.001$) were associated with lower pain intensity. All other bivariate analyses were not significant.

### *Multivariable models*

We determined a priori that all variables that demonstrated associations with physical limitations activity or pain intensity at $p < 0.05$ would be included in two-stage multivariable hierarchical regression models. The significant demographic and clinical variables were entered at the first stage of the hierarchical model and the significant positive-psychology factors were entered in the second stage to identify unique contributions of positive-psychology factors beyond clinical and demographic variables, and to determine which positive-psychology construct(s) are most important for both pain and physical function. We used an α level of $p < 0.05$ to determine statistical significance and the squared semipartial correlation ($sr^2$) as a measure of variance in outcomes explained by each individual variable in the multivariable regression for this cross-sectional data with imposed predictors (demographics, clinical variables, and positive-psychology variables) and outcomes (pain and physical function) The $R^2$ was calculated to show the entire amount of variance explained by all variables in the model, and $R^2$ change was calculated to depict the amount of variance explained by the positive-psychology variables together over and above demographics and clinical variables.

***Power analyses***

An a priori analysis indicated that a sample size of 116 patients would provide 90% statistical power ($\alpha = 0.05$) to detect a medium effect size (Cohen's $f^2 = 0.15$) in a multivariable linear regression model with five tested predictors. The regression models met assumptions with regard to sample size, multicollinearity (minimum r = 0.20, maximum r = 0.561 between positive-psychology factors), and heteroskedasticity.

# RESULTS



Of the positive-psychology variables examined, mindfulness was the only factor we examined that was associated with lower physical limitations (ß = 0.228, t = 2.293, p = 0.024; sr2 = 0.0353; 4% variance explained). Lack of prior surgical treatment and longer duration since pain onset were associated with fewer physical limitations in step one of the hierarchical model and explained 16% of the variance in physical limitations ($R^2 = 0.162$; F[2,108] = 10.42, p < 0.001; Table 2). After controlling for these confounding clinical variables in step 1 of the model, all the positive-psychology variables were added in step 2 and together explained an additional 15 % ($R^2$ change = 0.145, F change [5,103] = 4.297, p = 0.001) of the variance in physical limitations, beyond that explained by the clinical variables alone. The entire model explained31% (16% in step 1 and 15% in step 2) of the variance ($R^2$ total = 0.306; F[7,103] = 6.50) in physical limitations. Of the positive-psychology variables, satisfaction with life was the only factor associated with higher pain intensity (ß = -0.237, t = -2.16, p = 0.03; 3% variance explained). Given that there were no observed differences in pain intensity according to any demographic or clinical variables, the multivariable model was a single-stage regression model in which all positive-psychology variables were entered simultaneously (Table 2; F[5,106] = 6.38, p < 0.001). All positive-psychology factors together explained 23% of the variance in pain intensity ($R^2 = 0.231$).

**Table 2.** Results of hierarchical linear regression models for upper extremity physical function and pain intensity

| **Criterion** | **Predictor variable** | **ß value** | |
|---|---|---|---|
| | | **Step 1** | **Step 2** |
| Physical function | Prior surgery | -0.331† | -0.275* |
| | Pain duration | 0.234† | 0.286* |
| | Satisfaction with life | | 0.139 |
| | Gratitude | | 0.013 |
| | Coping humor | | 0.105 |
| | Mindfulness | | 0.228* |
| | Optimism | | 0.031 |
| | $R^2$ | 0.162 | 0.306 |
| | F for change in $R^2$ | 10.419† | 6.501† |
| Pain intensity | Satisfaction with life | -0.237* | |
| | Gratitude | -0.114 | |
| | Resilience | 0.036 | |
| | Mindfulness | -0.170 | |
| | Optimism | -0.120 | |
| | $R^2$ | 0.231 | |
| | F for $R^2$ | 6.380† | |

*$R^2$ represents the percentage of the variance in physical function and pain intensity accounted for by the variables in the model; ß is the standardized regression coefficient; for every increase of 1 SD in the explanatory variable, the response variable changes by ß SDs; F for change in $R^2$ is a test for significance of $R^2$; it tests the null hypothesis that, when entering variables in the model, all regression coefficients will equal zero; a significant F test shows that variables entered in the model significantly contributed variance in the dependent variable; *significant at $p < 0.05$; †significant at $p < 0.01$.*

# DISCUSSION

Distress and less-effective coping strategies contribute to increased pain intensity and greater magnitude of limitations among patients with orthopaedic injuries.[1–6] Addressing these deficiencies has been historically challenging with this population because of the stigma associated with these problems. Using a positive-psychology lens, with its focus on strengths rather than deficits, is a novel approach that may be better received by this population. After controlling for potential demographic and clinical confounding variables, we found that mindfulness was the sole positive-psychology factor associated with fewer physical limitations and satisfaction with life was the sole positive-psychology factor associated with pain intensity. Although the other positive-psychology factors did not show an association with pain or physical limitations after controlling for confounding variables, positive-psychology factors did contribute to a substantial increase in the amount of variance explained in both pain and physical function.

This study had several limitations. First, this is a cross-sectional study and although we imposed predictors and outcomes as required by the regression analyses, causal inferences cannot be made. Prior research in patients with chronic pain depicts a bidirectional association between pain/limitations on one hand, and psychosocial variables on the other.[3,22] In line with this, it is likely that positive-psychology constructs in the current sample influence pain and limitations, which, in turn, influence positive-psychology constructs. However, it is important to mention that the positive-psychology factors are more easily modifiable than pain and physical limitations.[31–35] Thus, addressing these factors can foster recovery and stop a potential vicious cycle of pain and disability in this population. Second, we recruited patients from a single academic medical center in the northeast United States. Our sample, albeit representative of patients seen in our medical center, was primarily white and highly educated. This may limit generalizability, as it is uncertain whether patients at other locations, who may differ in clinical and demographic characteristics, would exhibit similar associations between positive-psychology constructs and levels of pain and physical limitations. Future studies should replicate our findings through prospective studies with more diverse patient populations. In addition, PROMIS UE-PF may have limitations, including substantial ceiling effects.[36] The PROMIS UE-PF however, is one of the few questionnaires that have been validated specifically for use in patients with upper extremity disorders.

Mindfulness was the only positive-psychology factor correlated with physical function after controlling for clinical and demographic variables (Table 2) such that patients with higher mindfulness also reported fewer physical limitations. Mindfulness might therefore be the most-promising factor to target in interventions focused on decreasing physical limitations. Mindfulness-based interventions appear to reduce the severity of physical limitations.[37–39] Among patients with upper extremity conditions, brief mindfulness exercises have been found to be feasible, accepted, and associated with a substantial decrease in pain and distress in both open and randomized controlled trials.[40,41] A primary emphasis of mindfulness is facing experiences with acceptance and without judgment rather than striving to control and change the experiences, particularly those that are beyond our control.[42] Although the current work cannot offer causal inference, it is likely that fostering such an accepting and nonjudgmental attitude in the face of orthopaedic injury may help decrease physical limitations. Our results support mindfulness-based interventions as means of reducing physical limitations in orthopaedic patients. Recent evidence suggests that mindfulness training can measurably improve other positive-psychology constructs besides mindfulness, including satisfaction with life, optimism, gratitude, and resilience.[31–35] Mindfulness independently explained 4% of the variance in physical function, but this should be considered in the context of the interrelation between the rest of the positive-psychology constructs. Its 4% contribution is thus in addition to that derived from the other positive-psychology factors, which together explained a substantial 15% of the variance in physical function. These positive-psychology constructs, and particularly mindfulness, thus may provide an opportunity to improve function in this population.

Satisfaction with life was the only positive-psychology variable we found that was independently associated with pain (Table 2). This supports previous research indicating that satisfaction with life plays an important role among orthopaedic patients in moderating the indirect effect of pain intensity on pain interference.[22] These results coupled with those of the current study reinforce the need to account for the interrelation of pain with satisfaction with life in understanding reports of pain in orthopaedic patients. Similar to our findings for physical limitations, although satisfaction with life was the only factor we investigated that was associated with pain after controlling for relevant confounding variables, the rest of the positive-psychology variables explained a substantial amount of variance in pain intensity suggesting that they, too, are important in understanding reports of pain in this population.

Our study has important implications for clinical care. Positive-psychology factors are more easily modifiable through skills-based interventions than pain and physical limitations. Psychosocial interventions used as an adjunct to medical care may benefit from focusing on teaching positive-psychology skills. A primary focus should be on mindfulness-based interventions, that can measurably improve positive-psychology constructs in addition to mindfulness. Such interventions focused on cultivating strengths rather than eliminated deficiencies are likely to be feasible, acceptable and efficacious, as evidenced by prior reports.[40,41] There is thus a tremendous opportunity for improving pain and physical function in this population.

# REFERENCES


1. Özkan S, Zale EL, Ring D, Vranceanu AM. Associations Between Pain Catastrophizing and Cognitive Fusion in Relation to Pain and Upper Extremity Function Among Hand and Upper Extremity Surgery Patients. Ann Behav Med. 2017;51(4):547-554
2. Dimitriadis Z, Kapreli E, Strimpakos N, Oldham J. Do psychological states associate with pain and disability in chronic neck pain patients? J Back Musculoskelet Rehabil. 2015;28(4):797-802
3. Talaei-Khoei M, Fischerauer SF, Lee S-G, Ring D, Vranceanu A-M. Pain Catastrophizing Mediates the Effect of Psychological Inflexibility on Pain Intensity and Upper Extremity Physical Function in Patients with Upper Extremity Illness. Pain Pract. 2016;17(1):129-140
4. Van Leeuwen WF, Van Der Vliet QMJ, Janssen SJ, Heng M, Ring D, Vranceanu AM. Does perceived injustice correlate with pain intensity and disability in orthopaedic trauma patients? Injury. 2016;47(6):1212-1216
5. Das De S, Vranceanu AM, Ring DC. Contribution of kinesophobia and catastrophic thinking to upper-extremity-specific disability. J Bone Jt Surg - Ser A. 2013;95(1):76-81.
6. Ring D, Kadzielski J, Fabian L, Zurakowski D, Malhotra LR, Jupiter JB. Self-reported upper extremity health status correlates with depression. J Bone Jt Surg - Ser A. 2006;88(9):1983-1988
7. Vranceanu AM, Beks RB, Guitton TG, Janssen SJ, Ring D. How do Orthopaedic Surgeons Address Psychological Aspects of Illness? Arch bone Jt Surg. 2017;5(1):2-9
8. Seligman MEP, Csikszentmihalyi M. Positive psychology: An introduction. Am Psychol. 2000;55(1):5-14
9. Duckworth A, Steen T, Seligman MEP. Positive psychology in clinical practice. Annu Rev Clin Psychol. 2005;1:629-651
10. Vranceanu AM, Cooper C, Ring D. Integrating Patient Values into Evidence-Based Practice: Effective Communication for Shared Decision-Making. Hand Clin. 2009;25(1):83-96
11. Zale EL, Ring D, Vranceanu A-M. The Future of Orthopaedic Care. J Bone Jt Surg. 2018;100(13):e89
12. Diener E, Emmons RA, Larsen RJ, Griffin S. The Satisfaction with Life Scale. J Pers Assess. 1985;49(1):71-75
13. McCullough ME, Emmons RA, Tsang J-A. The grateful disposition: A conceptual and empirical topography. J Pers Soc Psychol. 2002;82(1):112-127
14. Martin RA, Lefcourt HM. Sense of humor as a moderator of the relation between stressors and moods. J Pers Soc Psychol. 1983;45(6):1313-1324
15. Smith BW, Dalen J, Wiggins K, Tooley E, Christopher P, Bernard J. The brief resilience scale: assessing the ability to bounce back. Int J Behav Med. 2008;15(3):194-200
16. Kabat-Zinn J. Mindfulness-based interventions in context: Past, present, and future. Clin Psychol Sci Pract. 2003;10(2):144-156
17. Feldman G, Hayes A, Kumar S, Greeson J, Laurenceau JP. Mindfulness and emotion regulation: The development and initial validation of the Cognitive and Affective Mindfulness Scale-Revised (CAMS-R). J Psychopathol Behav Assess. 2007;29(3):177-190
18. Scheier MF, Carver CS. Optimism, coping, and health: assessment and implications of generalized outcome expectancies. Health Psychol. 1985;4(3):219-247
19. Bolier L, Haverman M, Westerhof GJ, Riper H, Smit F, Bohlmeijer E. Positive psychology interventions: A meta-analysis of randomized controlled studies. BMC Public Health. 2013;13(1)
20. Beks R, Mellema J, Menendez M, Chen N, Ring D, Vranceanu A. Does mindfulness correlate with physical function and pain intensity in patients with upper extremity illness? Hand. 2017;Mar 1(1558944717697429):Epub ahead of print.

21. Westenberg RF, Zale EL, Heinhuis TJ, et al. Does a Brief Mindfulness Exercise Improve Outcomes in Upper Extremity Patients? A Randomized Controlled Trial. Clin Orthop Relat Res. 2018
22. Talaei-Khoei M, Chen N, Ring D, Vranceanu A-M. Satisfaction with life moderates the indirect effect of pain intensity on pain interference through pain catastrophizing. J Consult Clin Psychol. 2018;86(3):231-241
23. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)-A metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009
24. Döring AC, Nota SPFT, Hageman MGJS, Ring DC. Measurement of upper extremity disability using the patient-reported outcomes measurement information system. J Hand Surg Am. 2014;39(6):1160-1165
25. Tyser AR, Beckmann J, Franklin JD, et al. Evaluation of the PROMIS physical function computer adaptive test in the upper extremity. J Hand Surg Am. 2014;39(10):2047-2051
26. Beckmann JT, Hung M, Voss MW, Crum AB, Bounsanga J, Tyser AR. Evaluation of the Patient-Reported Outcomes Measurement Information System Upper Extremity Computer Adaptive Test. J Hand Surg Am. 2016;41(7):739-744.e4
27. Pavot W, Diener E, Colvin CR, Sandvik E. Further Validation of the Satisfaction With Life Scale; Evidence for the Cross-Method Convergence of Well-Being Measures. J Pers Assess. 1991;57(1):149-161
28. George D, Mallery P. SPSS for Windows Step by Step: A Simple Guide and Reference. 11.0 Update. 4th ed. Boston: Allyn & Bacon; 2003.
29. McCullough ME, Tsang JA, Emmons RA. Gratitude in Intermediate Affective Terrain: Links of Grateful Moods to Individual Differences and Daily Emotional Experience. J Pers Soc Psychol. 2004;86(2):295-309
30. Scheier MF, Carver CS, Bridges MW. Distinguishing optimism from neuroticism (and trait anxiety, self-mastery, and self-esteem): a reevaluation of the Life Orientation Test. J Pers Soc Psychol. 1994;67(6):1063-1078
31. Kiken LG, Shook NJ. Looking up: Mindfulness increases positive judgments and reduces negativity bias. Soc Psychol Personal Sci. 2011;2(4):425-431
32. Carmody J, Baer RA. Relationships between mindfulness practice and levels of mindfulness, medical and psychological symptoms and well-being in a mindfulness-based stress reduction program. J Behav Med. 2008;31(1):23-33.
33. Mackenzie CS, Poulin PA, Seidman-Carlson R. A brief mindfulness-based stress reduction intervention for nurses and nurse aides. Appl Nurs Res. 2006;19(2):105-109
34. Simão C, Seibt B. Friendly touch increases gratitude by inducing communal feelings. Front Psychol. 2015;6(JUN)
35. Hoge EA, Bui E, Marques L, et al. Randomized controlled trial of mindfulness meditation for generalized anxiety disorder: effects on anxiety and stress reactivity. J Clin Psychiatry. 2013;74(8):786-792
36. Beleckas CM, Padovano A, Guattery J, Chamberlain AM, Keener JD, Calfee RP. Performance of Patient-Reported Outcomes Measurement Information System (PROMIS) Upper Extremity (UE) Versus Physical Function (PF) Computer Adaptive Tests (CATs) in Upper Extremity Clinics. J Hand Surg Am. 2017;42(11):867-874
37. deVibe M. Mindfulness based stress reduction (MBSR) for improving health, quality of life, and social functioning in adults. Campbell Syst Rev. 2012;13(11)
38. Veehof MM, Oskam MJ, Schreurs KMG, Bohlmeijer ET. Acceptance-based interventions for the treatment of chronic pain: A systematic review and meta-analysis. Pain. 2011;152(3):533-542

39. Lengacher C, Post-White J, Moscoso M, et al. Randomized controlled trial of mindfulness-based stress reduction (MBSR) for survivors of breast cancer. Psychooncology. 2009;18(12):1261-1272
40. Westenberg RF, Zale EL, Heinhuis TJ, et al. Does a Brief Mindfulness Exercise Improve Outcomes in Upper Extremity Patients? A Randomized Controlled Trial. Clin Orthop Relat Res. 2018;476(4):790-798
41. Chad-Friedman E, Talaei-Khoei M, Ring D, Vranceanu A-M. First use of a brief 60-second mindfulness exercise in an orthopedic surgical practice; results from a pilot study. Arch Bone Jt Surg. 2017;5(6):400-405
42. Kabat-Zinn J. Full Catastrophe Living: Using the Wisdom of Your Body and Mind to Face Stress, Pain, and Illness. New York: Delta Trade; 1990.

# PART III

## General discussion

# Chapter 12

## General discussion and future perspectives

# GENERAL DISCUSSION

This thesis was designed to provide insights regarding the complexity and coherence between pathologies in ulnar-sided wrist pain, while evaluating outcomes after different surgical procedures with a focus on the influence of specific characteristics and psychological aspects on these outcomes.

## Pathology in ulnar-sided wrist pain

Accurate diagnosing of ulnar-sided wrist pain can pose a challenge for even the most experienced clinicians. This diagnostic challenge is mainly caused by the complex overlap and interaction of the anatomy at the ulnar wrist and by consequence the complex biomechanics, combined with the numerous pathologies that can be found.[1–4] Obtaining a thorough history and performing a systematic physical examination are essential to develop a comprehensive differential diagnosis, which prompts to selectively perform provocative maneuvers and request relevant diagnostic imaging studies.[1–5]

Ulnar-sided wrist pathology can roughly be categorized as symptoms of isolated pain, pain with instability, or pain with arthritis.[1] Isolated pain can be seen in various cases including a LT ligament tear or sprain, ulnocarpal synovitis, lesions of the TFCC, tenosynovitis of the ECU or FCU, ulnar nerve entrapment, or PT joint pathology. Pain with instability may be secondary to the deep dorsal and palmar radioulnar ligaments, a transverse tear of the ulnotriquetral and ulnolunate ligaments, a LT ligament tear, an ECU subsheath tear, or lesions of the TFCC. Pain with arthritis may occur in ulnar impaction syndrome, PT arthritis or DRUJ arthritis. By no means these lists are complete, several other pathologies can be named. Categorizing the patient's symptoms into one of these groups can help the clinician to determine the appropriate treatment, ranging from repairing the injured structure to performing a salvage procedure.[1]



The complexity and overlap of pathologies at the ulnar wrist are demonstrated in several chapters of this thesis. In **Chapter 4** we demonstrated significantly higher rates of TFCC tears, DRUJ arthritis, ECU tears on MRI scans in patients who underwent TFCC repair compared to controls with radial-sided symptoms. This may be due to the damage to the TFCC itself, altering relationships to the DRUJ and the ECU subsheath, or it may reflect various pathologies that cause ulnar-sided wrist pain and drive patients toward surgery.

MRIs of patients who underwent a TFCC repair more often showed an ulnar styloid fracture compared to MRIs of controls with radial-sided symptoms. A potential explanation of this finding is that the majority of patients sustained a Palmer 1B tear, where traumatic avulsions of the TFCC at distal ulnar attachment often involve an ulnar styloid fracture.[6,7]

The ECU tendon passes through a fibro-osseous tunnel (the sixth extensor compartment) as it leaves the forearm, lying within an osseous groove on the dorsal surface of the ulna. The ECU is stabilized within its osseous groove by the ECU subsheath, which is in continuity with the TFCC.[8–10] In **Chapter 7** we assessed patients who underwent an operative treatment for

ECU subluxation. Two of 15 patients who underwent ECU sling reconstruction, concomitantly underwent a procedure to the TFCC. Of the 10 patients that could be contacted at a median of 8 years after ECU sling reconstruction, 1 additionally had undergone arthroscopic TFCC debridement and 1 had undergone USO. These findings reflect the close relationship between the ECU and the TFCC.

In **Chapter 8** we reviewed patients who underwent pisiformectomy, predominantly for arthritis of the PT joint. Additional imaging (other than radiographs) to confirm diagnosis and exclude other pathology was obtained for 56% of the patients, which is relatively high compared to other studies.[11,12] No reoperations were performed among our patients. Other studies describe patients who went on to have a Darrach procedure or other surgery to treat DRUJ pathology.[13,14] This speaks to the confounding nature of ulnar-sided wrist pain, which implicates that a thorough examination should be performed before proceeding to pisiformectomy.

The ulnar nerve is an anatomic structure with a variable course, which has consequences for interpretation of symptoms.[15–21] In **Chapter 10** we examined variations and frequencies of the arborization patterns and communicating branches of the ulnar nerve in the palm in a cadaver study. Variations in arborization patterns of the ulnar nerve and the existence of communicating branches between the ulnar and median nerves were common. This may lead to atypical distribution of symptoms in compression neuropathies, and to unforeseen risks during hand surgery.

## Diagnostic imaging modalities

Diagnostic imaging is an important adjuvant in ulnar-sided wrist pain.[1–3,5] With a detailed understanding of the anatomy of the ulnar wrist, and after a thorough history and a systematic physical examination, relevant diagnostic imaging can assist in establishing the right diagnosis and exclude other pathology.

In many clinical settings, imaging begins with standard radiographs including posterioanterior (PA), lateral, and oblique views. The ulnar variance can be measured on PA radiographs of the wrist, for instance according to the method of perpendiculars as we discussed in **Chapter 2**.[22] Special views should be considered based on the suspected pathology. For example a carpal tunnel view is useful to visualize the hook of the hamate and a PT view (lateral view with the hand in 20 degrees of supination) is used to visualize the PT joint more clearly.[1,2,5]

CT may be needed to identify occult or nondisplaced fractures, intra-articular fractures, non- or malunions, and subtle joint subluxations that are not readily apparent on standard radiographs. In addition, CT can be helpful in identifying pathology in the DRUJ and degenerative changes of the ulnar head. The use of CT has allowed for more accurate assessment of injury morphology, which has resulted in the development of novel classification systems.[1–3,5] In **Chapter 9** we demonstrated the importance of CT in CMC 4/5 fracture dislocations in order to assess injury morphology and guide surgical planning.

While CT provides superior osseous detail, MR imaging has greater sensitivity to evaluate soft-tissue injuries and subtle bone marrow changes such as bone marrow edema.[1–3,5] In **Chapter 4** we reported a sensitivity of 81% for the detection of a TFCC tear by MRI. In the literature, the reported sensitivity varies widely, between 65% and 94%.[23–26] In 21% of our control group, a TFCC tear was found. Other studies report between 15% and 38% TFCC signal changes in asymptomatic wrists, with the rate increasing with an age of > 50 years.[27–29] Similarly, in **Chapter 7** and **Chapter 8** high rates of various abnormalities to the ulnar wrist were found on MRIs obtained in patients undergoing ECU sling reconstruction and pisiform excision, respectively. These findings suggest that it may be difficult to differentiate structural sources of ulnar-sided wrist pain from unrelated incidental findings, which once again highlights the importance of taking a thorough history and performing a detailed physical examination.

Ultrasound imaging is increasingly used in clinical practice and many hand surgeons apply it themselves in the office when examining patients; it offers the advantage of low cost, it is noninvasive, is readily available and lacks ionizing radiation. Ultrasound can be employed to detect dynamic changes and tendon instability, but it can also be used to evaluate tendon rupture or tendinitis, ulnar neuropathy at the Guyon canal and blood flow in the ulnar artery. Moreover, its applicability and scope is still expanding.[1–3,5]

Arthroscopy plays an important role in the diagnosis and management of intra-articular ulnar-sided wrist pathology. It allows direct visualization of the TFCC and surrounding ligaments but is minimally invasive. However, after pathology is identified, it can be addressed immediately if it is amenable to surgical treatment.[1,2] Arthroscopy is the golden standard for the diagnosis and treatment of TFCC tears as we showed in **Chapter 2**. TFCC tears are commonly categorized according to the Palmer classification differentiating traumatic (class 1) and degenerative (class 2) causes.[6,7] Based on the category, a TFCC tear can be suitable for arthroscopic debridement, as demonstrated in **Chapter 2**, or repair, as demonstrated in **Chapter 4**. Ligament injuries to the SL or LT can be addressed simultaneously, as discussed in **Chapter 2** and **Chapter 4**.

In conclusion, several imaging studies may be relevant in the diagnostic work-up of ulnar-sided wrist pain. However, it must be noted that each modality has its own specific indications and set of advantages and disadvantages.

## Outcomes in ulnar-sided wrist surgery

The last years there has been a greater focus on the importance and incorporation of patients' interpretation of their care.[30,31] The use of PROMs is an important component of medical care because it has the potential to narrow the gap between the clinician's and patient's view of clinical reality. Furthermore, it can assist in the development of a treatment plan to meet the specific preferences and needs of a particular patient. PROMs quantify patients' perspectives about the frequency and severity of their symptoms, how their disease impacts their functioning, and the degree to which it limits their health-related quality of life.[32–35]

In this thesis, we reported on PROMs, complications, and reoperations after various ulnar-sided wrist procedures. We assessed differences in patient-reported outcomes after a Darrach and Sauvé-Kapandji procedure, and reported on patient-reported outcomes after HIT arthroplasty, ECU sling reconstruction, pisiformectomy and ORIF of CMC 4/5 fracture-dislocations. We reported on rate and type of complications after arthroscopic TFCC debridement, USO, Darrach procedure, Sauvé-Kapandji procedure, HIT arthroplasty, ECU sling reconstruction, pisiformectomy and ORIF of CMC 4/5 fracture-dislocations.

Overall, we found relatively high rates of complications and reoperations after ulnar-sided wrist surgery. Clinicians should be aware of these high rates, and should take these into account when opting for a specific procedure or get informed consent from patients. However, the high rates of complications and reoperations in ulnar-sided wrist surgery did not always necessarily lead to inferior patient-reported outcomes, as shown in **Chapter 5 and 6**. This again reflects that PROMs encompass a wide range of measurable outcomes of care from the patient's perspective, including symptoms, functional status and quality of life. Moreover, in this thesis we reviewed patient-reported outcomes after various surgical interventions. In **Chapter 11** we discussed the influence of psychological factors and coping strategies on level of pain and physical functioning. One can argue that it is not clear how the patient-reported outcomes would have been affected when patients were treated conservatively with a greater focus on revalidation and coping strategies, instead of being treated surgically.

This thesis underlines the complexity of ulnar-sided wrist pain, with a wide variation in pathology in a relatively small anatomic region. To adequately treat ulnar-sided wrist pathology, a clinician thus requires 1) a detailed understanding of the anatomy of the ulnar wrist, 2) knowledge about relevant available diagnostic imaging studies, and 3) comprehensive understanding of specific procedures and sufficient surgical skills to perform these procedures.

# FUTURE PERSPECTIVES

We previously discussed the substantial role of imaging studies in establishing the accurate diagnosis and excluding pathology in ulnar-sided wrist pain. Medical imaging technology continues to advance with use of artificial intelligence (AI) in radiology and new techniques such a 4D-CT.

The rapid development of artificial intelligence (AI) and its implementation into routine clinical imaging will likely cause a major transition to the practice of radiology.[36] Historically, trained clinicians visually assessed medical images for the detection, characterization and monitoring of diseases. AI methods excel at automatically recognizing complex patterns in imaging data and providing quantitative, rather than qualitative, assessments of radiographic characteristics.[37] The field of AI thus offers opportunities to improve the speed, accuracy, and quality of image interpretation and diagnosis in radiology.[36,37]

The development of 4D-CT, in which objects are imaged over time to produce dynamic 3D volumes, may allow the improved assessment of wrist kinematics and pathology. Adequate assessment of subtle wrist motion changes resulting from ligament injuries is crucial for diagnosis and adequate treatment, in order to prevent progression to osteoarthritis.[38–40] The 4D-CT acquisition includes the isotropic volume of an entire wrist with a temporal resolution to dynamically demonstrate wrist kinematics over various pre-defined arcs of motion. Recent advances in post-processing tools, such as multiplanar reconstruction (MPR), may aid in the detection of subtle motion abnormalities of the carpus.[38–40]

One of the potential sources of ulnar-sided wrist pain is pathology to the PT joint, as discussed in **Chapter 8**. The most common pathologies described in this joint are osteoarthritis and adjacent FCU tendon injuries, both of which can be diagnosed using static MRI or CT imaging. However, subtle dynamic instabilities in the PT joint can be difficult to detect using MRI or CT because injury and pathology can alter the complex ligament structure of the ulnar wrist, causing alterations in the kinematic behavior of the individual carpal bones. 4D-CT can provide a clinically feasible dynamic assessment of the PT joint.[41,42]

Questions still remain regarding normal wrist kinematics, the most appropriate method for measurement of carpal stability, the accuracy of 4D-CT compared with standard modalities, and its use in postoperative assessment.

Despite extensive scientific research, there is no clear consensus with respect to which factors and treatments have the greatest influence on symptom intensity and magnitude of limitations using PROMs for upper-extremity disorders. The World Health Organization (WHO) International Classification of Functioning, Disability and Health (ICF) framework encourages a more holistic, comprehensive, biopsychosocial approach to human illness.[43]

There is mounting evidence for a strong influence of psychosocial factors (e.g., depression, anxiety, catastrophic thinking, lack of emotional and practical social support, ineffective coping strategies) on PROMS and comparatively limited influence of impairment (or objective pathophysiology) across a range of upper-extremity disorders. It is becoming clear that there is more to generating optimal outcomes than resolving pathophysiology, restoring anatomy, and focusing on the technical components alone.[44–50]

Our findings support routine assessment of psychological and social factors and referral for behavioral interventions in addition to the usual clinical care. Future studies should test such efforts to improve patient engagement and psychosocial support in order to improve health outcomes and the patient's experience of care.

In line with these findings, it would be interesting for future studies in ulnar-sided wrist pain to investigate the impact of early assessment and provision of interventions, e.g. coping strategies, social support, behavioral activation and cognitive-behavioral therapy on long-term PROMs. More large-scale and prospective studies are required to compare several ulnar-sided wrist procedures, ideally with implementation and a great focus on the influence of psychological and social factors.

# REFERENCES


1. Brogan DM, Berger RA, Kakar S. Ulnar-sided wrist pain: A critical analysis review. JBJS Rev. 2019;7(5):1-13.
2. Dasilva MF, Goodman AD, Gil JA, Akelman E. Evaluation of ulnar-sided wrist pain. J Am Acad Orthop Surg. 2017;25(8):e150-e156.
3. Sachar K. Ulnar-sided wrist pain: Evaluation and treatment of triangular fibrocartilage complex tears, ulnocarpal impaction syndrome, and lunotriquetral ligament tears. J Hand Surg Am. 2012;37(7):1489-1500.
4. Vezeridis PS, Yoshioka H, Han R, Blazar P. Ulnar-sided wrist pain. Part I: Anatomy and physical examination. Skeletal Radiol. 2010;39(8):733-745.
5. Watanabe A, Souza F, Vezeridis PS, Blazar P, Yoshioka H. Ulnar-sided wrist pain. II. Clinical imaging and treatment. Skeletal Radiol. 2010;39(9):837-857.
6. Palmer A. Triangular fibrocartilage disorders: Injury patterns and treatment. Arthroscopy. 1990;6(2):125-132.
7. Palmer AK. Triangular fibrocartilage complex lesions: A classification. J Hand Surg Am. 1989;14(4):594-606.
8. Spinner M, Kaplan E. Extensor carpi ulnaris. Its relationship to the stability of the distal radio-ulnar joint. Clin Orthop Relat Res. 1970;68:124-129.
9. Iorio ML, Huang JI. Extensor carpi ulnaris subluxation. J Hand Surg Am. 2014;39(7):1400-1402.
10. Iorio ML, Bayomy AF, Huang JI. Morphology of the extensor carpi ulnaris groove and tendon. J Hand Surg Am. 2014;39(12):2412-2416.
11. Gómez CL, Renart IP, Pujals JI, Palou EC, Busquets RC. Dysfunction of the pisotriquetral joint: degenerative arthritis treated by excision of the pisiform. Orthopedics. 2005;28(4):405-408.
12. Van Eijzeren J, Karthaus RP. The effect of pisiform excision on wrist function. J Hand Surg Am. 2014;39(7):1258-1263.
13. Carroll RE, Coyle MP. Dysfunction of the pisotriquetral joint: Treatment by excision of the pisiform. J Hand Surg Am. 1985;10(5):703-707.
14. Johnston GH, Tonkin MA. Excision of pisiform in pisotriquetral arthritis. Clin Orthop Relat Res. 1986;210:137-142.
15. Bonnel F, Vila RM. Anatomical study of the ulnar nerve in the hand. J Hand Surg Am. 1985;10(2):165-168.
16. Lindsey JT, Watumull D. Anatomic study of the ulnar nerve and related vascular anatomy at Guyon's canal: A practical classification system. J Hand Surg Am. 1996;21(4):626-633.
17. Murata K, Tamai M, Gupta A. Anatomic study of variations of hypothenar muscles and arborization patterns of the ulnar nerve in the hand. J Hand Surg Am. 2004;29(3):500-509.
18. Depukat P, Henry BM, Popieluszko P, et al. Anatomical variability and histological structure of the ulnar nerve in the Guyon's canal. Arch Orthop Trauma Surg. 2017;137(2):277-283.
19. Konig PSA, Hage J, Bloem JJA, Prose LP. Variations of the Ulnar Nerve and Ulnar Artery in Guyon ' s Canal : A Cadaveric Study. J Hand Surg Am. 1994;19A:617-622.
20. Loukas M, Louis RG, Stewart L, et al. The surgical anatomy of ulnar and median nerve communications in the palmar surface of the hand. J Neurosurg. 2007;106(5):887-893.
21. Griot JPWD, Van Kooten EO, Zuidam JM, Prosé LP, Hage JJ. Internal anatomy of the communicating branch between the ulnar and median nerves in the hand and its relevance to volar digital sensibility. J Hand Surg Am. 2002;27(1):143-146.

22. Steyers CM, Blair WF. Measuring ulnar variance: a comparison of techniques. J Hand Surg Am. 1989;Jul;14(4):607-612. doi:10.1016/0363-5023(89)90175-5
23. Cherian BS, Bhat AK, Rajagopal K V., Maddukuri SB, Paul D, Mathai NJ. Comparison of MRI & direct MR arthrography with arthroscopy in diagnosing ligament injuries of wrist. J Orthop. 2020;19(October 2019):203-207.
24. Petsatodis E, Pilavaki M, Kalogera A, Drevelegas A, Agathangelidis F, Ditsios K. Comparison between conventional MRI and MR arthrography in the diagnosis of triangular fibrocartilage tears and correlation with arthroscopic findings. Injury. 2019;50(8):1464-1469.
25. Smith TO, Drew B, Toms AP, Jerosch-Herold C, Chojnowski AJ. Diagnostic accuracy of magnetic resonance imaging and magnetic resonance arthrography for triangular fibrocartilaginous complex injury: A systematic review and meta-analysis. J Bone Jt Surg - Ser A. 2012;94(9):824-832.
26. Boer BC, Vestering M, van Raak SM, van Kooten EO, Huis in 't Veld R, Vochteloo AJH. MR arthrography is slightly more accurate than conventional MRI in detecting TFCC lesions of the wrist. Eur J Orthop Surg Traumatol. 2018;28(8):1549-1553.
27. Chan JJ, Teunis T, Ring D. Prevalence of Triangular Fibrocartilage Complex Abnormalities Regardless of Symptoms Rise With Age: Systematic Review and Pooled Analysis. Clin Orthop Relat Res. 2014;472(12):3987-3994.
28. Bendre HH, Oflazoglu K, van Leeuwen WF, Rakhorst H, Ring D, Chen NC. The Prevalence of Triangular Fibrocartilage Complex Signal Abnormalities on Magnetic Resonance Imaging Relative to Clinical Suspicion of Pathology. J Hand Surg Am. 2018;43(9):819-826.e1.
29. Iordache SD, Rowan R, Garvin GJ, Osman S, Grewal R, Faber KJ. Prevalence of triangular fibrocartilage complex abnormalities on MRI scans of asymptomatic wrists. J Hand Surg Am. 2012;37(1):98-103.
30. Michael E. Porter P. Perspective - What Is Value in Health Care? N Engl J Med. 2010;363(1):1-3.
31. Fleurence RL, Beal AC, Sheridan SE, Johnson LB, Selby J V. Patient-powered research networks aim to improve patient care and health research. Health Aff. 2014;33(7):1212-1219.
32. Brodke DJ, Saltzman CL, Brodke DS. PROMIS for Orthopaedic Outcomes Measurement. J Am Acad Orthop Surg. 2016;24(11):744-749.
33. Weldring T, Smith SMS. Article Commentary: Patient-Reported Outcomes (PROs) and Patient-Reported Outcome Measures (PROMs). Heal Serv Insights. 2013;6:61-68.
34. Cheung EC, Moore LK, Flores SE, Lansdown DA, Feeley BT, Zhang AL. Correlation of PROMIS with orthopaedic patient-reported outcome measures. JBJS Rev. 2019;7(8):1-13.
35. Gagnier JJ. Patient reported outcomes in orthopaedics. J Orthop Res. 2017;35(10):2098-2108.
36. Liew C. The future of radiology augmented with Artificial Intelligence: A strategy for success. Eur J Radiol. 2018;102(March):152-156.
37. Hosny A, Parmar C, Quackenbush J, Schwartz LH, Aerts HJWL. Artificial intelligence in radiology. Nat Rev Cancer. 2018;18(8):500-510.
38. Zhao K, Breighner R, Holmes D, Leng S, McCollough C, An KN. A technique for quantifying wrist motion using four-dimensional computed tomography: Approach and validation. J Biomech Eng. 2015;137(7):1-5.
39. White J, Couzens G, Jeffery C. The use of 4D-CT in assessing wrist kinematics and pathology: A narrative review. Bone Jt J. 2019;101-B(11):1325-1330.
40. Tay SC, Primak AN, Fletcher JG, et al. Four-dimensional computed tomographic imaging in the wrist: Proof of feasibility in a cadaveric model. Skeletal Radiol. 2007;36(12):1163-1169.
41. Demehri S, Wadhwa V, Thawait GK, et al. Dynamic evaluation of pisotriquetral instability using 4-dimensional computed tomography. J Comput Assist Tomogr. 2014;38(4):507-512.

42. Demehri S, Hafezi-Nejad N, Thakur U, et al. Evaluation of pisotriquetral motion pattern using four-dimensional CT: Initial clinical experience in asymptomatic wrists. Clin Radiol. 2015;70(12):1362-1369.
43. World Health Organisation (WHO). International Classification of Functioning, Disability and Health (ICF). Geneva; 2001.
44. Das De S, Vranceanu AM, Ring DC. Contribution of kinesophobia and catastrophic thinking to upper-extremity-specific disability. J Bone Jt Surg - Ser A. 2013;95(1):76-81.
45. Dimitriadis Z, Kapreli E, Strimpakos N, Oldham J. Do psychological states associate with pain and disability in chronic neck pain patients? J Back Musculoskelet Rehabil. 2015;28(4):797-802.
46. Özkan S, Zale EL, Ring D, Vranceanu AM. Associations Between Pain Catastrophizing and Cognitive Fusion in Relation to Pain and Upper Extremity Function Among Hand and Upper Extremity Surgery Patients. Ann Behav Med. 2017;51(4):547-554.
47. Ring D, Kadzielski J, Fabian L, Zurakowski D, Malhotra LR, Jupiter JB. Self-reported upper extremity health status correlates with depression. J Bone Jt Surg - Ser A. 2006;88(9):1983-1988.
48. Talaei-Khoei M, Fischerauer SF, Lee S-G, Ring D, Vranceanu A-M. Pain Catastrophizing Mediates the Effect of Psychological Inflexibility on Pain Intensity and Upper Extremity Physical Function in Patients with Upper Extremity Illness. Pain Pract. 2016;17(1):129-140.
49. Jayakumar P, Eng M, Teunis T, et al. Early psychological and social factors xxplain the recovery trajectory after distal radial fracture. J Bone Jt Surg Am. 2020;102(9):788-795.
50. Jayakumar P, Overbeek CL, Lamb S, et al. What factors are associated with disability after upper extremity injuries? A systematic review. Clin Orthop Relat Res. 2018;476(11):2190-2215.

# PART IV

## Appendices

# Chapter 13

English summary

# PART I: GENERAL INTRODUCTION

## Chapter 1 – General introduction and thesis outline

Ulnar-sided wrist pain encompasses a variety of pathologies including arthritis, tendinopathy, ligament injuries, fractures and instability. Accurate diagnosing can be challenging due to a wide overlap and interaction of the anatomy at the ulnar wrist and by consequence its complex biomechanics, combined with the numerous pathologies that can be found. Treatment strategies for these various pathologies should be evaluated continuously to improve patient care. There has been a shift from physician- reported outcome measures to PROMs to evaluate health care. PROMs quantify patients' perspectives about the frequency and severity of their symptoms, how their disease impacts their functioning, and the degree to which it limits their health-related quality of life. There is mounting evidence that functioning and level of pain have more correlation with subjective, psychosocial aspects of illness and pain (such as emotional distress and coping mechanisms) than with objective measures of impairment and pathophysiology.

This thesis aimed to improve care for patients suffering from ulnar-sided wrist pain. First, by giving insight into the complexity of the differential diagnosis and coherence between pathologies. Second, by identifying characteristics associated with complications and other adverse outcomes of treatment modalities that are used in ulnar-sided wrist surgery. Third, by evaluating patient-reported outcomes after different interventions and the influence of psychological aspects on these outcomes.



# PART II: THESIS

## Chapter 2 – Predictors of secondary ulnar shortening and reoperation after arthroscopic TFCC debridement

Large-scale studies investigating predictive factors for reoperation after TFCC debridement are lacking, and findings are often inconsistent. In this chapter, we aimed to assess the rate and type of complications and reoperations after arthroscopic TFCC debridement. Furthermore, we aimed to identify factors associated with reoperation and specifically USO after this procedure.

A complication rate of 14% and a reoperation rate of 19% were reported (most common USO with 10%). Chondromalacia was independently associated with reoperation. Forty percent of patients with a positive ulnar variance later proceeded to USO. Our data suggest that patients with a positive ulnar variance with frank chondral loss at the time of arthroscopic TFCC debridement may benefit from simultaneous USO.

## Chapter 3 – Non-union and reoperation after ulnar shortening osteotomy

To date, many types of diaphyseal USO and fixation techniques are available, ranging from freehand transverse osteotomies and fixation with a dynamic compression plate to the use of advanced jigs and compression devices to achieve more precise oblique osteotomies and compression at the osteotomy site

In this chapter, we aimed to identify factors associated with reoperation after USO. Furthermore, we aimed to determine the rate and type of reoperation procedures.

Among 98 USO procedures, there were 34 reoperations (35%), most often due to hardware irritation or non-union of the osteotomy. Factors independently associated with reoperation were the dominant side being affected and traumatic origin. Younger age and prior surgery of the affected wrist were associated with hardware removal. More operations for re-fixation due to non-union of the osteotomy were performed in patients with a transverse osteotomy compared to patients with an oblique osteotomy. Awareness of these rates and predictive factors may be helpful for pre-operative discussions and surgical decision-making.

## Chapter 4 – MRI findings in patients undergoing triangular fibrocartilage complex repairs versus patients without ulnar-sided wrist pain

The clinical picture of ulnar-sided wrist pain is oftentimes confusing, because various pathologies may be co-existent. In this chapter, we aimed 1) to compare the prevalence of potential causes of ulnar-sided wrist pain on MRI in patients who underwent TFCC repair to control subjects, 2) to evaluate whether inferior clinical results were associated with specific patient characteristics or other potential causes of ulnar-sided wrist pain.

Significantly higher rates of DRUJ arthritis and ECU pathology were observed in patients with TFCC tears undergoing repair compared to age- and sex-matched controls. This may be due to damage to the TFCC itself altering relationships of the DRUJ and the ECU subsheath, or it may reflect various pathologies that cause ulnar-sided wrist pain and drive patients towards surgery. With increasing age, increasing pathology in the PT joint, more ulnocarpal abutment and more degenerative tears were seen in both groups. No demographic characteristics or MRI findings were significantly associated with our outcomes.

## Chapter 5 – A comparative study between Darrach and Sauvé-Kapandji procedures for post-traumatic distal radioulnar joint dysfunction

Comparative studies with large sample sizes between these different techniques are lacking and confounded by heterogeneous cohorts that include patients with both osteoarthritis and inflammatory arthritis. In this chapter, we reported on differences in long-term patient-reported outcomes on physical function, pain and satisfaction, between the Darrach and Sauvé-Kapandji procedure for post-traumatic indications.

In a post-traumatic setting, the Darrach and Sauvé-Kapandji procedures yielded similar patient-rated outcomes. In both groups, complications were somewhat common; however, patients who underwent a Sauvé-Kapandji procedure had a higher risk of heterotopic ossification that may result in reoperation. In our cohort, stabilization appeared to protect patients from reoperation for convergence.

## Chapter 6 – Hemiresection interposition arthroplasty of the distal radioulnar joint: a long-term outcome study

The theoretical advantage of the HIT arthroplasty compared to procedures such as the Darrach and Sauvé-Kapandji is the preservation of the attachment of the TFCC to the ulnar styloid process. By using an oblique distal ulnar resection, the DRUJ remains stable while the arthritic portion of the DRUJ is removed. However, some warn that this technique should be used with caution in patients with inflammatory or posttraumatic arthritis, because the TFCC may be structurally incompetent. The aim of this chapter was to assess factors associated with long-term patient reported functional, pain and satisfaction scores in patients who underwent (Bower's) HIT arthroplasty of the DRUJ.

Overall, patients expressed satisfaction with HIT arthroplasty, despite a mean QuickDASH score of 31.0. In our cohort, patients with inflammatory arthritis had higher satisfaction and lower pain scores. Patients who had prior trauma, prior surgery, or DRUJ subluxation were generally less satisfied. Males, older patients and post-traumatic patients had higher long-term pain scores; however, PIN neurectomy is associated with improved pain scores. The complication rate and reoperation rate were 14% and 8%, respectively. Our findings support the use of HIT arthroplasty in patients with inflammatory arthritis.



## Chapter 7 – Long-term outcomes after extensor carpi ulnaris subsheath reconstruction with extensor retinaculum

Although many patients who experience symptomatic ECU tendon subluxation do well with conservative treatment; operative treatment is an option when this approach is not succesful. In this chapter, we investigated the long-term outcomes and complications of patients that underwent ECU sheath reconstruction using a radially based extensor retinacular sling for symptomatic ECU subluxation. Overall, high satisfaction and validated outcomes were reported in most patients, despite some residual symptoms. This technique allows the surgeon to address pathology in the tendon sheath, unlike procedures that rely on preservation of sheath integrity, and appears to have reasonable and durable results.

## Chapter 8 – Long-term results of pisiformectomy in a cohort of 57 patients

Pisiformectomy is a surgery used sparingly in cases with refractory pain associated with arthrosis of the pisotriquetral joint or enthesopathy of the FCU/pisiform interface. In this chapter, we reviewed patient-reported outcomes and complications of patients treated with pisiformectomy.

When utilized in this fashion, patients reported limited disability on patient-rated outcome measures, low pain scores and high satisfaction at mid- to late- follow-up

## Chapter 9 – Carpometacarpal 4/5 fracture dislocations: fracture morphology and surgical treatment

Treatment options for fractures of the hamate range from non-operative immobilization to operative internal fixation with Kirschner wires and/or interfragmentary screws. Displaced hamate fractures, or those with an associated metacarpal fracture and dislocation, are probably better treated with ORIF. In this chapter, we reviewed several patients with CMC 4/5 fracture-dislocations managed with ORIF.

Favorable outcomes were found after ORIF of the hamate body fracture with interfragmentary screws, when combined with stabilization of the CMC dislocation with percutaneous Kirschner wires. Fracture morphology did not appear to guide choice for specific hardware (size screw, headed/headless) or use of a washer.

## Chapter 10 – Patterns of ulnar nerve arborization in the palm: clinical implications for nerve decompression in the hand and wrist

Understanding the variations in arborization pattern and communicating branches is important for diagnosis and also for surgical planning of carpal tunnel and/or Guyon's canal decompression, as there may be an increased risk to the ulnar and/or median nerve branches if appropriate care is not taken during surgery. In this cadaver study we aimed 1) to assess variations and frequencies of the arborization patterns and communicating branches, 2) to review existing literature, and 3) to relate these findings to nerve decompression near the wrist.

Variations in arborization patterns of the ulnar nerve and existence of communicating branches between the ulnar and median nerve in the palm were common. They may lead to atypical distribution of symptoms and unforeseen risks during hand surgery.

## Chapter 11 – What role does positive psychology play in understanding pain intensity and disability among patients with hand and upper extremity conditions?

Emotional distress (such as symptoms of depression and anxiety) and maladaptive coping strategies (like catastrophic thinking in response to nociception) are consistently associated with increased pain and physical limitations in heterogeneous patients with upper extremity disorders. However, little is known about the relationship between positive psychology (constructs that enable individuals to thrive and adapt to challenges) and pain and physical limitations in this population. In this chapter, we aimed to investigate the association between positive-psychology factors on the one hand and physical limitations and pain intensity on the other hand.

Positive-psychology variables explained 15% of the variance in physical limitations and 23% of the variance in pain intensity among patients with heterogenous upper extremity disorders within a hand and upper extremity practice. Of all positive-psychology factors, mindfulness and satisfaction with life were most important for physical limitations and pain intensity, respectively. As positive-psychology factors are more easily modifiable through skills-based interventions than pain and physical limitations, results suggest implementation of such interventions to potentially improve outcomes in this population.

# PART III: GENERAL DISCUSSION

## Chapter 13 – General discussion and future perspectives

In this chapter the research findings as described in this thesis were interpreted and discussed in relation of current knowledge of ulnar-sided wrist surgery. Furthermore, future perspectives on these topics were delineated.

As was stated in the introduction, the findings in this thesis underlined the confounding nature of ulnar-sided wrist pain. It is crucial to be aware of the complex overlap and interaction of the pathologies at the ulnar wrist, to guide accurate diagnosis.

Relevant diagnostic imaging can assist in establishing the right diagnosis and exclude other pathology. However, it must be noted that each modality has its own specific indications and set of advantages and disadvantages. Furthermore, it may be difficult to differentiate structural sources of ulnar-sided wrist pain from unrelated incidental findings, which once again highlights the importance of taking a thorough history and performing a detailed physical examination.



We stated that PROMs can assist in the development of a treatment plan to meet the specific preferences and needs of a particular patient, as they quantify care from the patient's perspective. In this thesis we found relatively high rates of complications and reoperations after ulnar-sided wrist surgery. However, these high rates did not always necessarily lead to inferior patient-reported outcomes. We believe that psychological factors and coping strategies have a great influence on level of pain and physical functioning.

Advances in medical imaging technology with the use of artificial intelligence (AI) in radiology and new techniques such as 4D-CT, may allow improved assessment of wrist kinematics and pathology in ulnar-sided wrist pain.

Furthermore, there is growing evidence for a strong influence of psychosocial factors on PROMs across a range of upper-extremity disorders. We believe that that there is more to generating optimal outcomes than resolving pathophysiology, restoring anatomy, and focusing on the technical components alone. More large-scale and prospective studies are required to compare several ulnar-sided wrist procedures, ideally with implementation and a great focus on the influence of psychological and social factors.

# Chapter 14

## Dutch summary (Nederlandse samenvatting)

# DEEL I: INTRODUCTIE

Ulnaire polsklachten kunnen veroorzaakt worden door een verscheidenheid aan pathologieën, waaronder artrose, tendinopathie, ligamentair letsel, fracturen en instabiliteit. Het diagnostische proces wordt in de klinische praktijk veelal als uitdagend beschouwd vanwege de grote overlap en interactie van de anatomie van de ulnaire pols, tezamen met de talrijke pathologieën die gevonden kunnen worden.

Gezien de uitgebreidheid van de verschillende pathologieën dienen de behandelstrategieën voortdurend te worden geëvalueerd. Daarbij heeft in de afgelopen jaren een verschuiving plaatsgevonden van arts-gerapporteerde uitkomstmaten naar patient-gerapporteerde uitkomstmaten (PROMs) om zowel de inviduele gezondheid van patiënten als de algehele gezondheidszorg te evalueren. De introductie van de PROMs heeft het mogelijk gemaakt om de perspectieven van patiënten ten aanzien van de frequentie en ernst van hun symptomen en ten aanzien van de invloed van ziekte op hun dagelijks functioneren te kwantificeren. Daarnaast kunnen PROMs inzicht geven in hoe ziekte kan interfereren met de kwaliteit van leven van patiënten. Verder blijkt uit recent klinisch wetenschappelijk onderzoek dat het functioneren en de mate van pijn een sterkere correlatie hebben met subjectieve, psychosociale aspecten van ziekte en pijn (zoals emotionele stress en coping-mechanismen) dan met objectieve metingen van beperkingen en pathofysiologie.

Het primaire doel van dit proefschrift was om de zorg voor patiënten met ulnaire polsklachten te verbeteren. Ten eerste door inzicht te geven in de complexiteit van de differentiaaldiagnose en samenhang tussen pathologieën. Ten tweede door karakteristieken te identificeren die verband houden met complicaties en andere nadelige uitkomsten van de behandelingsmodaliteiten die worden gebruikt binnen de ulnaire polschirurgie. Ten derde door de patiënt-gerapporteerde uitkomsten na verschillende interventies en de invloed van psychologische aspecten op deze uitkomsten te evalueren.



# DEEL 2: PROEFSCHRIFT

## Hoofdstuk 2 – Voorspellers van secundaire ulna verkorting en heroperatie na arthroscopisch TFCC debridement

In de huidige literatuur ontbreken grootschalige studies naar voorspellende factoren voor heroperatie na TFCC debridement. Daarbij zijn de resultaten van de beschikbare literatuur veelal inconsistent. In dit hoofdstuk onderzochten wij de frequentie en het type complicaties en heroperaties na arthroscopisch TFCC debridement. Daarnaast werden factoren die verband houden met heroperatie (en specifiek ulna verkortings-osteotomie) na deze procedure geïdentificeerd.

Deze studie toonde aan dat bij 14% van de patiënten een complicatie optrad en dat 19% van de patiënten een heroperatie onderging (meest voorkomend ulna verkortings-osteotomie met 10%). De aanwezigheid van chondromalacie was onafhankelijk geassocieerd met heroperatie. Veertig procent van de patiënten met een positieve ulnaire variantie onderging later een ulna verkortings-osteotomie. Onze gegevens suggereren dat patiënten met een positieve ulnaire variantie met evident kraakbeenverlies op het moment van arthroscopisch TFCC debridement baat kunnen hebben bij het gelijktijdig uitvoeren van een ulna verkortings-osteotomie.

## Hoofdstuk 3 – Non-union en heroperatie na ulnaire verkortings-osteotomie

Tot op heden zijn er verschillende technieken beschikbaar voor diafysaire ulna verkortings-osteotomie en fixatie. Deze variëren van transversale osteotomieën uit de vrije hand en fixatie met een dynamische compressieplaat tot het gebruik van geavanceerde mallen en compressie-materiaal. Door middel van dit geavanceerde materiaal kan een preciezere oblique osteotomie en betere compressie ter plekke van de osteotomieplaats bewerktstelligd worden.

In dit hoofdstuk identificeerden wij factoren die verband houden met heroperatie na ulna verkortings-osteotomie. Verder rapporteerden wij over het aantal en het type heroperatie-procedures. In een groep van 98 ulna verkorting-osteotomieën werden 34 heroperaties uitgevoerd (35%), meestal ten gevolge van irritatie door het osteosynthese materiaal of non-union van de osteotomie. Deze studie toonde aan dat patiënten met klachten aan hun dominante hand vaker een heroperatie ondergingen dan patiënten met klachten aan hun niet-dominante hand. Tevens was een traumatisch origine onafhankelijk geassocieerd met heroperatie. Jongere patienten en patiënten die eerder een operatie aan dezelfde pols hadden ondergaan, lieten vaker het osteosynthese materiaal verwijderen.

Bij patiënten met een transversale osteotomie werden meer operaties voor refixatie wegens non-union van de osteotomie uitgevoerd dan bij patiënten met een oblique osteotomie. Bewustwording van deze percentages en voorspellende factoren is van groot belang voor preoperatieve discussies en de uiteindelijke chirurgische besluitvorming.

## Hoofdstuk 4 – MRI bevindingen bij patiënten die een TFCC herstel ondergaan versus patiënten zonder ulnaire polsklachten

Het klinische beeld van ulnaire polsklachten kan uiteenlopend zijn gezien het feit dat verschillende pathologieën naast elkaar kunnen bestaan. Onze doelen in dit hoofdstuk waren 1) de prevalentie van mogelijke oorzaken van ulnaire polsklachten op MRI vergelijken tussen patiënten die TFCC-herstel ondergingen en controlepersonen, 2) evalueren of specifieke patientkarakteristieken of andere potentiële oorzaken van ulnaire polsklachten geassocieerd waren met inferieure klinische resultaten.

Aanzienlijk hogere percentages van DRUJ artrose en ECU pathologie werden waargenomen bij patiënten die een TFCC herstel ondergingen in vergelijking met de controlegroep die gematcht was op leeftijd en geslacht. Dit is mogelijk toe te wijden aan schade aan het TFCC zelf, hetgeen direct invloed heeft op de relatie met het DRU gewricht en de ECU subsheath. Daarnaast is het mogelijk een weerspiegeling van verschillende pathologieën die ulnaire polsklachten veroorzaken en patiënten in de richting van een operatieve ingreep sturen. Naar mate de leeftijd toenam, werden in beide groepen meer pathologie in het PT-gewricht, meer ulnocarpaal abutment en meer degeneratieve TFCC letsels gezien. Tot slot toonde deze studie aan dat er geen demografische kenmerken of MRI-bevindingen significant geassocieerd waren met onze primaire uitkomsten.

## Hoofdstuk 5 – Een vergelijkende studie tussen Darrach en Sauvé-Kapandji procedure voor posttraumatische DRUJ dysfunctie

In de huidige literatuur zijn studies die Darrach en Sauve-Kapandji procedures vergelijken zeer schaars. Daarnaast worden de resultaten van de studies die deze verschillende procedures met elkaar vergelijken vertroebeld door de heterogeniteit binnen de cohorten waarbij patiënten met zowel artrose als inflammatoire artritis worden geïncludeerd. In dit hoofdstuk rapporteerden wij over verschillen in lange-termijn patiënt-gerapporteerde resultaten op het gebied van fysiek functioneren, pijn en tevredenheid tussen de Darrach- en Sauvé-Kapandji-procedure voor posttraumatische indicaties.

Deze studie toonde aan dat in een posttraumatische setting de patiënt-gerapporteerde resultaten na een Darrach- en Sauvé-Kapandji-procedure vergelijkbaar waren. In beide groepen werd een groot aantal complicaties gezien; patiënten die een Sauvé-Kapandji-procedure ondergingen, hadden echter een groter risico op heterotope ossificatie, hetgeen tot heroperatie kan leiden. In ons cohort bleek stabilisatie van de distale ulna te beschermen tegen heroperatie voor convergentie.



## Hoofdstuk 6 – Hemiresectie interpositie (HIT)-arthroplastiek van het DRU gewricht: een lange-termijn uitkomststudie

Het theoretische voordeel van de HIT-arthroplastiek ten opzichte van procedures zoals de Darrach en Sauvé-Kapandji is dat de aanhechting van het TFCC aan het ulnaire styloïd behouden wordt. Door een oblique distale ulnaire resectie te gebruiken, blijft het DRU gewricht stabiel terwijl het artrotische deel van het gewricht kan worden verwijderd. Een aantal studies heeft laten zien dat voorzichtigheid geboden is bij het toepassen van deze techniek bij patiënten met inflammatoire of posttraumatische artritis, vanwege het feit dat het TFCC structureel incompetent kan zijn. Het doel van dit hoofdstuk was om factoren te evalueren die mogelijk verband houden met patiënt-gerapporteerde functionele, pijn- en tevredenheidsscores op lange termijn bij patiënten die een (Bower's) HIT-arthroplastiek van het DRU gewricht ondergingen.

De resultaten van deze studie toonden aan dat patiënten over het algemeen tevreden waren na een HIT-arthroplastiek, ondanks een gemiddelde QuickDASH-score van 31,0, hetgeen suggereert dat zij een hoge mate van functionele beperkingen ervoeren. In ons cohort hadden patiënten met inflammatoire artritis een hogere score voor tevredenheid en lagere score voor pijn. Patiënten die een eerder trauma, eerdere operatie of DRUJ-subluxatie hadden gehad, waren over het algemeen minder tevreden. Mannen, oudere patiënten en posttraumatische patiënten hadden hogere pijnscores op de lange termijn; PIN-neurectomie is echter geassocieerd met verbeterde pijnscores. Het percentage complicaties en heroperaties was respectievelijk 14% en 8%. Onze bevindingen ondersteunen het gebruik van HIT-arthroplastiek bij patiënten met inflammatoire artritis.

## Hoofdstuk 7 – Lange-termijn resultaten na extensor carpi ulnaris (ECU) subsheath reconstructie met extensor retinaculum

Hoewel veel patiënten met een symptomatische subluxatie van de ECU pees goede resultaten laten zien na een conservatief beleid, is een operatieve behandeling een optie wanneer deze aanpak niet succesvol is. In dit hoofdstuk hebben wij de lange-termijn uitkomsten en complicaties onderzocht van patiënten met een symptomatische ECU subluxatie die ECU subsheath reconstructie ondergingen met behulp van een radiaal gesteelde sling van het extensor retinaculum.

Over het algemeen werden bij de meeste patiënten hoge tevredenheid en gevalideerde resultaten gemeld, ondanks enkele restsymptomen. Deze techniek stelt de chirurg in staat pathologie in de peesschede aan te pakken, in tegenstelling tot procedures die berusten op het behoud van de integriteit van de schede. Daarbij lijkt de techniek acceptabele en duurzame resultaten te hebben.

## Hoofdstuk 8 – Lange-termijn resultaten van pisiformectomie in een cohort van 57 patiënten

Pisiformectomie is een chirurgische ingreep die beperkt wordt uitgevoerd bij patiënten met refractaire pijn door artrose van het PT gewricht of enthesopathie van de FCU er hoogte van het os pisiforme. In dit hoofdstuk evalueerden wij de patiënt-gerapporteerde uitkomsten en complicaties van patiënten die een pisiformectomie hadden ondergaan.

Bij toepassing in een selecte patiëntenpopulatie werden weinig fysieke beperkingen, lage pijnscores en hoge tevredenheid bij lange-termijn follow-up gerapporteerd.

## Hoofdstuk 9 – Carpometacarpale (CMC) 4/5 fractuur-dislocaties: fractuur morfologie en chirurgische behandeling

Behandelingsopties voor fracturen van het os hamatum variëren van niet-operatieve immobilisatie tot interne fixatie met Kirschner-draden en/of interfragmentaire schroeven. Gedisloceerde fracturen van het os hamatum, of die met een bijbehorende metacarpale fractuur en dislocatie, zijn waarschijnlijk beter te behandelen met ORIF. In dit hoofdstuk hebben wij verschillende patiënten beoordeeld met CMC 4/5 fractuur-dislocaties die behandeld werden met ORIF.

Gunstige resultaten werden gevonden na ORIF van een fractuur ter hoogte van het corpus van het os hamatum met interfragmentaire schroeven, in combinatie met stabilisatie van de

CMC-dislocatie met percutane Kirschner-draden. Fractuurmorfologie leek de keuze voor specifiek osteosynthese materiaal niet te leiden.

## Hoofdstuk 10 – Patronen van nervus ulnaris arborisatie in de handpalm: klinische implicaties voor zenuwdecompressie in de hand en pols

Inzicht in de variaties in het arborisatie-patroon en communicerende takken is belangrijk voor de diagnose en ook voor de chirurgische planning van de carpale tunnel en/of Guyon's kanaaldecompressie, aangezien er een verhoogd risico kan zijn voor de ulnaire en/of mediane zenuwtakken als de juiste zorg niet wordt genomen tijdens de ingreep. In deze kadaverstudie waren onze doelen om 1) variaties en frequenties van de arborisatie-patronen en communicerende takken te beoordelen, 2) bestaande literatuur te evalueren en 3) deze bevindingen relateren aan zenuwdecompressie in de hand en pols.

Variaties in arborisatie-patronen van de nervus ulnaris en communicerende takken tussen de nervus ulnaris en nervus medianus in de handpalm kwamen vaak voor. Ze kunnen leiden tot een atypische verdeling van symptomen en onvoorziene risico's tijdens handchirurgie.

## Hoofdstuk 11 – Welke rol speelt positieve psychologie bij het begrijpen van pijnintensiteit en fysieke beperkingen bij patiënten met aandoeningen aan de bovenste extremiteit?

Emotionele stress (zoals symptomen van depressie en angst) en maladaptieve copingstrategieën (zoals catastrofaal denken als reactie op pijn) worden consequent geassocieerd met verhoogde mate van pijn en discomfort en fysieke beperkingen bij heterogene patiënten met aandoeningen van de bovenste extremiteit. Er is echter weinig bekend over de relatie tussen positieve psychologie (constructies die individuen in staat stellen zich goed te ontwikkelen en zich aan te passen aan uitdagingen) en pijn en fysieke beperkingen in deze populatie. In dit hoofdstuk onderzochten wij de associatie tussen positieve psychologie-factoren enerzijds en fysieke beperkingen en pijnintensiteit anderzijds.

Positieve psychologie-variabelen verklaarden 15% van de spreiding in scores voor fysieke beperkingen en 23% van de spreiding in scores voor pijnintensiteit bij patiënten met heterogene aandoeningen van de bovenste extremiteit. Van alle positieve-psychologie factoren waren mindfulness en tevredenheid met het leven het belangrijkst voor respectievelijk fysieke beperkingen en pijnintensiteit. Omdat positieve psychologie-factoren makkelijker te beïnvloeden zijn door vaardigheidstrainingen dan pijn en fysieke beperkingen, suggereren de resultaten dat implementatie van dergelijke interventies uitkomsten in deze populatie mogelijk kunnen verbeteren.

# DEEL 3: DISCUSSIE

In hoofdstuk 13 werden de onderzoeksbevindingen zoals beschreven in dit proefschrift geïnterpreteerd en bediscussieerd in relatie tot de huidige kennis van ulnaire polschirurgie. Daarnaast werden de toekomstperspectieven met betrekking tot deze onderwerpen uiteengezet.

Zoals in de inleiding werd vermeld, onderstreepten de bevindingen in dit proefschrift de complexiteit van ulnaire polsklachten. Het is van cruciaal belang om inzicht te hebben in de overlap en interactie van de pathologieën bij de ulnaire pols, om een nauwkeurige diagnose te kunnen stellen.

Relevante diagnostische beeldvorming kan helpen bij het stellen van de juiste diagnose en het uitsluiten van andere pathologieën. Er moet echter worden opgemerkt dat elke modaliteit zijn eigen specifieke indicaties en een reeks voor- en nadelen heeft. Bovendien kan het moeilijk zijn om structurele oorzaken van ulnaire polsklachten te onderscheiden van niet-gerelateerde incidentele bevindingen, waarmee nogmaals het belang van een grondige anamnese en het uitvoeren van een gedetailleerd lichamelijk onderzoek benadrukt wordt.

Wij stelden dat PROMs kunnen helpen bij de ontwikkeling van een behandelplan om te voldoen aan de specifieke voorkeuren en behoeften van een bepaalde patiënt, aangezien PROMs de zorg kwantificeren vanuit het perspectief van de patiënt. In dit proefschrift vonden wij relatief veel complicaties en heroperaties na diverse operatieve ingrepen aan de ulnaire pols. Deze hoge percentages leidden echter niet altijd tot inferieure patiënt-gerapporteerde uitkomsten. Wij geloven dat psychologische factoren en copingstrategieën een grote invloed hebben op de mate van pijn en fysiek functioneren.

Vooruitgang in medische beeldvormingstechnologie met het gebruik van kunstmatige intelligentie (AI) in radiologie en nieuwe technieken zoals 4D-CT, kunnen een betere beoordeling van polskinematica en pathologie bij ulnaire polsklachten mogelijk maken. Bovendien is er groeiend bewijs voor een sterke invloed van psychosociale factoren op PROMs bij een reeks aandoeningen van de bovenste extremiteiten. Wij zijn van mening dat het genereren van optimale resultaten meer is dan het behandelen van pathofysiologie, het herstellen van de anatomie en louter focussen op de technische componenten. Grootschalige prospectieve studies zijn nodig om verschillende procedures aan de ulnaire pols te vergelijken, idealiter met aandacht voor de invloed van psychologische en sociale factoren.

# Chapter 15

## Acknowledgements (Dankwoord)

Geachte prof. Ritt, beste Marco. Het is alweer ruim 4 jaar geleden dat ik bij jou aanklopte met mijn ambitie om een promotietraject in Boston op te zetten. Direct hadden we een fijne klik, wellicht ook iets te maken met onze gemeenschappelijke 'roots' in Limburg, zelfs beide geboren in de stad 'Gelaen'. Je hebt me de vrijheid gegeven om mijn ambitie waar te maken, en daar waar nodig sturing gegeven binnen mijn projecten. Ik wil je bedanken voor het vertrouwen en de begeleiding (zowel op wetenschappelijk gebied als daar buiten) gedurende de afgelopen jaren!

Dear Dr. Chen. I feel honored to have worked under your direct supervision at the Hand and Upper Extremity Department of MGH. Your knowlegde, kindness and commitment to the team are admirable. It is impressive how you manage to guide a research team alongside your clinical job at a world-leading orthopaedics department. Thank you for all the opportunities that you gave me during my time in Boston.

Mijn bijzondere dank gaat uit naar de leden van de leescommissie, dr. Lameijer, dr. Hoogbergen, dr. Strackee, prof. dr. Coert en prof. dr. Maas voor het beoordelen van dit proefschrift.

Dear Dr. Jupiter, Dr. Mudgal and Dr. Eberlin. Thank you for making me feel part of your team and for guiding me throughout various studies included in this thesis. I have learned a lot from all of you during the Research Meetings, Grand Rounds, Smith day and not to forget the multiple (soccer) Journal Clubs that were organized at Dr. Jupiters' house.

Dear fellow long-termers and short-term students of the MGH Hand Research Team, Jonathan, Ritsaart, Femke, Jan-Jonas, Lazin, Luca and Juliette, thank you for your help and collaboration. Special thanks to Rachel, you were so much more than a research coördinator, showing us Dutchies around and making sure we would experience the real Boston.



Lieve Bo, in Boston gingen we door het leven als 'de meisjes van de Hand'. Naast lange dagen samen in een kantoortje van 6m2 deelden we lief en leed in de avonden en weekenden. Middagen op de vlonder aan de Charles, avonden in de Phoenix Landing en talloze sleep-overs. Dank voor de mooie momenten en bovenal vriendschap.

Lieve Laura, lieve Christy. Door jullie als huisgenoten voelde mijn huis ook echt als een thuis. Menige hardloopsessies vroeg in de ochtend terwijl de temperatuur ver onder het vriespunt lag, standaard op zaterdag brak naar de markt, urenlang kletsen met thee op de bank, ik heb ervan genoten.

Lieve Juul, Jacq, Beau, Brech, Mark, Reinier, Flo, Bas, Tiuri, Tert en Daan, het leven op de Chandler Street was soms wel te vergelijken met GTST, 'never a dull moment..' Niet alleen in

Boston zelf, maar ook daar buiten werd elke kroeg onveilig gemaakt. Ik heb mooie herinneringen aan onze reisjes naar de White Mountains, New York, Montreal, Miami en Tampa.

Lieve Maartje, ik vind het geweldig dat jij naast mij staat tijdens de verdediging van mijn proefschrift. Sinds onze ontmoeting in de brugklas van het Stella Maris College zijn we heel wat jaren en verhuizingen verder. Desondanks hebben wij elkaar nooit uit het oog verloren. Ik ben gek op je ongezouten mening en droge humor. Onze vriendschap is mij zeer dierbaar!

Lieve Maud, Amber, Jonne en Famke, als 'mentorkindjes van Maria' werden we al snel echt vriendinnen. Het is mooi om te zien dat iedereen zijn eigen weg gevonden heeft in verschillende vakken binnen de geneeskunde. Ook al spreken we elkaar soms lange tijd niet, als we dat wel doen, dan is het goed. Ik kijk er naar uit om weer vaker met jullie bij te kletsen en gezellige avonden te beleven.

Lieve Lisette, toen ik je leerde kennen bleken we al snel veel raakvlakken te hebben, hetgeen uitgegroeid is tot een bijzondere vriendschap. Ik heb ontzettend veel bewondering voor hoe jij je carrière combineert met het opvoeden van 3 heerlijke mannetjes en daarbij ook altijd nog in bent voor een wijntje of een feestje.

Lieve Maartje, Nadine, Pien, Fleur en Liz, als 'Rossies' waren jullie mijn steun en toeverlaat thuis in Amsterdam. Altijd oprecht geïnteresseerd in mij en daarnaast een welkome afleiding tijdens mijn onderzoek. Dank voor jullie luisterend oor, de positiviteit en gezellige momenten die wij samen beleefd hebben.

Team Plastische Chirurgie in het HagaZiekenhuis, beste Marjorie, Jarl, Jan, Sander en natuurlijk alle poli-assistentes en secretaresses. Niks gelogen aan de naam 'De leukste afdeling', het was een voorrecht om in zo'n leuk team mijn eerste ervaring als ANIOS binnen de Plastische Chirurgie op te doen.

Team Plastische Chirurgie in het Eindhovense, stafleden, arts-assistenten en ondersteunend personeel. Bedankt voor de prettige begeleiding en de ruimte die ik krijg om mijzelf te ontplooien. Het maakt dat ik als ANIOS in dit hechte team veel werkplezier beleef en dat mijn ambitie om Plastisch Chirurg te worden nog verder is gegroeid.

Lieve papa en mama, van kleins af aan hebben jullie mij gestimuleerd om mijn plannen en dromen na te jagen. Ook al waren de door mij gemaakte keuzes voor jullie niet altijd even makkelijk, jullie steun was onvoorwaardelijk. Bedankt voor jullie glunderende trots, ik hou van jullie! Lieve Jelca en Sabine, ik kan niet wachten om tante te worden in december!

Lieve schoonfamilie Peek, als 'koude kant' ben ik bij de familie Peek in een heel warm bad terecht gekomen. Ik kom tot rust als ik in jullie tuin mag genieten van een glaasje wijn terwijl er een heerlijk stuk vlees op de Green Egg wordt bereid. Ik ben blij dat ik deel mag uitmaken van jullie gastvrije en liefdevolle gezin.

Allerliefste Jesse, jij betrok op Chandler Street 112 de bovenste kamer maar verhuisde langzamerhand een paar etages naar beneden.. Nu ruim 3 jaar later zijn wij ook in Nederland nog steeds verliefd en samenwonend. Je hebt vanaf het begin van mijn promotietraject aan mijn zijde gestaan. Als ik er even geen vertrouwen meer in heb, weet jij me weer te motiveren. Als ik niet durf, geef jij mij nog een extra duwtje in de rug. Ik geniet van onze momenten samen en wil je nooit meer missen!

# Chapter 16

## List of publications

**S.H.W.L. Verhiel**, M.J.P.F Ritt, N.C. Chen. Predictors for secondary ulna shortening and reoperation after arthroscopic TFCC debridement. *Hand (N Y)*. 2021 Feb 3 [Epub ahead of print].

J. Lans, R.F. Westenberg, **S.H.W.L. Verhiel**, R. Garg, J.B. Jupiter, N.C. Chen. An economic analysis of direct costs of distal radius fixation and the implications of a disposable distal radius kit. *J Orthop Trauma*. 2021 Sep 1;35(9):e346-e351.

**S.H.W.L. Verhiel**, W.J. Knaus, F.J. Simeone, C.S. Mudgal. Carpometacarpal 4/5 fracture dislocations: fracture morphology and surgical treatment. *J Hand Microsurg*. 2020 Oct;12(Suppl 1):S21-S27.

**S.H.W.L. Verhiel**, J.L.R.K. Blackburn, M.J.P.F Ritt, N.C. Chen. Long-term results of pisiformectomy in a cohort of 57 patients. *J Wrist Surg*. 2020 Dec;9(6):465-469.

**S.H.W.L. Verhiel**, J.L.R.K. Blackburn, M.J.P.F Ritt, F.J. Simeone, N.C. Chen. MRI findings in patients undergoing triangular fibrocartilage complex repairs versus patients without ulnar-sided wrist pain. *Hand (N Y).* 2020 Jul 19 [Epub ahead of print].

**S.H.W.L. Verhiel,** S. Özkan, C.G. Langhammer, N.C. Chen. The serially-operated Essex-Lopresti injury: long-term outcomes in a retrospective cohort. *J Hand Microsurg*. 2020 Apr;12(1):47-55.

F. Nawijn, **S.H.W.L. Verhiel**, K.N. Lunn, K.R. Eberlin, N.C. Chen. Factors associated with mortality and amputation caused by necrotizing soft tissue infections of the upper extremity: a retrospective cohort study. *World J Surg*. 2020 Mar;44(3):730-740.

F. Nawijn, **S.H.W.L. Verhiel**, J.B. Jupiter, K.R. Eberlin, N.C. Chen. Hemiresection interposition arthroplasty of the distal radioulnar joint: a long-term outcome study. *Hand (N Y).* 2019 Sep 13 [Epub ahead of print].

**S.H.W.L. Verhiel,** S. Özkan, N.C. Chen, J.B. Jupiter. Long-term outcomes after extensor carpi ulnaris subsheath reconstruction with extensor retinaculum. *Tech Hand Up Extrem Surg.* 2020 Mar;24(1):2-6.

**S.H.W.L. Verhiel**, S. Özkan, M.J.P.F Ritt, N.C. Chen, K.R. Eberlin. A comparative study between Darrach and Sauve-Kapandji procedures for post-traumatic distal radioulnar joint dysfunction. *Hand (N Y)*. 2021 May;16(3):375-384. Epub 2019 Jun 27.

**S.H.W.L. Verhiel,** J. Greenberg, E.L. Zale, N.C. Chen, D.R. Ring, A.M. Vranceanu. What role does positive psychology play in understanding pain intensity and disability among patients with hand and upper extremity conditions. *Clin Orthop Relat Res*. 2019 Aug;477(8):1769-1776.

N.H.A. Wolvetang, J. Lans, **S.H.W.L Verhiel**, B.J.W. Notermans, N.C. Chen, K.R. Eberlin. Surgery for symptomatic neuroma: anatomic distribution and predictiors of secondary surgery. *Plast Reconstr Surg.* 2019 Jun;143(6):1762-1771.

**S.H.W.L. Verhiel**, S. Özkan, K.R. Eberlin, N.C. Chen. Non-union and reoperation after ulna shortening osteotomy. *Hand (N Y).* 2020 Sep;15(5):638-646. Epub 2019 Mar 8.

**S.H.W.L. Verhiel,** A.A. Piatkowski de Grzymala, E. van den Kerckhove, C. Colla, R.R.W.J. van der Hulst. Three-dimensional imaging for volume measurement of hypertrophic and keloid scars, reliability of a previously validated simplified technique in clinical setting. *Skin Res Technol*. 2016 Nov;22(4):513-518.

**S.H.W.L. Verhiel,** A.A. Piatkowski de Grzymala, R.R.W.J. van der Hulst. Mechanism of action and efficacy of calcium antagonists in hypertrophic scars and keloids: a systematic review. *Dermatol Surg*. 2015 Dec;41(12):1343-50.

T. van der Aa, **S.H.W.L. Verhiel,** M. Erends, A.A. Piatkowski de Grzymala, E. Van den Kerckhove, C. Colla, R.R.W.J. van der Hulst. A simplified three-dimensional volume measurement technique in keloid scars; validity and reliability. *J Plast Reconstr Aesthet Surg*. 2015 Nov;68(11):1574-80.

**S.H.W.L. Verhiel,** L.T. Hoekstra. "Een man met erythemateuze, gehyperpigmenteerde papels." MUMC, Maastricht. Ned Tijdschr Geneeskd. 2015;159:A8690.

# Chapter 17

Curriculum vitae

Svenna Verhiel was born in Geleen, the Netherlands, on the 8th of November 1989. After graduating from the Stella Maris College in Meerssen, she was admitted to Medical School at Maastricht University in 2008. During her clinical internships she gained a particular interest in plastic surgery. She dedicated her whole last year of medical school to this subject (WESP and GEZP internships). During this period she discovered her interest in research and got involved in studies related to hypertrofic and keloid scars, under supervision of Dr. A.A. Piatkowski. These studies lead to several publications.

After graduating she worked as a resident (not in training) at the general surgery department of the Amstelland Hospital in Amstelveen and as a resident (not in training) at the cardiothoracic surgery department of VU Medical Center in Amsterdam. In 2017 she was accepted for a Research Fellowship at the Hand and Upper Extremity Department of the Massachusetts General Hospital/ Harvard University in Boston, USA. She was rewarded multiple grants, which enabled her to continue her research abroad for two years. During this fellowship, she was supervised by Dr. N.C. Chen and Prof. M.J.P.F. Ritt.

Upon returning to the Netherlands in 2019, she started working as a resident (not in training) at the plastic surgery department of the Haga Hospital in the Hague. Currently, Svenna works as a resident (not in training) at the plastic surgery department of the Catharina Hospital in Eindhoven, under supervision of Dr. M.M. Hoogbergen.