TURUN YLIOPISTO
UNIVERSITY OF TURKU

TREATMENT OF OLECRANON FRACTURES

With emphasis on the elderly

Ida Rantalaiho

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SARJA – SER. D OSA – TOM. 1664 | MEDICA – ODONTOLOGICA | TURKU 2022

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“Try not. Do or do not. There is no try.”
-Yoda

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ABSTRACT

Olecranon fractures are common upper extremity injuries affecting the extensor mechanism of the elbow joint. Olecranon fractures have features of osteoporotic fractures and epidemiological data suggests that their incidence is rising among the elderly. The standard treatment for displaced olecranon fractures is operative osteosynthesis, and the most frequently used fixation methods are tension band wiring (TBW) and plate fixation (PF). Both methods lead to bone healing and good elbow function but are associated with numerous complications and re-operations.

The operative approach is giving way to conservative treatment among elderly patients. Comparable functional outcome, as well as pain-free results, might be achieved with conservative treatment and a lower complication burden compared to operative treatment. However, there is still a lack of reliable research data to back up this change in treatment practice.

The aims of this thesis are 1) to evaluate the best current evidence on the treatment modalities of displaced olecranon fractures, 2) to assess early complications, re-operations and their predictive factors after operative treatment of olecranon fracture, 3) to design and present a protocol for a randomized, controlled trial comparing the results of operative and conservative treatment of displaced olecranon fractures among the elderly, and 4) to determine whether patients with olecranon fractures are similar as patients with other upper extremity osteoporotic fractures.

We found that the current literature supports the use of standard operative fixation methods, but evidence is insufficient to draw conclusions on the superiority of one method over another. High risk of complications and re-operations is related to both TBW and PF. Transcortical positioning of K-wires may reduce the complications related to TBW. We designed an RCT comparing operative and conservative treatment of olecranon fractures in the elderly, published the protocol, and initiated the recruitment of patients. According to our local data, olecranon fractures can be grouped with distal radius fractures in terms of demographics and mortality, but the risk of subsequent osteoporotic fractures is higher with olecranon fractures and comparable to that after proximal humerus fractures.

KEYWORDS: olecranon fractures, osteoporotic fractures, fracture fixation, tension band wiring, plate fixation, conservative treatment

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TIIVISTELMÄ

Kyynärlisäkkeen murtuma on yleinen yläraajamurtuma, joka vaikuttaa kyynärnivelen ojennukseen. Tutkimukset osoittavat, että näiden murtumien ilmaantuvuus vanhusväestössä on kasvussa. Kyynärlisäkkeen murtuman tavallinen hoito on kirurginen murtuman kiinnitys jännitelankasidoksella tai levyllä. Molemmilla metodeilla saavutetaan luutuminen sekä hyvä kyynärnivelen toiminta, mutta niihin liittyy riski lukuisiin komplikaatioihin sekä uusintaleikkauksiin.

Kyynärlisäkkeen murtumien konservatiivinen hoito on lisännyt suosiotaan iäkkäiden potilaiden joukossa. Näyttää siltä, että konservatiivisella hoidolla on mahdollista saavuttaa yhtä hyvä kyynärnivelen toiminta sekä kivuttomuus ja samalla välttää leikkaushoitoon liittyviä komplikaatioita. Riittävää luotettavaa tutkimusnäyttöä hoitokäytäntöjen muuttamiseen ei kuitenkaan vielä ole olemassa.

Tämän tutkimuksen tavoitteena on: 1) arvioida nykyistä parasta mahdollista tutkimusnäyttöä kyynärlisäkkeen murtumien hoitomuodoista, 2) selvittää varhaisia komplikaatioita ja uusintaleikkauksia, sekä niitä ennustavia tekijöitä kyynärlisäkkeen murtuman kirurgisen hoidon jälkeen, 3) suunnitella ja esitellä satunnaistettu, kontrolloitu tutkimusprotokolla vertailemaan kirurgista ja konservatiivista hoitoa iäkkäiden kyynärlisäkkeen murtumien hoidossa, ja 4) arvioida voidaanko kyynärlisäkkeen murtumia pitää samanlaisina muiden yläraajan osteoporoottisten murtumien kanssa.

Nykyisen kirjallisuuden perusteella perinteisillä kirurgisilla metodeilla saavutetaan hyvä lopputulos kyynärlisäkkeen murtumien hoidossa, mutta riittävää näyttöä tietyn metodin paremmuudesta muita vastaan ei ole. Kirurgiseen hoitoon liittyy huomattava riski komplikaatioille sekä uusintaleikkauksille. Jännitelankasidokseen liittyviä komplikaatioita voitaisiin vähentää kiinnittämällä huomiota oikeaan leikkaustekniikkaan ja K-piikkien sijoittamiseen luun kuoren läpi. Olecranonmurtumien kirurgista ja konservatiivista hoitoa vertailevan tutkimuksen protokolla suunniteltiin, se julkaistiin ja potilaiden rekrytointi tutkimukseen päästiin aloittamaan. Kyynärlisäkkeen murtumat voidaan rinnastaa rannemurtumien kanssa demografian ja kuolleisuuden osalta, mutta riski uusille osteoporoottisille murtumille kyynärlisäkkeen murtuman jälkeen on huomattavampi.

AVAINSANAT: olecranonmurtuma, osteoporoottinen murtuma, murtuman kiinnitys, jännitelankasidos, levykiinnitys, konservatiivinen hoito

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Abbreviations

AO	Arbeitsgemeneischaft für Osteosynthesefragen
AP	Antero-posterior
ASA	American Society of Anesthesiologists Physical Status Classification System
CENTRAL	Cochrane Central Register of Controlled Trials
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CPS	Cable Pin System
DASH	Disabilities of the Arm, Shoulder and Hand
ER	Emergency room
GLMM	Generalized linear mixed models
HR	Hazard Ratio
ICHOM	International Consortium for Health Outcomes Measurement
IQR	Interquartile range
ISS	Injury Severity Score
ITT	Intention to treat
K-wire	Kirschner wire
MCID	Minimal clinically important difference
NVF	Non-vertebral fracture
OMC	Olecranon Memory Connector
PEDro	Physiotherapy Evidence Database
PF	Plate fixation
PICOS	Population, Intervention, Comparison, Outcome, Studies
PP	Per protocol
PREE-F	Patient Rated Elbow Evaluation, Finnish version
QuickDASH	Quick Disabilities of the Arm, Shoulder and Hand
RCT	Randomised, controlled trial
SCORE	Scandinavian Olecranon Research in the Elderly
SOFIE	Surgery for Olecranon Fractures in the Elderly
SPIRIT	Standard Protocol Items: Recommendations for Interventional Trials
TBW	Tension band wiring

VAS	Visual analogue scale
VIF	Variance Inflation Factor

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Rantalaiho I, Miikkulainen A, Laaksonen I, Äärimaa V, Laimi K. Treatment of Displaced Olecranon Fractures: A Systematic Review. *Scand J Surg*, 2019; 1: 13–21.

II Rantalaiho I, Laaksonen I, Ryösä A, Perkonoja K, Isotalo K, Äärimaa V. Complications and reoperations related to tension band wiring and plate osteosynthesis of olecranon fractures. *J Shoulder Elbow Surg,* 2021; 10: 2412–2417.

III Rantalaiho I, Laaksonen I, Launonen P, Luokkala T, Flinkkilä T, Salmela M, Adolfsson L, Olsen B, Isotalo K, Ryösä A, Äärimaa V. Scandinavian Olecranon Research in the Elderly (SCORE): Protocol for a non-inferiority, randomized, controlled, multicenter trial comparing operative and conservative treatment of olecranon fractures in elderly. *BMJ Open*, 2022; 12: e055097.

IV Rantalaiho I, Laaksonen, Kostensalo J, Ekman E, Ryösä A, Äärimaa V. Mortality and subsequent fractures of patients with olecranon fractures compared to other upper extremity osteoporotic fractures. *Shoulder Elbow*, 2022; published online September 1.

1 Introduction

Olecranon fractures account for roughly 1% of all fractures. Current epidemiological data suggest that the incidence of olecranon fractures is increasing in the elderly population after the seventh decade. It has been suggested that olecranon fractures should be considered osteoporotic fractures precisely because their distribution curve shows a marked increase in incidence in the elderly. (Court-Brown and Caesar, 2006; Duckworth *et al.*, 2012) In addition, olecranon fractures are known to have osteoporotic features such as age-dependent low bone quality and low-energy trauma as a cause of injury. (Duckworth *et al.*, 2012; Park *et al.*, 2017; Brüggemann, Mukka and Wolf, 2021) The relationship of olecranon fractures to other osteoporotic fractures has, however, not been adequately studied.

Displaced olecranon fractures have traditionally been treated operatively to restore the ulnar joint surface and to re-attach the triceps tendon to ensure extension power of the elbow. (Powell *et al.*, 2017) The most frequent operative methods for fixation of a displaced fracture are tension band wiring (TBW) and plate fixation (PF). Both of these methods seem to lead to adequate union and functioning but are also associated with high rates of re-operations due to operative complications and removal of the prominent metalwork after fracture union. (De Giacomo *et al.*, 2016; Ren *et al.*, 2016) These re-operations increase patient morbidity and are costly. Reported re-operation rates vary, reaching up to 16–50% for TBW and 15–33% for PF (Liu *et al.*, 2012; De Giacomo *et al.*, 2016; A. D. Duckworth *et al.*, 2017; Andrew D. Duckworth *et al.*, 2017; Chen *et al.*, 2021). Co-morbidities, fracture comminution, and osteoporotic bone structure are known to predict an even poorer outcome. (R.B., Gustilo and Anderson, 1976; Claessen *et al.*, 2016)

In addition to these two main fixation options, TBW and PF, also other operative techniques and instruments have been suggested. Results with a cable pin system and olecranon memory connector initially seemed promising in single RCTs. (Liu *et al.*, 2012; Chen *et al.*, 2013)

As they relied on observational and mainly retrospective studies, previous reviews and a meta-analysis have shown a lack of evidence to support one implant over another. (Ren *et al.*, 2016; Powell *et al.*, 2017) In a Cochrane review from 2014

insufficient evidence was found on the best treatment for displaced olecranon fractures based on RCT's. (Matar *et al.*, 2014)

Non-operative, also known as conservative, treatment has been suggested as a primary treatment option for elderly patients in whom the function of the injured elbow does not necessarily limit their daily life. Based mainly on data from small retrospective or prospective case series, it seems that conservative treatment could provide a similar functional outcome, with a lower complication burden, for this population. (Duckworth *et al.*, 2014; Gallucci *et al.*, 2014; Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018) A recent study of a US population reported a 0.66% annual increase in non-operative management of olecranon fractures in patients aged over 75 years. (Motisi *et al.*, 2017) Brüggeman et al. also found that in Sweden between 2014 and 2018, patients aged 65 years and older were more often treated conservatively for all fracture types compared to younger patients. (Brüggemann, Mukka and Wolf, 2021)

To our knowledge, there is only one published and one ongoing randomized study comparing operative and conservative treatment in elderly patients (Symes *et al.*, 2015; A. D. Duckworth *et al.*, 2017). The published trial was terminated prematurely because of an unacceptably high complication rate in the operative group (A. D. Duckworth *et al.*, 2017). As operative treatment of isolated displaced olecranon fractures is still common in the elderly, further research is needed on the role of primary conservative treatment in this patient group.

The aim of this thesis was to evaluate the current evidence on the treatment of displaced olecranon fractures in the form of a literature review, assess complication and re-operation rates in patients treated operatively for an olecranon fracture at a single university hospital, design and present a protocol for an RCT to study the difference between operative treatment, either with TBW or PF, and conservative treatment of traumatic, displaced olecranon fractures in the elderly population in a non-inferiority study setting, and assess the relationship of olecranon fractures to subsequent osteoporotic fractures and mortality.

2 Review of the Literature

2.1 Anatomy of the olecranon

The olecranon is the proximal end of the ulna, one of two forearm bones. The olecranon articulates with the trochlea of the distal humerus and with the radial head. The radial head also articulates with the capitulum of the distal humerus. This articulation of three bones forms the elbow joint. (Fig. 1.) The joint surface of the trochlea and capitellum is positioned in 6 degrees of valgus and 5 degrees of external rotation in relation to the shaft of the humerus. In addition, the joint surface points 30 degrees anteriorly in relation to the axis of the humerus. The ulnohumeral joint bends and extends like a hinge. Three to four degrees of varus-valgus movement is allowed throughout the range of movement. The normal range of motion of the elbow joint is from full extension (straight arm, 0° flexion) to 150 degrees of flexion. Sometimes the elbow joint extends to mild hyperextension as a normal anatomical variant. The elbow joint is held together by its bony architecture as well as ligaments, tendons, and muscles.

The triceps is the main muscle responsible for extending the elbow. It is a strong three-headed muscle originating from the proximal humerus (lateral and medial heads) and the scapulae (long head). The three heads come together to form a strong tendon attaching to the tip of the olecranon. Thus, the olecranon plays a crucial role in extension function. The olecranon is directly under the skin of the elbow, without much protection from muscles or other soft tissues, and is therefore prone to injuries.

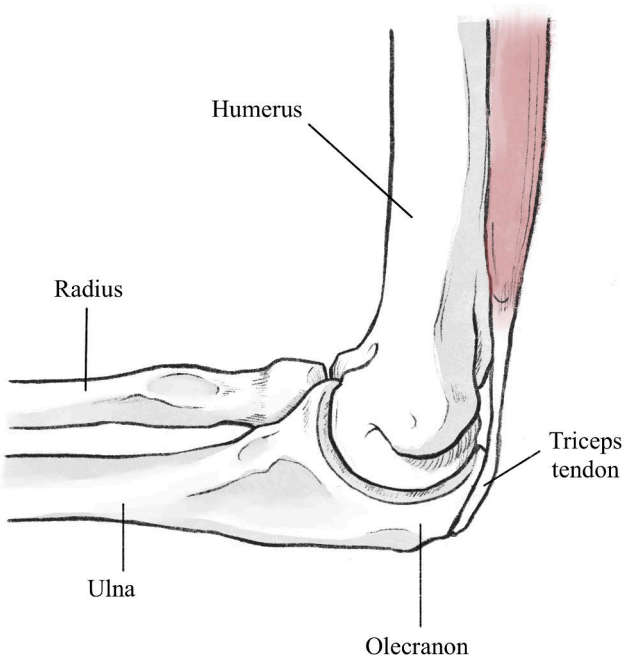

Figure 1. Anatomy of the elbow. Illustration by Saara Nikulainen (2022).

2.1.1 Surgical exposure of olecranon

The olecranon is easily surgically exposed through a straight midline posterior incision. The posterolateral approach was first described by Boyd in 1940 to provide exposure to the radial head, proximal radius, and proximal ulna. (Boyd, 1940) The incision used to expose solely the olecranon is slightly more posterior compared to Boyd's original exposure. (Fig. 2.) The incision runs from a few centimeters proximal to the tip of the olecranon distally following the shaft of the ulna. Under the subcutaneous tissue lies the triceps tendon, which is attached to the tip of the olecranon and the apex, i.e., dorsal surface, of the ulna. All olecranon fractures can be fixed through this exposure. Depending on the fixation method, the triceps tendon can be incised longitudinally where necessary to gain bony exposure to the very tip of the olecranon. Further dissection of the periosteum and muscles should be kept to a minimum to preserve blood supply. Normally, there is no need to expand the dissection, as just an interval split between the flexor capri ulnaris and extensor carpi ulnaris allows enough space for application of the fixation materials. However, if the dissection is continued, relevant adjacent anatomical structures should be borne in mind. This applies especially to dissection in the medial direction, where ulnar nerve lies in close proximity. Other nerves and blood vessels run anteriorly and therefore cannot be accessed through this approach.

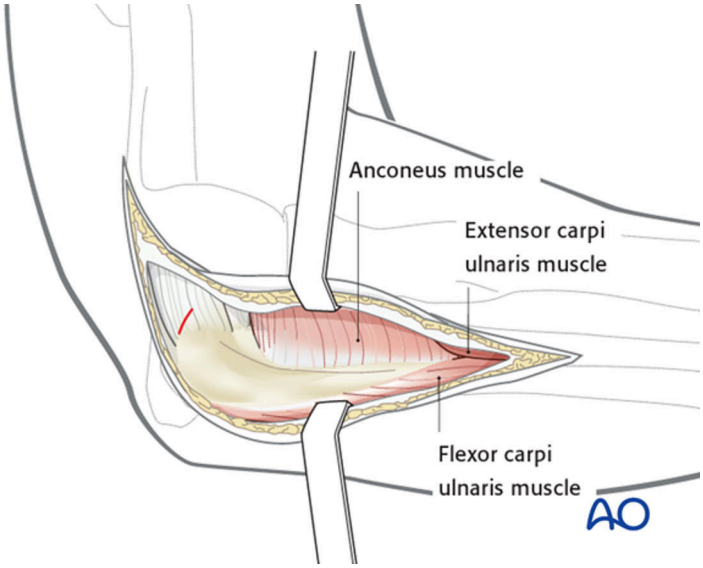

Figure. 2. Posterior approach to the proximal ulna. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.aosurgery.org.

2.2 Epidemiology of olecranon fractures and associated injuries

Olecranon fractures account for approximately 1% of all fractures and 20% of all proximal forearm fractures. (Court-Brown and Caesar, 2006; Duckworth *et al.*, 2012) The incidence of olecranon fractures is approximately 12 per 100 000 person-years. (Karlsson *et al.*, 2002; Duckworth *et al.*, 2012) The incidence starts to increase in both men and women at over 60 years of age and peaks at over 80 years. (Court-Brown and Caesar, 2006; Duckworth *et al.*, 2012; Brüggemann, Mukka and Wolf, 2021) Men with olecranon fractures are generally significantly younger than women. (Duckworth *et al.*, 2012; Brüggemann, Mukka and Wolf, 2021; Cantore *et al.*, 2022) Currently, in Finland and the Nordic countries the population is aging, which raises the incidence of olecranon fractures. (*NordicStatistics*)

Olecranon fractures seem to have features of fragility fractures. Women are more prone than men to sustain an olecranon fracture and women tend to be older at the time of fracture than men. (Brüggemann, Mukka and Wolf, 2021) In 1993, Lauritzen et al. reported a 2.6 relative risk for a subsequent hip fracture after an olecranon fracture compared to a female population without an olecranon fracture. (Lauritzen and Lund, 1993) Since then, no analogous studies have been reported.

Most commonly, the mechanism of injury is a fall from standing height. (Karlsson *et al.*, 2002; Duckworth *et al.*, 2012; Brüggemann, Mukka and Wolf, 2021) In Sweden, 71% of all patients over 65 years of age sustained their fracture by

falling from standing height, and in Scotland, 70% of all patients had the same mechanism of injury. High-energy injuries are rarer and occur in the younger population. (Duckworth *et al.*, 2012; Brüggemann, Mukka and Wolf, 2021) Men more often sustain their olecranon fractures following higher energy injuries than women do. (Brüggemann, Mukka and Wolf, 2021)

Olecranon fractures can be isolated, or more complex when associated with other injuries around the elbow. Soft tissue trauma might occur due to elbow joint dislocation. (Hildebrand, Patterson and King, 1999) Fractures to the radial head are seen in 17% of all olecranon fractures. (Kaas *et al.*, 2010; Duckworth *et al.*, 2012; Duckworth, McQueen and Ring, 2013) In addition, fractures of the coronoid process are possible but are more often associated with complex elbow dislocations. (Hildebrand, Patterson and King, 1999; Ring, 2006) Open olecranon fractures are rare, with reported incidence of 4 to 6% of all olecranon fractures. (Duckworth *et al.*, 2012; Brüggemann, Mukka and Wolf, 2021)

2.3 Olecranon fracture classifications

There are several classification systems for olecranon fractures. Some of which are reportedly easier to use and more reliable in clinical practice. (Benetton *et al.*, 2015) All classifications have a different rationale for grouping the fractures: fracture morphology and biomechanical stability (Schatzker), displacement and fracture pattern (Colton), stability, displacement and comminution (Mayo). (Colton, 1973; Morrey, 1995; Schatzker, 2005)

The Arbeitsgemeneischaft für Osteosynthesefragen (AO) classification system is consistent with their comprehensive fracture classification system; type A fractures are extra-articular, type B are partial intra-articular, and type C are total intra-articular involving both ulnar and radial articulations. (Meinberg *et al.*, 2018) The AO classification may be useful for some research purposes, but its complexity limits its use in clinical practice.

The most commonly used classifications by Mayo and Schatzker are described below in greater detail.

2.3.1 Mayo classification

The Mayo classification is probably the most widely used due to its relative simplicity and relevance in clinical decision making. The Mayo classification distinguishes the three factors that have a direct influence on treatment: fracture displacement, presence of comminution, and ulnohumeral stability. (Cabanela and Morrey, 1993) It provides a treatment algorithm and prognosis based on fracture type. (Cabanela and Morrey, 1993; Morrey, 1995) Fractures are divided into three

groups according to fracture dislocation, each of which is further subdivided into A and B groups depending on the presence or absence of comminution. (Fig. 3.)

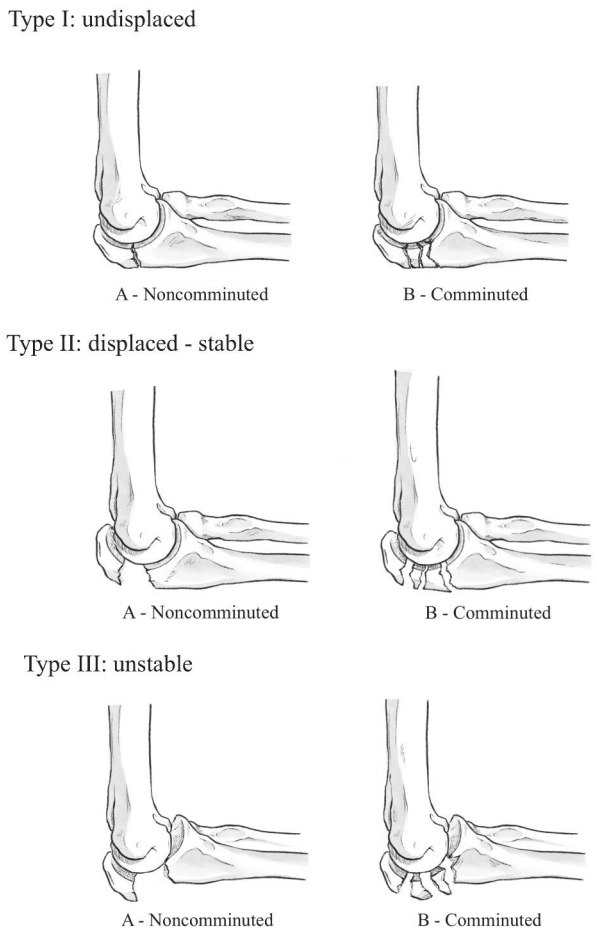

Figure 3. The Mayo classification of olecranon fractures. Illustration by Saara Nikulainen (2022).

2.3.2 Schatzker classification

The Schatzker classification focuses on fracture morphology and biomechanical stability. (Fig. 4.) This classification divides fractures into six groups from A to F. Type A includes transverse fractures where the fracture line passes through the articular surface of the ulnohumeral joint. Type B includes type A fractures with associated articular impaction or comminution. Type C and D are oblique fractures proximal to the midpoint of the trochlear notch and comminuted fractures, respectively. Type E fractures are oblique fractures where the fracture line lies

completely distal to the midpoint of the trochlear notch. Type F includes fracture-dislocations that are associated with radial head fractures and soft tissue injuries. (Schatzker, 2005)

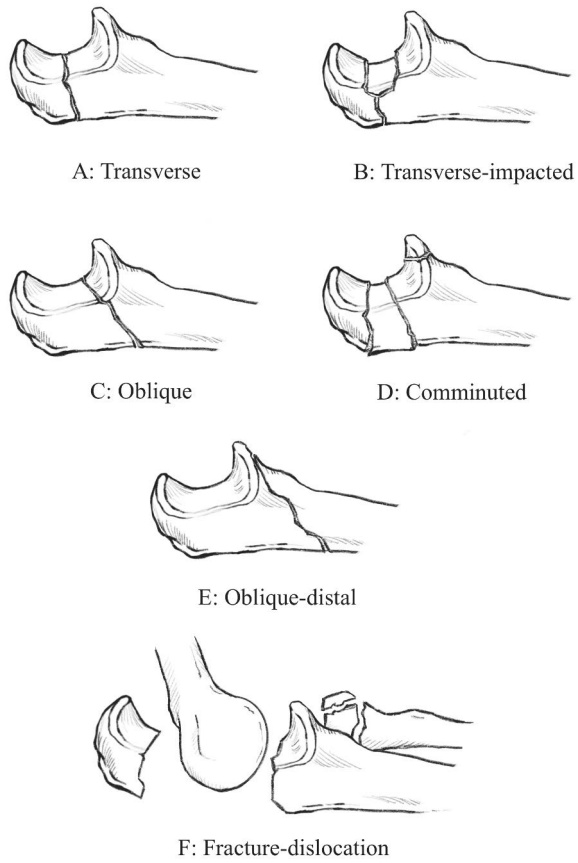

Figure 4. The Schatzker classification of olecranon fractures. Illustration by Saara Nikulainen (2022).

2.4 History of fracture management

The earliest signs of active fracture management in humans, from around 300 BCE, were discovered by archaeologists in Egypt in 1903. Two specimen were found of splinted extremities. (Smith, 1908) Some form of wooden splints are known to have been used already in antiquity, as described by Hippocrates and Celsus. (Milne, 1909) Since then, many different illustrations and descriptions of splinting have appeared in literature. (Fang, Ku and Shang, 1963) The earliest plaster bandages were made of rags dipped in clay gum mixtures or flour and egg-white and wrapped around fractured extremities. (Walker, 1839; Bacon, 1923) These materials were

commonly used up until the middle of the 19th century. Although, functional bracing was first described by Gooch as far back as 1767 (Gooch, 1767), it only became accepted in the 1960s when Sarmiento developed a special cast for managing tibial fractures, launching a renaissance in functional bracing. (Sarmiento, 1967) Inspired by Sarmiento, in 1970 Mooney et al. described hinged casts for the treatment of femoral fractures treated initially with 6 weeks of traction. (Mooney *et al.*, 1970)

One of the best known splints in history is the Thomas splint, developed in the mid-19th century by Hugh Owen Thomas, known as the father of British orthopaedics, originally to assist in the management of tuberculous disease of the knee joint. (Thomas, 1974) (Fig. 5.) Use of Thomas splint in World War I saved many lives, and it is still in use today in many centers around the world for managing fractures of the femur.

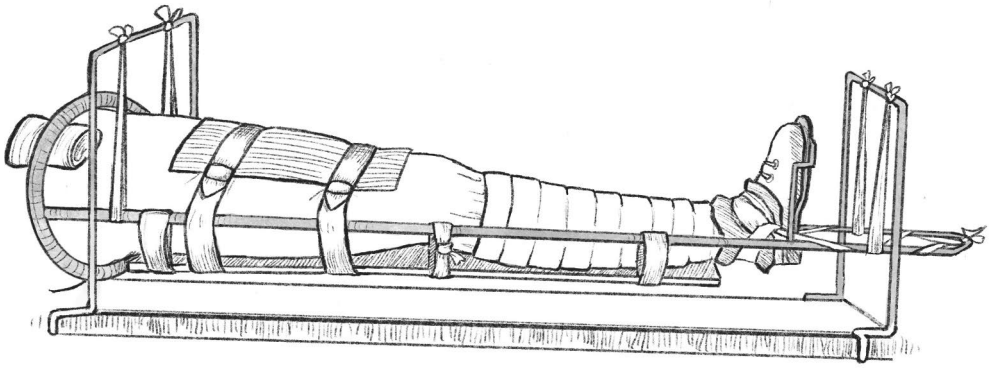

Figure 5. The Thomas splint. Illustration by Saara Nikulainen (2022).

2.4.1 Early fracture surgery

The earliest account of open fracture reduction and fixation is a bone suture description from the 1770s. It is controversial whether the method was truly used that early, but in 1827 Dr. Rodgers is recorded as having performed a bone suture. (Hartshorne, 1841; Colton, 2009) The use of screws in fracture surgery most likely started in the late 1840s and in 1850 Cucuel and Rigaud described two cases of fracture management with screws—the first a sternum fracture, and the other a displaced fracture of the olecranon. The first plate fixation was performed by Hansmann of Hamburg in 1886. The bent end of the plate and long screw shanks were left protruding through the skin to facilitate removal after union. (Colton, 2009)

Robert Danis is regarded as the father of modern osteosynthesis. In his publication *Théorie et Pratique de l'Ostéosynthèse* he describes the objectives for a satisfactory osteosynthesis: the possibility of immediate and active mobilization,

complete restoration of the bone to its original form, and primary bone healing without formation of an apparent callus. (Danis, 1949) Swiss physician Maurice Müller was impressed with Danis' work and determined to develop the principles of osteosynthesis even further and investigate the science behind them.

2.4.2 Arbeitsgemeinschaft für Osteosynthesefragen, AO

The AO was founded in 1958 by Dr. Müller and 14 close colleagues who shared his passion for improving the techniques for internal fixation of fractures. This involved three channels of activity: First, an experimental surgery laboratory was founded in Davos. Second, collaboration with metallurgists and engineers was set up to design a system of implants and instruments enabling application of the osteosynthesis principles to fracture fixation. Third, it was decided to document all the clinical experience obtained, which continues to the present day from all over the world. (Colton, 2009)

As stated by the AO in 1962, the original goals for fracture reduction and internal fixation were: anatomic reduction of the bone, stable fixation, preservation of blood flow to the fracture site—i.e., atraumatic surgical techniques—and early mobilization. Since then, the growing understanding of biomechanics and mechanisms of bone healing has pushed forward the evolution of the principles. Current AO principles can be summarized as follows:

1. Reduction of the fracture and restoration of the anatomy
2. Absolute or relative stability depending on fracture, patient, and injury–related factors
3. Atraumatic surgical technique to preserve and restore vascularity to the fracture site
4. Early and safe mobilization and rehabilitation. (Buckley, Moran and Apivatthakakui, 2018)

2.5 Conservative treatment of olecranon fractures

2.5.1 Non-displaced fractures

Non-displaced or minimally displaced olecranon fractures represent approximately 5–10% of all olecranon fractures. (Duckworth *et al.*, 2012; Lubberts *et al.*, 2017; Morrey, Sanchez-Sotelo and Morrey, 2017; Brüggemann, Mukka and Wolf, 2021) They are classified as Mayo type 1, present less than 2mm of articular surface

displacement when the elbow is flexed at 90°, and have an intact extensor mechanism.

These fractures have widely and safely been treated conservatively and symptomatically with immobilization with a splint or collar cuff for 1–2 weeks followed by initiation of an active range-of-motion program. Gradual increases in extension are allowed and close radiographic follow-up is recommended during the first month to assess for displacement and possible need for further intervention. Union and good function are ultimately accomplished. (Ring, 2011; Adams and Steinmann, 2018) (Fig. 12)

2.5.2 Displaced fractures

Conservative treatment has been suggested as a treatment option for elderly patients in whom the function of the injured elbow does not necessarily significantly limit their daily activities. Several publications already exist on the conservative treatment of simple displaced olecranon fractures in elderly patients. (Jaskulka and Harm, 1991; Veras Del Monte *et al.*, 1999; Duckworth *et al.*, 2014; Gallucci *et al.*, 2014; Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018) A pilot report has also been published on the conservative treatment of Mayo type 2 fractures in any-age adult patients. (Putnam, Christophersen and Adams, 2017) Recently, two population-based studies from the United States and Sweden have reported a marked increase in conservative management of displaced olecranon fractures specifically in the elderly population. (Motisi *et al.*, 2017; Brüggemann, Mukka and Wolf, 2021)

It should be noted that in all these publications the fractures treated conservatively are displaced fractures involving the mid-portion of the olecranon, where the anterior parts of the collateral ligament complexes are intact and the ulnohumeral joint remains congruent. In these Mayo type 2 fractures, ligamentous stability between the upper arm and forearm is thought to be intact, maintaining stability of the elbow regardless of the fracture. (Morrey BF, 1993; Morrey, 1995) Instable fracture-dislocations (Mayo type 3) are still considered best treated operatively to regain joint congruency. (Hak and Golladay, 2000; Buijze and Kloen, 2009) (Fig. 12)

Considering the lack of research, no established protocol for conservative treatment of displaced fractures exists. In most reports, the treatment has mimicked the treatment protocols for non-displaced fractures. In some studies the fractured arm has been splinted in extension followed by active motion practices beginning 3 to 4 weeks after injury. (Putnam, Christophersen and Adams, 2017) In others, an elbow-to-body-sling has been used to immobilize the arm in a comfortable position (70–90° of flexion) for 2 weeks, followed by passive mobilization until 6 weeks and active ranges of motion and muscle reinforcement at 8 weeks. (Marot V, Bayle-

Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018) Also, a collar and cuff with primary active mobilization or above-the-elbow plaster cast with 60–90° of flexion has been used for varying periods in several retrospective reports. (Veras Del Monte *et al.*, 1999; Duckworth *et al.*, 2014; Gallucci *et al.*, 2014)

2.6 Operative treatment of olecranon fractures

Displaced olecranon fractures have traditionally been treated operatively with osteosynthesis (Powell *et al.*, 2017). The aim of operative treatment is to achieve anatomical reduction and rigid fixation to restore stability and extension power and allow early mobilization and pain-free rehabilitation. (Powell *et al.*, 2017; Adams and Steinmann, 2018)

The original principle behind osteosynthesis was to create compression to the fracture site to improve bony union. (King, 1957) To date, there are a number of different reported methods for achieving this for displaced olecranon fractures, but the most frequently used are TBW and PF. (Molloy *et al.*, 2004; Liu *et al.*, 2012; Chen *et al.*, 2013; Matar *et al.*, 2014; Ren *et al.*, 2016; Andrew D. Duckworth *et al.*, 2017; Koziarz *et al.*, 2019) TBW is effective with isolated, simple and stable fractures where compression to the fracture line is desirable. (Anderson, 1992) On the other hand, comminuted and unstable fractures are best treated with PF following slightly different principles. (Fyfe, Mossad and Holdsworth, 1985; Hume and Wiss, 1992; Buijze and Kloen, 2009)

2.6.1 Tension band wiring

The philosophy of TBW is to convert tensile extension forces into compression forces at the joint line during flexion. TBW is generally performed according to AO recommendations. (Anderson, 1992)

As described previously, a posterolateral approach is used for surgical exposure. The fracture is reduced using one or two small pointed reduction forceps. Two parallel K-wires are then introduced through the proximal end of the olecranon and drilled obliquely into the anterior cortex of the ulna, passing as close to the joint as possible. A hole is drilled into the ulnar metaphysis area approximately 40 mm distal to the fracture line and 5 mm from the posterior cortex. A cerclage wire is inserted through the drilled hole and passed beneath the triceps tendon, around the K-wires in a figure-of-eight configuration with two tightening loops. The proximal ends of the K-wires are then cut, bent, and buried into the triceps tendon. (Müller *et al.*, 1991; Anderson, 1992) (Fig. 6.)

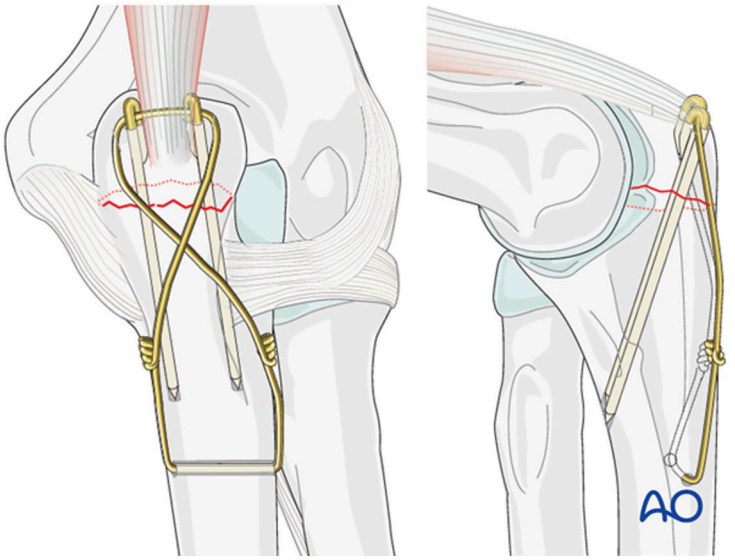

Figure 6. Tension band wire fixation of a transverse olecranon fracture. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.aosurgery.org.

2.6.2 Plate fixation

There are two possible philosophies behind plate fixation. Bridge plating can in principle be used with multifragmentary intra-articular fractures, where compression of the fracture site is not possible and bone alignment must be corrected with as little interference to the fracture site as possible, while still reducing the joint surface. (Heitemeyer *et al.*, 1987). Another indication for PF is an oblique fracture where a lag screw can be used to create compression to the fracture site. (Müller, 1963) The same posterolateral approach as in TBW is used for both methods to gain exposure.

2.6.2.1 Bridge plating

To reduce the joint surface, the distal humeral joint can be used as a template. The fragments are temporarily reduced with K-wires and pointed reduction forceps, where possible. The K-wires must be positioned in such a way that they do not interfere with positioning of the plate. An anatomic, pre-contoured plate is then placed along the dorsal surface of the bone. At least three screws should be inserted both proximally and distally to the fracture site. Bicortical screws should be used where possible. (Kloen, 2018a) (Fig. 7.)

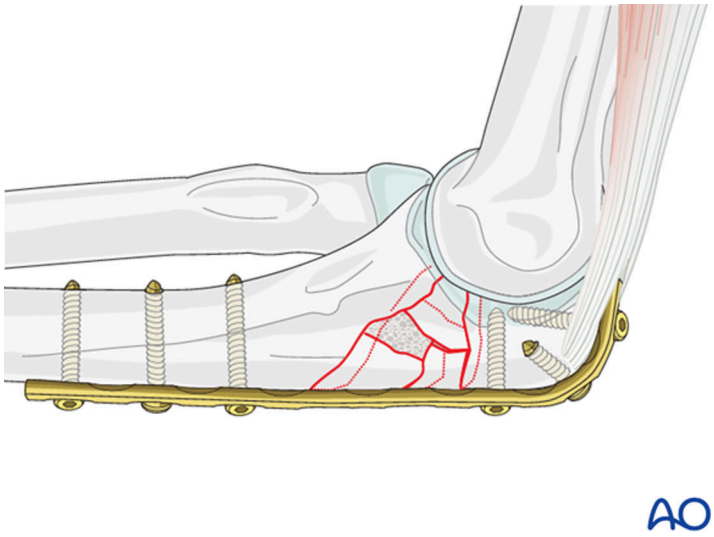

Figure 7. Bridge plating of a multifragmentary olecranon fracture. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.aosurgery.org.

2.6.2.2 Lag screw with neutralization plate

In an oblique fracture, compression to the fracture line can be achieved using a lag screw. The lag screw is inserted perpendicularly through the fracture plane. The thread pulls the opposite fragment towards the head of the screw, compressing the fracture plane. As a lag screw alone is not stable enough for osteosynthesis and to resist torsion forces, a neutralization plate can be added for stability. When possible, the lag screw should always be inserted through the plate to achieve a more stable construct. (Müller, 1963)

The fracture is reduced using pointed reduction forceps and K-wires as per the surgeon's preference. A pre-contoured anatomical plate is applied, and the lag screw is the first to be drilled. The plate is then fixed to the bone with at least three screws proximal and distal to the fracture line. (Kloen, 2018b) (Fig. 8.)

Alternatively to a lag screw, a "home run screw" passed through the plate from the tip of the olecranon can act as an intramedullary screw. (Kloen, 2018b) (Fig. 9.)

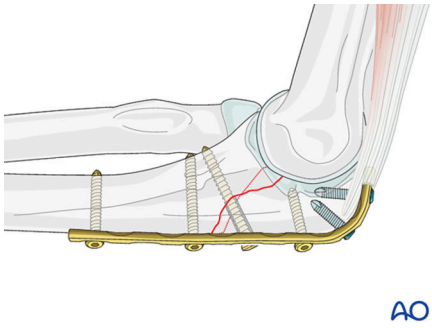

Figure 8. Lag screw neutralization plate. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.aosurgery.org

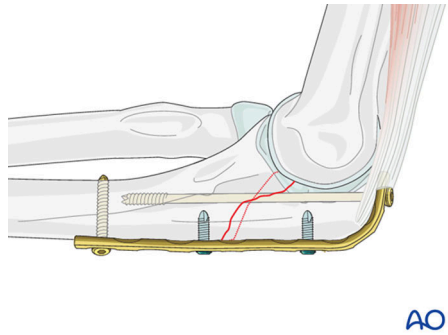

Figure 9. Plate fixation with a "home run screw". Copyright AO Foundation, Switzerland. Source: AO Surgery Reference: www.aorsurgery.org

2.7 Outcome measures

Physicians need outcome measures to be able to evaluate the quality of treatment and patient satisfaction. Several types of joint and disease-specific outcome measures have been developed for the shoulder, elbow, wrist, and hand. They may consist of simple questions to the patients (patients-reported outcome measures) or be more complex in structure evaluating interrelated domains that affect the function of the upper extremity. Some of the more complex ones are based only on an evaluation by physicians, others are combinations of evaluation by physicians and questions to patients. (Velstra, Ballert and Cieza, 2011; Smith *et al.*, 2012)

International Consortium for Health Outcomes Measurement (ICHOM) is an international community of medical professionals based in the US, devoted to creating recommendations for the best usable patient-centered outcome measures for each disease group. For the upper extremity they have completed and harmonized a recommendation for hand and wrist conditions, but for the elbow a recommendation still does not exist. (*ICHOM Healthcare Improvement Patient-Centered Outcome Measures*)

2.7.1 Clinician-reported outcome measures (CROM)

The most basic clinician-reported outcome measure of the elbow is range of motion (ROM). It is always reported when assessing the function of the elbow. As mentioned earlier, the normal ROM of the elbow is from full extension (straight arm, 0° flexion or mild hyperextension) to 150 degrees of flexion. Practically all injuries and conditions to the elbow decrease the ROM.

Secondly, extension strength can be measured. Measuring devices for elbow extension are not found as commercial products, at least not in Finland, and thus every department has their own systems operated mainly by physiotherapists in

special circumstances such as research. For this reason, measurement of elbow extension strength is not routinely in clinical use.

Two of the combination tools for elbow assessment most commonly seen in research are the Broberg and Morrey scale (B&M) and Mayo Elbow Performance Score (MEPS). (Broberg and Morrey, 1986; Morrey and Adams, 1992; Smith *et al.*, 2012) These scales are rarely seen in clinical use in Finland. The B&M scale is validated for general elbow disorders and consists of physician assessment of motion, strength and stability and, patient assessment of pain. The scale ranges from 0 to 100, with a higher score indicating a better outcome. No MCID has been reported for this scale. The MEPS was developed to evaluate outcomes of total elbow arthroplasty but it is also validated for general elbow disorders. (Turchin, Beaton and Richards, 1998) The scale consists of physician assessment of pain, ROM, and stability and, a patient assessment of daily function. This scale also ranges from 0 to 100, with a higher score indicating a better outcome. MCID of 15 points was reported for patients with rheumatoid arthritis after an arthroplasty or synovectomy. (De Boer *et al.*, 2001)

In addition, documenting all possible adverse events related to the treatment must be counted as clinician-reported evaluation of the treatment.

2.7.2 Patient-reported outcome measures (PROM)

Disabilities of the Arm, Shoulder and Hand (DASH) is a validated patient-reported outcome measure assessing upper extremity-related deficits and symptoms in daily life. It is designed to evaluate single or multiple disorders in any region of the upper limb. DASH consists of 30 core questions and additional eight questions related to work, sports and arts activities. The scale ranges from 0 to 100, with higher scores indicating more disability. (Hudak PL, Amadio PC, 1996; Gummesson, Atroshi and Ekdahl, 2003) An MCID of 10 points is reported, but there is also a suggestion that 10 points should be considered only with shoulder diagnoses and 17 points for the distal part of the upper extremity (elbow, wrist and hand) diagnoses. (Davis *et al.*, 1999; Gummesson, Atroshi and Ekdahl, 2003; Schmitt and Di Fabio, 2004)

A shorter and time-saving version of the DASH, named QuickDASH consists of 11 questions, where a higher score indicates more disability, as in the DASH. A high correlation between DASH and QuickDASH has been reported. (Beaton *et al.*, 2005) In a 35 participants' study the MCID for QuickDASH is evaluated to be 19 points. (Polson *et al.*, 2010)

Patient-rated elbow evaluation (PREE) is an elbow-joint specific measure which is validated with psychometric methods. The instrument consists of two subsections of pain and disability weighing both equally. The scale ranges from 0 to 100 with a higher score indicating more pain and functional disability. (Vincent *et al.*, 2015)

The simplest patient-rated evaluation method is the visual analog scale (VAS), which is usually used to assess pain, but may also be used to assess satisfaction towards a specified subject. VAS is a continuous line with 0, standing for “no pain”, at the left end of the line and 100, standing for “worst possible pain”, on the right. The patient draws a perpendicular line across the scale to indicate their situation. VAS evaluation of pain is structurally easy and widely used in clinical settings. (Hjermstad *et al.*, 2011)

2.8 Outcomes and adverse events of olecranon fracture treatment

2.8.1 Conservative treatment

Conservative treatment of non-displaced olecranon fractures is known to be successful, but not many recent publications on this subject can be found. (Fig. 12) The only considered adverse event is stiffness of the elbow associated with prolonged immobilization. (Ring, 2011; Adams and Steinmann, 2018; Steinmetz *et al.*, 2018)

Conversely, conservative treatment of displaced, simple olecranon fractures in the elderly population has recently raised interest among researchers and the number of publications is rising (Figs. 10A, 10B and 12). A couple of reports from the 1990s suggest that patients treated conservatively due to unfitness for surgery had subjectively satisfactory or excellent results. None of the patients reported limitations in their daily living (Jaskulka and Harm, 1991; Veras Del Monte *et al.*, 1999), and even pseudo arthrosis in nine cases did not worsen patient satisfaction (Veras Del Monte *et al.*, 1999). Two small retrospective case series of 28 and 43 patients showed excellent results in the conservative treatment of displaced olecranon fractures in the elderly. Practically all patients were pain free at the end of follow-up and no reoperations were needed for symptomatic non-unions. (Duckworth *et al.*, 2014; Gallucci *et al.*, 2014) Another 14-patient retrospective report on conservatively treated Mayo type 2 fractures reported good or excellent results and only one nonunion. (Putnam, Christophersen and Adams, 2017) A very recent study on olecranon fractures in patients aged 70 and older also found that no patient treated non-operatively had to undergo any further operative intervention. (Parkes *et al.*, 2022) Additionally, a prospective study of 22 conservatively treated Mayo type 1 and 2 olecranon fractures reported excellent results in MEPS and QuickDASH scores at 6 months. (Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018)

Figure 10A. Displaced Mayo type 2 fracture treated conservatively at Turku University Hospital.

Figure 10B. The same conservatively treated olecranon fracture at 3 months' follow-up.

Although a non-union might at first sight be considered an adverse event, in a study by Gallucci et al., 22 of 28 patients developed a non-union that was painless, and none of the patients required surgical treatment. (Gallucci *et al.*, 2014) Duckworth et al. reported that 78% of patients in their retrospective database had developed a painless non-union and that no correlation was found between fracture non-union and DASH score. In addition, no patient had undergone additional surgery for a symptomatic non-union or any other cause within the first year of follow-up. (Duckworth *et al.*, 2014) Marot et al. treated conservatively any-age adults with Mayo type 2 fractures and reported that, 18 of 22 patients developed a non-union with no need for additional treatment, even when the dominant arm was affected, and no cases of elbow instability. (Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018)

Pain and limiting, symptomatic stiffness have been reported to be rare adverse events of conservative treatment of simple, displaced olecranon fractures. (Duckworth *et al.*, 2014; Gallucci *et al.*, 2014; Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018) Marot et al. reported signs of osteoarthritis in 18 of 22 conservatively treated fractured elbows, but radiological signs were not connected to symptoms. (Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018)

Based on the data presented above, it seems that conservative treatment could provide a similar functional outcome to operative treatment, with a lower complication burden, for the elderly population. (Fig. 12) However, there is no reliable data on to what extent patients regain their extension strength, as there is often a vast gap between the bone fragments probably filled with scar tissue and the triceps tendon is shortened.

2.8.2 Operative treatment

The most frequently used methods for osteosynthesis of olecranon fractures, TBW and PF, are widely compared in the literature. The current literature supports the use of these methods over other introduced and experimental approaches. However, it does not support one implant over another, since significant differences between these two methods have not been found concerning patient satisfaction, improvement rate, ROM, operation time, or blood loss. (Matar *et al.*, 2014; Ren *et al.*, 2016; Andrew D. Duckworth *et al.*, 2017) (Fig. 12) Both methods achieve adequate union and function. The DASH scores after operative treatment have been reported to be good, ROM well restored, and pain infrequent. (Karlsson *et al.*, 2002; Tarallo *et al.*, 2014; Andrew D. Duckworth *et al.*, 2017; Patiño *et al.*, 2020)

Both TBW and PF are associated with a high rate of re-operations for multiple reasons. Reported re-operation rates vary, reaching up to 16–50% for TBW and 15-

33% for PF. (Liu *et al.*, 2012; De Giacomo *et al.*, 2016; A. D. Duckworth *et al.*, 2017; Andrew D. Duckworth *et al.*, 2017; Chen *et al.*, 2021; Parkes *et al.*, 2022)

One of the most common reasons for complaints and re-operations is prominence of metalwork. (Figs. 11A and 11B) Reportedly, prominent metalwork complications can be as frequent as in 30–50% of treated patients regardless of the fixation method used. (Matar *et al.*, 2014; De Giacomo *et al.*, 2016; Ren *et al.*, 2016; Andrew D. Duckworth *et al.*, 2017; Koziarz *et al.*, 2019) Younger patients and women more often suffer from prominent and symptomatic hardware leading to hardware removal than do older patients and men. (Claessen *et al.*, 2016; Bugarinovic *et al.*, 2020).

Wound problems, infections, and loss of reduction are also quite frequent adverse events following operative treatment. All such events can lead to re-operations. Infections have been reported in 4–13% and loss of reduction in 13–20% of all operatively treated patients. (Matar *et al.*, 2014; De Giacomo *et al.*, 2016; Ren *et al.*, 2016; Andrew D. Duckworth *et al.*, 2017; Chen *et al.*, 2021).

ASA grade, comminution of the fracture, and poor bone quality are reported to predict an overall poorer long-term outcome (R.B., Gustilo and Anderson, 1976; Claessen *et al.*, 2016; Chen *et al.*, 2021). Reflecting this, a French report recently questioned the need for operative treatment of simple, displaced olecranon fractures in elderly patients aged 75 years and older after analyzing retrospectively the results of 29 patients after surgery. The used fixation methods were TBW in 70%, PF in 23%, and double-plate fixation in 7% of cases. Complications occurred in 40% of the patients and 37% required revision surgery. The most frequent complications were prominence of metalwork and loss of reduction. (Beaudouin and Augustin, 2021)

Non-union often leads to problems, significant limitations in function, and re-operations after operative treatment and should be considered an adverse event. Most often the reason behind a non-union after operative treatment is an infection or loss of reduction, which themselves are also considered adverse events. The rates for non-unions are reported to vary from 0 to 8%. (Liu *et al.*, 2012; Tarallo *et al.*, 2014; Andrew D. Duckworth *et al.*, 2017; Patiño *et al.*, 2020)

The risk of osteoarthritis after olecranon fracture has been poorly studied. Karlsson et al. reported a 15 to 25 year follow-up after olecranon fractures in 73 adult patients. They found radiographic signs of degenerative changes in approximately 50% of formerly fractured elbows and signs of osteoarthritis in 6%. Patients' healthy elbows served as controls and the same numbers for those healthy elbows were 11% and 0%, respectively. Only two patients of those with signs of osteoarthritis were reported to have a poor outcome. (Karlsson *et al.*, 2002) Just recently, the authors of a retrospective analysis from Argentina found a significant association between risk of developing osteoarthritis and fracture type independent of age and sex. With greater complexity of the fracture, the risk of osteoarthritis increased markedly. (Patiño *et al.*, 2020)

Figure 11A. TBW fixation of an olecranon fracture in an 83 year-old woman treated at Turku University Hospital.

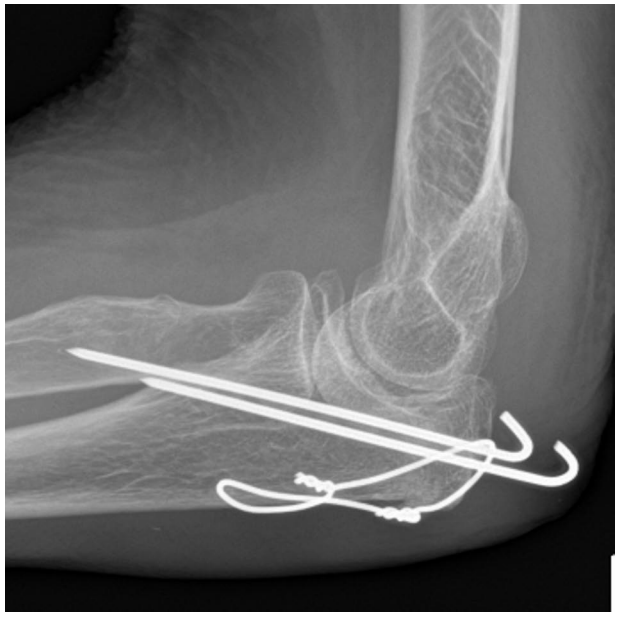

Figure 11B. At 3-month follow-up of the same patient, a K-wire has receded from the bone, requiring removal of the fixation material during revision surgery.

2.9 Operative versus conservative treatment of olecranon fractures in the elderly population

Comparison of the results of conservative and operative treatment of olecranon fractures was already a subject of interest in the 1950s. (Balthasar, 1952; Knysh, 1959) Unfortunately there is still a lack of good-quality research on this matter. Only one, prematurely terminated, RCT has been published.

Kaiser et al. analyzed retrospectively the results from a single center in Austria from July 2015 to February 2019. They compared the results of conservative treatment and surgery for displaced Mayo type 2A and 2B olecranon fractures in patients over 70 years of age. During this time six patients had been treated conservatively and 11 operatively. There was no significant difference in ROM, extension strength, or patient-reported outcome measures. The only significant differences were found in physician-reported measures. All patients in the conservative group developed a non-union, and all fractures in the surgery group healed. One ulnar nerve palsy was considered a complication in the conservative treatment group, but in the surgical group five patients needed revision surgery and one suffered from prolonged lymphedema. The authors concluded that displaced olecranon fractures can successfully be treated conservatively in this elderly, low-demand age group with a satisfactory outcome. (Kaiser *et al.*, 2021)

Another retrospective analysis by Batten et al. in 2016 compared the results in patients 74 years of age or older, 36 of whom had a displaced olecranon fracture treated with TBW, 14 had PF, and 24 were managed conservatively. The patients were divided into groups according to the amount of displacement. Comparably to the findings of Kaiser et al., the functional scores were worse in non-operatively treated patients, with 5–10 mm of displacement compared to operatively treated patients, but non-operatively treated patients had significantly lower mean pain. Patients in the 10–20 mm dislocation group did not have any difference in functional scores or pain between operative and non-operative treatment groups. The authors concluded that non-operative treatment is acceptable in this age group to avoid risks related to surgery, and it results in low pain and satisfactory function, comparable to tension band wiring. (Batten, Patel and Birdsall, 2016)

A Scottish randomized, controlled trial comparing operative treatment of isolated dislocated olecranon fractures with conservative treatment in patients 75 years of age or older was terminated prematurely because of an unacceptable complication rate (nine of 11) in the operative group. A total of 19 patients were randomized, eight to conservative treatment and 11 to operative treatment. Loss of reduction was the most frequent complication in the operative group (six of 11) although displacement was initially accepted in the non-operative group by the study setup. Randomized patients were followed-up for 1 year and there was no difference in any of the outcome measures between the groups at any time. The authors

concluded that the results support the role of conservative treatment as a primary option in elderly patients. However, non-inferiority of the conservative treatment could not be proven, as the trial was terminated prematurely. (A. D. Duckworth *et al.*, 2017)

Chen et al. published a systematic review and meta-analysis addressing this issue in January 2021. However, the review does not add much value or information, considering the heterogeneity and low quality of the original publications included. 10 case series, two retrospective cohort studies, one prospective cohort study, and one RCT. Only the RCT and one retrospective cohort study had conservative and operative treatment groups. All the other publications concerned only conservative or operative treatment alone with no control group. The conclusions were that conservative treatment in the elderly population can provide comparable outcomes to operative treatment, a high rate of complications and re-operations follow operative treatment, and thus conservative treatment offers an acceptable option as primary treatment for stable, displaced olecranon fractures in the elderly population. (Chen *et al.*, 2021)

It seems that any additions to the literature and knowledge on this subject are raising mainly in Australia and New Zealand. In 2015, Symes et al. published a protocol for an RCT of operative versus non-operative treatment of olecranon fractures in the elderly. The primary objective of the trial was to compare the results of the DASH at 12 months between treatment groups. Patients had to be 75 years of age or older, medically fit for surgery, have an isolated, displaced (>2mm) olecranon fracture, and present within 14 days of injury. No results from this trial have yet been published. (Symes *et al.*, 2015)

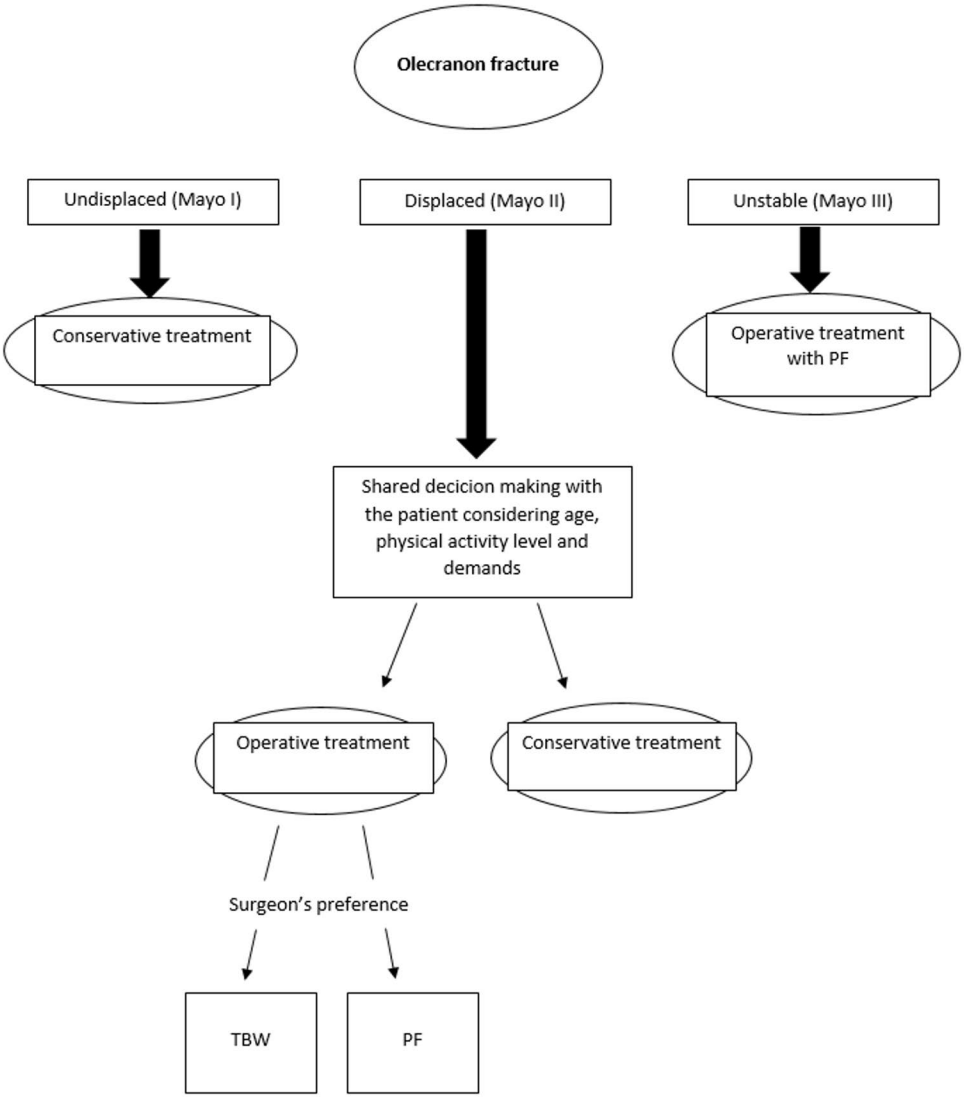

Figure 12. Flow chart of the selection of treatment method of olecranon fractures based on current literature.

3 Aims

1. To evaluate the current evidence on the treatment of displaced olecranon fractures based on randomized controlled studies.
2. To assess the complication and re-operation rates for patients treated with TBW or PF and to find possible patient, fracture, or operation technique-related predictive factors for complications and re-operations.
3. To design a study to assess differences between operative treatment, either with TBW or PF, and conservative treatment of traumatic, displaced (Mayo 2) olecranon fractures in the elderly population in a non-inferiority study setting. Our null hypothesis is that conservative treatment does not yield inferior outcomes to operative treatment.
4. To assess the demographic features of patients with olecranon fractures, their mortality, and risk of subsequent fractures compared to other common upper extremity fractures.

4 Materials and Methods

4.1 Patients

4.1.1 Study I

In a systematic review (study I), the pooled patient population of five selected, RCTs was 229 of whom 85 were treated with TBW for olecranon fractures, 75 with PF, 61 with different introduced operation methods, and eight conservatively. The size of the study populations of the included RCTs varied from 19 (11 cases vs eight controls) to 67 (34 cases vs 33 controls). The duration of follow-up ranged from 5 months to 3 years. (Liu *et al.*, 2012; Chen *et al.*, 2013)

4.1.2 Study II

The patients in study II were identified retrospectively from Turku University Hospital's (Turku, Finland) electronic patient record systems, which were searched for proximal ulnar fracture diagnosis S52.0 according to the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10-CM) and type of surgery NCJ62 or NCJ64 according to the NOMESCO Classification of Surgical Procedures Version 1.14 by the Nordic Medico-Statistical Committee, over an 11-year period from 2007 to 2017.

For study II a total of 434 patients who had undergone surgery for olecranon fracture between 2007 and 2017 were identified. Median age of all the patients was 64 years (range 16–95) and most of the patients (66.4%) were female. Median time to the last outpatient clinic visit was 6 weeks (range 1–52). (Table I)

Table I. Baseline characteristics in Study II. Modified from Rantalaiho et al. (2021)

	ALL	TB	PLATE
PATIENTS N (%)	434	387 (89.2)	47 (10.8)
FEMALE N (%)	288 (66.4)	260 (60.0)	28 (6.5)
AGE YEARS MEDIAN (RANGE)	64 (16–95)	65 (16-95)	59 (16-86)
ISS MEDIAN (RANGE)	(4-17)	(4-13)	(4-17)
FRACTURE TYPE N (%)			
MAYO 1	8 (1.8)	8 (2.1)	0 (0.0)
MAYO 2	409 (94.2)	367 (94.8)	42 (89.4)
MAYO 3	17 (3.9)	12 (3.1)	5 (10.6)
TRAUMA MECHANISM (%)			
FALLING FROM STANDING HEIGHT	267 (61.5)	244 (56.2)	23 (5.3)
OTHER*	167 (38.5)	142 (32.7)	25 (5.8)
NA	1 (0.2)		
OPEN FRACTURE (%)			
GUSTILO 1	14 (3.2)	10 (2.3)	4 (0.9)
GUSTILO 2	10 (2.3)	8 (1.8)	2 (0.5)
NA	1 (0.2)		

ISS=INJURY SEVERITY SCORE; MAYO=MAYO FRACTURE CLASSIFICATION[4,13]; *OTHER TRAUMA MECHANISMS INCLUDE FALLING DOWN STAIRS, FALLING WITH A BICYCLE, FALLING FROM >1M HEIGHT, OTHER HIGH ENERGY MECHANISM OR UNKNOWN; NA=NOT ANNOUNCED

4.1.3 Study III

For the SCORE trial, patients with a displaced olecranon fracture following a traumatic event and referred to the ER of any of the investigating centers will be screened for eligibility. An X-ray will be taken of all elbows with signs of a possible

fracture in the ER. Patients with displaced olecranon fractures on X-ray will be screened by one of the investigating physicians, and those fulfilling the radiological and anamnestic criteria will be explained the rationale for the study, asked to participate in the trial, and asked to sign a written informed consent. The patients will be openly explained the two treatment modalities at recruitment. Patients who have consented will then be randomized to either operative or non-operative treatment using the online randomization system at randomize.net.

Criteria for inclusion:

1. Radiologically (standard AP and lateral radiographs) confirmed, displaced (≥2 mm dislocation of the joint surface) fracture of the olecranon
2. Age of patient 75 years or more at time of injury

Criteria for exclusion:

1. Delay of >2 weeks from traumatic event to day of intervention
2. Mayo type 3 fracture
3. Fracture continuation distal to the coronoid process
4. Other acute fracture or nerve damage of the ipsilateral upper limb
5. Old fracture (<6 months) or pseudo arthrosis or unhealed nerve injury of the ipsilateral upper limb
6. Open fracture
7. Pathological fracture
8. History of alcoholism, drug abuse, psychological or other emotional problems likely to jeopardize informed consent
9. Patient's inability to understand written and spoken Finnish, Swedish, or Danish
10. Patient's refusal to participate or cognitive inability to provide consent
11. Patient physically unfit for surgery

Patients who meet the criteria but refuse to participate or choose to drop out of the trial will be asked permission for possible later patient file follow-up and to participate in a follow-up study. These patients will form the declined cohort. These patients will receive the usual care, and shared decision making will be used to determine the treatment method once the patient has received information on both treatment methods. Baseline demographics, treatment modality, and DASH score at 12 months will be collected. Analysis of outcome measures will be done separately from the RCT and the results compared with those of the RCT.

Recruitment and randomization will be continued until at least 34 patients are enrolled in each treatment group. The group sizes are based on power calculations. The randomization will be stratified according to the participating hospital and patient's sex. Hospitals will be grouped for stratification.

4.1.4 Study IV

Patients suffering an upper extremity fracture were identified retrospectively from the electronic patient record system of Turku University Hospital (Turku, Finland). The information pool contains all electronic data of patients' visits to Turku University Hospital and its emergency department. The specific fractures, olecranon fractures, distal radius fractures, and proximal humerus fractures were identified using the ICD-10-CM code (S52.0, S52.5 or S52.6, S42.2, respectively). The search was limited to patients living in the Turku area aged 18 or older over a 3-year period between 2014 and 2016. All visits by Turku inhabitants have since autumn 2013 been centralized to one emergency department (Turku University Hospital emergency department); hence our study period started in 2014 to ensure good coverage of patients with upper extremity fractures. The cutoff year was 2016 to ensure a minimum 5 years' follow-up of all patients.

After initial identification the patients were followed through medical records until the end of February 2022 and data on possible surgeries, subsequent fractures of the olecranon, distal radius, proximal humerus or hip, or time of death were recorded. The NOMESCO Classification of Surgical Procedures Version 1.14 from the Nordic Medico-Statistical Committee was applied for identification of the surgeries with operation codes NCJ62 and NCJ64 for olecranon, NCJ62, NCJ64, NCJ70, and NCJ99 for distal radius, and NBL00, NBJ62, NBJ64, NBJ60, NBJ70, NBJ91, NBB10, NBB15, NBB20 for proximal humerus fractures. In addition, available demographic data such as sex and age were retrieved.

4.2 Methods

4.2.1 Study I

A literature search of the CENTRAL, MEDLINE, Embase, CINAHL, PEDro, and Scopus databases was conducted in May 2018, unrestricted by date. Search clauses for each database were constituted and recorded. To avoid missing relevant studies, use of limits was restricted and further selection was done manually. The references of the identified studies were also checked for relevancy.

The inclusion criteria were based on the PICOS framework as follows: Population: adults (>18 y) with acute, traumatic and displaced olecranon fracture excluding multiple and open fractures and fractures associated with malignancy; Intervention: operative treatment using TBW or PF; Comparison: any other treatment (also TBW or PF when not used as intervention); Outcome: any outcome; Studies: RCTs and if under five, controlled studies with at least 10 participants in

any language with English abstract excluding conference proceedings, theses, reviews, case studies, etc.

Data were extracted from the included studies using a standardized form based on recommendations in the Cochrane Handbook for Systematic Reviews of Interventions, Version 5.1.0. The methodological quality of articles was assessed according to the Cochrane Collaboration's domain-based framework. (Higgins and Green, 2008)

A meta-analysis was inapplicable due to missing baseline values and differing outcome measures. The effect sizes of the outcomes of the included studies could not be calculated either, because baseline values were not reported. Analysis of studies was reported by absolute numbers with percent and mean values with standard deviations.

4.2.2 Study II

For this retrospective data-analysis, all patient data were manually extracted from electronic patient record systems in May 2019. Demographic data and relevant medical co-morbidities which could affect the quality of bone, wound healing or co-operation regarding post-operative rehabilitation and instructions were recorded. Date of injury, side of injury, trauma mechanism, Mayo classification of the fracture and whether it was open or closed were recorded; open fractures were classified according to the Gustilo Andersson classification (R.B., Gustilo and Anderson, 1976; Morrey BF, 1993; Morrey, 1995). ISS was calculated to determine the total trauma burden on each patient. (Baker *et al.*, 1974) Regarding treatment, the date of operation, implants used, level of experience of the operating and assisting surgeon, and follow-up schedule were recorded. Possible early complications, re-operations and their reasons were recorded until the last follow-up visit to the outpatient clinic.

Postoperative radiographs were evaluated from two aspects: adequacy of the fixation according to AO principles and method instructions, and quality of reduction of the joint surface by measuring possible gap or step-off. (Anderson, 1992) The fixation material was considered malpositioned if the K-wires were too long and far from the ulnar cortex in the soft tissues of the forearm or were penetrating the joint surface.

Maintenance of the reduction was evaluated from follow-up radiographs by comparing the joint surface positioning with the post-operative radiographs. If the patient was deceased, the date was recorded.

4.2.2.1 Statistics

Univariate analyses were carried out on all variables to get an overview of the patients and derive their descriptive statistics. Binary variables were formed for complications and reoperations to represent their occurrence in general and were used in the analyses. Age was rescaled into tens of years for the models.

The association between occurrences and other variables was studied using simple logistic regression; from this we decided to investigate the association between the complications and tension band K-wire placements with multiple logistic regression adjusted for age and sex. Visual inspection of the deviance and partial residuals were used for justification of the analyses. The association between other categorical variables was studied using Fisher's exact test.

Odds ratios with 95% confidence intervals and p-values are reported for logistic regression models and p-values are reported in conjunction with Fisher's exact test. P-values of at most 0.05 were considered statistically significant. R version 3.6.3 was used for statistical analyses.

4.2.3 Study III

A protocol for a non-inferiority, randomized, controlled, multicenter trial for comparing operative and conservative treatment of olecranon fractures in the elderly population was designed in accordance with the SPIRIT 2013 Statement. (Chan *et al.*, 2013) In addition to the RCT, a declined cohort was introduced. This trial will be conducted according to the revised Declaration of Helsinki by the World Medical Association and ICH guidelines for good clinical trial practice. The study protocol was approved by the Ethics Committee of the Hospital District of Southwest Finland and will be submitted for approval to the local Ethics Committees in Sweden and Denmark. The trial was registered on ClinicalTrial.gov and assigned number NCT04401462.

The study will be conducted as a multicenter study at the following locations: Turku, Helsinki, Tampere, Jyväskylä and Oulu, Finland; Copenhagen, Denmark; and Linköping, Sweden.

4.2.3.1 Interventions

The randomized patients must receive their designated treatment within 2 weeks after the initial traumatic event. In the operative group patients will be prepared for surgery following standard protocol. Patients will undergo surgical fixation either with TBW or PF according to the treating surgeon's preferred technique consistent with the usual care of the participating institution. The postoperative protocol will

include immobilization either with a sling or a long-arm plaster splint for 2 weeks followed by progressive ROM as tolerated.

Conservative treatment will consist of a sling and immediate progressive ROM as tolerated. A long-arm plaster splint may be applied for 2 weeks if needed for pain control, and after splint removal active movement will be started as tolerated. In both treatment groups the patients will be referred to physiotherapy at 2 weeks.

Cross-over between treatment groups is considered improbable but plausible. Final treatment results will be evaluated at 1 year. Crossover from the nonoperative to operative group could occur if there is unsatisfactory treatment due to e.g., painful pseudoarthrosis, or an adverse event. All adverse events will be dealt with in a symptomatically adequate and timely manner, and the patients will be hospitalized and operated on if needed.

4.2.3.2 Outcomes

The primary objective of this study is to compare the DASH questionnaire at 12 months between patients treated operatively and conservatively. (Hudak PL, Amadio PC, 1996; Gummesson, Atroshi and Ekdahl, 2003)

The secondary outcome measures are: DASH at 3 months, PREE-F questionnaire, VAS pain and VAS satisfaction at 3 and 12 months, postoperative radiographs at 2 weeks, 3 and 12 months in both groups, analyzed ROM at 3 and 12 months, comparison of extension strength between patients' affected and unaffected arms at 12 months, and adverse events at any time. In addition, a clinical frailty scale and baseline DASH questionnaire will be completed for comparison of the treatment groups. (Rockwood *et al.*, 2005; Vincent *et al.*, 2015)

4.2.3.3 Sample size

The power calculations are based on assumed behavior of DASH. The non-inferiority margin was determined to be MCID for this questionnaire which is 10 points. (Gummesson, Atroshi and Ekdahl, 2003; Longo *et al.*, 2008) The standard deviation of DASH is assumed to be 15. (Hunsaker *et al.*, 2002) Estimated sufficient sample size is based on a simple two-sample t-test with a one-sided alternative hypothesis. Using alpha of 0.05 and statistical power of 80% yields a sample size of at least 34 patients per group assuming a drop-out rate of 20%.

4.2.3.4 Blinded data interpretation

To diminish interpretation bias, the authors and statistician will be blinded to both treatment groups when analyzing the results. The approach involves developing two

interpretations of the results based on a blinded review of the primary outcome data (treatment A compared with treatment B). One interpretation assumes that A is the operative group and another that A is the conservative group. After agreeing that there will be no further changes, the investigators record their decisions and sign the resulting document. The randomization code is then broken, the correct interpretation chosen, and the manuscript finalized. (Gotzsche, 1996; Järvinen *et al.*, 2014)

4.2.3.5 Statistics

After completion of follow-up the cohort data will be analyzed by an independent statistician. The ITT principle is applied in the analyses. In case of protocol violations, analyses will be carried out for both ITT and PP patient populations.

All demographic, pre-intervention, and intervention related variables will be tabulated and summarized. All outcome measures will be summarized by visits, and in addition to absolute values, changes relative to the baseline values will also be summarized, if feasible. Reasons for discontinuation and study duration will be tabulated for all patients by treatment group.

Missing questionnaire items would skew the score interpretation, thus imputation methods are applied. Missing individual items in the DASH and PREE-F are considered missing at random and will be substituted with the average value of other items. If there are more than just 3 missing values, the scores are not computed. If scores at follow-up are missing or not computable, hot deck imputation is used where missing score values are substituted with an average score of other patients with similar demographic and baseline data such as age, center, sex and baseline DASH.

Possible multicollinearity between study variables will be investigated in terms of VIF. The analysis of outcome measures will be done using GLMM suitable for repeated measures with adjusting demographic and operational variables. An auto-regressive covariance structure for spatiality of measurement time points is assumed to be suitable in this study setup. If GLMM is not feasible, an alternative analysis method will be selected according to measurement scale and variable type (e.g., independent or paired data and binary, ordinal, nominal, or continuous nature). Possible analysis methods that could be used are McNemar's test, Wilcoxon signed rank test, Cochran-Mantel-Haenszel test, Cochran-Armitage trend test, and Jonckheere-Terpstra test.

All results will be presented with 95% confidence intervals. A one-sided significance level of 0.05 will be used across the analyses.

4.2.4 Study IV

4.2.4.1 Statistics

The survival function of patients was estimated for each index fracture separately using a Kaplan-Meier (KM) estimator. Censoring was done at the beginning of February 2022, when the data was updated for the last time (Kaplan and Meier, 1958). The effect of age, sex, and treatment method (operative vs. conservative) was investigated using the Cox proportional hazard model (Cox, 1972). The association between subsequent fractures and mortality was also explored in further analyses. The risk of additional fractures simultaneously or subsequent fractures during the 5 years following the index fracture were estimated with a KM estimator, with death being treated as a censoring event. Finally, the risk of mortality and subsequent fractures were considered in parallel with competing risk analysis (Gray, 1988). The difference in mortality and likelihood of subsequent fractures between the index fractures were investigated with a competing risk regression model controlled for age and sex with mortality and subsequent fracture as endpoints. While this model makes it possible to compare outcomes between index fractures in the population, the underlying assumption of the model is that the effects of age and sex are similar for all fractures. The statistical analyses were carried out using the statistical software R (R Core Team (2021), 2021). The KM estimators and Cox proportional hazard models were fitted using the R package survival and package cmprsk (Therneau and Lumley, 2020).

5 Results

5.1 Current operative treatment of olecranon fractures (Study I)

Of the 1518 records identified in the systematic literature search, five RCTs were finally considered relevant for analysis (Fig. 13.). Three studies compared TBW to PF or a modified technique of TBW, the cable pin system (CPS). (Hume and Wiss, 1992; Liu *et al.*, 2012; Andrew D. Duckworth *et al.*, 2017) One study compared PF to the olecranon memory connector (OMC) and one compared operative treatment to conservative treatment. (Chen *et al.*, 2013; A. D. Duckworth *et al.*, 2017) The risk of bias was considered high in three of the five trials. The descriptive characteristics of the included studies are presented in Table II.

Overall, all included studies showed a good prognosis regardless of the chosen treatment. There were no statistically significant differences between groups in patient rated outcome scores (DASH) or in ROM when comparing the different operative methods. Physician rated scores (Broberg&Morrey or Mayo Elbow Performance Score) were statistically similar when comparing TBW and PF, but had a statistically significant difference in studies comparing PF to OMC and TBW to CPS in favor of the latter. (Hume and Wiss, 1992; Liu *et al.*, 2012; Chen *et al.*, 2013; Andrew D. Duckworth *et al.*, 2017) In the comparison of operative and conservative treatment in elderly patients, there were no differences between groups in patient or physician rated outcome evaluations or ROM. (A. D. Duckworth *et al.*, 2017)

Reoperations in TBW groups varied from 16% to 50% across studies, eventually concerning 27% of all participants in the TBW groups. (Hume and Wiss, 1992; Liu *et al.*, 2012; Andrew D. Duckworth *et al.*, 2017) In the PF groups, removal rates were lower, one study reporting a 22% removal rate for PF (Andrew D. Duckworth *et al.*, 2017). Infection rates varied from 0 to 14%. Loss of reduction was more common in TBW groups than in control treatments. (Hume and Wiss, 1992; Liu *et al.*, 2012; A. D. Duckworth *et al.*, 2017; Andrew D. Duckworth *et al.*, 2017)

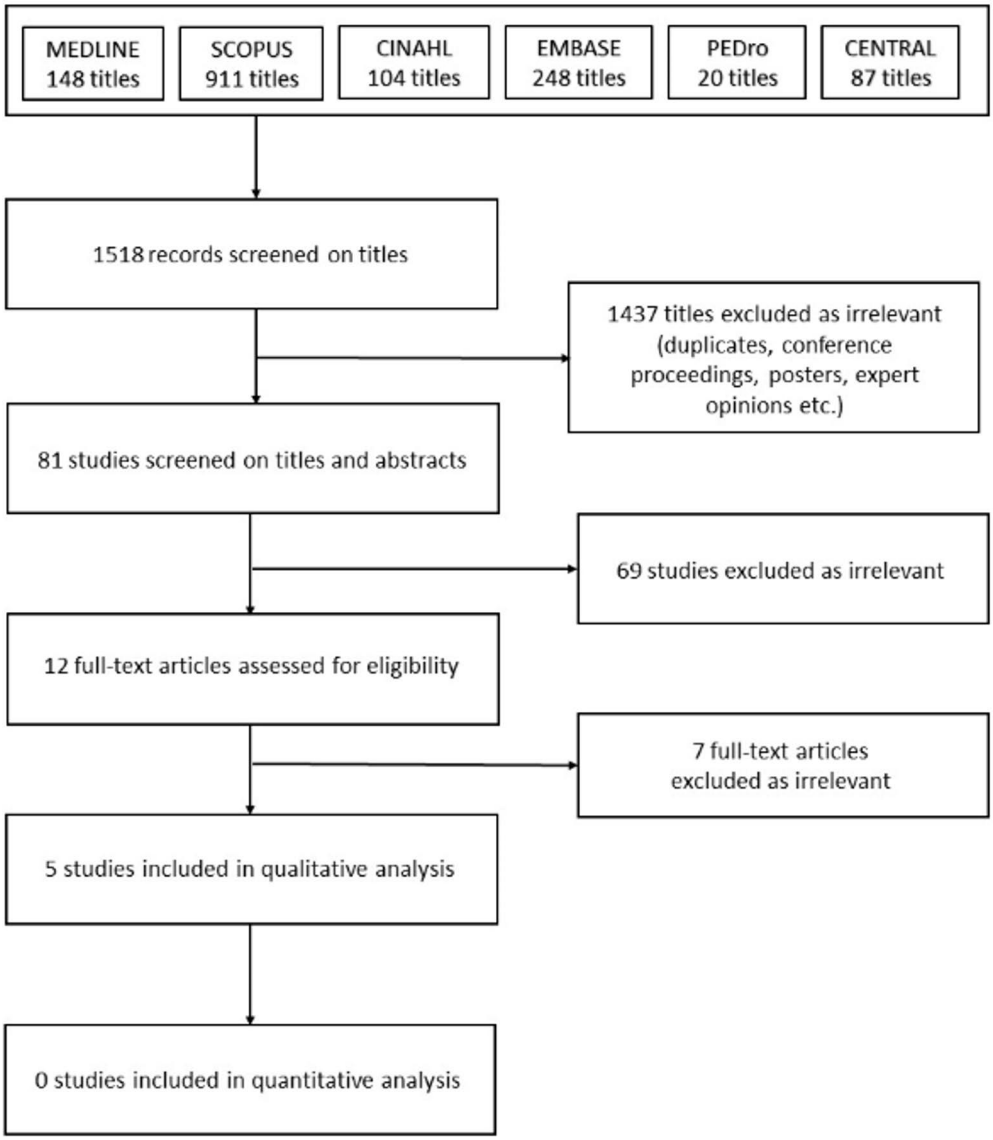

Figure 13. Flow chart of the search process.

Table II. Descriptive characteristics of the included studies. Modified from Rantalaiho et al. (2021)

Study	*Country*	*Case Treatment*	*Control Treatment*	*N Cases (% Women)*	*N Controls (% Women)*	*Mean Age (yr)*		*Follow-up Time (w)*	
						Cases	Controls	*Mean*	*Other points*
Duckworth et al. 2017	United Kingdom	TBW	PF	34 (38)	33 (48)	43	52	NA	6, 12, 26, 52
Duckworth et al. 2017	United Kingdom	Operative treatment (TBW or PF)	Collar cuff sling for two weeks	11 (91)	8 (86)	85	80	NA	6, 12, 26, 52
Chen et al. 2013	China	PF	OMC	20 (50)	20 (40)	49	48	159	NA
Hume et al. 1992	United States of America	TBW	PF	19 (NA)	22 (NA)	NA	NA	28.5	NA
Liu et al. 2012	China	TBW	CPS	32 (56)	30 (47)	46	48	cases 21.3; controls 20.9	NA

N = number; TBW = Tension band wiring; PF = Plate fixation; OMC = olecranon memory connector designed on the basis of the anatomy of the olecranon and manufactured from 1.8–2.5 mm thick Ni-Ti shape memory alloy plate (Ni 50–53%) and composed of an intramedullary fixing lock, a base arc and two compression fixing arms; CPS = Zimmer® Cable-Ready® Cable Pin System *(Zimmer, Warsaw, IN, USA)* implants include two 4.0-mm diameter, specially sharpened, partially threaded cancellous lag screws (pin length 35 – 60mm), the tail of the pin is connected to a stainless steel multifilament cable (diameter1.3 mm, length 448 mm) attached to a smooth shank end which is used as a leader needle; NA = not announced

5.2 Complications and reoperations related to operative treatment of olecranon fractures (Study II)

A total of 434 operatively treated olecranon fractures were included in this retrospective analysis. The most common fracture type was Mayo 2, 94%. The most common mechanism of trauma was falling from standing height, 61.5%. The majority, 89.2%, of the fractures were fixated with TBW, but PF was more often used for Mayo type 3 fractures than TBW, 10.6% vs. 3.1% respectively (p=0.048). In the TBW group, 70.8% of the patients had the K-wires placed transcortically through the volar cortex of the ulna according to AO instructions, and 16% had intramedullary placement.

Altogether 217 early complications were recorded in 202 patients (46% of all patients). The most common early complications were symptomatic fixation material (n=125, 29% of all complications) and failure of reduction (n=55, 13%). (Table III) A total of 155 (36%) patients had undergone 173 re-operations. The most common re-operation was removal of hardware (n=151, 35%). (Table IV)

There was no significant difference in the number of early complications (p=0.262) or reoperations (p=0.079) between patients treated with TBW or PF. The odds of re-operation decreased by 24% for every 10 years of age (OR=0.76, 95%CI: 0.68–0.83, p<0.001). The simple logistic regression results are shown in Table V.

When the configuration of TBW was examined from the postoperative radiographs and patients were divided into groups according to placement of TBW K-wires, patients in whom the K-wires were intramedullary had significantly more early complications in the multiple logistic regression model compared to those whose K-wires were placed transcortically through the volar cortex of the ulna (OR=1.94, 95%CI: 1.1–3.5, p=0.026). Age and sex were taken into account in the model. (Table VI)

Table III. Numbers of early complications. Modified from Rantalaiho et al. (2021)

	ALL	TBW	PF
N (%)	434 (100)	387 (100)	47 (100)
FAILURE OF REDUCTION	55 (12.7)	47 (12.1)	8 (17.0)
WOUND INFECTION	8 (1.8)	8 (2.1)	0 (0)
DEEP INFECTION	10 (2.3)	8 (2.1)	2 (4.3)
SYMPTOMATIC FIXATION MATERIAL	125 (28.8)	110 (28.4)	15 (31.9)
MALPOSITION OF FIXATION MATERIAL	16 (3.7)	14 (3.6)	2 (4.6)
NERVE DAMAGE	3 (0.7)	1 (0.3)	2 (4.6)
TOTAL EARLY COMPLICATIONS	217 (50.0)	188 (48.6)	29 (61.7)

N=NUMBER; TBW=TENSION BAND WIRING; PF=PLATE FIXATION

Table IV. Numbers of reoperations. Modified from Rantalaiho et al. (2021)

	ALL	TBW (n=387)	PF (n=47)
N (%)	434 (100)	387 (100)	47 (100)
RE- FIXATION DUE FAILURE OF REDUCTION OR MALPOSITION OF FIXATION MATERIAL	19 (4.4)	16 (4.1)	3 (6.4)
REMOVAL OF HARDWARE	151 (34.8)	129 (33.3)	22 (46.8)
INFECTION REVISION	3 (0.7)	3 (0.8)	0 (0)
TOTAL REOPERATIONS	173 (39.9)	148 (38.2)	25 (53.2)

N=NUMBER; TBW=TENSION BAND WIRING; PF=PLATE FIXATION

Table V. Association of early complications with different variates based on simple logistic regression. Modified from Rantalaiho et al. (2021)

	OR	95% CI	p
OPERATION METHOD			
TENSION BAND	Reference		
PLATE FIXATION	1.46	0.77-2.64	0.262
TENSION BAND KIRSCHNER WIRES PLACEMENT			
TRANSCORTICAL	Reference		
INTRAMEDULLAR	1.72	0.98-3.05	0.060
AGE (CONTINUOUS)	0.91	0.83-1.00	0.054
FRACTURE TYPE			
MAYO 1	Reference		
MAYO 2	1.99	0.42-14.0	0.415
MAYO 3	2.81	0.46-23.7	0.285
OPEN FRACTURE			
CLOSED	Reference		
GUSTILO 1	3.18	1.04-11.7	0.054
GUSTILO 2	0.16	0.01-0.88	0.084
TRAUMA MECHANISM			
FALLING FROM STANDING HEIGHT	Reference		
HIGH ENERGY	1.42	0.77-2.64	0.262
OPERATING DOCTOR			
CONSULTANT	Reference		
RESIDENT	1.06	0.71-1.58	0.774

OR=ODDS RATIO; CI=CONFIDENCE INTERVAL

Table VI. Association between placement of tension band Kirschner wires and early complications. Subgroup multivariate analysis. Modified from Rantalaiho et al. (2021)

	ALL EARLY COMPLICATIONS			SYMPTOMATIC FIXATION MATERIAL		
	Adj. OR	95% CI	p	Adj. OR	95% CI	p
TENSION BAND KIRSCHNER WIRES PLACEMENT						
TRANSCORTICAL	Reference			Reference		
INTRAMEDULLAR	1.94	1.08-3.48	0.026	2.17	1.15-4.07	0.016

MODELS ADJUSTED FOR AGE AND GENDER
OR=ODDS RATIO; CI=CONFIDENCE INTERVAL

5.3 Scandinavian Olecranon Research in the Elderly, SCORE (Study III)

A protocol for a non-inferiority, randomized, controlled, multicenter trial for comparing operative and conservative treatment of olecranon fractures in the elderly was presented. Methodological issues concerning premature discontinuation, selection of the age group, maximizing internal and external validity, and chosen outcome measures were discussed.

5.4 Demographics, mortality and subsequent fractures related to upper extremity fractures (Study IV)

During the 3-year period from January 2014 to December 2016, altogether 1630 upper extremity fractures were identified; 157 of them were olecranon fractures, 1022 distal radius fractures, and 451 proximal humerus fractures. Of the patients, 62% with an olecranon fracture were women, and 75% with a distal radius fracture and 70% with a proximal humerus fracture were women. (Table VII) The median age at the time of fracture was 65 years for patients with an olecranon and a distal radius fracture (IQR 37 and 26, respectively) and 68 (IQR 23) years for patients with a proximal humerus fracture. The age distribution and number of fractures in each age group is shown in Figure 14.

The risk of mortality for patients with an olecranon fracture was 4% at 1 year and 13% at 5 years (Table VIII, Fig. 15). For patients with olecranon fractures, there was no statistically significant difference in mortality between men and women in a competing risk analysis when age was considered (HR 1.2, 95% CI 0.5–2.9, $p<0.63$).

For patients with a distal radius fracture, the risk of mortality at 1 year and 5 years was 3% and 13%, respectively, and no statistically significant difference was found compared to the mortality of the olecranon fracture population (HR 1.3, 95% CI 0.79–2.15, p=0.30). For patients with a proximal humerus fracture, the risk of mortality was statistically significantly higher at both time points, 8% and 22% (HR 1.97, 95% CI 1.19–3.27, p=0.009) respectively, compared to the olecranon fracture population. Male sex was associated with increased risk of mortality for patients with a distal radius or proximal humerus fracture (HR 2.4, 95% CI 1.7–3.3, p<0.001; HR 2.4, 95% CI 1.7–3.5, p<0.001).

For patients with an olecranon fracture, the risk of a subsequent distal radius, proximal humerus or hip fracture was 10% within 1 year and 14% within 5 years of follow-up (Table IX). The risk of a subsequent fracture after a distal radius fracture was lower than after an olecranon fracture, 2% at 1 year and 5% within 5 years (HR 0.35, 95% CI 0.22–0.56, p<0.0001), but for patients with a proximal humerus fracture the risks, 6% and 11% respectively, did not differ statistically significantly from the risk after an olecranon fracture (HR 0.65, 95% CI 0.40–1.06, p=0.08).

Table VII. Baseline demographics in Study IV. Modified from Rantalaiho et al. (2022)

FRACTURE	TOTAL N	FEMALE, %	AGE, MEDIAN (IQR)			OPERATED, N (%)
			M	F	ALL	
OLECRANON	157	62.4	51 (32)	70 (32)	65 (37)	90 (57.3)
DISTAL RADIUS	1022	75.3	54 (35)	68 (24)	65 (26)	253 (24.8)
PROXIMAL HUMERUS	451	70.3	61 (25)	70 (20)	68 (23)	67 (14.9)
N=NUMBER; IQR=INTERQUARTILE RANGE; M=MALE; F=FEMALE						

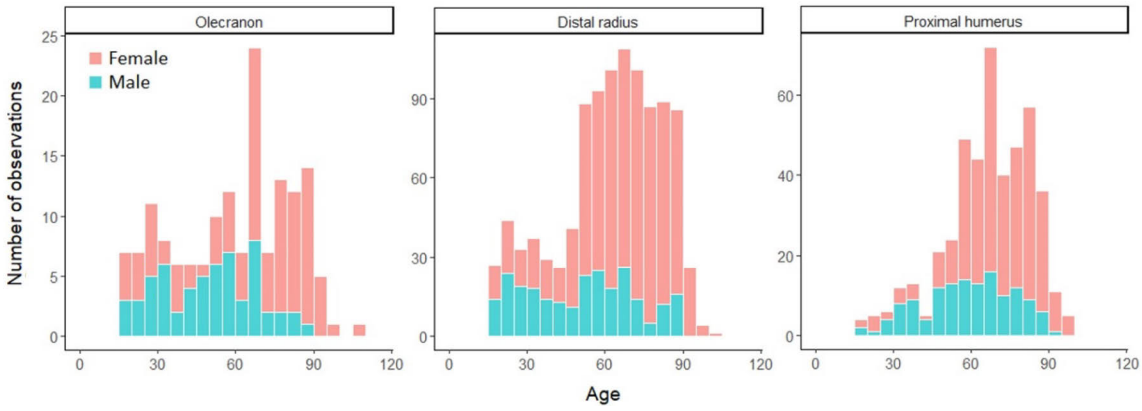

Figure 14. Age distribution for olecranon, distal radius, and proximal humeral fractures in Study IV. Reprinted with permission from Rantalaiho et al. (2022)

Table VIII. Risk of mortality after olecranon, distal radius, and proximal humerus fractures in the competing risk analysis in Study IV. Modified from Rantalaiho et al. (2022)

FRACTURE	RISK OF MORTALITY, % (95% CI)					
	1 y			5 y		
	M	F	ALL	M	F	ALL
OLECRANON	1.7 (0.0-5.0)	5.1 (0.7-9.5)	3.8 (0.8-6.8)	6.8 (0.3-13.3)	16.3 (9.0-23.7)	12.7 (7.5-18.0)
DISTAL RADIUS	4.3 (1.8-6.9)	3.0 (1.8-4.2)	3.3 (2.2-4.4)	12.7 (8.6-16.8)	13.6 (11.2-16.1)	13.4 (11.3-15.5)
PROXIMAL HUMERUS	9.0 (4.1-13.8)	7.9 (4.9-10.9)	8.2 (5.6-10.7)	26.1 (18.6-33.6)	20.8 (16.3-25.3)	22.3 (18.5-26.2)

CI=CONFIDENCE INTERVAL; Y=YEAR; M=MALE; F=FEMALE

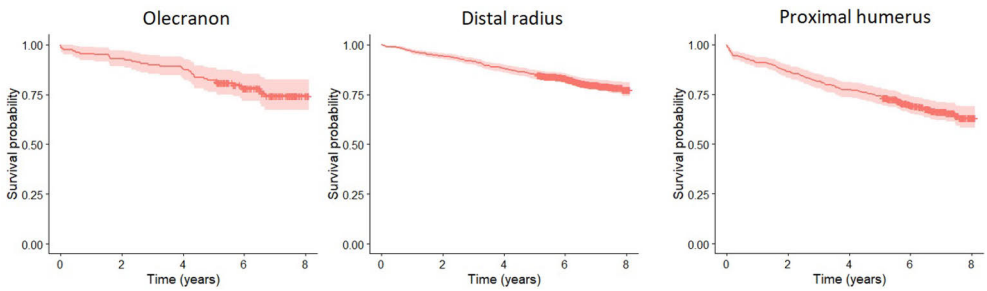

Figure 15. Kaplan-Meier analysis for mortality after olecranon, distal radius, and proximal humerus fractures. Reprinted with permission from Rantalaiho et al. (2022)

Table IX. Risk of subsequent osteoporotic fractures (olecranon, distal radius, proximal humerus, hip) after olecranon, distal radius, and proximal humerus fractures in the competing risk analysis in Study IV. Modified from Rantalaiho et al. (2022)

FRACTURE	RISK OF AN ADDITIONAL FRACTURE, % (95% CI)					
	1 y			5 y		
	M	F	ALL	M	F	ALL
OLECRANON	6.8 (0.3-13.3)	12.2 (5.7-18.8)	10.2 (5.4-14.9)	8.5 (1.3-15.6)	17.3 (9.8-24.9)	14.0 (8.6-19.5)
DISTAL RADIUS	3.6 (1.3-5.9)	1.9 (0.9-2.9)	2.3 (1.4-3.3)	4.0 (1.6-6.4)	5.6 (4.0-7.2)	5.2 (3.8-6.5)
PROXIMAL HUMERUS	6.0 (1.9-10.0)	6.0 (3.4-8.6)	6.0 (3.8-8.2)	9.0 (4.1-13.8)	11.7 (8.1-15.2)	10.9 (8.0-13.7)

CI=CONFIDENCE INTERVAL; Y=YEAR; M=MALE; F=FEMALE

6 Discussion

The common perception of regaining the function of an elbow joint after an olecranon fracture has been that the congruency of the ulnohumeral joint surface must be restored and the triceps tendon re-attached to restore extension strength. Hence, displaced olecranon fractures have traditionally been treated operatively.

The literature to date supports operative treatment of displaced olecranon fractures in fracture-dislocations and simple, dislocated fractures in young patients. The literature provides support for use of the traditional fixation methods, TBW and PF, for fixation of simple, displaced olecranon fractures, but does not give reason to favor one method over the other. Also, some novel fixation methods and instrumentations are presented without sufficient support for their use over traditional methods. The evidence is based mainly on retrospective and prospective case series, and only a few RCTs have been published.

Knowledge to date concerning simple, dislocated fractures in the elderly leans towards providing conservative treatment as the primary treatment option for this population. (Veras Del Monte *et al.*, 1999; Duckworth *et al.*, 2014; Gallucci *et al.*, 2014; Batten, Patel and Birdsall, 2016; A. D. Duckworth *et al.*, 2017; Putnam, Christophersen and Adams, 2017; Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, 2018; Chen *et al.*, 2021; Kaiser *et al.*, 2021) However, there is still a lack of robust evidence on this issue; it is safe to say that the literature supports the need for further, high-quality research.

6.1 Principal findings

In our literature review (study I), the main findings were a lack of quality evidence, a good prognosis regardless of the treatment method, high complication and re-operation rates with all methods, and small, clinically insignificant differences or no differences at all in different outcome measures between the studied treatment methods. These results are consistent with previous results and especially with the single previous systematic review of RCTs published in 2014. (Matar *et al.*, 2014) Compared to this earlier review, we were able to include more recent RCTs and studies assessing conservative treatment in our review.

In study II, we assessed the outcomes of 434 patients with an olecranon fracture treated either by TBW of PF. Total rates of early complications (50%) and reoperations (40%) were high in both groups, comparably to previous the literature. This means that almost half the patients in our study had a complication and re-operation during short-term follow-up, yet in literature operative treatment is still considered the gold standard for displaced olecranon fractures in adults. No statistically significant differences could be found between TBW and PF groups regarding numbers of complications and reoperations, comparably to the previous literature. (Andrew D. Duckworth *et al.*, 2017; Chen *et al.*, 2021)

Older age was associated with lower complication and reoperation risks: the older the patient, the fewer early complications and re-operations. This is in line with the previous literature, in which older patients are known to suffer less frequently from symptomatic fixation materials and less frequently have their fixation materials removed (Claessen *et al.*, 2016; Bugarinovic *et al.*, 2020) We assume that a lower degree of physical activity and fewer demands on the elbow reduce the patient's subjective need for revision surgery and also the probability of proximal migration of the K-wires. In addition, elderly patients have more comorbidities, which might affect the treating physician's decision on whether to refer the patient for surgery. In contrast, in younger patients with higher demands for performance and physical activity, and with a higher rate of complications, physicians and patients might more easily be driven to reoperations.

In the subgroup analysis of patients treated with TBW, those with intramedullary K-wires were more likely to have problems with symptomatic fixation material. In the AO operative instructions for TBW, the distal part of the K-wires should pass through the volar cortex of the ulna, but in reality they are often positioned in the intramedullary canal. (Anderson, 1992) We saw this in our study population, in whom the K-wire fixation was intramedullary in 16.0% of TBW cases. Intramedullary placement of the K-wires was associated with significantly abundant early complications compared to transcortical placement (OR=1.9). This is in line with the previous literature, in which intramedullary K-wires have been reported to migrate proximally more often than transcortical ones. (Mullett *et al.*, 2000; van der Linden, van Kampen and Jaarsma, 2012)

In the SCORE protocol, we describe an RCT comparing conservative treatment of simple, displaced olecranon fractures in the elderly with standard operative treatment. As stated in the literature review, to our knowledge there is only one ongoing RCT with the same design. (Symes *et al.*, 2015) Duckworth et al. had to prematurely terminate their RCT in Scotland due to unacceptable amount of complications in the operative group. (A. D. Duckworth *et al.*, 2017) Loss of reduction was the most frequent complication (six of 11), although major displacement was initially accepted in the conservative group by the study setup.

There was no difference in any of the outcome measures between the groups. This data supports the need for further research on the role of primary conservative treatment for isolated displaced olecranon fractures in the elderly. In our study, premature discontinuation will be considered if there are significantly more serious adverse events, other than hardware removal, within any of the treatment modalities. It is worth noting that loss of reduction or increase in displacement is not considered a reason for discontinuation, contrary to Duckworth's study.

In study IV, we assessed whether olecranon fractures are comparable to other upper extremity fractures, of the distal radius and proximal humerus, when considering the age-sex distribution of patients and the risk of mortality and subsequent fractures. We found that the median age of patients with olecranon fractures was the same as in the distal radius fracture population (65 years), and the median age of the proximal humerus fracture population was only slightly higher (68 years). The distribution of olecranon fracture patients in different age groups, however, was more even than in distal radius and proximal humerus fracture populations, and the median age of men with olecranon fractures (51 years) was younger than in the other fracture populations. Female predominance was seen in all fracture groups in the older age groups, as reported in previous publications. (O'Neill and Roy, 2005; Piirtola et al., 2008; Somersalo et al., 2015)

The risk of mortality after an olecranon fracture was 4% within the first year of follow up and rose to 13% at 5 years. The risk of mortality after a distal radius fracture was statistically comparable to that after an olecranon fracture, but significantly higher after a proximal humerus fracture. The overall risk of mortality among Turku inhabitants aged 50-74 years in 2020 was under 1%, meaning that the mortality risk is significantly higher in this age group after an upper extremity fracture. (*lounaistieto.fi*; *Tilastokeskus*) In the previous literature, proximal humerus fractures are known to be related to higher mortality, but distal radius fractures have a lower mortality rate than other upper extremity fractures. (Shortt and Robinson, 2005; Piirtola et al., 2008; Somersalo et al., 2015) In this light, we consider our findings to be in line with previous knowledge. We also found that male sex was an independent risk factor for mortality in distal radius and proximal humerus fracture groups, and this connection of male sex to greater mortality has been reported previously. (Piirtola et al., 2008; Somersalo et al., 2015)

In the distal radius fracture population, the risk of subsequent osteoporotic fractures was lower than for the other analyzed upper extremity fractures. The risk in the olecranon fracture population was comparable to that after a proximal humerus fracture. We found the 14% risk of subsequent fractures after an olecranon fracture within 5 years' follow-up to be considerable and noteworthy. To our knowledge, this particular risk has only once been previously studied; after an olecranon fracture that risk ratio of a subsequent hip fracture was found to be 4.1 compared to the female

background population. (Lauritzen and Lund, 1993) The probability of subsequent fractures after any fracture is, then again, well studied and the probability is considered notable regardless of the index fracture type or age of the patient. (Clinton et al., 2009; Hansen et al., 2015)

6.2 Clinical implications

Based on our results in study I, current evidence, or lack of it, does not support changing treatment practices in working-age patient populations. Both methods, TBW and PF, achieve adequate union and elbow function but are associated with high rates of complications and reoperations because of infections or removal of the prominent metalwork after fracture union.

In two RCTs included in study I, Liu et al. concluded that modification of TBW, a CPS, was better than standard TBW, and Chen et al. concluded that a novel invention resembling TBW, an OMC, was superior to locking PF. In both studies, the differences between groups in the follow-up values were minor, with overlapping standard deviations. Positive results with OMC were reported by the designers of this technique. (Liu *et al.*, 2012; Chen *et al.*, 2021) Involvement of the developing clinic predisposes to at least some level of bias. Therefore, the findings of both studies should be confirmed by other study groups before implementing OMC in clinical practice or choosing CPS as a treatment method over TBW.

In study II, both TBW and PF groups had a high number of complications and reoperations, which suggests that more careful consideration should be given to selecting the treatment method for simple, displaced olecranon fractures in adults. Physicians should inform their patients and ascertain that they understand the consequences and possible complications of operative treatment, as well as the possible need for later reoperation. When using TBW to fix an olecranon fracture, careful attention should be paid to correct surgical technique according to AO guidelines, since patients are more likely to suffer a complication if the K-wires are placed in the intramedullary canal. (Anderson, 1992) Since this correlation has been shown in multiple studies, including ours, intramedullary K-wires should not be allowed to exit an OR when using the traditional TBW configuration.

In the SCORE protocol we describe a non-inferiority RCT comparing the outcome of conservative treatment of displaced olecranon fractures in the elderly with operative treatment with TBW or PF. We chose a non-inferiority setting because we do not aim to prove that conservative treatment is superior to standard operative treatment, but we attempted to find out whether the results are comparable and sufficient from the patient's perspective, using patient-reported outcome measures. We chose to compare conservative treatment with TBW and PF, as these are globally the most popular surgical methods for treating olecranon fractures. We

chose patient-reported outcome measures as primary outcomes, since surgeon-reported outcomes or radiological analyses alone do not provide enough insight into how patients manage their daily life and how satisfied they are with the treatment provided. As the patients determine the success of their treatment, we will be able to distinguish which factors lead to satisfaction or dissatisfaction. We also use elbow extension strength power measurements and elbow range-of-motion measurements to assess the functional outcomes. If conservative treatment turns out to be equal, shared decision-making will need to be implemented in the process of deliberating the treatment modality in this population.

In study IV, patients suffering an olecranon fracture were somewhat comparable age- and sex-wise to the other studied upper extremity fracture populations, but the age distribution was more even and there were more younger men, which lowered the median age of men with olecranon fractures (51 years) compared to men with distal radius fractures (54 years) and men with proximal humerus fractures (61 years). In the literature, olecranon fractures are said to have osteoporotic features and our findings strengthen this perception, as elderly patients suffering an olecranon fracture were predominantly women. (Court-Brown and Caesar, 2006; Duckworth et al., 2012; Park et al., 2017; Brüggemann, Mukka and Wolf, 2021) As osteoporosis is more common in women than in men, olecranon fractures in elderly women might indeed have common features with other upper extremity osteoporotic fractures. Anyhow, we do not claim the fracture to be solely osteoporotic especially in the younger male population.

We found that considering mortality, the olecranon fracture population can be assimilated with patients suffering a distal radius fracture, but proximal humerus fractures were associated with significantly higher mortality. In all fracture groups, the risk of mortality was clearly higher than in the entire population in the same area of Finland. (*Tilastokeskus*; *lounaistieto.fi*) We assume that these fractures do not influence mortality as independent factors, but overall health can be assessed from suffering a certain fracture. We theorized that if a patient can receive a fall on an extended arm or elbow rather than falling on their side and shoulder, their reflexes, muscle strength and overall health status might be better. Overall health, naturally, influences survival.

When assessing the risk of subsequent fractures, the olecranon fracture population is more comparable to the patient population suffering a proximal humerus fracture than to the distal radius fracture population, and the risk of a subsequent osteoporotic fracture is considerable.

6.3 Strengths and limitations of present studies

We acknowledge that all the studies included in this thesis have their limitations.

The results of a wide systematic review (study I) always depend on the search clauses and databases used. Even though we kept the search wide, and if we assume

that these five studies reflect this patient population, we only have limited outcome measures to assess. As the evidence is still very limited, the results may change drastically after high-quality, low-bias-risk studies in the future. We considered long-term outcome to be most important when choosing treatment options and we did not assess short-term outcomes in this review. Despite the weaknesses, this review was the first update on reviewing RCTs since 2014. (Matar *et al.*, 2014)

A retrospective case series (study II) always has several limitations, and we acknowledge these. First, the approach of retrospectively gathering demographic data on patients from electronic medical records might easily be biased, since some information might be coded wrongly or missing entirely. Second, our follow-up was relatively short for most patients, since it was based on our trauma center's routine outpatient clinic schedule. However, it is likely that if a patient had had any problems with their operated elbow or had required a reoperation, they would have returned to our outpatient clinic, as the Finnish healthcare system, especially as regards operative treatment, is strongly public driven and people are treated based on where they live. Third, the study cohort was heterogeneous and TBW and PF groups might differ from each other, with possibly different indications for different fixation methods. This was seen to some extent in our material, where PF was used more often for Mayo type 3 fractures than was TBW. TBW is known to be more commonly used for isolated and simple olecranon fractures (Anderson, 1992), whilst PF is reportedly better for comminuted and unstable fractures (Fyfe, Mossad and Holdsworth, 1985; Hume and Wiss, 1992; Buijze and Kloen, 2009). However, the fracture pattern did not show a correlation with complication or reoperation risks, therefore we assume that this did not bias our results significantly. Finally, we did not have any patient-reported outcome measures to assess the end result with, and due to the limited follow-up time we were unable to address long-term complications such as loss of ROM, non-unions, or painful pseudo arthroses.

The strengths of our study II include the high number of consecutive patients with extensive data and careful analysis of radiographs pre- and post-operatively.

All RCTs have limitations related to the study design, but we aimed to eliminate all possible bias. We ensured the internal validity of our trial by using an online computer-based randomizing system, appropriate statistical testing, blinded data interpretation, and an adequate sample size based on power calculation. The external validity of the trial is considered relatively good, since inclusion criteria and exclusion criteria are not too numerous, this is a multicenter trial setup, and the results of the RCT will be compared with the declined cohort results.

Study IV has several limitations related to the study setting, which was a retrospective diagnosis coding derived database analysis. First, the variables number was quite limited, and as the data was gathered retrospectively from an electronic database, some information might be erroneously coded or missing. Second, the

coding did not include sidedness and therefore we could not analyze subsequent fractures to the same location or the same fracture on the contralateral side. Third, we could not count incidence numbers, since it is possible that some patients had their fractures treated at private sector clinics. On the other hand, the strength of our study is the high number of systematically collected public sector consecutive patients in each fracture group, as the vast majority of all traumas potentially needing operative care are treated in the public health sector in Finland.

6.4 Future aspects

The most frequently used method of care for olecranon fractures has been operative treatment. However, the proportion of conservative treatment is increasing among low-demand, elderly patients and, therefore, we feel that our literature review is a valuable addition to the previous literature.

For more definite conclusions more high-quality research is needed; thus we designed the SCORE trial. In this trial we will study whether conservative treatment of displaced olecranon fractures in the elderly population gives sufficient results regarding pain and function to be considered a primary treatment option. If the hypothesis of conservative treatment providing a comparable functional outcome to that of operative care holds true, the burden of hospitalization and complications related to operative treatment could be avoided in this fragile population.

It will also be interesting to compare the results of SCORE with the upcoming results of the SOFIE trial from Australia and New Zealand. (Symes *et al.*, 2015) If the results are comparable, it might be possible to make modifications to the standard care recommendations for olecranon fractures in the elderly, especially if the SCORE and SOFIE results resemble those of the prematurely terminated RCT of Duckworth et al. (A. D. Duckworth *et al.*, 2017)

In the SCORE trial we initiated a Nordic collaboration in trauma research. We strive to continue this collaboration, since it could provide an advantage in gaining more knowledge and treatment experience concerning infrequent fractures, such as olecranon fractures in the elderly. Our aim is to enhance the collaboration and resolve interesting questions together.

The standard operative treatment methods, TBW and PF, widely described in the literature, are unlikely to be totally replaced with any other method or instrumentation anytime soon. Study II outlines the vast number of complications and reoperations related to operative treatment of olecranon fractures and gives reason for careful treatment planning as well as meticulous execution of the surgical method according to given AO recommendations.

As the population ages, osteoporosis and fractures related to osteoporosis are becoming ever more abundant. Any way of preventing or reducing the number of

fractures will be important. Elderly women suffering an olecranon fracture would probably benefit from a geriatric evaluation concerning possible underlying osteoporosis and reasons behind the fall. This might be one way to decrease future osteoporotic fractures in this patient population.

7 Conclusions

The following conclusions can be drawn from the present studies:

1. The current literature of randomized controlled studies supports the standard methods, TBW and PF, for the fixation of displaced olecranon fractures in adults. The evidence to date suggests that neither of these methods is inferior to the other. Selection of the fixation method is considered individually for each patient and according to the surgeon's preference. In the elderly population, conservative treatment may be considered a safe option to avoid unnecessary operations and complications.

2. Both frequently used fixation methods for displaced olecranon fractures, TBW and PF, are prone to complications and reoperations. Older age seems to be associated with a lower complication and reoperation rate, likely representing the lower functional needs and higher reoperation threshold of this population. When TBW is applied, careful attention should be paid to correct operative technique, placing the K-wires through the anterior ulnar cortex rather than the intramedullary canal to minimize complications.

3. A protocol was presented for a non-inferiority, randomized, controlled, multicenter trial comparing operative and conservative treatment of olecranon fractures in the elderly.

4. Patients with olecranon fractures have similar demographic characteristics to patients with distal radius fractures. Olecranon and distal radius fractures are associated with increased risk of mortality, but the risk after a proximal humerus fracture is even higher. The probability of sustaining a subsequent osteoporotic fracture after an olecranon fracture is notable. There is also a large male-dominant population of younger patients, and this fracture type cannot be labelled as purely osteoporotic.

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