Diploma Thesis

Results in the Treatment of Medial Humeral Epicondyle Fractures in Children and Adolescents

submitted by

Martin Ortner

DOB: 01.11.1984

in order to obtain the degree of

Doktor der gesamten Heilkunde

(Dr. med. univ.) (MD)

at the

Medical University of Graz

completed at the

Department of Pediatric and Adolescent Surgery

supervised by

Dr. med. univ Elke Maria Zani-Ruttenstock

Ass. Prof. Priv.-Doz. Dr. med. univ. Georg Singer

Graz, 26.02.2014 Martin Ortner

Eidesstattliche Erklärung

Ich erkläre ehrenwörtlich, dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe verfasst habe, andere als die angegebenen Quellen nicht verwendet habe und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Graz, am 26.02.2014 *Martin Ortner*

Acknowledgements

First and foremost I like to thank my supervisors Dr. med. univ. Elke Maria Zani-Ruttenstock and Ass. Prof. Priv.-Doz. Dr. med. univ. Georg Singer for their support during the process of writing my diploma thesis. Thank you for providing me with your knowledge and experience throughout the course of completing my first scientific work. I sincerely hope that many more students will have the privilege and joy to work with you on their diploma theses.

I would like to thank my unique family for giving me the opportunity to follow my dream of studying medicine and becoming a medical doctor and for all the encouragement during this journey. Words cannot describe my gratitude for all the love, support and guidance you have given me, and that pushed me so much to make my dream come true.

Last but not least I would like to thank my dear friends for their friendship, support and for the great moments I was lucky enough to share with them throughout this part of my life.

Thank you!

Zusammenfassung

***Hintergrund*:** Die optimale Behandlung von Frakturen des medialen Humerusepikondyls bei Kindern und Jugendlichen ist ein kontroverses Thema in der gegenwärtigen Literatur. Grundsätzlich kommen, in Abhängigkeit vom Behandlungszentrum und vom Chirurgen, sowohl die konservative also auch die operative Behandlungsmethode zur Anwendung. Obwohl hinsichtlich absoluter Indikationen für eine operative Behandlung als auch hinsichtlich der konservativen Behandlung von nicht verschobenen Frakturen Einigkeit herrscht, so fällt dennoch eine beträchtliche Anzahl der Fälle in eine Art Grauzone.

Ziel der Studie war es, die an unserer Klinik erzielten Ergebnisse von Frakturen des medialen Humerusepikondyls nach konservativer und chirurgischer Therapie zu evaluieren, mit der diesbezüglich relevanten Literatur zu vergleichen und in weiterer Folge Verbesserungsmöglichkeiten in der Behandlung zu identifizieren.

Patienten und Methoden: In der vorliegenden Studie wurden die Daten aller Patienten ausgewertet, welche zwischen den Jahren 2004 und 2011 aufgrund einer Fraktur des medialen Humerusepikondyls an unserer Klinik behandelt wurden.

Von allen Patienten, welche die Einschlusskriterien der vorliegenden Studie erfüllt hatten, wurden Daten hinsichtlich Verletzungsart, Diagnose, Behandlung und Nachsorge erhoben und statistisch ausgewertet. Die Daten der verschiedenen Behandlungsgruppen wurden anschließend gegenübergestellt, um Vor- und Nachteile der einzelnen Behandlungsmethoden untereinander zu vergleichen.

***Ergebnisse*:** Insgesamt erfüllten 81 Patienten die Einschlusskriterien der vorliegenden Studie. Sechsundfünfzig Patienten (69,1%) wurden durch offene Reposition und Osteosynthese der Fraktur behandelt. Fünfundzwanzig Patienten (30,9%) wurden konservativ durch Ruhigstellung behandelt. In sechs dieser Fälle (24%) wurde im Laufe der Behandlung eine Konversion zur chirurgischen Behandlung indiziert. Komplikationen während und nach dem Heilungsprozess waren selten und zogen wenig bis keine weiteren klinischen Konsequenzen nach sich. Mit Ausnahme eines chirurgischen Falles, zeigte das Management von

Frakturen des medialen Humerusepikondyls gute klinische Ergebnisse in allen Behandlungsgruppen.

***Schlussfolgerung*:** Basierend auf den Ergebnissen der vorliegenden Studie stimmen wir mit den Empfehlungen zu den etablierten absoluten Indikationen zur Operation auch in Zukunft überein. Beide Behandlungsmethoden, offene Reposition mit Osteosynthese der Fraktur sowie konservative Therapie durch Ruhigstellung, haben ihre berechtigte Anwendung. Doch anstatt die Entscheidung für die Operation vor allem aufgrund des Dislokationsgrades des Fragments zu fällen, empfehlen wir, klinische Stabilitätstests des Gelenks zur Entscheidungsfindung mit einzubeziehen. Obwohl eine chirurgische Therapie eine höhere Chance auf eine knöcherne Ausheilung der Faktur verspricht, weisen die funktionellen Ergebnisse beider Therapieformen kaum Unterschiede auf. Deshalb, aber auch wegen der Vermeidung zweier chirurgischer Eingriffe, sowie der bestehenden Möglichkeit zur späteren Konversion, ist in unseren Augen in kontroversen Fällen die konservative gegenüber der chirurgischen Therapie zu bevorzugen.

Abstract

Purpose: Medial humeral epicondyle fractures (MHEF) in children and adolescents have been the objective of various studies in the past. Both, surgical and conservative treatments are offered, dependent on the type of MHEF fracture. While there exists common consensus on the conservative treatment for non-displaced MHEF and there have been established a number of absolute indications for surgery, many cases fall into a grey zone where recommendations for the appropriate treatment are still subject of discussion.

The aim of our study was to retrospectively analyze the pediatric and adolescent population in our hospital treated for MHEF. The results achieved through conservative and surgical treatment approaches were compared to the literature, with the target of identifying possible areas for improvement.

Patients and methods: We retrospectively reviewed patients' data concerning injury, diagnosis, treatment and follow-up of MHEFs, treated in our clinic between the years 2004 and 2011. The data was grouped according to method of treatment in order to compare results and identify advantages and disadvantages of each method.

Results: In total there were 81 patients treated for MHEF that met the inclusion criteria for the present study. Fifty-six patients (69.1%) were treated with open reduction and internal fixation (ORIF). Twenty-five patients (30.9%) were initially treated conservatively with immobilization. In 6 of these cases (24%) a conversion to ORIF was necessary at some point during treatment because of failure of the initial conservative treatment. Complications during and after the recovery process were rare and with little to no further clinical consequence. The treatment of MHEF in our hospital showed good clinical results in all treatment groups. Only one surgical case presented with complications that made a revision necessary.

Conclusion: Based on the findings of our study, we agree to adhere to the well-established absolute indications for surgery. Both methods of treatment, ORIF and conservative approach, are equally eligible. However, rather than basing the decision for surgery mainly on the grade of dislocation, we recommend to implement clinical stability tests of the elbow joint in the decision process for

surgery. While a surgical approach seems to provide higher chances for bony union, the functional outcome between surgery and conservative approach does not differ. This fact, as well as the avoidance of two surgical interventions and the possibility for a conversion at a later stage, leaves us with the conclusion, that especially in controversial cases of MHEF a conservative approach may be favorable.

Table of Contents

List of Figures

List of Tables

Abbreviations

CS	cannulated screw
GST	gravity stress test
K-wires	Kirschner wires
MCL	medial collateral ligament
MHE	medial humeral epicondyle
MHEF	medial humeral epicondyle fracture
ROM	range of motion
VST	valgus stress test

1. Introduction

Medial humeral epicondyle fractures (MHEF) are common fractures of the elbow region in the pediatric population and they are often associated with luxations of the elbow. Injuries of the medial humeral epicondyle (MHE) of the elbow have been first described by Granger as far back as 1818 and MHEFs in children and adolescents have become the focus of various studies since the 1930s (1,2). However, the management of MHEF still remains a controversial topic in pediatric trauma care.

Incidence

Elbow fractures represent up to 7% of all fractures in the pediatric population and MHEFs constitute around 8% of these fractures (3). With a reported incidence of 33% to 55%, MHEFs are the most common fractures associated with elbow luxations (4,5). Conversely, elbow luxations are associated with MHEFs in 60% of the cases, especially with a higher degree of fracture dislocation (6,7). MHEFs show an increased incidence among boys, with a ratio of 2:1 (8). Most MHEFs are reported between the ages 9 and 14, with a peak incidence between 11 to 12 years (9,10).

Anatomy

Knowledge of the anatomy of the MHE is important for the comprehension of the injury mechanisms, the fracture's clinical and radiographic diagnosis and the complications associated with MHEFs.

The MHE is the second of four ossification centers responsible to form the distal humerus. The ossification process starts at around 5 years in girls and 7.5 years in boys. Fusion with the metaphysis of the humerus begins at around 14 years in girls and 17 years in boys (11).

The MHE lies extra-articular and is considered as an apophysis. It serves as origin for the anterior and posterior band of the medial collateral ligament (MCL) as well as the superficial flexors of the forearm (12). During development it does not contribute to growth in length of the humerus and therefore injuries to the MHE during growth do not influence the final dimensions of the mature humerus (10).

The MHE's eccentric postero-medial position and the fan-shaped extension of the MCL's anterior band to the medial aspect of the coronoid process of the ulna provide medial stability throughout the whole range of motion (ROM) of the elbow joint (12,13). In the event of an elbow luxation, the MCL is strained and the applied force is passed on to the MHE. If the force is big enough and the ligaments do not tear, this can subsequently result in a MHEF

The muscles originating from the MHE through the common flexor tendon are part of the superficial flexor group including the flexor carpi radialis, the palmaris longus and the humeral heads of the flexor carpi ulnaris and the flexor digitorum superficialis. Also the humeral head of the pronator teres originates partially from the proximal portion of the MHE (12,13). In 55% of the cases an accessory humeral head of the flexor pollicis longus originates from the MHE (Gantzer's muscle) (14).

Another important anatomical structure in this area, playing a major role in the complications of MHEF, is the ulnar nerve. It passes through a bony groove, which is part of the cubital tunnel located posterior to the MHE. The fascia of the flexor carpi ulnaris and Osborne's ligament form the roof of the cubital tunnel. The posterior and transverse bands of the MCL form the floor. The sides are bordered by the olecranon laterally and the MHE medially (12). Initially around 9-10% of patients sustaining MHEFs present with ulnar nerve symptoms. Up to 16% of patients with MHEFs develop neural symptoms throughout the course of treatment (8,15).

Mechanism of injury

The mechanisms of injury responsible for MHEFs are well understood and typically include one of the following three (5,9,10,16):

a. An avulsion mechanism, typically occurring in the event of a fall on the outstretched arm and often accompanied by a valgus stress to the elbow joint.
b. The injury in association with an elbow luxation.
c. The fracture as a result of a direct blow to the medial aspect of the elbow region.

MHEFs obtained through a direct blow to the elbow are very rare and usually result in a multi-fragmented fracture of the MHE as well as clinically notable soft-tissue swelling and ecchymosis in the area (10).

Especially in athletes exercising arm wrestling, frequent overhead throwing or weight bearing activities, a chronic tension stress on the MHE can subsequently develop into an acute MHEF through isolated muscle avulsion (10,17,18). More commonly, the acute force created in the event of a fall onto the outstretched arm, often with the wrist and fingers hyperextended, leads to MHEF when the MHE cannot withstand the sudden pull. In this event an additional valgus stress strains the MCL and can increase the likelihood of MHEF (9).

Diagnosis and treatment

The diagnosis of MHEF in children and adolescents, and subsequently the decision for the recommended treatment, rely on the clinical presentation together with radiographs of the injured elbow. No commonly used classification system of MHEF has been proposed yet, though several authors have made efforts to describe different types of MHEF. While they can be useful for the diagnosis and the statistical analysis, the consequences for treatment of MHEF are relatively arguable.

Table 1 shows a range of classifications of MHEF with different levels of complexity and different clinical and radiological factors included in the considerations. The classifications in Table 1 are organized in chronological order of the year of publication.

Author	Year	Classification of MHEF
Smith (9)	1950	I. Fracture not apparent on x-ray II. Minimally displaced fracture III. Significantly displaced fracture IV. Incarcerated fracture V. Fracture of the MHE in adults
Bede et al. (19)	1975	I. Simple fracture II. Fracture-dislocation with spontaneous reduction III. Fracture-dislocation
Woods and Tullos (13)	1977	• Stable non-displaced fractures • Stable elbow + displaced fracture >1.0cm • Unstable MHEF I. Age ≤ 14 II. Large fragment, age ≥ 15 a. Ligament intact b. Ligament torn III. Small fragment, age ≥ 15
Papavasiliou (20)	1982	I. Small degree of avulsion II. Avulsed fragment at the level of the joint but not entrapped III. Fragment incarcerated in the joint IV. Association with elbow luxation
Rang (18)	2006	I. Non-displaced and minimally displaced fractures II. Displaced and rotated fractures III. MHEF + incarcerated fragment IV. MHEF + incarcerated fragment and elbow dislocation
Louahem et al. (6)	2009	I. Non-displaced or minimally displaced fractures II. Moderate displacement (>½ of metaphyseal fracture area) + positive valgus stress test (VST) III. Major displacement (MHE remains at level of articular line) + obvious elbow luxation or luxation during VST IV. Posterior displacement of MHE + intra-articular incarceration of epicondylar muscles (MHE + muscular attachments above + periosteum and triceps layer detached from the humeral diaphysis below) resisting closed reduction V. Intra-articular entrapment of MHE + elbow luxation or subluxation (possibly spontaneously reduced and masking the incarceration)
Rockwood et al. (10)	2010	• Initial differentiation between acute and chronic injuries • Non-displaced fractures • Minimally displaced fractures • Significantly displaced fractures ○ Associated with elbow luxation ○ Without elbow luxation • Fractures with entrapment of the fragment into the joint ○ Associated with elbow luxation ○ Without elbow luxation • Fractures through the epicondylar apophysis ○ Displaced ○ Non-displaced

Table 1 - Classification systems of MHEF

The present literature demonstrates consensus regarding conservative treatment of non-displaced MHEFs (Figure 1). The clinical manifestations usually consist only of swelling and local tenderness over the MHE. On radiographs (anterior-posterior and lateral view), the smoothness of the edge of the physeal line remains intact and therefore a fracture line may not be visible (7,10,18).

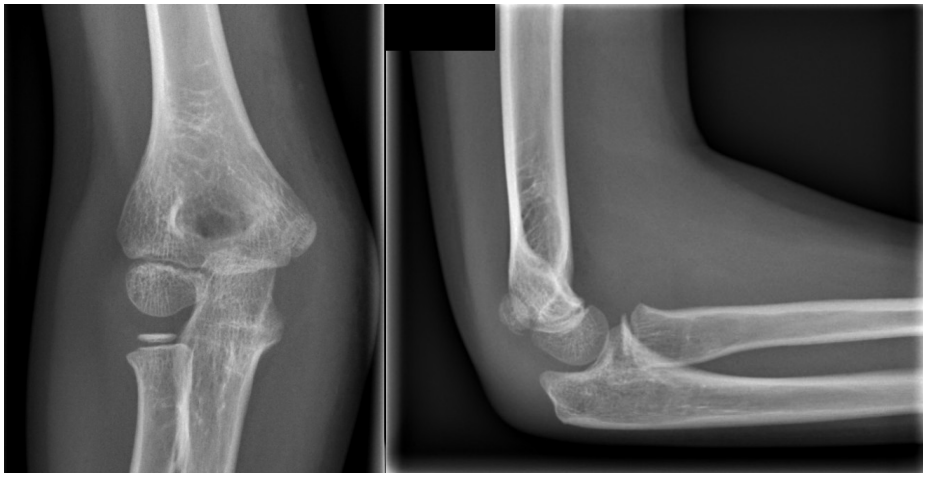


Figure 1 - Six-year-old girl with non-displaced MHEF (right arm)

Conservative treatment usually consists of immobilization of the affected elbow in a 90° flexed position through application of an upper arm splint or cast for 3 to 4 weeks, with the forearm in neutral rotation (7,21). It is recommended to start moving the joint as early as possible, perhaps replacing the splint or cast with a sling, since stiffness of the joint can be a complication of immobilization of the elbow. Physical therapy is recommended to encourage the patient to actively move the joint, whereas passively enforced movement should be avoided (10).

Advantages of a conservative approach in treatment are (22):

- Avoiding the general risks of surgery (wound infection, bone infection, postoperative bleeding).
- Avoiding the risks of general anesthesia.
- Avoiding iatrogenic damage to the ulnar nerve or further fracture fragmentation.
- Better cosmesis.
- No need for a follow-up surgical procedure (implant removal).

On the other hand, a number of absolute and relative indications for open reduction and internal fixation (ORIF) of the fracture have been recognized (10,13,22).

Absolute indications for ORIF are:

- Open fractures.
- Failure to reduce an incarcerated fragment from the elbow joint.
- A complete lesion or displacement of the ulnar nerve into the fracture gap.

Relative indications for ORIF are:

- Simple injuries to the ulnar nerve.
- Valgus instability.
- High-demand upper extremity-function of the patients (e.g. athletes).

The advantages of ORIF over the conservative approach are (22):

- Possibility of a thorough assessment of the injury.
- Visualization of the anatomical structures injured.
- Anatomical refixation of the fragment.
- Quick restoration of the stability of the joint.

Preparations for ORIF should include thorough assessment and documentation of peripheral circulation, motor activity and sensibility. Adequate pain therapy, immobilization and required radiographs should be obtained before initiation of surgical intervention (22). When the patient is under general anesthesia and placed in a supine position, the closed reduction of a present elbow luxation should be attempted. This allows further clinical assessment of the injury as well as further radiological examinations if necessary (22).

The operative techniques of ORIF, which are used in our clinic, have been described by Haxhjia et al. (22) and Kamath et al. (23). Figures 2 through 4 chronologically illustrate the steps of ORIF using K-wires. The illustrations (Figures 2, 3, 5 and 6) are used with the kind permission of Haxhjia et al. (22).

- A posteromedial skin incision starts about 3 cm proximal to the affected MHE and extends approximately 0.5 cm distal to the joint, slightly anterior to the sulcus medialis. The incision should allow the identification of the fragment (most likely displaced anteriorly and distally), the fracture site and the ulnar nerve (Figure 2).

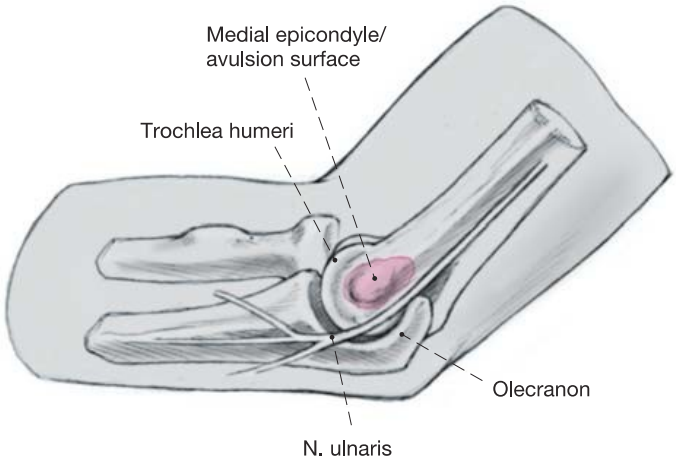


Figure 2 - Surgical site of MHEF with anatomical structures (22)

- Fracture hematoma and soft-tissue obstructions should be evacuated to allow thorough visual and clinical evaluation of the joint in order to identify any further injuries to the bone or surrounding anatomical structures. If a more thorough assessment of the ulnar nerve is necessary or recommended, the nerve can be exposed and retracted with a rubber band. Fragments entrapped into the joint should be carefully mobilized preventing trauma to the cartilage surface. Smaller fragments, which cannot be re-attached, should be excised from the site (Figure 3)

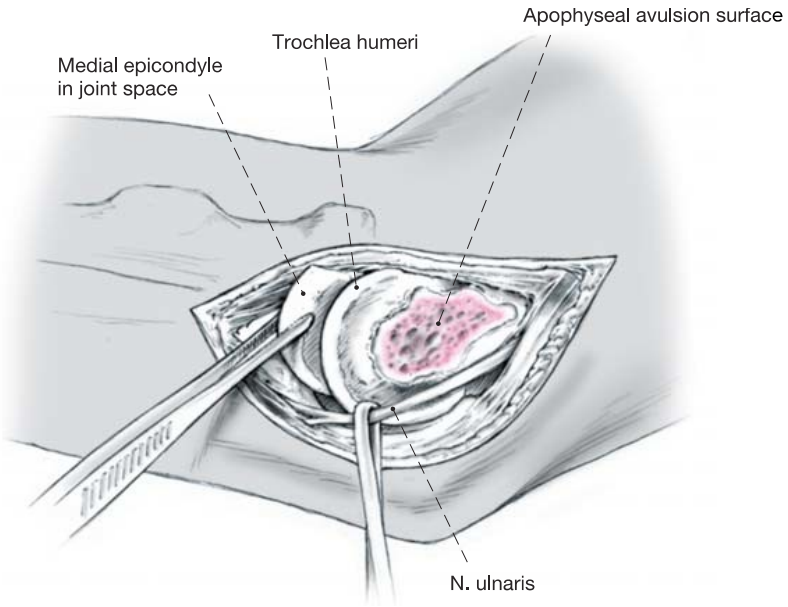


Figure 3 - Inspection of the fracture site with exposition of the ulnar nerve (22)

- After debridement of the fracture surfaces, anatomical reduction of the fracture is attempted. Full flexion of the wrist and fingers, as well as supination of the arm and 90° flexion in the elbow facilitate this procedure through the relaxation of the musculature. Optionally the application of an Esmarch bandage from distally to proximally can push the soft-tissue, and subsequently the attached fragment, towards the fracture site (23).

- After manual reduction of the fragment in its anatomical position and the placement of a guide wire in the center of the fragment, a cannulated, cancellous bone screw (cannulated screw; CS) is inserted. The trajectory follows the roof of the olecranon fossa towards cranio-laterally (Figure 4). To prevent rotation or displacement of the fragment during the process, a K-wire can be previously placed to hold the fragment in the correct position. The screw's designated path must not be interfered within the process.

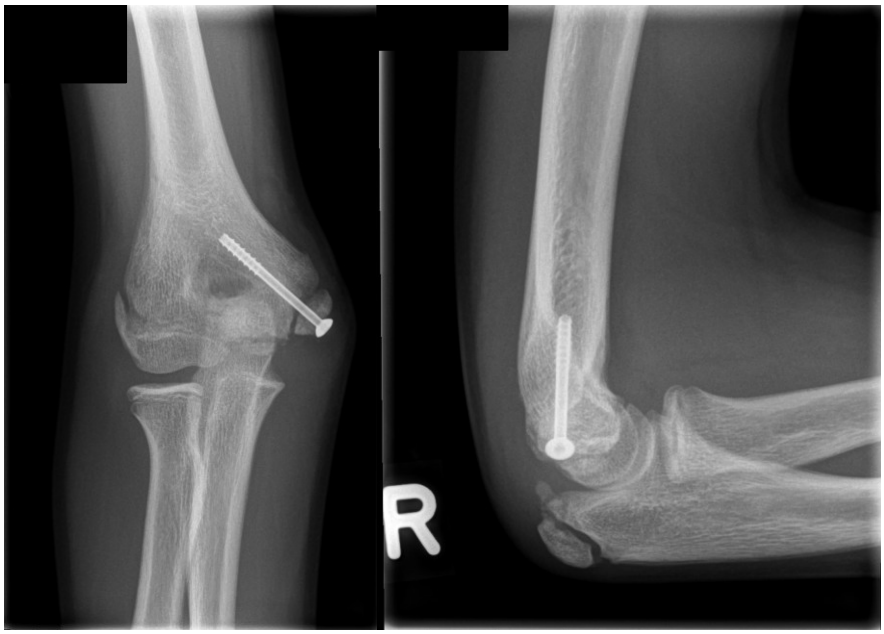


Figure 4 - CS implant in 12-year-old boy (right arm)

- Placement of two Kirschner wires (K-wires), as an alternative to a CS, follows the same principles. One K-wire follows the same direction as the path of the CS in the previous point. The second K-wire is inserted a little distally into the fragment and advanced transversely towards the lateral epicondyle, with the intention to prevent rotation of the fragment (Figure 5).

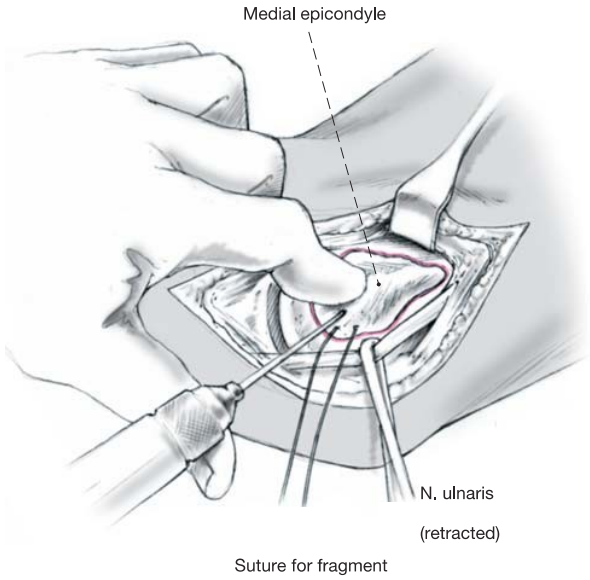


Figure 5 - Fixation of the fragment using K-wires and adjuvant suture (22)

- After final examination of the joint's stability and ROM, and a final radiological check of the correct reduction of the fracture and the implants´ placement, anatomically correct closure of the wound layers can be carried out (Figure 6).

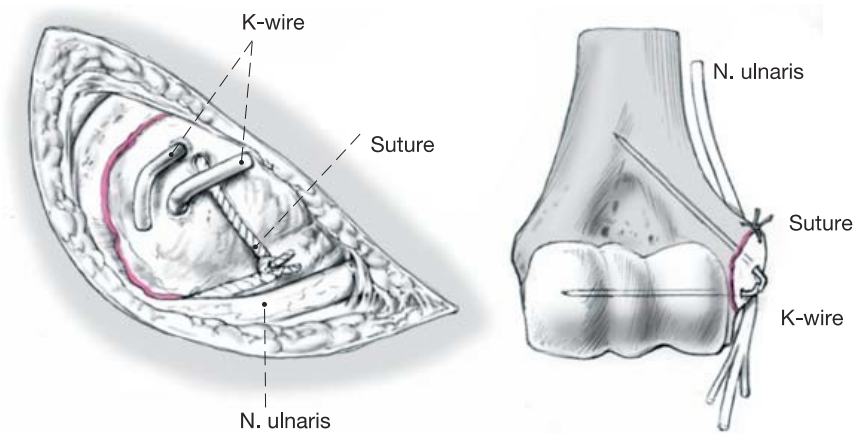


Figure 6 - Final position of K-wires after ORIF (22)

Implant placement and fragment position can be checked by fluoroscopic imaging throughout the procedure. Penetration of surrounding soft-tissue or skin by implants must be prevented as it can cause damage but more likely will cause discomfort for the patient. To further provide fragment stability, the cranial edge of the fragment can be sutured to the bone with a resorbable thread. The course of the ulnar nerve should be checked for irregularities and sharp edges that can lead to irritation (22,23).

The method of fragment fixation depends on the size of the fragment and the age of the patient. The preferred method of fixation in our department was the fixation by means of two K-wires in younger children with small fragments, and the use of a CS in older children. The dimensions of the implants should be age adapted (22). The K-wires used in our hospital were between 1.2 mm and 2.0 mm in diameter, while the CSs usually had a width of 4.0 mm and a length between 32 mm and 60 mm, depending on the anatomical circumstances of the fracture. In three older children with larger fragments, two CSs were used to reduce the fracture. These followed the same trajectory as two K-wires and provided a strong fixation (Figure 7).

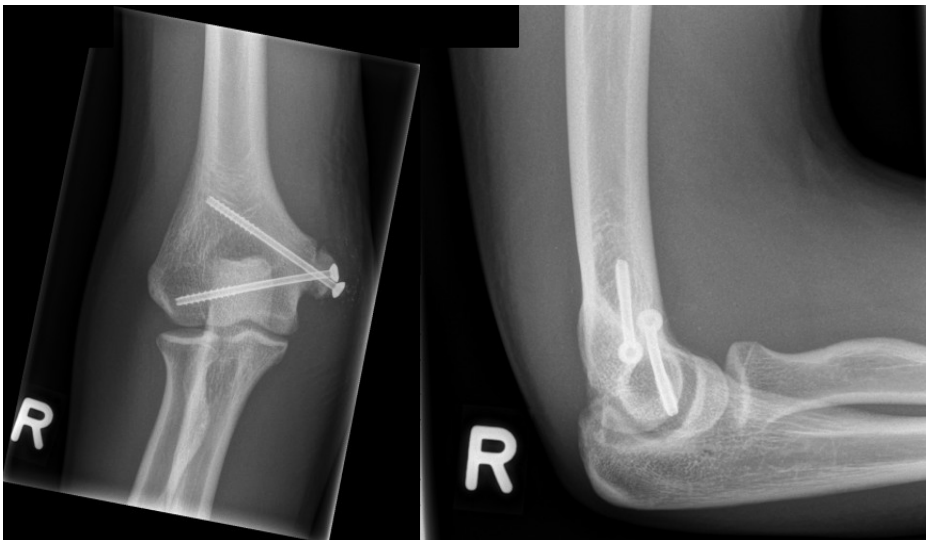


Figure 7 - Two CS implants in 15-year-old boy (right arm)

While the above-mentioned indications for conservative treatment or ORIF are commonly agreed upon, opinions differ regarding the treatment for uncomplicated MHEF with a displaced MHE. Disagreement arises in particular over the tolerable distance of displacement of the MHEF before ORIF is indicated, thus quantifying a “significant” displacement of the MHE: Some authors opt for a conservative treatment in cases of fragment displacement of up to 15 mm (21,24). Other authors seem to have lower threshold for ORIF, recommending surgical approach in cases of fragment displacement of as little as 2 mm (15,25).

Major complications of MHEF, resulting in a significant loss of function of the elbow joint, are rare and typically due to missed diagnosis of an entrapped intra-articular fragment or the development of an ulnar nerve dysfunction (10,18). Other minor complications are only of minimal functional or cosmetic consequences and usually require no further management (10). Nonunion between the fragment and the distal humeral metaphysis (fibrous union or pseudoarthrosis) is especially common in conservatively treated patients. The functional outcome is still satisfactory in the majority of cases, though athletes may require further treatment due to higher requirements on the joint, which can be difficult to achieve (10). Kamath et al. (8) reported that 92,5% of patients that underwent ORIF had reached bony union as compared to 49,2% of patients that were treated conservatively. Loss of 5% to 10% of ROM (especially in flexion/extension) was seen in up to 20% of patients and mostly due to longer periods of immobilization (10).

Myositis ossificans is a rare complication, mostly inflicted iatrogenic, through the wrong and forceful manipulation of the elbow to extract an entrapped fragment from the joint space (10). Recurring injuries of the epicondyle and ligamentous structures can cause asymptomatic ectopic calcifications in the medial elbow area, creating the aspect of an increased carrying angle of the joint (10).

The most important differential diagnosis of MHEF is an injury to the medial condylar physis with an intra-articular component (Kilfoyle II and Kilfoyle III), which is an indication for surgery. Especially on x-rays of younger children, these fractures can be confused with isolated MHEF, since the MHE starts the

ossification process earlier than the trochlea. A positive fat pad sign can hint an intra-articular component of the injury. The clinical presentation is similar to MHEF, with medial swelling and valgus instability. Additionally, varus instability and the tendency of the elbow to subluxate postero-medially are symptoms associated with medial condyle fractures because of loss of trochlear stability. Nonunion, loss of reduction, cubitus varus and avascular necrosis of the trochlea are complications of this injury and require further interventions. If in doubt of the location of the fracture, additional MRI, CT scan or arthrography of the joint should be performed (10,18,22).

In order to decide for either a conservative or a surgical treatment approach, absolute and relative indications for surgical treatment of MHEF were taken into consideration in our institution. MHEFs were then divided into isolated fractures and fractures associated with elbow luxation. Furthermore, displacement of the fragment was considered significant if the distance was 3 mm or more. The recommendation in our department was to refrain from surgery with displacements of a smaller distance. However, the final decision for surgery in debatable cases, with a dislocation of the MHE between 3-6 mm, was taken in accordance with the surgeon responsible, the patient and his/her parents, leaving room for discretion.

The aim of our present study was to analyze the results of MHEF in children and adolescents treated in our institution and to compare the outcome after conservative and surgical treatment.

2. Patients and Methods

The electronic system for patient documentation (MEDOCS®) was employed to retrieve the data of all patients with MHEF that had received conservative or surgical treatment at the Department for Paediatric and Adolescent Surgery of the Medical University of Graz between the years 2004 and 2011.

Inclusion criteria were the following:

- Age at the time of injury from 5 to 16 years.
- The patient received treatment for MHEF in our department.
- The patient was referred after initiation of MHEF treatment in a local hospital or was directly admitted to our department after the injury.
- The patient received at least 2 follow-up clinical examinations and 2 radiological examinations.
- The fracture was an isolated fracture to the medial epicondyle with no other fractures involving the affected arm's elbow joint.
- The fracture was the first MHEF of the affected arm in the patient's medical history.

For the purpose of the study patients were grouped according to their treatment in three different groups. Group 1 comprised patients, who were treated with ORIF of the fractured epicondyle (*surgical group*). Group 2 included all patients that were treated by means of immobilization of the affected elbow exclusively (*conservative group*). Group 3 included patients who were initially treated conservatively, but subsequently underwent surgery (*conversion group*).

Detailed data were collected and organized in the following four categories (Table 2):

1. Injury
2. Diagnosis
3. Treatment
4. Follow-up

Injury
Date of injury
Age at the time of injury
Gender
Cause of injury
Affected arm
Initial management of the injury (in our hospital or somewhere else)
Diagnosis
Radiological examinations leading to diagnosis (X-ray, MRI, CT)
Luxation of the affected elbow
Dislocation of the fractured medial humeral epicondyle
Neurological symptoms of the affected arm
Additional injuries
Treatment
Treatment group (ORIF, conservative, conversion)
In-patient or out-patient treatment
Date of admission
Age at admission
Duration of hospitalization
Date of operation *
Duration from injury to admission
Duration from admission to operation*
Duration of postoperative hospitalization*
Surgical method of treatment*
Implants used*
Perioperative antibiosis*
Perioperative complications*
Method of immobilization
Duration of immobilization
Physiotherapy
Number of visits from initial surgery to removal of implants*
Date of removal of implants*
Duration of implants in situ*
Extraction in day-clinic/out-patient treatment/in-patient care*
Follow-up
Overall number of presentations to our department
Date of last clinical presentation
Number of radiological examinations
Complications during follow-up
Date of last radiological examination
Last clinical findings
Last radiological findings
Duration from injury to last visit and discharge from treatment
Duration from beginning of treatment to discharge

Table 2 - Information gathered for patients included in the study (*only gathered in ORIF and conversion group)

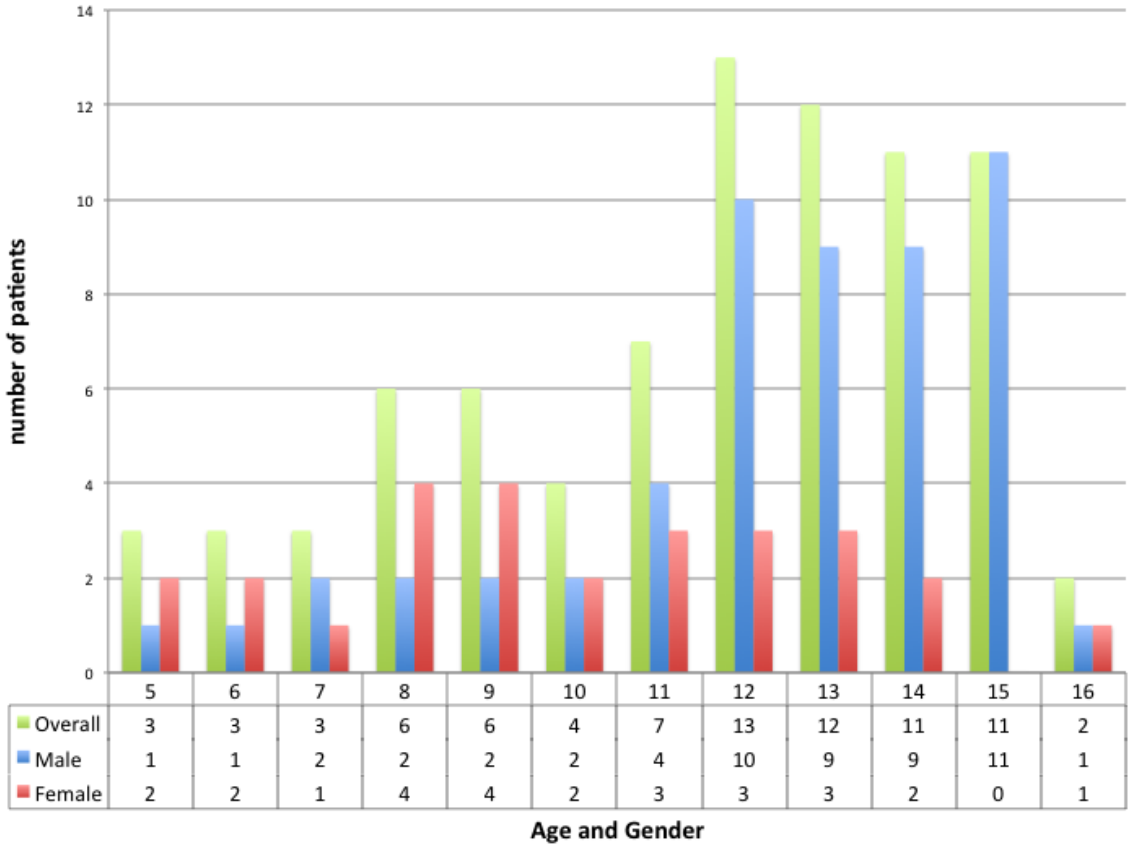
Microsoft Excel® was used to document the gathered information and to process data for further statistical analysis. To provide anonymization of patient records, clinical data were separated from patients´ personal information. Only age and gender were included to give an epidemiologic overview of the injury discussed.
Statistical analysis was made using Graph Pad Prism for Chi-Square and Chi-Square test for trend. Data are expressed in median and range. A P-value less than 0.05 was considered statistical significant.

Results were compared with other studies in the literature, which thematized surgical and non-surgical approaches for MHEF treatment. Studies related to diagnostics of injuries to the MHE in children and adolescents were also reviewed.

The study's design and approach was evaluated and approved by the ethics committee of the Medical University of Graz in their ruling "24-043 ex 11/12".

3. Results

In total, there were 81 patients with MHEF that met our study inclusion criteria. Injuries to the MHE occurred throughout all age groups with a median age of 12 years (range 5-16). Most of the patients, however, suffered from MHEF at an age between 12-15 years. Figure 8 demonstrates an earlier peak of injuries in female patients, between the ages 8 and 9, compared to the male patients, with a peak incidence between 12 and 15 years.



	5	6	7	8	9	10	11	12	13	14	15	16
Overall	3	3	3	6	6	4	7	13	12	11	11	2
Male	1	1	2	2	2	2	4	10	9	9	11	1
Female	2	2	1	4	4	2	3	3	3	2	0	1

Figure 8 - Distribution of patients (n=81) according to age and gender

The male to female ratio was 2:1, with 54 boys (66.7%) and 27 girls (33.3%) (Figure 9a). The median age for girls was 10 and for boys 13 years, both with a range of 5 to 16 years. (Figure 9b) and with no significant differences between the two genders (p=0.09).

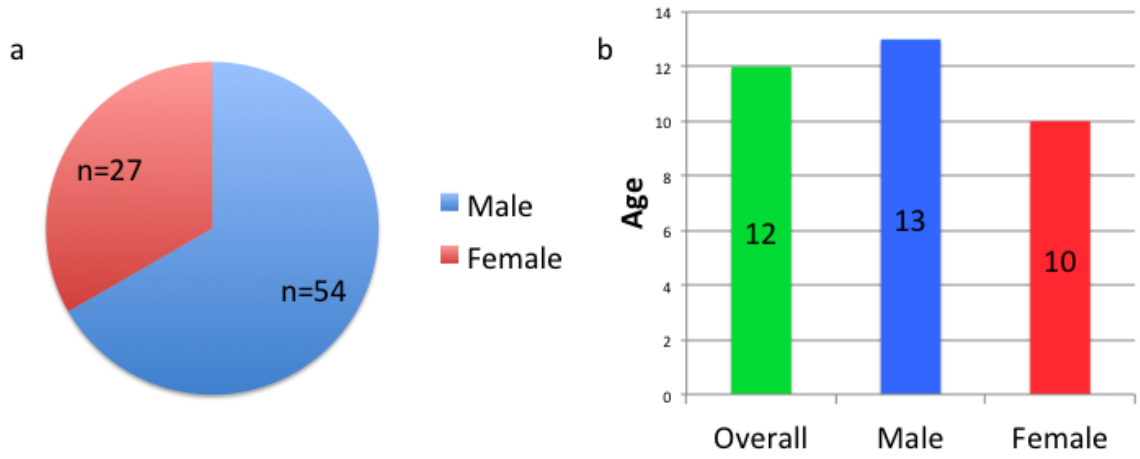


Figure 9 - Male to female ratio (a) and median age at time of injury (b)

The affected extremity was the right arm in 40 cases (49.4%) and the left arm in 41 (50.6%) cases. The affected arms were also evenly distributed within the two genders, with 27 injuries to the right arm and the same number of injuries to the left arm in boys, and 13 injuries the right arm and 14 injuries to the left arm in girls.

Causes for the injury were categorized and showed a majority of 55 injuries (67.9%) occurring during physical activities: 28 injuries (34.6%) during sport activities and 27 injuries (33.3%) while playing; here the differentiation was not easy because in this age group those activities are often intertwined. 19 fractures (23.5%) occurred during daily activities. Seven fractures (8.6%) occurred while part-taking in traffic (mainly riding a bicycle) (Figure 10).

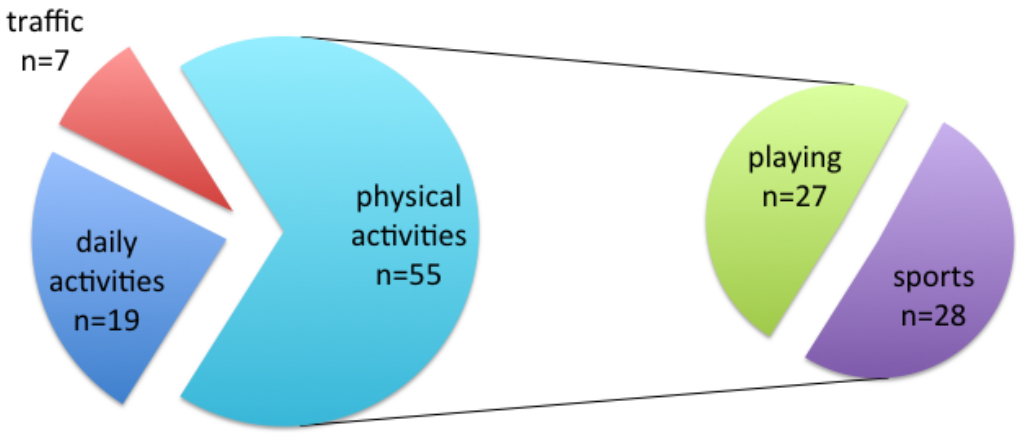


Figure 10 - Cause of injury

Forty patients (49.4%) were already diagnosed in their local hospital and usually treated with provisional immobilization of the injured elbow with a cast before referral to our Accident and Emergency department. Forty-one patients (50.6%) were initially treated directly at our hospital.

Diagnostics

In the majority of our cases (n=73; 90.1%) standard x-rays (lateral and anterior/posterior view) of the injured elbow were sufficient for diagnosis. However, additional CT scans were required in three patients (3.7%) and additional MRI in five patients (6.2%) in order to confirm diagnosis of MHEF.

In 28 cases (34.6%) the initial injury involved a luxation of the affected elbow and in 50 cases (61.7%) a luxation was excluded. In three cases (3.7%) an intermittent luxation could not be excluded, since there is a possibility for a dislocation of the elbow to reduce spontaneously (Figure 11a).

A significant dislocation of the fractured epicondyle fragment was described on radiographs in 50 cases (61.7%). In nine cases (11.1%) a dislocation of the fragment was explicitly excluded on radiograph reports, and in 22 cases (27.2%) no statement was made whether the fragment was dislocated or not (Figure 11b). As mentioned above, our department considered a fragment dislocation of 3 mm or more to be significant.

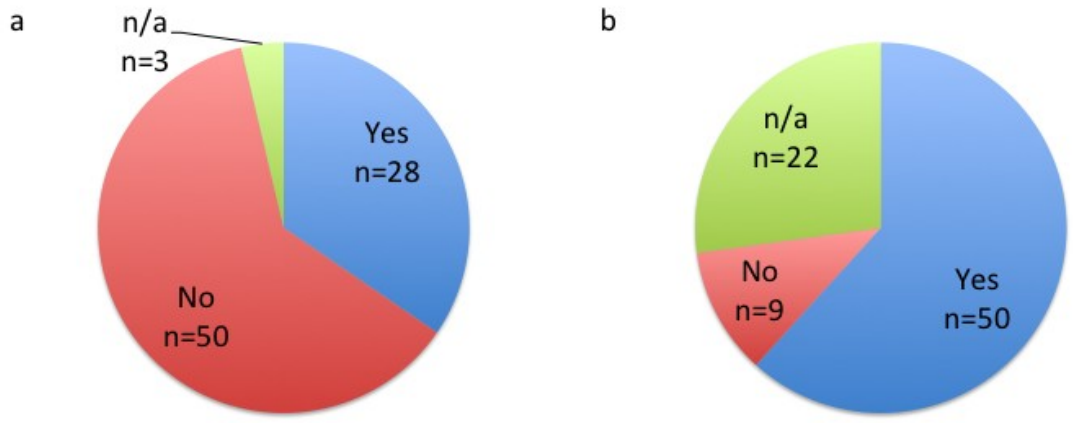


Figure 11 - Ratio of elbow luxation (a) and fragment dislocation (b) in our patients

Seventeen patients (21.0% of all patients) were diagnosed with a combination of elbow luxation and fragment dislocation at the time of admission. Five patients (6.2%) showed initial symptoms of ulnar nerve irritation; out of which one patient had an elbow luxation, and four patients were diagnosed with fragment dislocation.

Additional injuries, not involving the affected elbow joint per se, were present in 13 patients (16.1%). Those involved mainly contusions and excoriations of the body surface, as well as other bone injuries of the distal upper limb. The most common additional fractures involved the radius (n=7) with either a distal radius fracture or a fracture of the radius head.

Treatment

With regards to treatment modalities, patients were subdivided into three groups. The number of patients in each of these groups is presented in Figure 12.

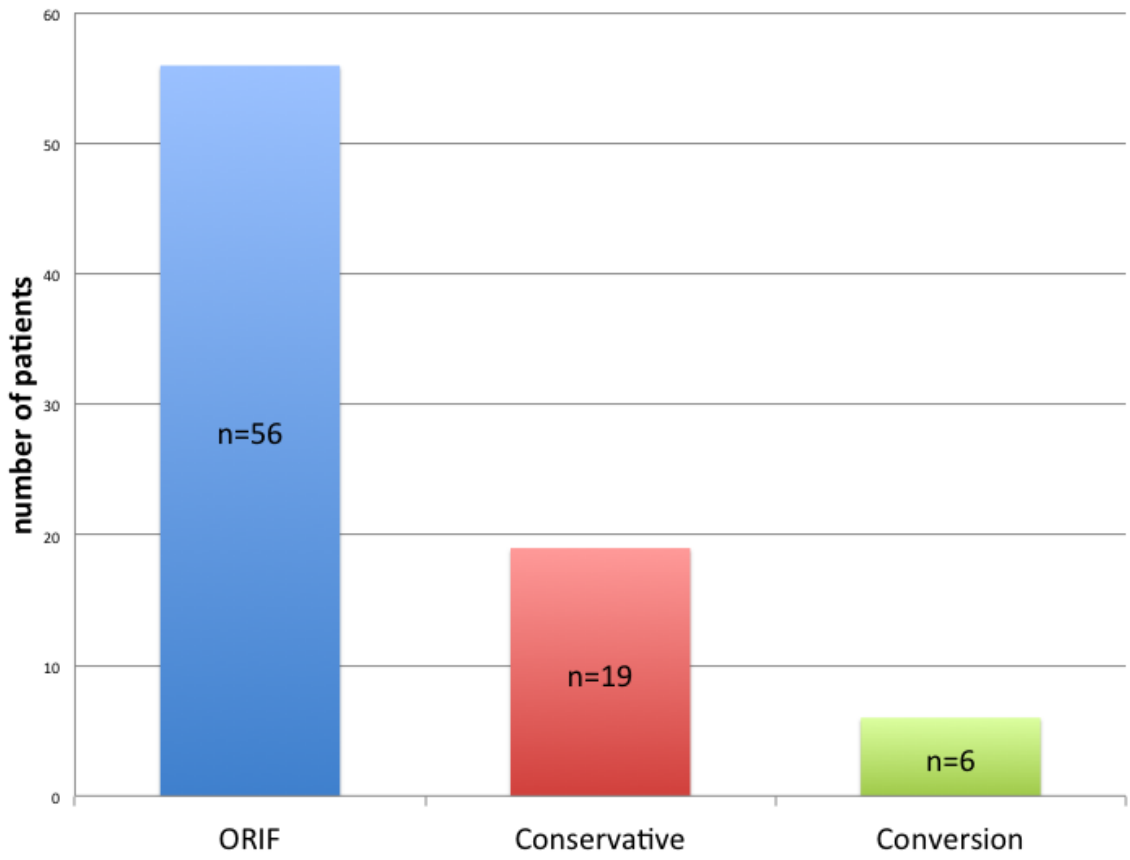


Figure 12 - Different treatment modalities in patients with MHEF

The epidemiology of the treatment groups is shown in Table 3. There were no differences in age and gender distribution among these groups.

	Total	Operative	Conservative	Conversion
Number of Patients (n)	81	56	19	6
Gender (m : f)	2 : 1	1.7 : 1	2.8 : 1	5 : 1
Median Age (range)	12 (5-16)	12 (5-16)	12 (5-16)	13.5 (12-15)
Elbow luxation	28 (34.6%)	21 (37.5%)	4 (21.1%)	3 (50%)
Fragment dislocation	50 (61.7%)	37 (66.1%)	7 (36.8%)	6 (100%)

Table 3 - Epidemiology of treatment groups

The ORIF group consisted of 56 patients (69.1%). Surgical treatment was performed by ORIF of the fractured MHE using either CSs or K-wires or a combination of both. Postoperatively the affected arm was immobilized with an upper arm splint or cast in almost all cases (Table 3).

Conservative treatment was initially attempted in 25 of our patients (30.9%). However, while in 19 cases (overall 23.5%; 76% of initially conservatively treated patients) conservative treatment was successful, six patients (overall 7.4%; 24% of initially conservatively treated patients) required a conversion to an operative management of the injury at some point during the treatment. Immobilization of the injured arm was provided with either an upper-arm plaster cast or splint (Table 3).

An elbow luxation or a fragment dislocation was more often seen in the operative group and conversion group when compared to the conservative group (Figure 13).

Out of the 28 patients (34.6%) with an elbow luxation, 21 patients (75.0%) were treated with ORIF of the medial epicondyle fragment. Four patients (14.3%) were treated conservatively by immobilization of the affected extremity, after closed reduction of the dislocation. However, 3 patients (10.7%) underwent conversion from conservative to surgical treatment (Figure 13)

Out of the 50 cases (61.7%) with MHE fragment dislocation, 37 (74.0%) were treated surgically, whereas 7 patients (14.0%) received conservative treatment. In the conversion group (n=6; 12.0%) all patients had a fragment dislocation (Figure 13).

Out of the 17 cases (21.0%) with a combination of elbow luxation and fragment dislocation only 12 patients (70.6%) underwent surgical treatment primarily. Three cases (17.6%) received a delayed surgical repair after initial conservative treatment and 2 patients (11.8%) were treated with immobilization only (Figure13).

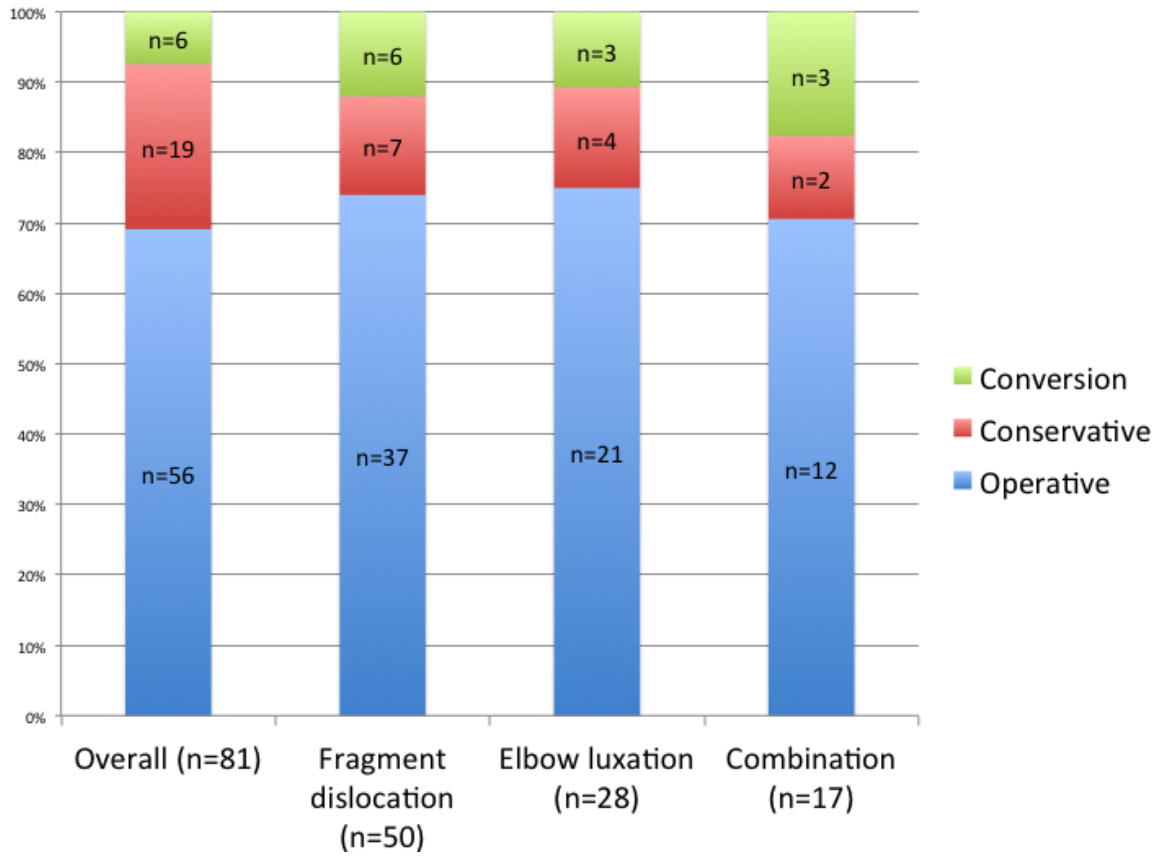


Figure 13 - Ratio of treatment groups with respect to injury

Operative treatment

The 56 patients in this group were further divided into 3 subgroups according to the surgical method used. In the majority of the cases (n=33; 58.9%) the surgical method of choice was ORIF of the fracture using K-wires alone. In 18 cases (32.1%) insertion of either one (n=16) or two (n=2) CSs were performed. For the remaining 5 patients (8.9%) who underwent ORIF a combination of a CS and K-wire was the method of choice (Table 4).

The median age of patients treated surgically was 12 years at the time of the procedure (range 5-16). Patients who had treatment with K-wires alone had a median age of 11 years (range 5-15), and were therefore 2 years younger than patients that underwent either ORIF by means of CSs alone (13 years, range 7-16) or the combination of CS and K-wires (13 years, range 9-15) (Table 4).

	Operative	K-wires	CS	Combination
Number of patients (n)	56	33	18	5
Median Age (a)	12 (5-16)	11 (5-15)	13 (7-16)	13 (9-15)
Median hospitalization (d)	2 (1-8)	2 (1-8)	2 (1-4)	3 (1-5)
Elbow luxation (n)	21 (37.5%)	12 (39.4%)	6 (33.3%)	3 (60%)
Fragment dislocation (n)	37 (66.1%)	21 (63.6%)	13 (72.2%)	3 (60%)

Table 4 - Number, age, hospitalization and fracture characteristics of patients that underwent ORIF

Patients who underwent surgery were usually admitted to the hospital at the day of the injury (n=39; 69.6%) or the following day (n=14; 25.0%). Only in 3 cases (5.4%) the time between injury and presentation was longer: 2 patients came to our hospital at the second day after the injury and 1 patient 4 days afterwards. After the admission to our hospital, 46 patients (82.1%) received surgical treatment on the same day and 9 patients (16.1%) on the following day. One patient in the operative group (1.8%) underwent surgery on the second day after admission.

In the majority of our patients (n=51; 91.1%) the time from injury to surgical treatment did not exceed 48 hours. Thirty-two patients (57.1%) were treated within the first 24 hours and another 19 patients (33.9%) within 48 hours. A minority of 5 patients (8.9%) received surgical treatment more than 48 hours after injury; out of which 1 patient had the intervention 3 days and 1 patient 5 days after the injury (Figure 14). The reasons for a delayed treatment were either the need for additional imaging or delay in the transfer to our hospital. However, this delay did not have any consequences for treatment or outcome for the patients.

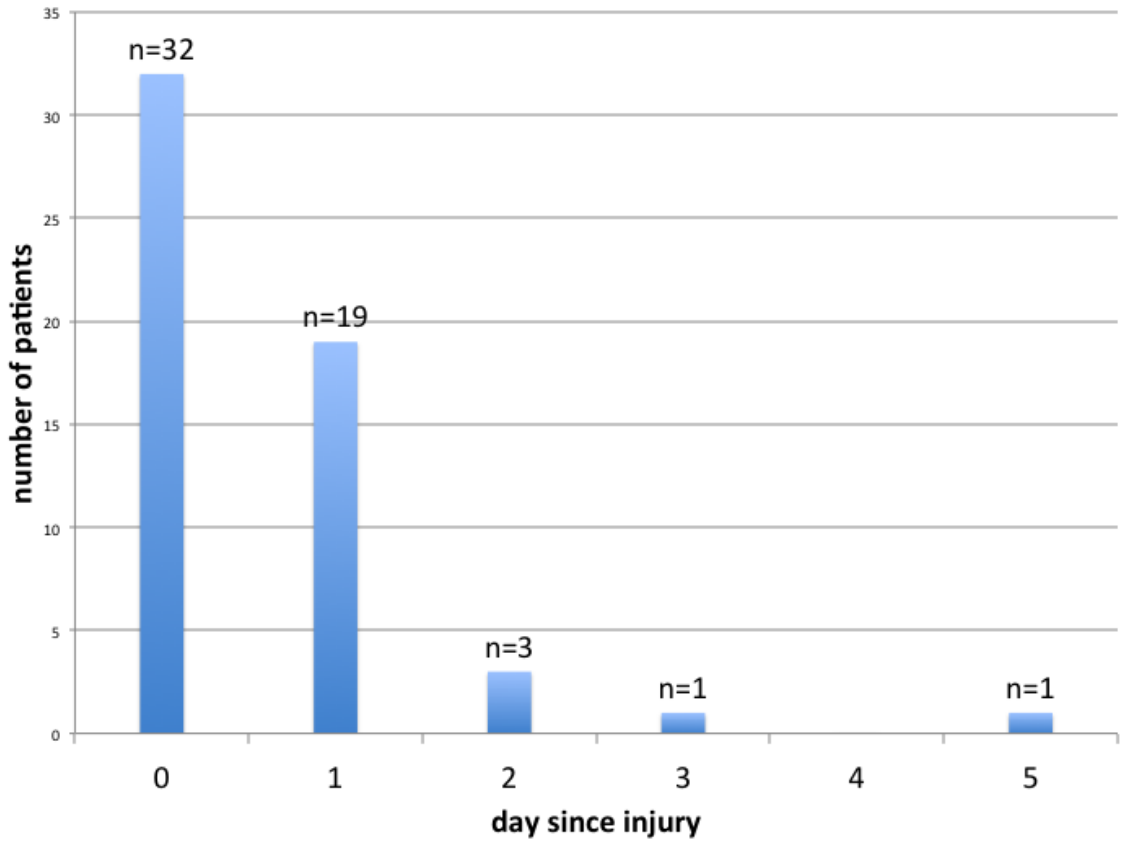


Figure 14 - Number of surgically treated patients with respect to days passed between injury and treatment

The median length of postoperative hospital stay was 2 days in all the surgical subgroups (range 1-8). Patients receiving either K-wires or CS had a range from 1-8 and 1-4 days, respectively. Patients with a combination had a range of 1-5 days. 40 patients (71.4%) could be discharged from hospital care within the first 48 hours after the intervention. By the fourth postoperative day 54 of our patients (96.4%) had left the hospital. One patient receiving a combination of both K-wire

and CS had an additional displaced fracture of the distal forearm, so he could be discharged after 5 days. In one case, where K-wires were used alone, the patient initially had a complex dislocation of the elbow, which made it necessary for him to stay for 8 days (Figure 15).

The median time of hospitalization for patients treated with K-wires alone was 2 days (range 1-8). In the cases with use of CSs, the median time spent in hospital care was also 2 days (range 1-4). Patients who received both K-wires and CS for fixation of the fragment spent a median of 3 days hospitalized (range 1-5). The overall median was 2 days of hospitalization for surgically treated patients (range 1-8). The total time spent in the hospital for the surgical treatment for each procedure is shown in Figure15.

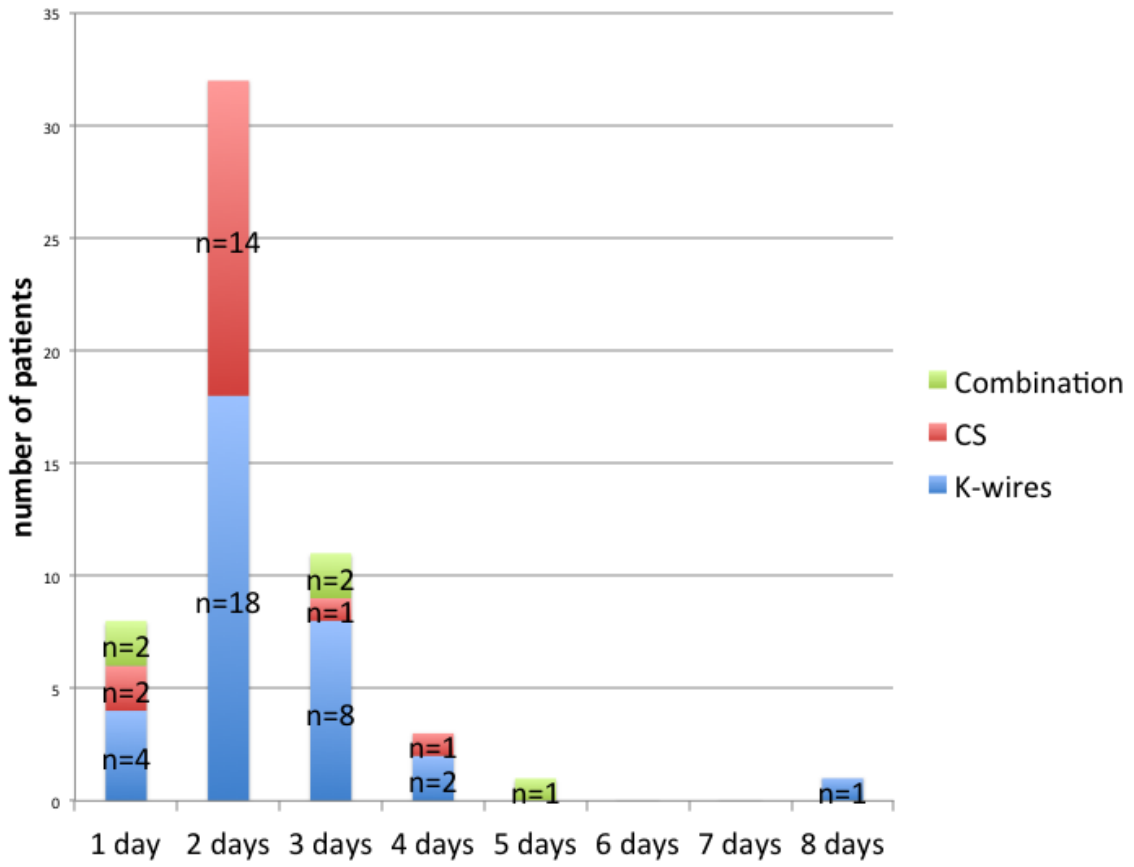


Figure 15 - Days of hospitalization with respect to surgical method of fixation

If an elbow luxation was present or a fragment dislocation was diagnosed, the favoured method of fixation in the operative group was the placement of K-wires alone. Second choice was CS implantation alone and third choice was the combination of both (Figure 16a and 16b). In the case of a combined elbow luxation and fragment dislocation, diagnosed in 12 patients (21.4%) treated surgically, this tendency did not change, with 6 patients (50.0%) treated with K-wires, 4 being treated with a CS implant (33.3%), and 2 receiving the combination of both methods (16.7%) (Figure 16c)

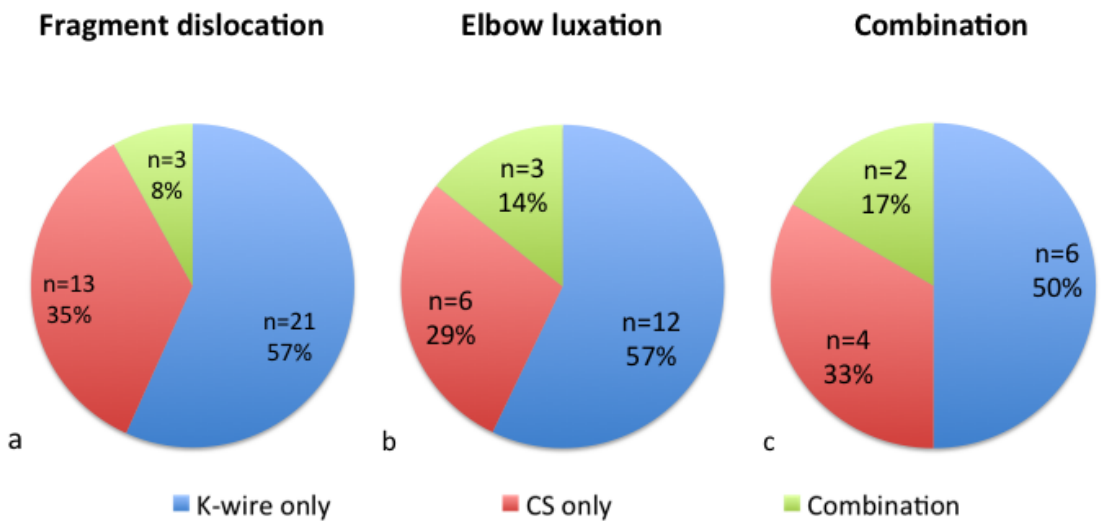


Figure 16 - Surgical method used with respect to injury

All but one of the patients in the operative group had the affected elbow immobilized after the surgical intervention. This was achieved by means of either an upper-arm cast or splint to ensure an adequate healing process. The patient who did not receive an immobilization of the arm had a single CS inserted to reattach the fractured epicondyle in its anatomically correct position.

The median time of immobilization in the surgical group was 22 days and ranged from 4 to 38 days. The median postoperative immobilization in the subgroup of patients treated with K-wires was 22 days and ranged from 8 to 38. In the cases were a CS was used a median of 19 days of immobilization was necessary with a range from 4 to 33 days.

The same median of 19 days of immobilization applied to patients who received the combination of K-wires and a CS (range 11-24). Figure 17 shows the differences in the duration of the postoperative immobilization of the arm in respect to the surgical methods used.

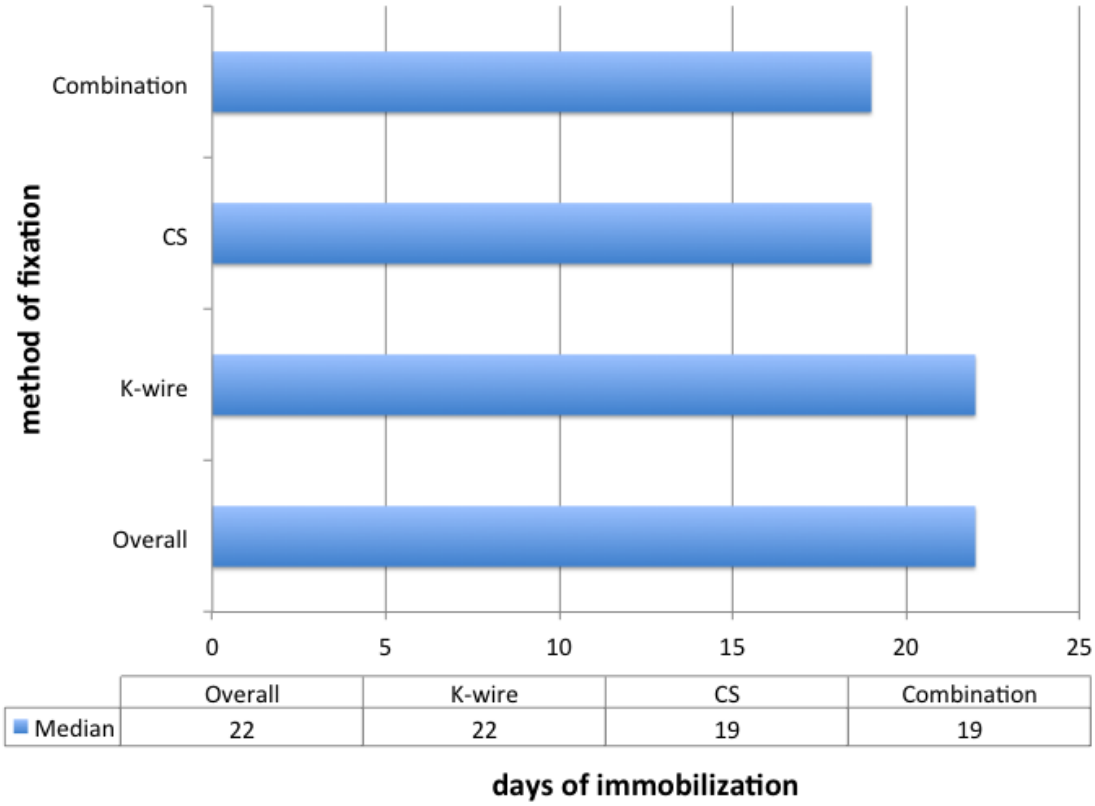
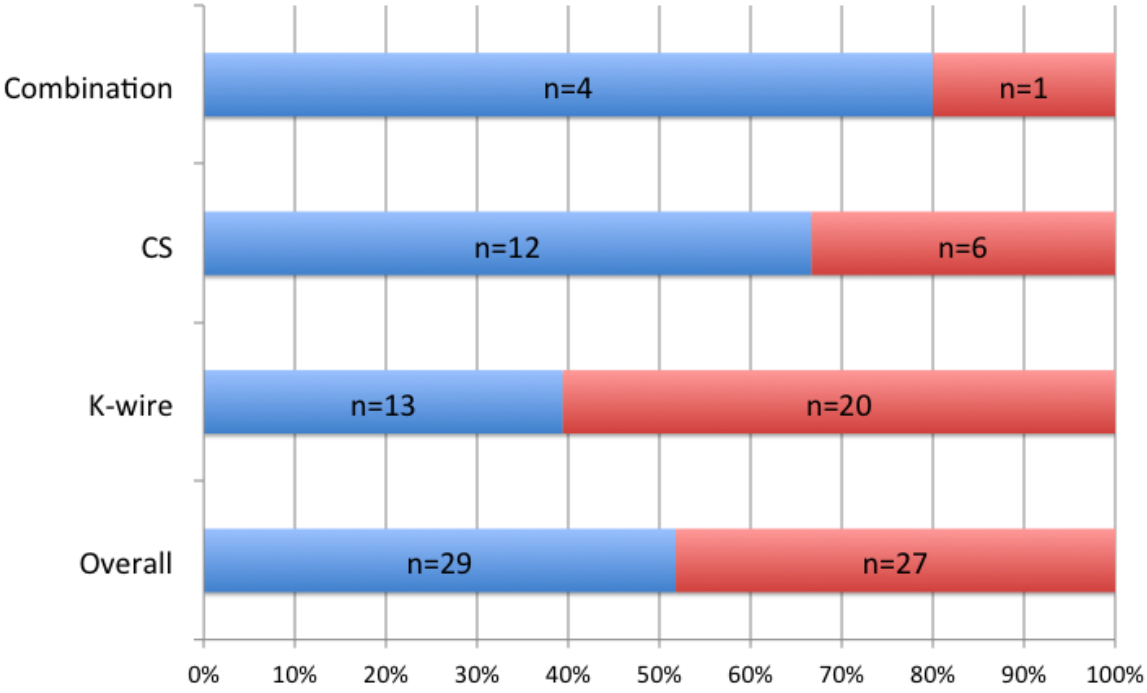


Figure 17 - Days of postoperative immobilization with respect to surgical method used

Complications during surgery were rarely seen and did not further influence the patients' condition postoperatively. Only in one case a postoperative clinical examination, 3 weeks after the surgery, revealed that the fractured epicondyle was not reattached to the humerus because the CS used was positioned proximally to it, missing the fragment. In this case a revision was necessary, in which the CS was removed and the fragment was reattached to the bone with 2 K-wires. This resulted in a longer treatment.

On top of the general recommendations to start mobilization of the elbow as soon as possible after immobilization, 29 surgical treated patients (51.8%) were referred to physiotherapy. This was to ensure the proper healing process and to prevent permanent reduced function of the affected joint.

With regards to the surgical method used, patients receiving a combination treatment with CS and K-wires had the highest rate (80.0%) of physiotherapy requirements, followed by patients with CSs alone (66.7%), whereas the lowest rate was found in patients where only K-wires were used (39.4%) (Figure 18).



	Overall	K-wire	CS	Combination
Yes	29	13	12	4
No	27	20	6	1

Figure 18 - Ratio of physiotherapy in surgical patients with respect to method of fixation

All but two surgically treated patients underwent implant removal at some point. In one case, where a combination of K-wires and CS was used, it was the patient's choice to refrain from removing the CS and to remove the K-wire only. In the other case the CS used was resorbable and no extraction was planned from the beginning. It should be mentioned that this case was one with a rather poor outcome. The patient, after being discharged from our care, returned approximately 1½ year later because of persisting complaints including neurological and muscular problems. This made another intervention necessary two years after the patient was initially released from our treatment, in which decompression of the ulnar nerve had to be performed.

The median time between initial surgery and the removal of the implants was 94 days (range 22-327) in total. The surgical method used for fixation influenced the duration the implants stayed in situ. Patients with K-wires alone had them removed after a median of 63 days (range 22-195), which was the shortest period of time. In the other two groups of surgically treated patients, those with a combination of K-wires and CS had them removed after a median of 96 days (range 31-178), and patients, who received only CSs, had removal after a median of 125 days (range 44-327) (Figure 19).

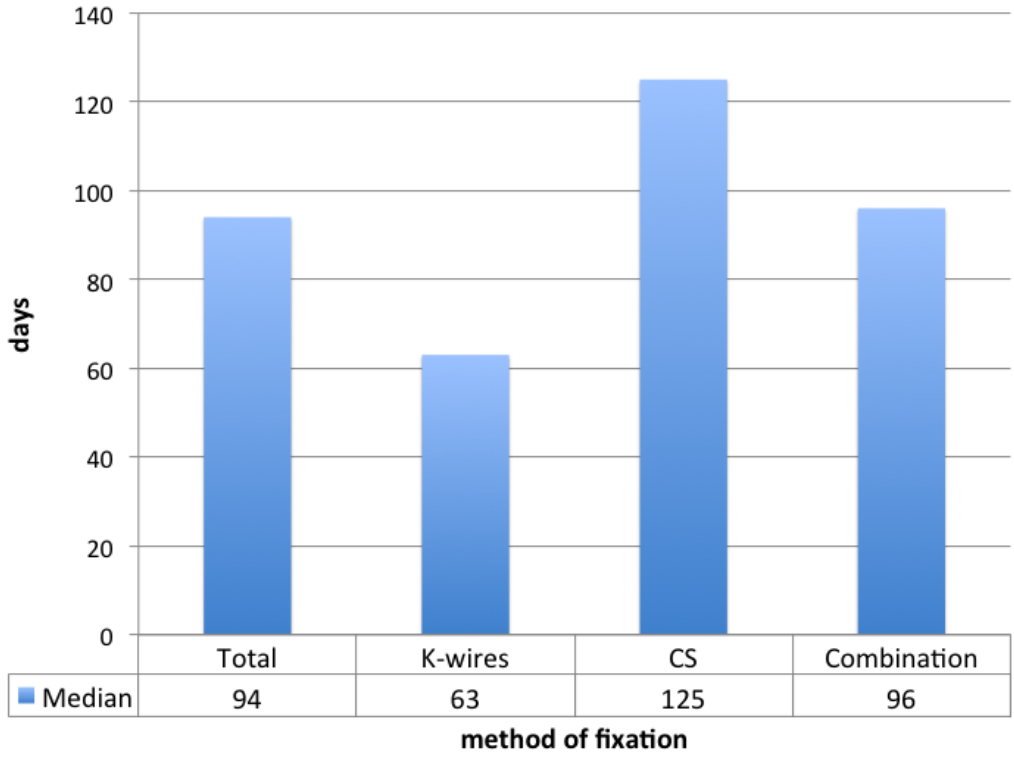


Figure 19 - Time of implants in situ in surgical patients

In 48 cases (87.3%) the removal of the implants could be performed without any complications in our day-surgery department. In 4 cases (7.3%) a hospitalization was necessary for the observation of the patient, but all patients were allowed to leave on the following day. The remaining 3 removals (5.5%) were performed in our outpatient department. Out of the 4 patients, who were hospitalized, 3 had a CS implanted and one only K-wires as means of fixation.

Conservative treatment

The median age of the 19 patients (23.5% of the total 81 cases) treated by immobilization of the affected arm alone, was 12 years (range 5-16). The methods of choice were either the application of an upper-arm plaster cast or the use of an upper-arm splint to keep the affected elbow in a 90° flexed position. Additionally, the arm was supported by the use of a sling. Out of the 19 patients in this group, 16 patients (84.2%) could be treated in outpatient care and 3 patients (15.8%) were treated as in-patients, but only because of late admission with no further therapeutic consequences and all of those 3 patients, however, could be discharged the following day. 17 of our conservative patients (89.5%) were treated within the first two days of injury. In 2 cases (10.5%) it took up to 5 days for the patients to be diagnosed and treated for MHEF. Both patients came to our department because of persistent swelling and pain after they initially underestimated the severity of their injury. The majority of patients in this conservatively treated group did not have a luxation of the affected elbow at the time of the first presentation. Elbow luxations were diagnosed in 4 cases (21.1%). Also, a fragment dislocation was diagnosed in 7 cases (36.8%). The combination of an elbow luxation and a fragment dislocation was diagnosed in 2 of our patients (10.5%). The median period of time the injured arm was immobilized was 21 days, with a range from 6 to 46 days. After immobilization was removed, 8 patients (42.1%) required further physiotherapy in order to improve recovery of the affected arm. There were three out of four patients with an elbow luxation, four out of seven patients with fragment dislocation, and two patients with combination of fragment dislocation and elbow luxation that were subsequently referred to physiotherapy to improve the healing process.

Conversion

The 6 patients (7.4% of the total 81 patients) in this group had a switch from conservative treatment to a surgical treatment after a median of 12 days (range 6 – 156 days). The surgical methods used for fixation of the fractured epicondyle in these cases showed an even distribution with 3 patients (50%) being treated by implantation of one - or in one case two - CSs and other 3 patients (50%) receiving K-wires as means of fixation of the fragment in its original position (Table 5).

	Total	K-wire	CS
Number of patients (n)	6	3	3
Median age (a)	13,5 (12-15)	14 (12-15)	13 (12-15)
Median hospitalization (d)	3 (2-6)	3 (2-3)	3 (2-6)
Elbow luxation (n)	3 (50%)	2 (66.7%)	1 (33.3%)
Fragment dislocation (n)	6 (100%)	3 (100%)	3 (100%)

Table 5 - Description of patients who had conversion

In all 6 cases the initial diagnosis missed the fracture of the medial humeral epicondyle and the fragment dislocation. Therefore, further investigation by means of MRI (in 2 cases, 33.3%) or CT scans (in 2 cases, 33.3%) had to be performed in the majority of these cases to determine the final diagnosis of MHEF. Overall the median duration until conversion was 12.5 days with a range from 7 to 156 days. Three patients, who received K-wires as means of fixation of the fracture, were a median of 14 years old (range 12-15) and the duration between the injury and the treatment ranged from 7 to 14 days with a median duration of 13 days. The other 3 patients, in whom CSs were used for the fixation of the epicondyle, were a median of 13 years old (range 12-15) and the period between the injury and the treatment ranged from 7 to 156 days with a median duration of 12 days as well (Table 6).

Gender	Age	Reason	Day of conversion	Treatment
14	M	Missed MHEF	156	CS (2)
15	M	Missed MHEF	14	K-wire
14	M	Ulnar instability	12	K-wire
13	M	Missed MHEF	12	CS
12	W	Missed MHEF	7	Screw
12	M	Rotated Fragment	6	CS

Table 6 - Patients who needed conversion

Three patients (50%) were operated on the day of admission and the other 3 patients (50%) on the following day, with a postoperative hospitalization of 2 days for all 3 patients treated with K-wires and a median of 3 days (range 2-5) for patients who had CSs implanted. This resulted in a total median hospitalization of 3 days (range 2-3) in the cases where K-wires were used and 3 days (range 2-6) in the cases where CSs were used as means of fixation.

All but one patient, who had two CSs implanted, received an upper-arm plaster cast or splint postoperatively, for the immobilization of the injured arm. The overall median duration of immobilization in the conversion group was 21 days (range 9 – 24 days), with a median of 23 days (range 21-24) if K-wires were used and 10 days (range 9-11) if CSs were used.

Out of the 6 patients in this group, who all were diagnosed with a dislocation of the fragment of the fractured epicondyle, 3 patients (50%) had an initial luxation of the affected elbow as well. Two of them (66.7%) were treated with K-wires as means of fixation and one patient (33.3%) had a CS implanted to stabilize the fractured medial humeral epicondyle.

Physiotherapy, after immobilization of the arm, was recommended in 3 cases (50%) in this group, with two patients that had received K-wires and one patient that had two CSs implanted.

Patients in the conversion group had the implants removed after a median of 60 days (range 47-241). The first subgroup of patients, which was treated with K-wires to fix the MHEF, had the implants removed after a median of 56 days (range 47-59). The second subgroup of patients, which was treated by implantation of CSs, had the implants in situ for a median of 147 days (range 61-241).

One of the patients (16.7%) in the conversion group treated with K-wires was hospitalized for one day for the extraction of the implants while the other 5 patients (83.3%) could be treated in our day surgery unit.

Follow-Up

The follow-up period was considered as the period after implant removal in the operative and conversion groups, and as the period after immobilization in patients, that were treated conservatively. Overall, patients presented themselves a median of 4 times (range 2 – 9) during treatment. In the operative group the median number of visits was 4 (range 2 – 9), including a median of 3 presentations (range 2 – 7) in-between the implantation and the extraction of the implants. Conservatively treated patients presented themselves a median of 4 times (range 2 – 9) to our department. Patients in the conversion group visited us a median of 3 times (range 2 – 5), including a median of 3 times (range 2 – 3) in between the implantation and the extraction of the metals and a median of 1 time (range 0-2) on follow-up (Figure 20).

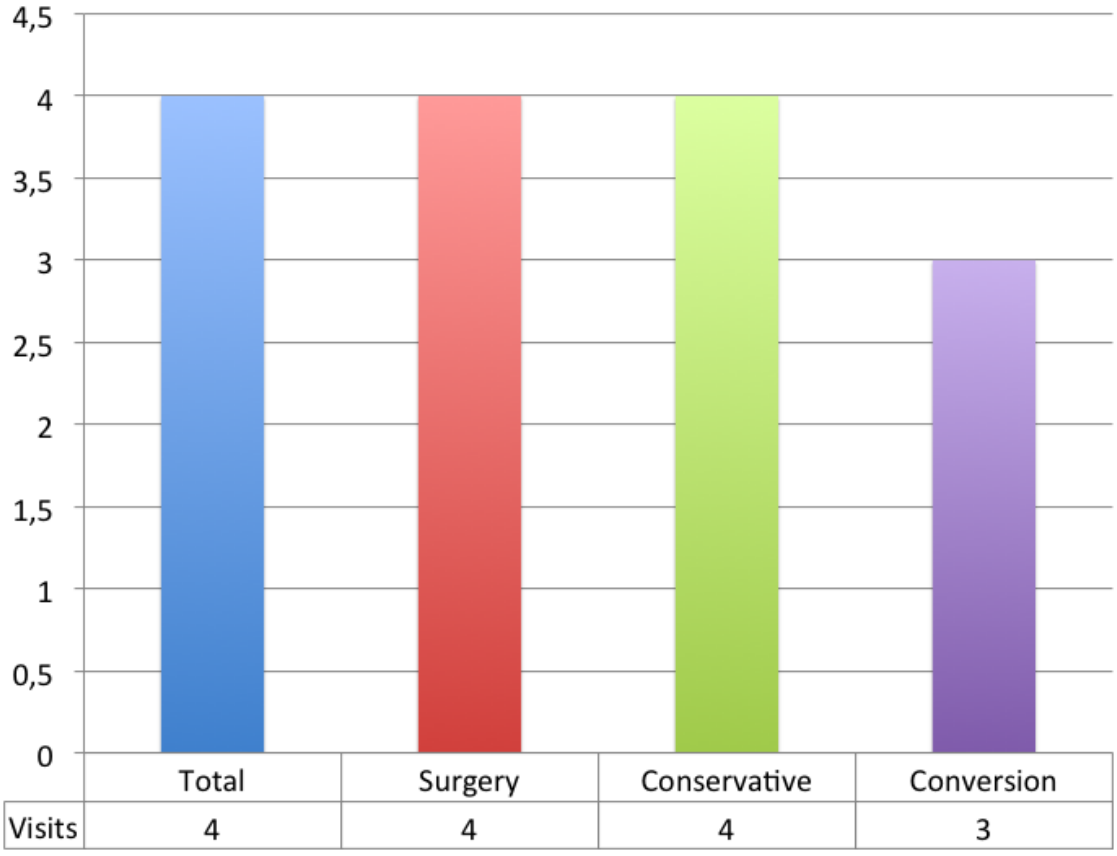


Figure 20 - Median number of visits to our department with respect to method of treatment

Among the surgically treated patients the subgroup that had only K-wires implanted had to visit our department a median of 3 times (range 2 – 8), including a median of 3 times (range 1 – 5) in between the first operation and the removal of the K-wires. In comparison, patients that were treated with implantation of CSs, visited our department a median of 4.5 times (range 3-9) including a median of 4 times (range 2-7) before the extraction of the CSs. Combination of a CS and K-wires made it necessary for the patients to frequent our department a median of 5 times (range 3 – 7), including a median of 3 visits (range 3-5) in between the implantation and the extraction of the metals and a median of 1 visit (range 0-2) after the extraction (Figure 21).

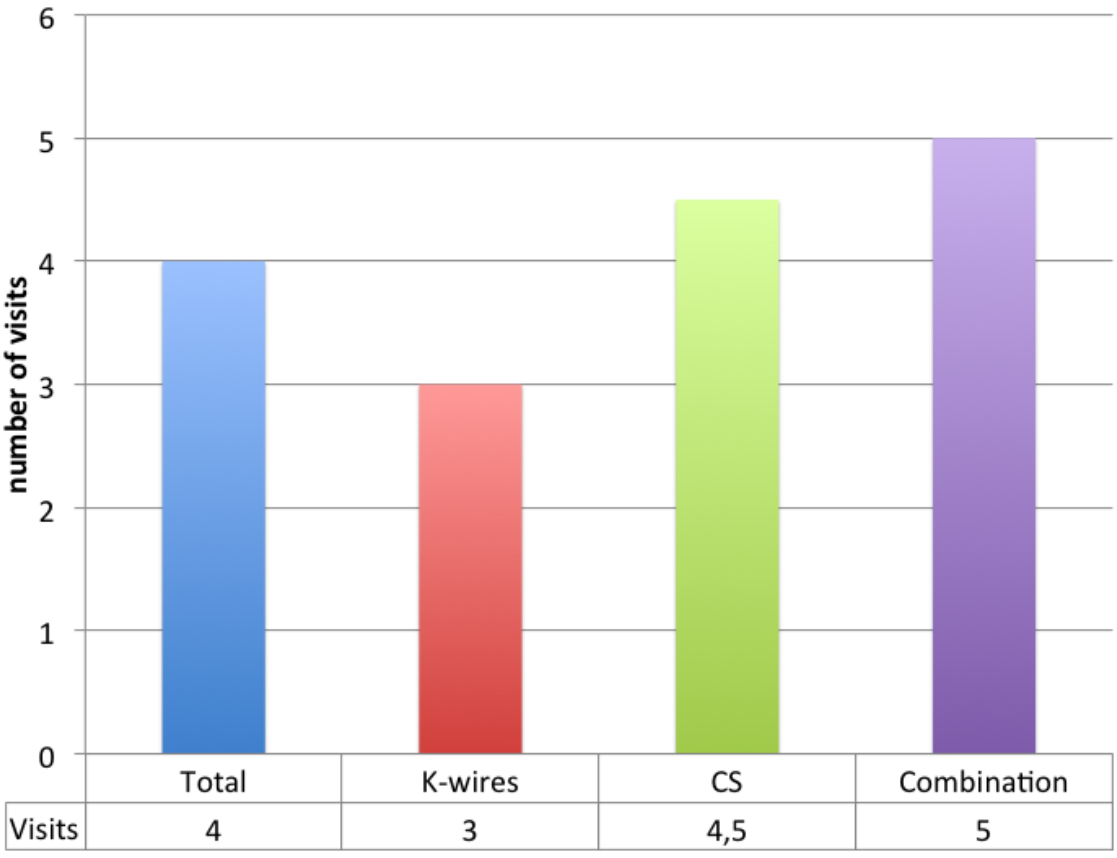


Figure 21 - Median number of visits to our department of surgical patients with respect to method of fixation

In the conversion group, all patients who had CSs implanted to fix the fractured epicondyle presented themselves 3 times in our department with a median of 3 times (range 2 – 3) while the screws were in situ. The patients in this subgroup, with K-wires for the fixation of the fracture, frequented our department a median of

4 times (range 2 – 5), including a median of 3 times (range 2 – 3) in between the implantation and the extraction of the K-wires and a median of 1 more visit (range 0-2) afterwards.

The number of x-ray examinations necessary during the whole process of treatment varied with the method of treatment used. Technically each examination consisted of two x-rays, since the imaging of the affected elbow routinely had to be done in anterior/posterior and lateral position. The following numbers indicate the median number of examinations. Overall the patients were radiologically examined a median of 6 times, with a range of 2 to 10 times during the whole treatment. The most examinations were necessary in the conversion group, with a median of 8 examinations (range 5-10), as compared to a median of 6 examinations (range 3-10) necessary in the group of primarily surgically treated patients. The fewest examinations were necessary in the group of patients that were treated conservatively with a median of 4 (range 2-7) (Figure 22).

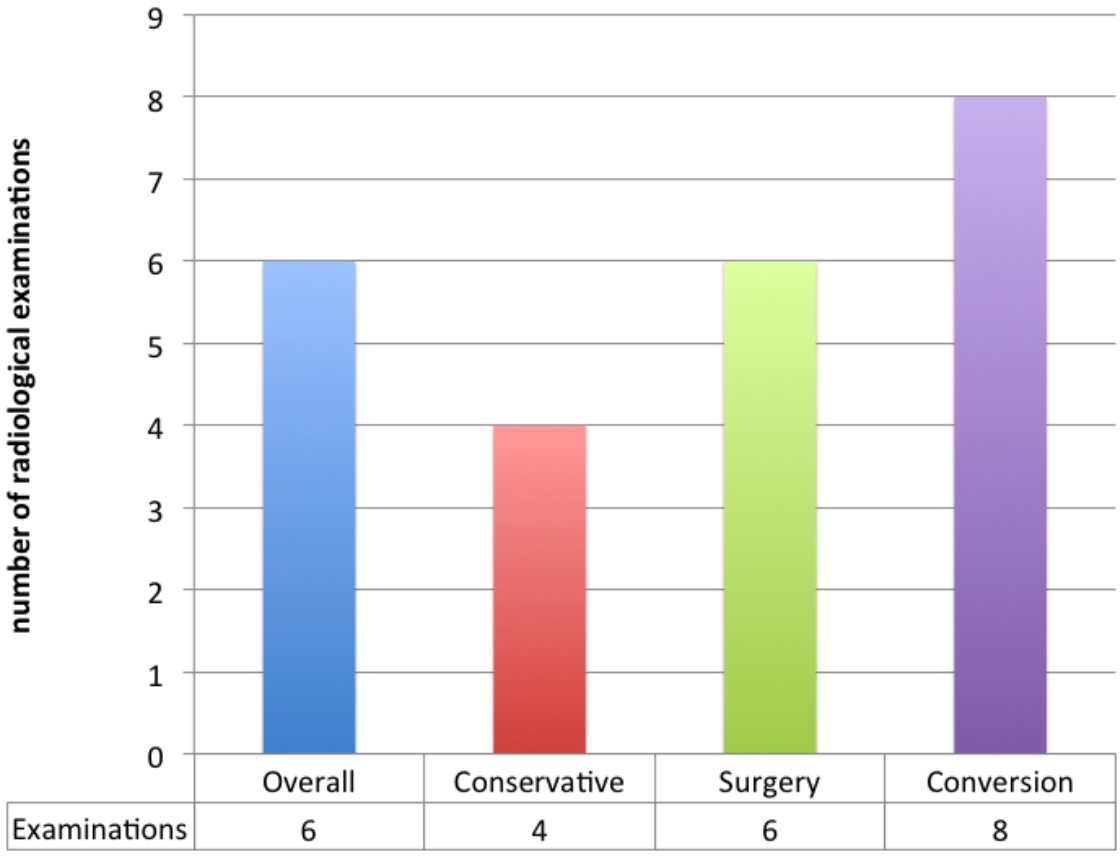


Figure 22 - Median number of radiologic examinations with respect to treatment

The method of fixation did not influence the median number of radiological examinations in the conversion subgroups. Both subgroups of patients had a median of 8 radiologic examinations with a range of 5-10 examinations in the cases where K-wires were used as means of fixation and a range of 6-9 examinations when CSs were used.

While the method of fixation did not influence the number of x-rays in the conversion group, it made a difference in the surgical group. Patients receiving K-wires alone had a median of 6 x-ray examinations (range 3-9). Patients, who had CSs, underwent a median of 6.5 x-ray examinations (range 3-10) during their treatment. The number of x-ray examinations was highest in the group of patients who received a combination of K-wires and CSs, with a median of 8 examinations (range 5-10) during the whole process of treatment (Figure 23).

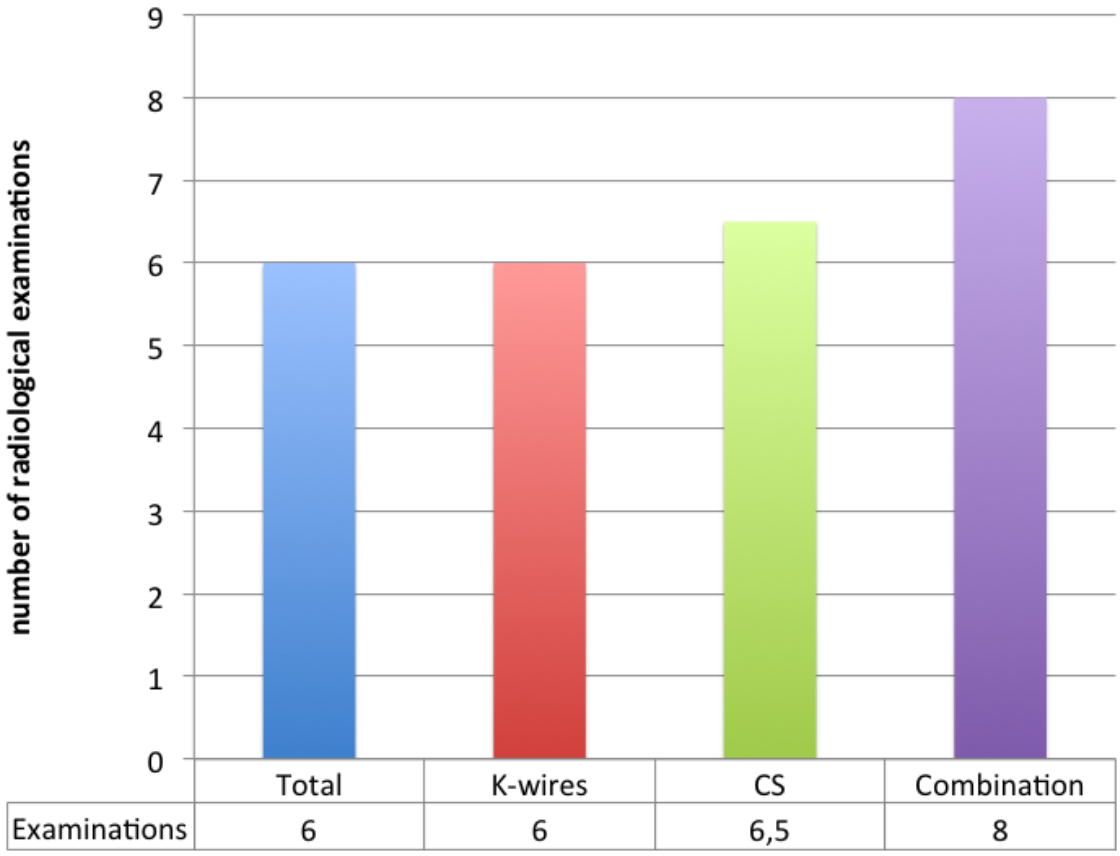
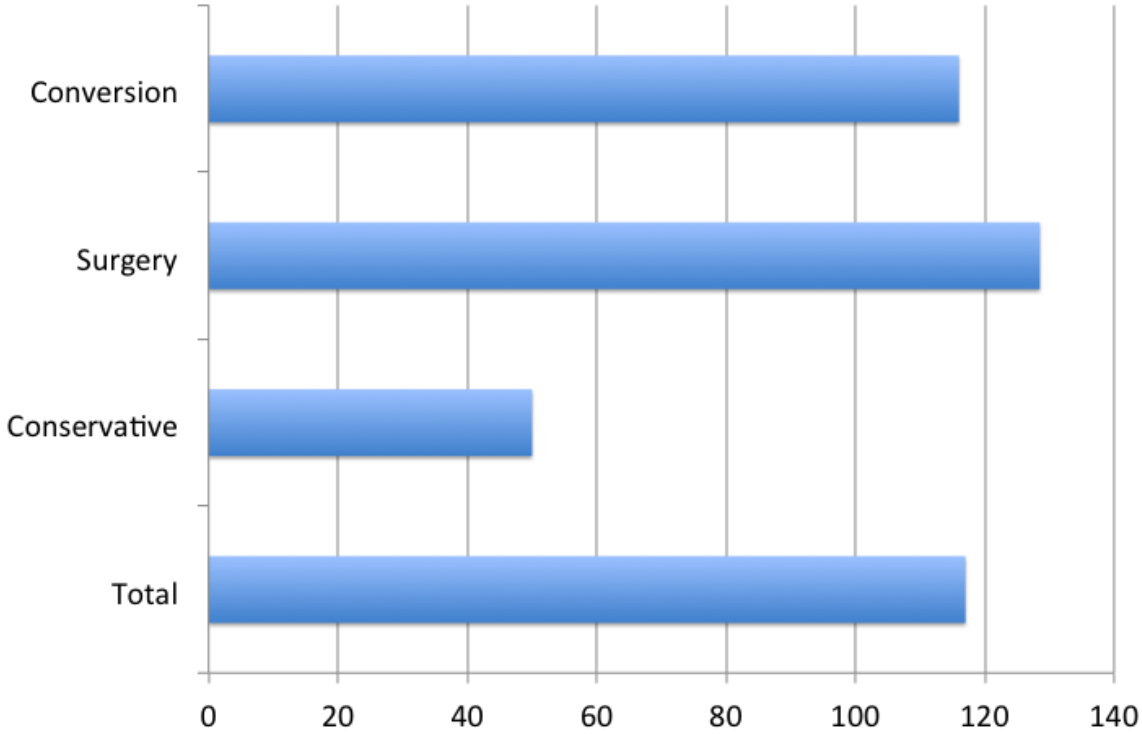


Figure 23 - Median number of radiologic examinations of surgical patients with respect to method of fixation

The overall median duration of treatment was 117 days (range 17 – 453 days). In the operative and conversion groups the start of treatment was set as the date of surgical intervention. In the conservative group the treatment started with the application of the immobilization. Especially in the group of conservatively treated patients this duration was lower, with a median of 50 days (range 17 – 303 days). The longest period of treatment was necessary in the surgically group with a median duration of 128.5 days (range 36 – 453 days) (Figure 24).



	Total	Conservative	Surgery	Conversion
Median	117	50	128,5	116

Figure 24 - Duration of treatment (days) with respect to method of treatment

At first glance the duration of treatment seems shorter in the group of patients that needed conversion, with a median of 116 days (range 59 – 241 days). However, this duration does not take into account the median of 12.5 days (range 12-156 days) needed for the conversion to the final treatment of the patients

With regards to the method used for fixation among our primarily surgically treated patients, the patients who received K-wires could only be dismissed after a median of 108 days (range 36 – 352). In the cases where only CSs were used, the duration of treatment was a median of 164.5 days (range 62 – 453 days). Patients who received a combination of K-wires and CS had the longest period of treatment with a median of 178 days (range 112 – 325 days) (Figure 25).

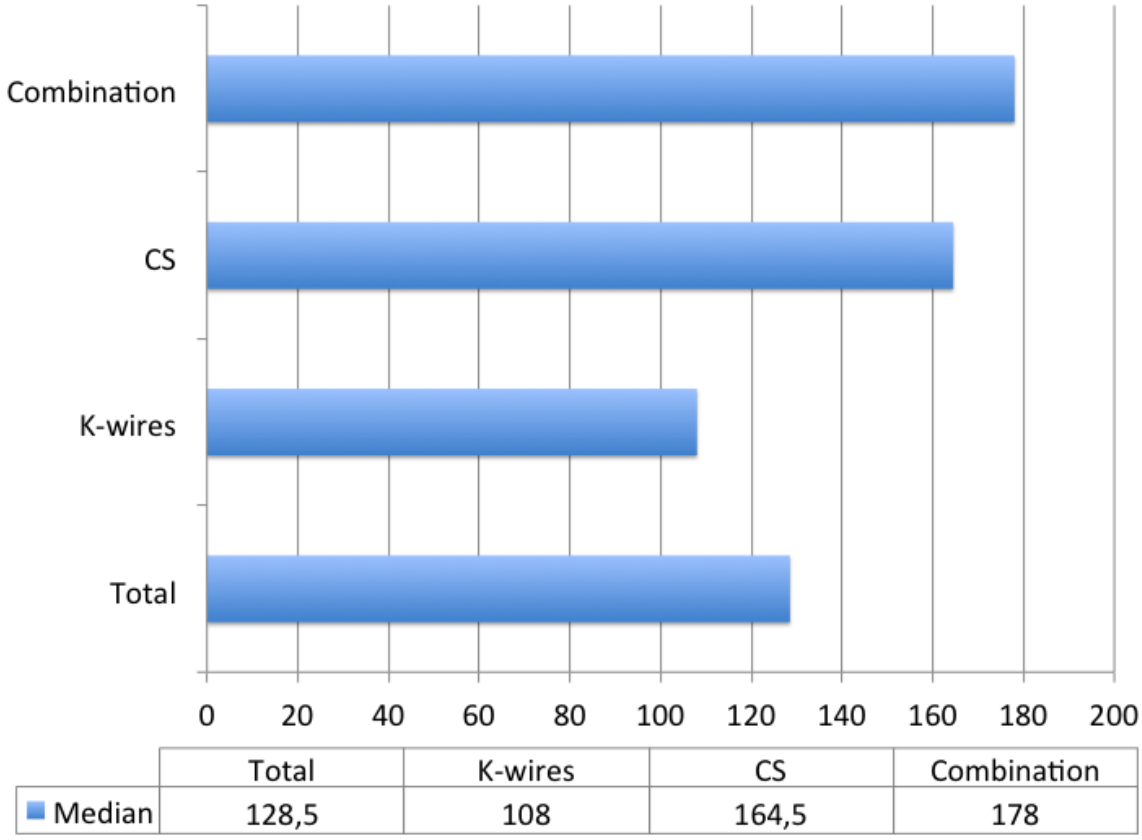
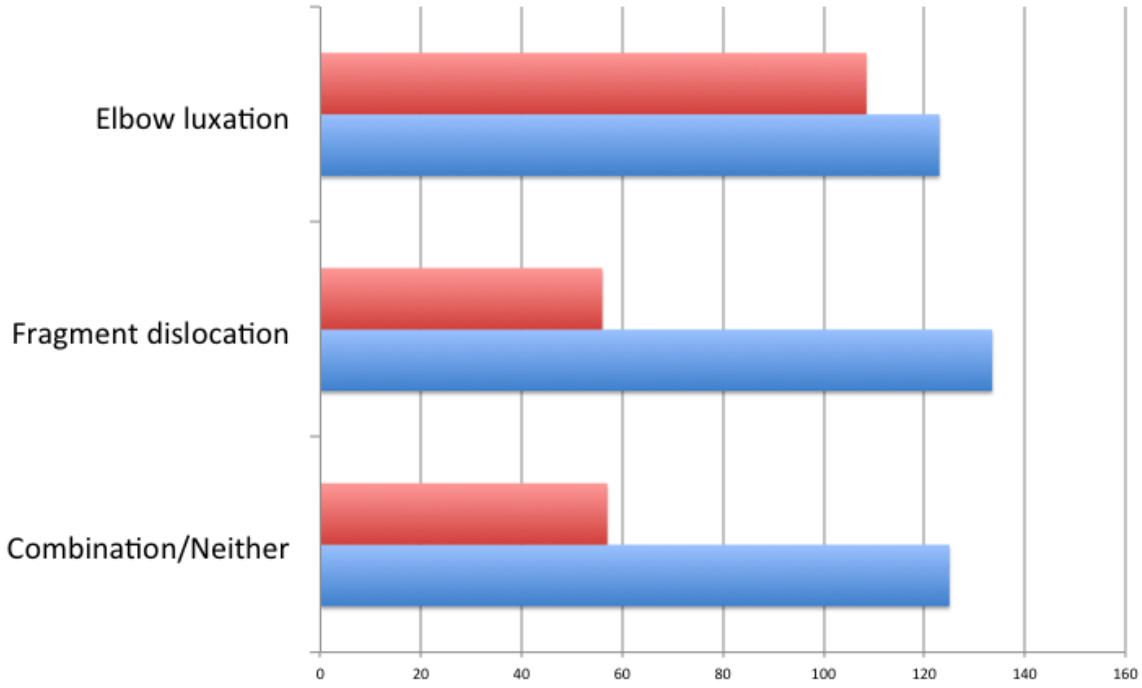


Figure 25 - Duration of treatment (days) in surgical patients with respect to method of fixation

Compared to the overall median duration of treatment (117 days), the presence of a luxation of the affected elbow at the time of admission extended the median duration of treatment by about 6 days (123 days; range 36-338), while its absence reduced it by 8.5 days (108.5 days; range 17-453).

The same, even stronger tendency could be seen in the presence of a dislocation of the medial humeral epicondyle. In those cases the period of treatment extended to a median of 133.5 days (range 27-453), whereas in those cases, where a dislocation of the fragment was excluded, the duration of treatment decreased to a median of 56 days (range 21-290). This shows that compared to elbow luxation the dislocation of the fragmented medial humeral epicondyle has a greater impact on the median duration of treatment.

Among the 17 patients, who were initially diagnosed with a combination of an elbow luxation and fragment dislocation, the median duration of treatment increased to 125 days (range 29-338). In 7 cases both of those injuries could be ruled out and the duration of treatment dropped to a median of 57 days. Figure 26 shows the influence of the type of injury on the median duration of treatment.



	Combination/Neither	Fragment dislocation	Elbow luxation
No	57	56	108,5
Yes	125	133,5	123

Figure 26 - Influence of injury on median period of treatment (days)

Complications during the healing process were rare and with little to no further consequence. According to documentations at follow-up, 15 patients (18.5% of all patients) still had reduced ROM (≤20°) of the affected elbow at the end of treatment. Eight of those patients were in the surgical group (14.3% of all surgical patients), 5 in the conservative group (26.3% of all conservative patients) and 2 in the conversion group (33.3% of all conversion cases). Three patients (3.7% overall; 5.4% of patients in operative group), who were in the surgically treated group, still had a minor nervous deficit in the ulnar nerve region but with steady improvement. Also, 3 operative patients (3.7% overall; 5.4% of surgical patients) reported a slight tenderness over the operated MHE on their final clinical examination. Seventeen patients (21% of all patients) showed persisting anatomical irregularities on their final x-rays. Nine of those patients were treated conservatively (47.4% of patients in conservative group), 6 surgically (10.7% of all surgical patients), and 2 underwent a conversion (33.3% of patients on conversion group). These irregularities included periarticular calcification, fragmented MHE, fibrous union of the MHEF and minimal deviations of the MHE from the anatomically correct position. Apart from one surgical patient, in whom a minimal dorsal deviation of the MHE might have been arguably associated with a transient ulnar nerve deficiency, none of the radiographic abnormalities were linked to any clinically relevant findings or needed further treatment.

One of the patients with persisting complaints was the patient mentioned before, who received a resorbable CS as a means of fixation of the fractured medial epicondyle. Apart from the longest period of treatment, with 453 days, he was complaining of persistent pain and muscular dysbalance in the ulnar nerve region, as well as a reduced ROM and valgus deformity of the affected elbow in comparison to the healthy arm. As mentioned above, he presented again 1½ years later to undergo a surgical decompression of the ulnar nerve. This was the only case in which an additional intervention was necessary.

4. Discussion

Demographics and epidemiology

In a large study evaluating the epidemiology of 8,682 fractures in children, Landin et al. (3), reported that elbow fractures make up to 7% of all fractures in the pediatric population. Out of those fractures of the elbow region, MHEF constitute around 8% of the fractures. In other, smaller studies these numbers are even higher, with MHEF representing up to 11.5% of all fractures in the elbow region and between 3.6 and 14.1% of all fractures of the distal humerus (10,26).

Fractures of the MHE have been the objective of various studies in the past. The main objective of these studies was the establishment of a universally accepted guideline for treatment. However, while there exists common consensus about the conservative treatment of non-displaced MHEF and a number of absolute and relative indications for surgery have been established, many cases fall into a grey zone where the recommendation of the appropriate treatment procedure is still subject of discussion among pediatric surgeons. The goal of our study was the retrospective analysis of the pediatric population in our hospital, which was treated for MHEF. The results, which we achieved through our conservative and surgical treatment approaches, were compared and evaluated under the light of past and present literature, with the target to identify possible areas for improvement in treatment.

The epidemiological analysis of the pediatric population of our patients showed a close resemblance to the epidemiologic aspects reported in many of the other studies about MHEF. In some studies the gender distribution showed an increased incidence as high as 5:1 in boys (27). In contrast, other studies reported an increased incidence in the female pediatric population (25,26). In a systematic review, Kamath et al. (8) reported a male to female ratio of approximately 2:1, which corresponds with the ratio we found in our patient group. In the literature most MHEFs were reported between the ages 9 and 14, with a peak incidence between 11 to 12 years (9,10). Kamath et al. (8) reported an average age of 11.9

years at the time of injury, which shows a close resemblance to the median age of 12 years that was recorded in our patients. The question about which arm was more likely to be injured, the dominant or the non-dominant one, is still controversial: Lee et al. (16) reported the injury to affect the non-dominant arm in 72% of their 25 cases. Whereas other studies with larger cohorts did not address this question and rather showed a right to left ratio of 1.4:1 (3). However, patients in our cohort showed an almost even distribution of left-to-right arm injuries.

Although the mechanisms of injury are well understood, a clear documentation the accident is often lacking. Especially differentiation between strictly sport activities and mere recreational play activities is challenging in this age group. Louahem et al. (6) related 53% of the injuries in their patients to sport activities. Haxhija et al. (22) connected as much as 84% of the injuries in their patients to sport activities. In the present study 67.9% of cases were related to either recreational or athletic physical activity. An interesting additional finding of our study was that a notable number (n=13; 16%) of MHEFs were trampoline injuries. Although MHEFs are not explicitly mentioned in the literature reporting trampoline injuries, fractures in general are seen more often in the upper extremities in these accidents (28–30). Fractures of the humerus and the elbow rank second after fractures of the forearm in these cases (31). Certainly a connection can be drawn to the most common mechanism of injury of a fall on the outstretched arm.

Outcome

Criteria for the assessment of MHEF treatment outcome show variations in different studies regarding MHEF. Some studies rely on subjective patient-reported questionnaires. Two scores which are commonly used, are the Mayo Elbow Performance Score (MEPS) (32) and the QuickDASH (Disability of Arm, Shoulder and Hand; a shortened version of the DASH outcome measure) (33). Other authors utilize, mostly self-developed, scoring systems with differently weighted functional and radiological parameters. However, there are some core elements present in most of the studies, which we compared to our results.

Bony union

Regarding the differences in outcome between surgical and nonsurgical treatment of MHEFs in children and adolescents, Kamath et al. (8) conducted a systematical review of 14 studies, published between 1975 and 2007 and including 498 patients. The most apparent and statistically significant (P<0.0001) difference found was the inferior rate of bony union in conservative patients (60 out of 122 cases; 49.2%) compared to surgical patients (260 out of 280; 92.5%). In a long term follow-up study of conservatively treated unreduced MHEFs in children, Josefsson and Danielsson (24) clinically reexamined 51 patients after 35 years and found a similar rate of fibrous union of the fracture (n=31; 60.1%). Interestingly, the pseudoarthrosis had developed independently from the initial degree of fracture displacement (1-15mm) in their patients. Mild to moderate residual symptoms were reported in 21% of their patients. However, none of these symptoms influenced daily routine or athletic activities. Apart from mild ulnar nerve symptoms, occurring in 3 patients in their pseudoarthrotic group only, the frequency of all other residual symptoms did not differ between patients with fibrous union and patients with bony union of the fracture. In the present study 3 out of 56 patients (5.4%) in the surgical group, and 3 out of 19 patients (15.8%) in the conservative group, showed a fibrous union of the MHEF at last follow-up. This shows an overall superior rate of bony union achieved in both treatment groups. In agreement with previous studies we still found a higher rate of bony union in the surgical group. After conversion, bony union was present in all of our patients, which demonstrates that bony union can still be achieved after an initial failure of conservative treatment.

Pain

While Kamath et al. (8) found a tendency of less pain reported on follow-up in conservative patients (10 out of 115; 8.7%) as compared to surgical patients (37 out of 246; 15%), the pooled difference was statistically not significant (P=0.140).
In a study of 139 surgically treated patients, Louahem et al. (6) reported that all of their patients were free of pain upon follow-up. Five of the 56 conservatively treated patients (9%), that were interviewed in the study of Josefsson and Danielsson (24), reported mild to moderate tenderness over the ulnar part of the

elbow. However, they experienced no restrictions in their work or athletic activities. Three of our surgical patients (5.4%) expressed slight tenderness in the MHE area in their last clinical examination, though without any limitations to their daily activities. None of the patients in the conservative group reported pain at last follow-up.

Ulnar nerve impairment

Kamath et al. (8) did not find a statistically significant difference in ulnar nerve symptoms between operative and conservative treatment. Also Louahem et al. (6) did not find any neurological impairments in their patients upon follow-up. All of initially eight patients (5.8%), who had presented themselves with neurological symptoms, recovered completely. As mentioned before, 3 out of 56 patients (5%) in the study of Josefsson and Danielsson (24) mentioned numbness in the ulnar part of the hand on follow-up. All 3 patients had fibrous union of the fragment and did not feel restricted in their daily routine. Similar to the literature, in the present study we identified 3 of our surgical cases (5.4%) with transient ulnar nerve deficit upon follow-up. Two of these patients did not need any further treatment for their symptoms. The third patient, treated with the resorbable screw, eventually returned to our department after 1.5 years due to persistent complaints. Surgical decompression of the ulnar nerve was subsequently performed.

Range of motion

Restriction in ROM is a very influential factor for functional outcome of MHEFs. The results we found in our patients suggest a slightly higher rate of reduced ROM after conservative treatment but results of various other studies are still inconclusive. Eight patients (14.3%) in our operative group showed a reduced ROM in flexion/extension of not more than 15° on last follow-up. The rate of reduced ROM in our conservative patients was slightly higher, with 26.3% of patients, again with a maximum deficit of 15°. We found reduced ROM in 2 of 6 patients (33.3%) that underwent a conversion, with a maximum deficit of 20°. Outcomes of various studies reported in the literature are very heterogenic: Louahem et al. (13) reported a reduced ROM of less than 20° in 6 cases (4.3%). Josefsson and Danielsson (24) observed reduction of ROM in both of their groups

(fibrous and bony union) equally, with an overall 2±6° loss of extension (range: 0-25°) in 21.6% of their patients. Farsetti et al. (21) found a limitation of elbow extension in 2 of their conservatively treated patients (10.5%) and 2 of their surgically treated patients (11.8%). Though some authors suggest an increased risk of joint stiffness and reduced ROM after prolonged periods of immobilization (9,10,16,34) we did not find any correlation between the time of immobilization and resulting reductions in ROM in our patient groups.

Clinical and radiological deformities

An abnormal valgus deviation of the injured elbow joint was only found in one of our patients (1.2%). This patient was treated surgically with a resorbable screw. Haxhija et al. (22) reported an average 3° valgus deviation in comparison to the uninjured elbow in their patients available for follow-up examination. The mechanism of the hypervalgus deformity in MHEF seems to be caused by damage to the distal physeal plate, either by the original injury or sometimes acquired through ORIF. This is supported also by the fact that as previously stated the MHE, as an apophysis in its nature does not contribute to growth of the distal humerus (7,21,35). Skak et al. (36) described different radiological deformities deriving from MHEFs, such as ulnar sulcus deformity, double epiphysis, hyperplasia, hypoplasia and pseudoarthrosis. However, only pseudoarthrosis and ulnar sulcus deformity could be related to incidence of ulnar neuritis while all other deformities did not affect the patients' daily activities. In the present study, radiological irregularities were found in 17 patients (21%). These radiological findings included periarticular calcification, fragmented MHE, fibrous union of the MHEF and minimal deviations of the MHE from the anatomically correct position. Apart from one surgical patient, in whom a minimal dorsal deviation of the MHE could have been responsible for transient ulnar nerve deficiency, all other patients were free from symptoms.

As mentioned before, one patient in our surgical group, treated with a resorbable screw implant, presented with several complications that made a surgical decompression of the ulnar nerve necessary 1.5 years after initial treatment. The presenting symptoms included persistent discomfort in the MHE area, reduced

ROM, valgus deformity and muscular dysbalance in comparison to the contralateral arm. Although this case could have been incidental, resorbable screws were not further used in our patients. Considering the good results we achieved with other implants, their use can not be recommended.

Conversion

To the author's knowledge, the topic of conversion from conservative to surgical MHEF treatment has not been addressed thoroughly in the literature. One study, however, evaluated the outcome of surgical treatment after an extended period of time in the case of symptomatic nonunion following initial conservative treatment. Smith et al. (37) reported 8 cases out of 42 (19%) that underwent ORIF after initial conservative treatment. Similarly, our conversion rate was 24% (n=6). Indications for conversion in the report of Smith and coworkers were radiographic evidence of nonunion and painful palpation of the MHE. ORIF was performed after a median of 12 month following the injury, which is significantly longer than the median duration of 12 days in our patients. While this limits the comparability to our conversion group, it shows a similar rate of failure of the initial conservative treatment as well as the possibility to convert to ORIF even after prolonged periods of time. Smith et al. (37) reported a patient-reported improvement in functional outcome, determined by Mayo Elbow Performance Score (MEPS), Timmerman-Andrews Elbow Score and QuickDASH (Disability of Arm, Shoulder and Hand) in all patients. Also pain, determined using a 10-point visual analog pain scale (VAPS), decreased notably (from a mean of 6.2 to 0.5) and all patients could return to sports activities. Bony union was achieved in all but one of their patients, who did not show any symptoms in a prolonged follow-up period though. Again this leads to the conclusion that, even after longer periods of time, an initially failed conservative treatment can still yield bony union after conversion.

Smith et al. (37) reported an average ROM of 130° in their converted patients. We found reduced ROM in 2 out of our 6 converted patients (33.3%), with a deficit of 20° in one patient and a deficit of 10° in the other patient. Irregularities on the last radiographs were present in the same 2 patients (33.3%) and included a slight deviation from the anatomically correct position of the MHE in the one patient and

an irregularity of the corticalis in the proximal area of the fracture in the other patient. However, no further intervention was required since our patients reported no discomfort or any other symptoms.

Fragment dislocation

As mentioned above, a number of indications for conservative treatment approaches as well as ORIF of MHEF have been identified in previous studies. The gray area of this injury in the literature revolves mostly around uncomplicated injuries and the distance of fracture displacement tolerable before ORIF is advised.

It seems that radiologic imaging is one contributing factor to this controversy. Edmonds (38) and Pappas et al. (39) raise the question of whether the decision of treatment should be based on the standard radiologic imaging in AP and lateral view of the elbow. Edmonds (38) reported that control three-dimensional computed tomography (CT) scans revealed a fragment displacement of more than 1 cm, though initial standard AP and lateral view radiographs had suggested non-displaced or minimally displaced MHEFs (by his definition <5mm). Pappas et al. (39) highlighted a high discrepancy of “intraobserver” and “interobserver” measurement of displacement of MHEF on standard AP and lateral view radiographs as well as additional oblique radiographs. In general, the correct radiologic imaging and interpretation of x-rays of fractures of the elbow in injured children and adolescents requires a lot of expertise and experience from both, the radiologist and the attending surgeon (18).

Farsetti et al. (21) treated 19 patients conservatively and 17 patients through ORIF with an average fragment displacement of 10mm in both groups (range 5-15mm and 5-14mm respectively). Their results were rated according to their own conducted criteria, which are shown in Table 7.

Good
• No symptoms • Reduced ROM of <10° • Negative valgus stress test (VST) • Atrophy of the muscles of the forearm of <1cm • Normal grip strength • No radiographic signs of osteoarthritis
Fair
• Occasional pain and/or ulnar nerve symptoms under stress • Reduced ROM between 11° and 30° • Moderately positive VST • Atrophy of the forearm muscles of ≤2cm • Reduced ipsilateral grip strength of <10% (<20% if non dominant side) • Mild radiographic signs of osteoarthritis
Poor
• Intermittent or continuous pain/ulnar deficit • Reduced ROM of >30° • Markedly positive VST • Atrophy of the forearm of>2cm • Reduced ipsilateral grip strength of >10% (>20% if non dominant side) • Radiographic signs of osteoarthritis

Table 7 - Criteria for the evaluation of outcome by Farsetti et al. (21)

Of the 19 conservatively treated patients, 16 patients (84.2%) had good results and 3 (15.8%) had fair results. Of the 17 surgically treated patients, fifteen (88.2%) had good results and 2 (11.8%) had fair results. Neither group showed any poor results. The authors concluded that even with fragment dislocation of more than 5mm, conservative treatment provides good long-term functional results.

Notably, Farsetti et al. (21) had a third group of patients, treated with excision of the MHE fragment. Of the 6 patients in this group, 2 had a fair result and 4 patients had a poor result. This demonstrates a markedly inferior outcome of this method.

Conclusion

Based on the findings of our study, we certainly agree to follow the well-established absolute indications for surgery also in the future. However, as far as relative indications for surgery are concerned, the following conclusions can be drawn:

From our point of view, both, surgical as well as conservative methods of treatment are eligible also in the future. But rather than basing the decision for surgery mainly on the distance of fragment dislocation, we recommend to focus on either positive valgus stress test or positive gravity stress test in the decision for surgery. While a surgical approach seems to provide a higher chance for bony union, the functional outcome between surgery and conservative approach does not differ. Furthermore, a reduced duration of treatment and avoidance of two surgical interventions (with possible complication risks) for implantation and extraction of K-wires and/or CSs are further arguments favoring a conservative approach. The possibility for a conversion to surgery after an initial non-satisfactory conservative approach should also be taken into consideration in debatable cases - especially since good functional results can still be expected with conversions at a later stage. In patients with high requirements regarding elbow stability, bony union is a desirable goal of treatment. A lower threshold for an operative approach is therefore justified in these cases.

References

1. Granger B. On a particular fracture of the inner condyle of the humerus. Edinb Med Surg J. 1818;14:196–397.
2. Higgs SL, Cantab BC. Fractures of the internal epicondyle of the humerus. Br Med J. 1936;2(3952):666.
3. Landin LA, Danielsson LG. Elbow fractures in children. An epidemiological analysis of 589 cases. Acta Orthop Scand. August 1986;57(4):309–12.
4. Rasool MN. Dislocations of the elbow in children. J Bone Joint Surg Br. September 2004;86(7):1050–8.
5. Frongia G, Günther P, Romero P, Keßler M, Holland-Cunz S. Ellenbogenluxationen im Kindesalter: Eine Langzeitbeobachtung. Unfallchirurg. 24. September 2010;115(2):125–33.
6. Louahem DM, Bourelle S, Buscayret F, Mazeau P, Kelly P, Dimeglio A, u. a. Displaced medial epicondyle fractures of the humerus: surgical treatment and results. A report of 139 cases. Arch Orthop Trauma Surg. 4. Dezember 2009;130(5):649–55.
7. Von Laer L, Kraus R, Linhart, Wolfgang E. Frakturen und Luxationen im Wachstumsalter. 6. Aufl. Stuttgart: Thieme; 2013.
8. Kamath AF, Baldwin K, Horneff J, Hosalkar HS. Operative versus non-operative management of pediatric medial epicondyle fractures: a systematic review. J Child Orthop. Oktober 2009;3(5):345–57.
9. Smith FM. Medial epicondyle injuries. J Am Med Assoc. 11. Februar 1950;142(6):396.
10. Rockwood and Wilkins' fractures in children. 7th ed. Philadelphia: Wolters Kluwer/Lippincott, Williams & Wilkins; 2010.
11. Cheng JC, Wing-Man K, Shen WY, Yurianto H, Xia G, Lau JT, u. a. A new look at the sequential development of elbow-ossification centers in children. J Pediatr Orthop. April 1998;18(2):161–7.
12. Waldeyer A. Waldeyer - Anatomie des Menschen. Lehrbuch und Atlas in einem Band. 19th ed. Streicher J, Anderhuber F, Pera F, Herausgeber. Berlin, Boston: De Gruyter; 2012.
13. Woods GW, Tullos HS. Elbow instability and medial epicondyle fractures.

Am J Sports Med. Februar 1977;5(1):23–30.

14. Hemmady MV, Subramanya AV, Mehta IM. Occasional head of flexor pollicis longus muscle: a study of its morphology and clinical significance. J Postgrad Med. März 1993;39(1):14–6.

15. Hines RF, Herndon WA, Evans JP. Operative treatment of Medial epicondyle fractures in children. Clin Orthop. Oktober 1987;(223):170–4.

16. Lee H-H, Shen H-C, Chang J-H, Lee C-H, Wu S-S. Operative treatment of displaced medial epicondyle fractures in children and adolescents. J Shoulder Elbow Surg. März 2005;14(2):178–85.

17. Lawrence JTR, Patel NM, Macknin J, Flynn JM, Cameron D, Wolfgruber HC, u. a. Return to Competitive Sports After Medial Epicondyle Fractures in Adolescent Athletes: Results of Operative and Nonoperative Treatment. Am J Sports Med. 18. März 2013;41(5):1152–7.

18. Rang M. Rang's children's fractures. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2006.

19. Bede WB, Lefebvre AR, Rosman MA. Fractures of the medial humeral epicondyle in children. Can J Surg J Can Chir. März 1975;18(2):137–42.

20. Papavasiliou VA. Fracture-separation of the medial epicondylar epiphysis of the elbow joint. Clin Orthop. Dezember 1982;(171):172–4.

21. Farsetti P, Potenza V, Caterini R, Ippolito E. Long-term results of treatment of fractures of the medial humeral epicondyle in children. J Bone Jt Surg. 2001;83(9):1299–305.

22. Haxhija EQ, Mayr JM, Grechenig W, Höllwarth ME. Die Behandlung der Apophysenabrissverletzung des Epicondylus ulnaris im Kindesalter. Oper Orthop Traumatol. Juni 2006;18(2):120–34.

23. Kamath AF, Cody SR, Hosalkar HS. Open reduction of medial epicondyle fractures: operative tips for technical ease. J Child Orthop. 9. Juni 2009;3(4):331–6.

24. Josefsson PO, Danielsson LG. Epicondylar elbow fracture in children: 35-year follow-up of 56 unreduced cases. Acta Orthop. 1986;57(4):313–5.

25. Duun PS, Ravn P, Hansen LB, Buron B. Osteosynthesis of medial humeral epicondyle fractures in children. 8-year follow-up of 33 cases. Acta Orthop Scand. August 1994;65(4):439–41.

26. Zanella FE, Piroth P. Injuries of the elbow and forearm in children. Röntgen-

Bl Z Für Röntgen-Tech Med-Wiss Photogr. März 1984;37(3):111–20.
27. Fowles J V., Kassab MT, Moula T. Untreated intra-articular entrapment of the medial humeral epicondyle. J Bone Joint Surg Br. August 1984;66(4):562–5.
28. Eberl R, Schalamon J, Singer G, Huber SS, Spitzer P, Höllwarth ME. Trampoline-related injuries in childhood. Eur J Pediatr. 24. Dezember 2008;168(10):1171–4.
29. Smith GA, Shields BJ. Trampoline-related injuries to children. Arch Pediatr Adolesc Med. Juli 1998;152(7):694–9.
30. Linakis JG, Mello MJ, Machan J, Amanullah S, Palmisciano LM. Emergency Department Visits for Pediatric Trampoline-related Injuries: An Update. Acad Emerg Med. Juni 2007;14(6):539–44.
31. Black GB, Amadeo R. Orthopedic injuries associated with backyard trampoline use in children. Can J Surg. 2003;46(3):199.
32. Morrey BF, Sanchez-Sotelo J, Herausgeber. The elbow and its disorders. 4th ed. Philadelphia, PA: Saunders/Elsevier; 2009.
33. Beaton DE, Wright JG, Katz JN. Development of the QuickDASH: comparison of three item-reduction approaches. J Bone Jt Surg. 2005;87(5):1038–46.
34. Case SL, Hennrikus WL. Surgical Treatment of Displaced Medial Epicondyle Fractures in Adolescent Athletes. Am J Sports Med. 1. September 1997;25(5):682–6.
35. Van Niekerk JL, Severijnen RS. Medial epicondyle fractures of the humerus. Neth J Surg. Oktober 1985;37(5):141–4.
36. Skak SV, Grossmann E, Wagn P. Deformity after internal fixation of fracture separation of the medial epicondyle of the humerus. J Bone Joint Surg Br. März 1994;76(2):297–302.
37. Smith JT, McFeely ED, Bae DS, Waters PM, Micheli LJ, Kocher MS. Operative Fixation of Medial Humeral Epicondyle Fracture Nonunion in Children: J Pediatr Orthop. 2010;30(7):644–8.
38. Edmonds EW. How Displaced Are “Nondisplaced” Fractures of the Medial Humeral Epicondyle in Children? Results of a Three-Dimensional Computed Tomography. J Bone Jt Surg Am. 1. Dezember 2010;92(17):2785.
39. Pappas N. Intraobserver and Interobserver Agreement in the Measurement of Displaced Humeral Medial Epicondyle Fractures in Children. J Bone Jt Surg

Am. 1. Februar 2010;92(2):322.