UNIL | Université de Lausanne
Faculté de biologie
et de médecine

Centre hospitalier
universitaire vaudois

RADIAL HEAD FRACTURES IN CHILDREN: A RETROSPECTIVE STUDY

Tutor
Dr Lutz Nicolas, MER
Unité Pédiatrique de Chirurgie Orthopédique et Traumatologique, CHUV

Student
Daria Daniela Müller
University of Lausanne, Medicine

Expert
Dr Vauclair Frédéric, MER
Service d'Orthopédie et de Traumatologie, CHUV

Lausanne
January 2020

1 Abstract

1.1 Introduction

Radial head fractures (RHF) account for less than 1% of all paediatric fractures. Most heal without complications following a 10-14 days course in a long arm cast applied without manipulation. Concomitant fractures occur in 20% to 34% of cases and affect the management, which vary greatly in published series. The most severe complication of RHF is a necrosis of the head. A critical appraisal of the management of this rare injury is of great value to evaluate the quality of care. The aims of this study were to assess the treatment modalities, complications and outcome of children with RHF treated in our institution.

1.2 Patients and Methods

Retrospective review of all paediatric RHF treated in a tertiary paediatric medical centre between the 1st of January 2011 and the 31st of December 2014. Collected data included age, gender, side of injury, time of immobilisation and concomitant fracture. Treatment modalities including in situ cast immobilisation, closed reduction, percutaneous reduction and open reduction were recorded. The degree of displacement was measured using the modified Judet and the AO classifications. Final functional outcome and radiographs were analysed, looking for mal- or non-union radial head necrosis, or radio-ulnar synostosis. The immobilisation time, number of concomitant fracture and type of different treatment methods were assessed. Complications and final range of motion were evaluated. The results were compared to the literature as well as the current guidelines of the University Hospital of Lausanne (CHUV).

1.3 Key words

Fracture, Radial Head, Children, Paediatrics, Classification of Judet

1.4 Results

Out of 54 identified cases, 47 were included in the study. The mean age of the patients was 7 years (y) 10 months (m) (2y3m - 12y5m). Judet 1,2,3 and 4 fractures were identified in 31 (66%), 3 (6%), 7 (15%) and 6 (13%) cases, respectively. A concomitant fracture was identified in 28% of the cases. Girls had twice as many concomitant fractures than boys. 100% of Judet 1 single fractures were treated with a cast and had an excellent outcome. Half the Judet 4 fractures were treated with closed reduction without any significant difference in the functional outcome when compared to the surgically treated. Almost half of the Judet 3 and 4 fractures (n=13) were treated using flexible elastic nails (ESIN). Open reduction was required in less than 10% of the cases. The mean immobilisation time of patients treated without surgery was of 18.5 days, compared to 25 days for the surgically treated. Complications were identified in 6 cases. No radial head necrosis occurred.

1.5 Conclusion

Paediatric RHF were immobilised too long, with presenting a 4 days excess of immobilisation time when compared to the current literature and the guidelines of the HEL.

Almost a third of all patients had concomitant fractures which were not related to the degree of displacement. In this study twice as many girls had concomitant fractures compared to boys. It is recommended to research concomitant fractures systematically. At HEL the open reduction was rarely needed. Few complications were seen in both, conservatively treated and operatively treated patients, but were more commonly seen after operative management. Regardless of the treatment method used no radial head necrosis was recorded.

The management of RHF in our institution was adequate when compared to the literature. Children with simple radial head fracture treated in our institution would further benefit from a shorter immobilisation time while there is no increase of complications or functional loss.

2 Table of contents

3 List of abbreviations

ARCHIMEDE	Archimede is the legal application used as an archive of the medical file of each patient. Archimede is connected to Soarian by an informatic file of the patient
BMI	Body Mass Index
CHUV	Centre hospitalier universitaire vaudois
CIMP	Closed reduction and intramedullary pinning
ESIN	Elastic stable intramedullary nailing
F/E	Flexion and extension
FIN	Flexible intramedullary nail
HEL	Hôpital de l'Enfance Lausanne
K Wire	Kirschner Wire
ORIF	Open reduction and internal fixation
PCCF	Paediatric Comprehensive Classification of Long-Bone Fractures
PIN	Posterior interosseous nerve
PR	Percutaneous reduction
P/S	Pronation and supination
RHA	Radial head angulation
RHF	Radial head fracture
ROM	Range of motion
SOARIAN	Soarian health archive is a digital archive and document management solution. This provides enhanced archiving and document management functionality for different kind of documents and data that occur in a hospital
T	Translation
m	month
n	number of patients
y	year

4 Introduction

The high amount of cartilage around the radial head and the epiphysis makes the fracture of the radial head a rare injury in children.[4] Only around 5-10% of the elbow fractures and about 1% of all child bone fractures are radial head fractures.[1,11]

The age at which ossification of the 6 ossification centres occurs is mostly variable between individuals, but normally occurs in a defined order (see fig. 1). While the radial head appears between the 3rd-5th year of age, the radial head fuses with the radial shaft between ages of 16-18.[11] Referring to the study of Cevik et al., radial head fractures are mostly seen in children at the age of 4-14 years, since radial head ossification does not occur prior to the age of 5.[18] According to Guyonnet et al. and Attaraf et al., the peak incidence of radial head fractures is between ages 8 and 13.[1,12] The age affects the decision of treatment modalities greatly as there is a significant potential for remodelling if the child is less than 10 years old.[4,5] In addition, radial head fractures must be treated as a potentially serious injury, with a necrosis of the radial head being the most dramatic complication. Not only a necrosis of the radial head but also pseudarthrosis, growth arrest, mal- or non-union, and radioulnar synostosis can result in stiffness and functional disability of the articulation.[1,12]

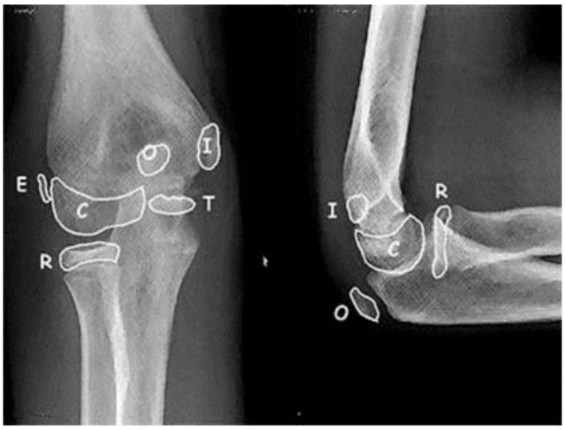

Figure 1: 6 Ossification centers CRITOE - capitellum (1y), radius (3y) internal or medial epicondyle (5y), trochlea (7y), olecranon (9y) and external or lateral epicondyle (11y).

The age and the radial head angulation determine the management of such fractures. According to Kruppa et al., fractures with less than 30° degrees of angulation and a translation of less than 3mm do not need reduction in skeletally immature children who have full pronation and supination.[4,5] In fractures with an angulation of more than 30°, a displacement greater than 50% in children younger than 10 years as well as fractures with an angulation greater than 15° in children older than 10 years, a closed reduction under anaesthesia should be performed.[4,5] Similar to these thresholds, Monson et al.[29] or Seung et al.[22] recommend simple immobilization for angulations less than 30° as remodelling is excellent, especially in younger children. The lower potential of remodelling in older children explains the less tolerated displacement and angulation compared to younger children.[5] In order to avoid stiffness and complications as mentioned above, if closed reduction fails and surgical treatment is needed, percutaneous techniques with elastic stable intramedullary nailing (ESIN) or Kirschner-Wire are now favoured over open techniques.[13] Open reduction as a treatment for radial head fractures should be avoided and only be used when other treatments were unsuccessful.[5,11,23]

The guidelines of traumatology in paediatrics from the Hôpital de l'Enfance (HEL) suggest slightly different guidelines in terms of angulation and displacement compared to the values shown above (see fig. 7).[24] Similar to the guidelines of the HEL, Tan and Mahadev et al.[16] recommend the same stepwise level of invasiveness protocol: undisplaced fractures or displaced fractures with an angulation of less than 45° should be treated conservatively with cast and without manipulation, and for those with angulation >45°, closed reduction should be attempted. If it fails, percutaneous reduction should be preferred over open reduction.[16]

Not only the treatment method is still debated but also the immobilisation time of radial head fractures stays a subject of discussion. For children treated with immobilisation only recent literature recommends an immobilisation time as short as possible. Similar to Laer et al.[15], the guidelines of Lausanne suggest that fractures treated with immobilisation only need a brachio-antebrachial cast for 2 weeks.[24] Rockwood and Tschierne et al. suggest an immobilisation time of 7 to 14 days.[26,27] According to Von Laer et al.[28], the immobilisation time should be even lower, suggesting 8 days of immobilisation.

The immobilisation time of the surgical treatment is different to the treatment with immobilisation only and must be defined by analysing the different methods as well as the age of the child. Cosma et al.[32] suggest after ESIN percutaneous reduction a sling for 10-15 days. After this time, elbow mobilisation is allowed, and normal activity is resumed after 3 weeks. In the guidelines of HEL no threshold for the immobilisation time for operative treatments is recorded.

4.1 Objectives and Hypothesis

Radial head fractures are potentially serious injuries because of possible complications, such as radial head necrosis. The management of such injuries is still controversial and highly discussed. This fact leads to the start of this study with 54 paediatric patients, aged between 2 and 15 years suffering from a radial head fracture. The purpose of this study is to analyse their treatment and immobilisation time as well as the related radiological und functional outcome. The study aims to assess a full picture of the demographics, treatment modalities and outcome of children with radial head fractures. Specific items such as the immobilisation time, rate of open reduction and radial head necrosis are evaluated. The management of such injuries and the time of immobilisation are compared to the guidelines of the CHUV as well as the literature. A critical appraisal of the management of such injuries in our clinic is of great value and the quality of care could be improved.

The daily clinical practice suggests that children with radial head fractures are operated too often and immobilized for too long. The hypothesis of this study is therefore the following:

"The length of immobilisation for radial head fractures is too long, and the rate of open reduction is low when compared to current literature."

5 Methods

5.1 Literature review

A literature research was done by using PubMed and Google Scholar with the key words: fracture, radial head, children, paediatric, treatment, complication, Judet’s classification. 32 published scientific articles were identified and used as references. In addition, the book, ”Frakturen und Luxationen” by Lutz von Laer was a further base of knowledge. The AO Paediatric Comprehensive Classification of Long-Bone Fractures (PCCF) was important for the classification of radial head fractures.

5.2 Description of the study

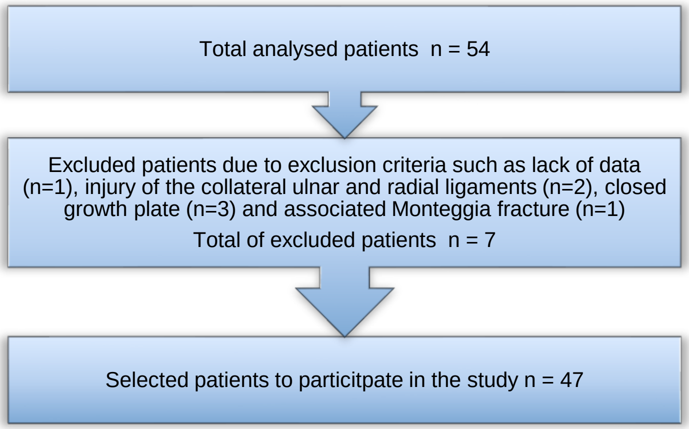

Figure 2: Exclusion criteria and number of final selected patients

A retrospective review of 54 cases of paediatric radial head fractures at the HEL between the 1st of January 2011 and the 31st of December 2014 was performed. The participants were selected at the HEL by using the system AO COIAC, which operates as a codification and recording system of medical files. The 54 selected patients were analysed with the program Soarian and Archimède, to consider the radiographs and to assess the functional and clinical outcome. After this analysis, there were 7 patients who had to be excluded from the study because of different exclusion criteria (fig.2/5.3.1). After having applied the exclusion criteria, a comparison between the management of 47 patients with a radial head fracture at the HEL and the existing guidelines was performed. The analysed guidelines are those from the CHUV/HEL[24] as well as those described in current literature.

The crucial parameter of this study was the immobilisation time of radial head fractures and if they accorded with the values given by the different guidelines. Second, the presence of concomitant fracture was of a big interest. Third, the rate of different treatment methods as well as the presence of complications such as radial head necrosis was recorded.

5.3 Origin and collection of data

5.3.1 Data Analysis

All the data used in this retrospective study was present in the medical file of each analysed patient. There was neither direct contact with the patient nor with their parents to achieve this study. With the selection code 21 r (2 = forearm (radius/ulna), 1 proximal / r = radius) of the AO COIAC system, 54 patients were selected. Only patients treated and followed at the HEL or first treated in another swiss centre with complete information of the follow-up were included. The collected data included characteristics of the patient such as age, gender, BMI, trauma side, as well as the type of fracture and the concomitant fractures, if present. The fractures were classified according to Judet’s classification with Metaizeau modification as well as with the AO classification PCCF. The orthopaedic treatment such as closed reduction or immobilisation with a cast as well as the chirurgical treatment such as percutaneous reduction or open reduction were identified and related to the personal data. To evaluate eventual complications, the radiographs and the clinical follow up were analysed. The final radiographs and the last clinical follow up were assessed looking for radial head necrosis, free fragments, mal- or non-union and radio-ulnar synostosis. Like this, the outcome of each patient was elaborated. The assessment of the outcome was possible due to the analysis of the data from

patients treated between 2011 and 2014 and therefore every patient selected for this study had a complete follow-up.
With the collected data an Excel table with the following content was established: name, birth date, gender, side of injury, date of injury, age at injury, BMI, trauma mechanism, Judet's classification, AO classification, concomitant fracture, treatment, complications, duration of immobilisation, number of radiographs, date of last radiograph, radiological and functional outcome.

5.3.2 Exclusion criteria

Children with chronic illnesses and/or bone and joint diseases as well as children with previous ipsilateral radial head fracture or previous neurovascular injury were excluded from the study. Furthermore, adolescents with closed growth plates, patients not followed in Lausanne and patients with any sign of pathological fractures or injury of the ulnar and radial collateral and annular ligaments were excluded from the study. Pathological fractures were defined as fractures related to a bone disease like bone cancer. The injury of the ligaments interferes with the immobilisation time and falsifies the results of the study. In addition, all polytrauma patients and patients, with not complete follow-up were excluded. Any existence of a document that attests a refusal of the patient to be included into the study resulted in an exclusion of the study. Patients were also excluded if there was insufficient radiographic or clinical documentation. The presence of a Monteggia fracture, known as a proximal ulnar fracture associated with radial head dislocation/instability described another exclusion criterion.

5.3.3 Inclusion criteria

Included in this study were patients suffering from paediatric radial head fractures with and without concomitant fractures occurred between 1st January 2011 – 31st December 2014. All the patients were treated and received their complete follow up at the University Hospital of Lausanne (CHUV/HEL) or in another Swiss Paediatric Hospital with available data. An important inclusion criterion was the fact that every analysed patient had their growth plates open, meaning that the growing process of the bone was not yet finished.
In addition, only children with one of the following treatments were included to this study: immobilisation only, closed reduction and cast, percutaneous reduction with either ESIN or K-wire and open reduction.

5.4 Analysis of the data

5.4.1 BMI

The Body Mass Index (BMI) is calculated by the following formula:

$$BMI = \frac{Weight\ (kg)}{[Height(m)]^2}$$

Since this is a retrospective study, it had to be accepted that there was not enough data to calculate a substantiated mean BMI. The lack of data in BMI was much more important compared to other information. Therefore, the mean BMI and the impact of the BMI on treatment method or immobilisation time could not be analysed in this study. Further prospective studies are needed.

5.4.2 Mechanism/Location

The mechanism of injury was mostly a fall on the outstretched hand, with the elbow in extension and the forearm in pronation.[11,18] The locations where the trauma happened were classified in 5 groups: playground/school, sports, wheel, home and other.

5.4.3 Radiographic evaluation

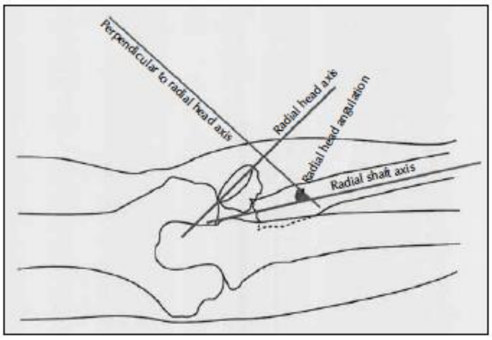

Figure 3: Measurement of radial head angulation

When a radial head fracture is suspected, the recommended view in x-ray are anterior/posterior (a.p) and lateral (lat.) view of the elbow.[11] However, nondisplaced fractures (Judet 1/see chapter 5.4.4.2) may be difficult to visualize. When in doubt, a fad pad sign can be sought.
In this study all patients underwent a.p. and lat. radiographs of the injured elbow at time of the arrival in the hospital. The radiograph was assessed, looking for any concomitant fracture (ulna, humerus) and any luxation or liquid in the articulation. The fractures, which underwent surgery, had another radiograph taken before and during surgery. The radiographs taken while recovering were added to the number of radiographs. Normally a last radiograph was taken at the end of the follow up to analyse the outcome of the performed treatment. The radial head (malunion, non-union, normal) was analysed. Further ectopic calcification or signs of growth arrest were researched.
All radiograph measurements were done by the author of this study (D.M), to avoid any interobserver error. The measurement was performed with a goniometer using the technique shown in fig. 3. If any radiographic measurements were unclear, the radiographs were reviewed with the tutor before recording definitive angulations.

5.4.4 Classification of the fractures

The radial head angulation in the x-ray measured by a goniometer is an objective value to determine the treatment method as well as to predict the functional outcome. With the measured angulation, the fracture was classified according to the AO Paediatric Comprehensive Classification of Long-Bone Fractures (see 5.4.4.1) and according to the Judet's classification with Metaizeau modification (see 5.4.4.2).

5.4.4.1 AO Paediatric Comprehensive Classification of Long-Bone Fractures (PCCF)[14]

The AO PCCF classification system is based on the fracture location and the fractures' morphology. The fracture location comprises the different long bones and their respective segments and subsegments.[14] So every bone has his own code (fig. 4): Humerus-1, Radius/Ulna-2, Femur-3, Tibia/Fibula-4. The segments stand for 1 = proximal, 2 = diaphyseal, and 3 = distal. The letters "r", "u", "t", "f" stand for radius, ulna, tibia and fibula and are added to the segment code in paired bones, when only one bone is fractured or both bones are fractured with a different pattern.[14] Segment 1 and 3 (proximal and distal) are divided into two subsegments, the epiphysis (E) and the metaphysis (M). The segment 2 is identical with the diaphyseal subsegment D (fig 3.) The letters "m" and "l" stand for medial and lateral to indicate the side of ligament avulsion. The morphology of the fracture is documented by a specific child code that stands for the fracture pattern, a severity code (1 = simple, 2 = multifragmentary), and an additional code that is used in certain types of displaced supracondylar humeral, displaced radial head

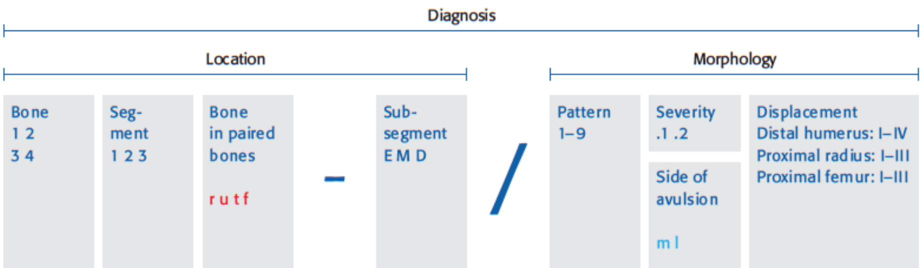

Figure 4: Classification system of the PCCF Code

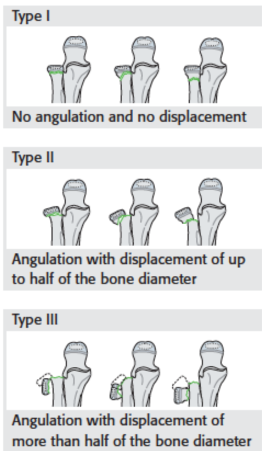

Figure 5: Additional code I-III for displaced radial head and neck fractures

and neck, and femoral neck fractures (fig.4).[14]
The radial head (21r-E/1 or /2) and neck fractures (21r-M/2 or /3) are described by an additional code I-III. This code considers the axial deviation and level of displacement (fig. 5).

The PCCF with the classification of fractures for the Radius/Ulna was used to analyse the 54 patients of the HEL/CHUV. The chapters 21-E (Proximal epiphyseal fractures/fig. 6) and 21-M (Proximal metaphyseal fractures/fig. 6) were used:

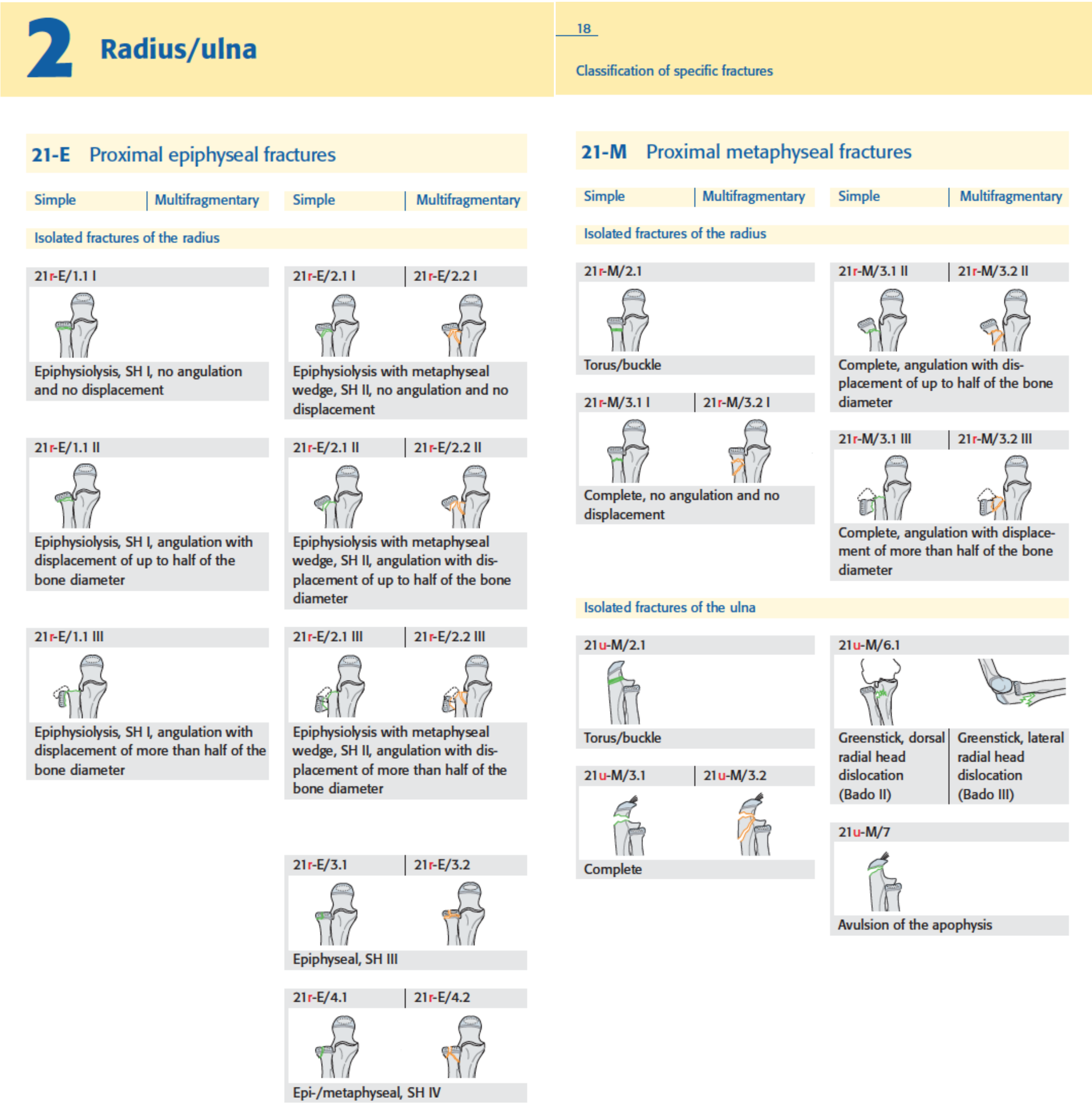

Figure 6: Classification of specific fractures Radius/ Ulna: Proximal epiphyseal/metaphyseal fractures

5.4.4.2 Judet classification with Metaizeau modification [6,7]

The Judet classification with Metaizeau modification analyses the translation (T) and the radial head angulation (RHA) of fractures and divides them in 5 groups summed up in table 1.[6]

Judet	1	2	3	4	
RHA	None	<30°	30°-60°	4a 60°-80°	4b >80°
T	< 3mm	<50%	>50%	>100%	
					

Table 1: Judet classification with Metaizeau modification RHA = Radial head angulation, T = Translation

5.4.5 Associated fractures

Any associated fracture of the ipsilateral arm or hand were identified and classified according to AO Paediatric Comprehensive Classification of Long-Bone Fractures (PCCF)[14] (see chapter 5.4.3.2). Any metaphyseal ulnar fracture was classified as 21M-u/2.1 (torus/buckle) or 21M-u/3.1 (complete), any diaphyseal fractures of the ulna were classified as 22u-D/2.1 and the humerus epitrochlear fracture was classified as 13-M/7m, which is an extraarticular avulsion of the epicondyle.

5.4.6 Treatment

The treatment methods were grouped in 5 different categories: immobilisation only (cast), closed reduction with cast, percutaneous reduction with ESIN or K-wire and open reduction with internal fixation (ORIF). The treatment methods can be classified in 2 groups: nonoperative treatment and operative treatment. Nonoperative treatments include the treatment with immobilisation only as well as closed reduction and cast. Percutaneous reduction as well as open reduction were classified in the operative treatment group.
The guidelines of the HEL classify the treatment methods in 2 slightly different groups: conservative treatment and surgical treatment. Conservative treatment means the treatment with immobilisation only while surgical treatment gathers closed reduction and cast, percutaneous reduction and open reduction. The decision criteria for the different treatment methods are summarized in figure 7.

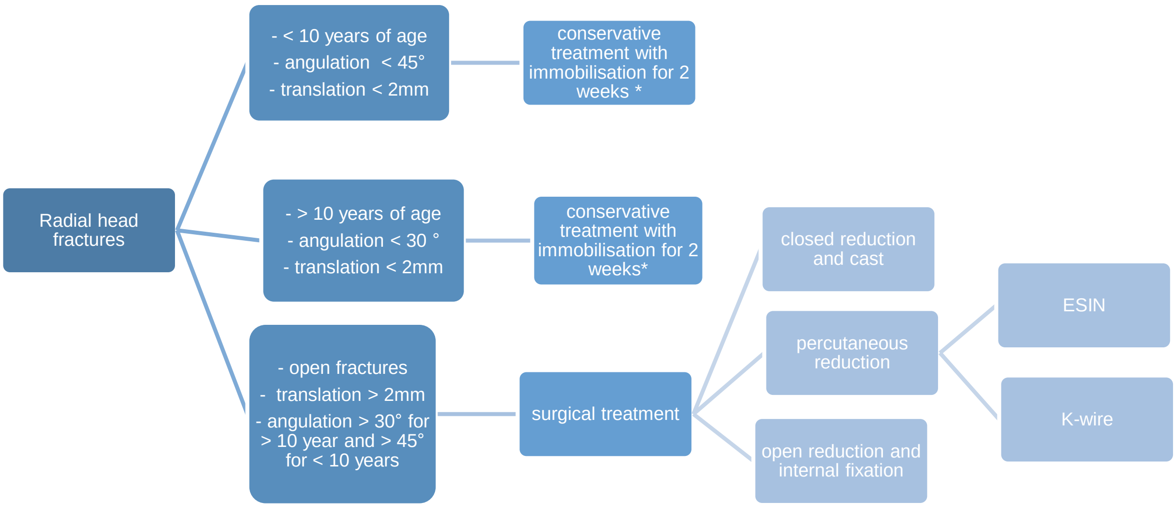

Figure 7: Treatment methods by the guidelines of HEL, CHUV[24]
** if there is important displacement of the radial head, the cast can be worn for 3 weeks maximum*

5.4.6.1 Percutaneous reduction [6,11,20]

Percutaneous reduction is performed if the angulation is more than 30 degrees (children older than 10 years) or more than 45° (children younger than 10 years) and if a closed reduction was unsuccessful. In this study the percutaneous reduction methods were classified in ESIN and K-Wire.

5.4.6.1.1 ESIN

While treating the patient with ESIN, Zhang et al.[20] used an elastic intramedullary nail which was inserted into the radius from the proximal side of the distal epiphyseal plate and then advanced to the fracture site. The nail head was positioned to the radial head and in the meantime manual reduction was used.[11,20] The lateral condyle acted as a brake for overcorrection.[32] The nail was rotated 180° to reduce the radial head. After the reduction, the range of motion of the forearm was restored. The excessive part of the nail was bended for 45°. A length of 5 mm of the nail was reserved outside of the bone.[20]

If manual reduction and CIMP (closed reduction and intramedullary pinning) was unsuccessful or if the radial neck shaft angle was still > 45° after manual reduction, a K-wire leverage technique was commonly used with ESIN. In this technique, under fluoroscopy a K-wire of 2 mm diameter was percutaneously and proximally inserted into the bone fragment from the displacement direction of the radial head fracture fragement.[20] Reduction of the fracture was achieved by leveraging the K-wire and by manual reduction. The proximal fragment was pressed on the distal end toward the proximal direction. If reduction was possible with the K-wire leverage, intramedullary nailing was finalized as described above. Fractures treated with K-wire leverage aided Metaizeau technique should be immobilized at the functional position using a cast for 4-6 weeks.[20] Compared to this, Cosma et al.[32] suggest that in radial head fractures treated with an ESIN only and no K-wire leverage, the forearm should be positioned in a sling for 10-15 days. After this period, elbow mobilization was allowed, and normal activity was resumed after 3 weeks. The nail was extracted after 2-3 months.[32]

5.4.6.1.2 K-Wire[18]

A K-wire of 1.5-2 mm diameter was selected according to the patients age and the width of the intramedullary canal. Under fluoroscopy guidance at the distal radius, the K-wire reached the cortex by avoiding the sensory branch of the radial nerve. Then, the K-wire was advanced through the radius head from the distal radius under fluoroscopic guidance. As a next step at the proximal end, another K wire was inserted percutaneously around the fracture line to treat the radial head angulation. Then the fracture line was distracted by moving the intramedullary K wire more proximal. Full reduction was achieved by rotation of the curved K wire tip 180°. Postoperatively, Cevik et al.[18] recommend wearing a cast for 3 weeks. The intramedullary wire was removed after clinical and radiographic consolidation of the fracture that takes place after approximately 6 weeks.[18]

To summarize K-wires can be used in three different ways. First, they can help as a percutaneous K-wire leverage technique helping the Metaizeau technique of intramedullary pinning as described above (see ESIN). Second, they can be used as intramedullary K-wires to stabilize the fracture. Third, K-wires can be used as a fixation of the fracture, not intramedullary but proximal percutaneous to fix the radial head to the radial shaft.

In our study, only the techniques with intramedullary nailing ESIN were used. In a few patients additional K-wire leverage was used for the reduction of the fracture. In this study, no patient was treated with an intramedullary K-wire.

5.4.6.2 Open reduction (ORIF)

According to the current literature, open reduction is one of the most contributing factors for postoperative poor outcomes, so it should be avoided whenever possible.[5] It is important to perform the surgery in a pronate position, with a lateral approach to the radio capitellar joint, in order to avoid the posterior interosseous nerve (PIN). Radial head fractures not successfully reduced with ESIN or K-wire, are treated with an open reduction and internal fixation.[11]

5.4.7 Duration of immobilisation

The duration of immobilisation was calculated as the time in which the patient wore a brachio-antebrachial cast. The immobilisation time with a bandage or a splint was not analysed in this study because the bandages were used only for specific activities and were not used full time.

5.4.8 Complications

The complications seen in this study were either fracture-related or treatment-related. For the fracture related complications, 4 subgroups were established: secondary displacement, mal- or non-union, radial head necrosis and radio-ulnar synostosis. For the treatment-related complications, 4 subgroups were established: pin-related, cast-related, infection and nerve damage.

5.4.9 Outcome

The outcome was analysed with the final radiographs (see chapter 5.4.3) and the last clinical follow-ups. In the final clinical follow up any functional loss of the elbow, pain or paresis was researched. If paresis was present PIN might have been injured. The percentage of the patients with full range of motion (ROM) of the elbow joint at the last follow up was recorded. A complete recovery was defined as a full radiographic healing and by gaining a full, painless range of motion. The ROM was measured in degrees with a goniometer using the neural zero method. Thus, the number of patients with persistent restriction of elbow ROM as well as the type and severity of this restriction were determined. Not all the physicians recorded the final F/E and the P/S in the same way. Some compared the range of motion with the contralateral (non-fractured) side, some compared it with given thresholds and out of the clinical experience. Therefore, the final functional outcome given by the ROM must be considered with caution and is more delicate than in a prospective study.

The severity of the ROM restriction can be analysed with different classifications. In the study of Badoi et al.[23] the severity of ROM restriction was classified in groups according to the direction of motion and the degrees of deficit (fig. 8).

- Minimal restriction: Only in one direction of motion and $\leq$ 10 degrees
- Moderate restriction: In two directions of motion and/or 11 to 20 degrees
- Severe restriction: In three directions of motion and/or $>$ 20 degrees

Figure 8: Classification by Badoi et al.[23]

Tan and Mahadev et al.[16] assessed the clinical outcome of 108 patients with another evaluation in which pain, ROM and valgus deformity were used (fig. 9). The same Tibone ve Stoltz functional evaluation was used in the study of Cevik et al.[18] who analysed 20 patients with Judet 3, 4a and 4b fractures as well as the study of Zhang et al.[20] who analysed their 50 patients treated with percutaneous K-Wire leverage and closed intramedullary pinning.

Outcome	Description
Excellent	No pain, full range of motion, no deformity
Good	Occasional insignificant pain, range of motion decreased <20° in any direction, <10° valgus deformity
Fair	Occasional insignificant pain, range of motion decreased >20°, >10° valgus deformity
Poor	Requiring further surgery

Figure 9: Classification by Tibone ve Stoltz [18]

Another classification system for the functional outcome was used in the study of De Mattos et al.[22]: They used a classification system by Leung and Peterson, based on the functional arc of the elbow motion and pain (fig 10).[22]

Rating	Pain	Loss of Extension	Flexion	Supination	Pronation
Excellent	None	None	> 145	> 85	> 70
Good	None	0-15	140-145	70-85	60-70
Fair	Mild	15-30	130-140	50-70	50-60
Poor	Moderate/severe	> 30	< 130	< 50	< 50

All values expressed in degrees.
ROM indicates range of motion.

Figure 10: Classification by Leung and Peterson [22]

Most physicians documented the restricted range of motions in degrees or if not restricted using the terms "normal" or "symmetrical". So, it was not possible to assess the functional outcome completely with the Leung and Peterson classification, which uses only exact degrees

thresholds. The Tibone ve Stolz classification was used for patients treated with percutaneous reduction but not for patients treated with immobilisation only or closed reduction.
After analysing the different classifications of the functional outcome, the classification of Badoi et al.[23] was used because the patients analysed by Badoi et al. were most similar to the patients of our study, in which conservative as well as operative treatments in paediatric patients were analysed.

5.4.10 Statistical analysis

This study is a descriptive analysis of clinical results and angulations with means, ranges and percentages.

6 Results

6.1 Epidemiology

The epidemiology characteristics such as gender, side of injury and mechanism are summarized in the following table (total n = 47).

Gender	Female Male	24 (51%) 23 (49%)
Side	Left Right	24 (51%) 23 (49%)
Mechanism	Sport Playground Home Wheel Other	24 (51%) 11 (23%) 8 (18%) 3 (6%) 1 (2%)

Table 2: Demographics of the cases with gender, side of injury and mechanism

As seen in figure 11 at the extremes there were fewer patients and a maximum of patients is seen at 11 years. The overall mean age was 7y10m. The mean age of the different treatment methods and Judet's classifications are summarized in table 3. The mean age was higher in the group of the patients treated with percutaneous reduction than the mean age in the group treated with cast only (6y10m vs 9y10m respectively).

Group (n = number)	**Mean age years, months (range)**
Mean overall (n=47)	**7,10** (2,3-12,5)
Cast only(n=30)	**6,10** (2,3-12,5)
Closed reduction and cast (n=6)	**10,2** (7,9-11,10)
Percutaneous reduction (n=6)	**9,10** (7,6-11,8)
Open reduction (n=5)*	**8,7** (5,9-12,2)
Judet 1 (n=31)	**6,11** (2,3-12,5)
Judet 2 (n=3)	**8,1** (2,5-11,4)
Judet 3 (n=7)	**10** (7,6-11,9)
Judet 4 (n=6)	**10** (8,0-11,10)

Table 3: Distribution of age (years,months) of different treatment groups according to Judet's classification with max. and min.
**mean age of all operative techniques = 9,6*

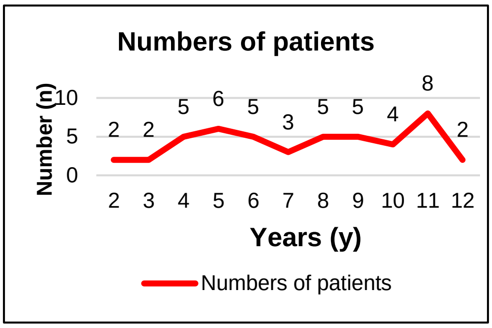

Figure 11: Number of patients according to age

It was not possible to carry out a deep analysis of the BMI because of a too important lack of data. In only 61.7 % of the cases the analysis of the BMI was recorded (29 out of 47). However, a tendency can be seen, that patients with a higher BMI suffer from fractures classified in a higher Judet's group. This tendency must be confirmed by a prospective study where BMI is systematically documented.

6.1.1 Gender comparison

The percentage of the different Judet classification according to gender is shown in the following figure:

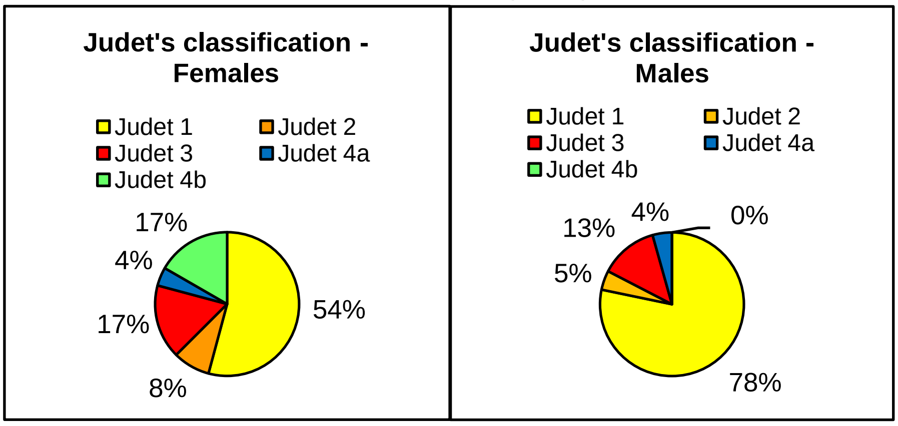

Figure 12: Judet classification according to gender

The table 4 shows a summary of the concomitant fractures according to gender. In this study, concomitant fractures were more frequent in females (n=9) than in males (n=4). In males, the proximal metaphyseal fracture of the ulna was associated to a radial head fracture, while in females, concomitant proximal metaphyseal and diaphyseal fracture of the ulna, but also a concomitant avulsion of epicondyle of the humerus were recorded.

Female	Number	9 (37.5%)	
	Type	3 x Judet 1 + 21u-M/2.1 1 x Judet 1 + 21u-M/3.1 1x Judet 1 + 22u-D/2.1/21u-M/2.1 1x Judet 1 + 13M/7m	1 x Judet 2 + 21u-M/3.1 1x Judet 4a + 21u-M/3.1 1x Judet 4b + 21u-M/3.1
Male	Number	4 (17.5%)	
	Type	3 x Judet 1 + 21u-M/3.1 1 x Judet 1 + 21u-M/2.1	

Table 4: Summary of the concomitant fractures in males and females, with number of fractures and type

The comparison of the treatment methods in males and females is summarized in table 5:

Treatment method	Males (n=23)	Females (n=24)
Immobilisation only	17 (74%)	13 (54%)
Closed reduction and cast	3 (13%)	3 (12.5%)
Percutaneous reduction	1 (4.3%)	5 (21%)
Open reduction	2 (8,7%)	3 (12.5%)

Table 5: Treatment method rates according to gender

As seen in figure 12 Judet 1 fractures were more frequent in males than in females (78% vs 54% respectively). In this study males had less fractures with angulations >60° (Judet 4) than females. Less females than males had a treatment with immobilisation only (54% vs 74% respectively). In males open reduction or percutaneous reduction was rarely used (13%) compared to females (33.5 %), which was due to a smaller percentage of fractures classified in Judet 3 or 4 in males than in females (17% vs 38% respectively). The female patients had a mean immobilisation time of 21 days while the mean immobilisation time of the males was 18.78 days.

A comparison of the complications showed that there were little differences between males and females. One male and 2 females had pain or erythema because of the cast. There was one major complication, which presented with a secondary implant perforation observed in a female patient with a Judet 4b fracture and was treated with open reduction and internal fixation. In the final radiological outcome of this case, there was no sign for radial head malunion, residual angulation, ectopic calcification or radial head necrosis.

The functional outcome in males and females was similar and is summarized in table 6. One male patient had a minimal hypoesthesia of the sensitive branch of the radial head but no pain in the last clinical follow up, while in females there was no neurovascular injury and one case with pain in the motion of the elbow.

Females (n=number)	Range of Motion restriction	14 = None 6 = Minor (10° or less) 3 = Moderate (11°-20°) 1 = Severe (>20°)
	Neurovascular injury	-
	Pain	1
Male (n=number)	Range of Motion restriction	15 = None 5 = Minor (10° or less) 2 = Moderate (11°-20°) 1 = Severe (>20°)
	Neurovascular injury	1*
	Pain	-

Table 6: Functional outcome according to gender
**(hypoesthesia of the radial nerve)*

In the assessment of the last x-ray, in the female group one ectopic calcification was found but further no anomaly such as residual angulation, radial head malunion, growth arrest or radial head necrosis was recorded. None of the anomalies mentioned above were found in the male group.

6.2 Fracture classification and concomitant injury

The distribution of the Judet fractures is summarized in figure 13. There were 31 patients with Judet 1 fractures, 3 with Judet 2 fractures, 7 with Judet 3 fractures and 6 with Judet 4 fractures. Patients with a fracture classified Judet 1 had in 30% (9 out of 31) of the cases a concomitant fracture compared to 33% for patients with a Judet 2 (1 out of 3), 14% for patients with a Judet 3 (1 out of 7), and 33,3% for patients with a Judet 4 fracture (2 out of 6).

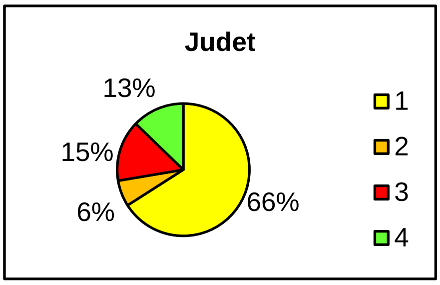

Figure 13: Judet classification in all patients

6.2.1 Judet 1 (n=31)

18 males and 13 females suffered from a Judet 1 fracture. The mean age was 6y10m (range: 2y3m-12y5m). 2 cases presented swelling of the fingers and eczema as complication of the cast. No complication while surgery or due to the fracture was found.

The mean immobilisation time was 18.25 days. The patient with the shortest immobilisation time (7 days) had no concomitant fracture and his functional and radiological outcome were good. The mean immobilisation time of all the patients with Judet 1 and no concomitant fracture was 17 days compared to 25 days for patients with a Judet 1 fracture and concomitant fracture. 9 cases (5 females/4 males) had a concomitant fracture (table 7).

Associated Fracture	Mean immobilisation time (days)
21u-M/2.1 (n=3)	**18**
21u-M/3.1 (n=4)	**21.5**
21u-M/2.1 / 22u-D/2.1 (n=1)	**28**
13 M/ 7m (n=1)	**28**

Table 7: Comparison of immobilisation time of different concomitant fractures.

While there were some minor limitations in the functional outcome in Judet 1 fractures, the radiological outcome was not diminished in any way: Nether ectopic calcification, nor radial head malunion, nor growth arrest, residual angulation or radial head necrosis was seen.

100% of Judet 1 fractures without concomitant fracture and 56% of Judet 1 fractures with concomitant fractures were treated with cast only. None of them had complications such as infections, problems with the cast or secondary dislocation as well no neurovascular damage and no pain. The remaining 4 cases were treated with an open reduction, had concomitant olecranon (n=3) and epitrochlear (n=1) fractures and were immobilised between 14 to 30 days. In patients treated operatively 2 cases had minor complications and minor deficit in P/S or E/F of less than 10°, but all had a satisfied outcome.

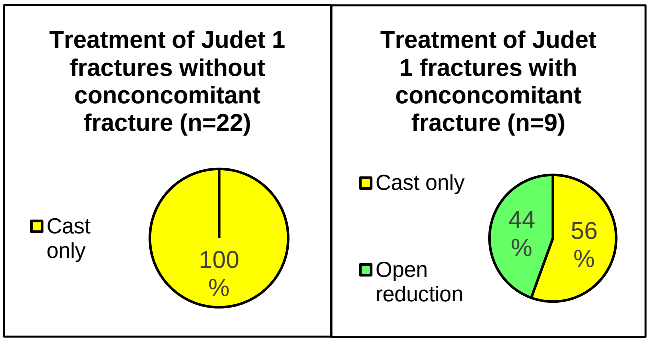

Figure 14: Treatment method of Judet 1 fractures with and without concomitant fracture

Out of 31 cases of Judet 1 fractures, all had normal radiographs in the last follow up. For analysing radial head fractures in children CT was still barely used with only one case having an additional CT. This 12-year-old patient had a Judet 1 fracture associated to a minimal shift of the secondary epitrochlear ossification nucleus.

6.2.2 Judet 2 (n=3)

3 patients had a Judet 2 fracture (6,3% overall, 2 males, 1 female). In the functional outcome there was no patient with any pain or neurovascular problems. 1 case had a concomitant fracture of the olecranon. This patient was treated with a cast only and had moderate restriction in the functional outcome. Besides, the other two cases without concomitant fracture were treated one with cast only and one with closed reduction and cast, both had no limitation in the functional outcome. Summed up 66,6% (n=2) were treated with a cast only and in 33,3% (n=1)

with closed reduction and cast. The cases without concomitant fractures were immobilized for 2.5 weeks, the case with a concomitant fracture was immobilized for 6 weeks, therefore the overall mean immobilisation time was 26 days.

6.2.3 Judet 3 (n=7)

Out of 7 Judet 3 fractures, 4 were female and 3 were male, with a mean age of 10 years. The treatment methods of Judet 3 fractures are summarized in figure 15. More patients were treated percutaneously (n=4) than with closed reduction or with cast only (n=2 and n=1 respectively). No case was treated with open reduction.

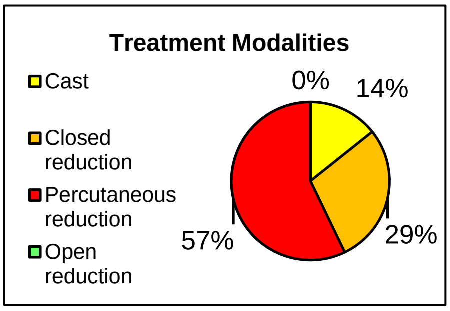

Figure 15: Treatment of Judet 3 fractures

One case had a concomitant fracture of the ulna. This case had the longest immobilisation time (5 weeks), was treated with ESIN and had no restriction in the functional outcome. All patients treated with ESIN had no restriction. The remaining patients were either treated with cast and no functional restriction (n=1) or closed reduction and no or minor functional restriction (n=2). In addition, no patient had any neurovascular problems or pain after the last clinical follow up. In the radiological outcome in no case any ectopic calcification, growth arrest, residual angulation or radial head necrosis was documented. The mean immobilisation time was between 13 and 35 days with a mean value of 20.57 days. The minimum (13 days) was for a patient, aged 11y5m, without any concomitant fracture and treated with closed reduction and cast.

6.2.4 Judet 4 (n=6)

Of all selected patients, 6 cases had a Judet 4 fracture (2=4a, 4=4b). 5 cases (83,3%) were female and one was male. The mean age was with 10 years similar to the patients with Judet 3 fractures and higher than for patients with Judet 1 and Judet 2 fractures. The Judet 4 fractures had a mean immobilisation time of 24 days (14-28). In 33,3% (n=2) of the cases there was a concomitant olecranon fracture (n=2). One was classified Judet 4a with a radial head angulation of 62° and the other was classified Judet 4b with a radial head angulation of 90°.

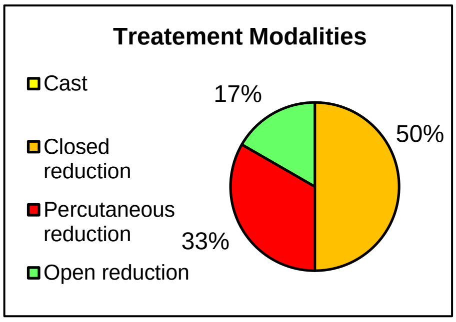

Figure 16: Treatment of Judet 4 fractures

In the functional outcome, 2 cases had no restriction, 2 cases had minimal restriction, one case had moderate and one severe restriction. In the last x-ray assessment, there was one case with ectopic calcification. It was seen in a patient with a Judet 4b fracture aged 11y8m. None of the patients had any indication for radial head malunion, growth arrest, residual angulation or radial head necrosis. The treatment methods are summarized in the figure 16: 3 patients were treated with a closed reduction and cast, 2 with a percutaneous reduction and 1 with an open reduction. None of Judet 4 fractures was treated with immobilisation only. However, in our study 50 % of the Judet 4 fractures were treated with closed reduction and cast. In the last clinical follow up of these 3 patients no or only minimal restriction in the function of the elbow was recorded. Closed reduction was performed in patients aged 8y -11y8m.

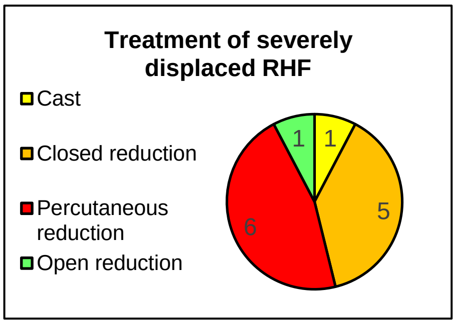

Figure 17: Treatment method of severely displaced RHF (Judet3/4)

Overall 13 Judet 3 and Judet 4 cases were recorded. Out of these severely displaced fractures, 3 had concomitant fractures which did not affect management of radial head fractures. Almost half of the severely displaced fractures were treated successfully with ESIN

(46%), more than a third were treated with closed reduction (38%), and only 7,7 % were treated with open reduction (see fig. 17).

6.3 Treatment

As summarized in figure 18, 30 patients were treated with immobilisation only, 6 cases with closed reduction and cast, 6 cases with percutaneous reduction and 5 were treated with open reduction.
The patients treated with percutaneous reduction were treated with an ESIN and in 2 patients a K-wire joystick leverage technique was used while surgery. The following table shows each treatment according to the different Judet's classification.

Treatment	Judet classification	n
Cast only (n=30)	1 2 3 4	27 2 1 -
Closed reduction (n=6)	1 2 3 4	- 1 2 3
Percutaneous Reduction (n=6)*	1 2 3 4	- - 4 2
Open reduction (n=5)	1 2 3 4	4 - - 1**

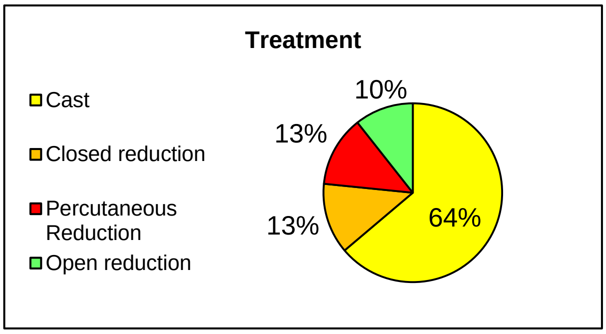

Figure 18: Treatment methods of the 47 analysed patients

Table 8: Treatment with corresponding Judet classification
**Joystick levereage technique with K-wire used in surgery only*
***in Judet 1 fractures open reduction only used for concomitant olecranon (n=3) and epitrochlear (n=1) fractures*

6.3.1 Cast only (n=30)

As it can be seen in figure 19, out of all the fractures treated with immobilisation only, most were Judet 1 fractures (n= 27), followed by Judet 2 (n=2) and Judet 3 fracture (n=1). The mean immobilisation time was of 18.46 days. Three patients had erythema or pain in the cast. There were no other complications seen such as secondary dislocation or necrosis of the radial head. In the last x-ray assessment of all the patients treated with immobilisation, no anomalies were found. The concomitant fractures of patients treated with cast only are summarized in table 9:

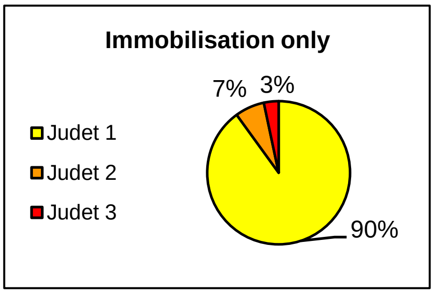

Figure 19: Classification of the fractures of all patients treated with cast only.

Concomitant fracture	Number	6 (20%)
	Type	- 3 x Judet 1 + 21u-M/2.1 - 1 x Judet 1 + 21u-M/3.1 - 1 x Judet 2 + 21u-M/3.1 - 1x Judet 1 + 22u-D/2.1/21u-M/2.1

Table 9: Concomitant fractures of patients treated with immobilisation only

6.3.2 Closed reduction and Cast (n=6)

12.7 % (6 out of 47, 3 females, 3 males) of all cases were treated with closed reduction and cast. The mean age was higher than the mean age of patients treated with immobilisation only (10y2m vs. 6y10m respectively). The mean immobilisation time was 18.66 days. Compared to the group with immobilisation only, there were fewer concomitant fractures (n=6 vs n=1). One patient had a concomitant proximal ulna fracture with a Judet 4a fracture. In the functional outcome there was neither restriction in the range of motion nor any pain or neurovascular injury.

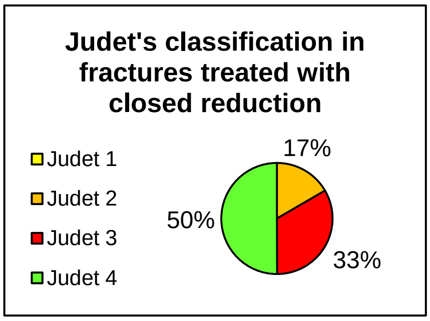

Figure 20: Judet classification of patients treated with closed reduction and cast

The distribution of the Judet's fractures in patients treated with closed reduction is seen in figure 20. In no case there was any ectopic calcification, growth arrest, residual angulation or radial head necrosis. Of all fractures treated with closed reduction and cast, all cases had excellent or good outcomes with 3 cases presenting no limitation and 3 cases presenting minor limitation.

6.3.3 Percutaneous ESIN (n=6)

Out of 6 patients treated with ESIN 16.6 % (n=1) were male and 83,3% (n=5) were female. 4 cases were Judet 3 and 2 cases were Judet 4b fractures. Patients treated with percutaneous reduction were older than patients treated with immobilisation only (9y10m vs 6y10m). The mean immobilisation time was 24.5 days.

33% (n=2) of the patients treated with percutaneous reduction had concomitant fractures of the ulna. One had an angulation of 45° (Judet 3) and one an angulation of 89° (Judet 4b). 33% (n=2) of the patients were confronted with complications. One patient had pain and swelling in the cast. The other patient had a minimal hypoesthesia of the sensitive branch of the radial nerve after a Judet 3 fracture. Most patients had an excellent functional outcome with no restrictions (n=5, 83,3%) one patient (n=1, 16,7%) had severe restriction in the range of motion of the elbow. In the last radiological assessment, in one patient suffering from a Judet 4b fracture, ectopic calcification was observed. In none of the cases any growth arrest, necrosis of the radial head or residual angulation of the radial head was found.

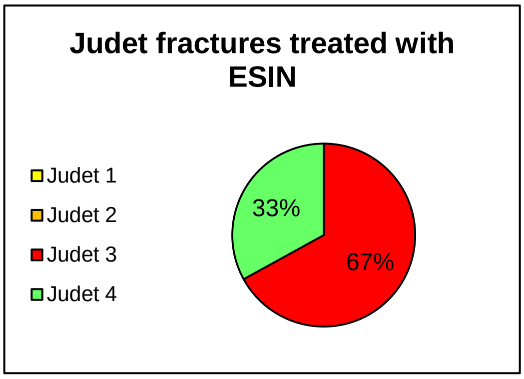

Figure 21: Only severely displaced fractures (Judet 3/4) were treated with percutaneous reduction

6.3.4 Open reduction (n=5)

Open reduction was performed for radial head fracture in 1 case. This patient had a Judet 4b fracture and suffered from minimal pain in pro and supination after the last follow-up. No indices for radial head necrosis was found in the last x-ray. The resting 4 patients treated with open reduction had a Judet 1 fracture with a concomitant fracture which is why open reduction was performed. Out of the 4 Judet 1 fractures with concomitant fracture 3 had a fracture of the proximal metaphyseal ulna and one case had an avulsion of the epicondyle of the humerus. The mean immobilisation time of the Judet 1 fractures with concomitant fracture was 25 days, while the immobilisation time of the Judet 4b fracture was 28 days.

In no patients treated with open reduction any indication of radial head malunion, residual angulation, radial head necrosis ectopic calcification or growth arrest was found. In the functional outcome 2 cases had no restriction, 2 cases had minimal restriction and 1 case had moderate restriction.

6.4 Complications

There were 5 different complications seen throughout this study. First, 3 patients had complications with their cast, revealed with pain and swelling of the fingers (n=2) or erythema (n=1). Second, one patient had a neurological complication presented by a hypoesthesia of the sensitive branch of the radial nerve. This patient was 11 years old, was suffering of a Judet 3 radial head fracture and was treated with ESIN percutaneous reduction. Third, 1 out of 47 patients had an epiphysiodesis with a reduced residual growth. This 9-year-old patient had a Judet 4b fracture treated by open reduction and internal fixation A secondary implant perforation most likely due to insufficient surgical technique was observed. In the clinical outcome minor limitation was found: deficit of 15° of pronation and 10° of supination, but no limitation in extension and flexion. This same patient suffered from pain in P/S against resistance in the last follow up. In the last radiological assessment, no anomaly was found.

Contrary to the others this patient had in addition to x-rays also an MRI and a CT. Forth, in one patient heterotopic calcification was found (see chapter 6.6).
In no patient in this study a radial head necrosis, malunion or secondary displacement was observed.

6.5 Functional Outcome

According to the Badoi et al.[23] classification shown in figure 21, in this study 85% of the patients had no or minimal restriction, 11% (n=5) had moderate restriction and 4% (n=2) had severe restriction in the functional outcome.

- Minimal restriction: Only in one direction of motion and $\leq$ 10 degrees
- Moderate restriction: In two directions of motion and/or 11 to 20 degrees
- Severe restriction: In three directions of motion and/or $>$ 20 degrees

Figure 22: Classification of the functional outcome according to Badoi et al.[23]

6.5.1 Functional Outcome in Judet 1-4

In Judet 1 fractures the percentage of patients with no restriction was of 64.5%, 22.6% had minimal restriction and 9.7% had moderate restriction. The percentage with no restriction in Judet 2 was 66%, in Judet 3 71% and in Judet 4 40%.
Judet 4 fractures had with 33.3% more moderate or severe restriction than Judet 2 and 3 (0% both), which shows that in this study, patients with lower angulation fractures had fewer restrictions in the functional outcome.

Restriction of ROM	Judet 1 (n=31)	Judet 2 (n=3)	Judet 3 (n=7)	Judet 4 (n=6)
None	20	2	5	2
Minimal	7	1	2	2
Moderate	3	-	-	1
Severe	1	-	-	1

Table 11: Range of motion with restriction of Judet I-IV fractures (n=numbers)

6.5.2 Functional outcome of different treatment methods

The functional outcome according to the treatment methods is summarized in figure 12:

Restriction of ROM	Cast only (n=30)	Closed reduction (n=6)	Percutaneous reduction (n=6)	Open reduction (n=5)
None	19	3	5	2
Minimal	6	3	-	2
Moderate	4	-	-	1
Severe	1	-	1	-

Table 12: Range of motion with restriction according the classification of Badoi et al.[23] (n= number)

Patients treated with immobilisation only had in 63% of all cases excellent outcomes with no restriction and in 20% of the cases minimal restriction. Moderate restriction was seen in 5 out of 47 cases (10.6%), of which 4 were treated with immobilisation only and 1 was treated with open reduction. Severe restriction was seen in 2 cases one was treated with percutaneous reduction and one with cast only. Percutaneous reduction was used in 6 cases: 4 times for Judet 3 fractures and 2 times for Judet 4b fractures. Of all these cases, 83.3% had excellent results and no restriction. In the patients treated with open reduction 40% had no restriction, 40% had minimal restriction and 20% had moderate restriction.
More restriction was seen in F/E than in P/S (14 cases vs 10 cases respectively).

The correlation between outcome, fracture grade and treatment method is summarized in the following table.

Fracture grade	Treatment	Outcome (n = number)			
		No restriction	Minimal restriction	Moderate restriction	Severe restriction
Judet 1	Cast (n=27)	18	5	3	1
	Open reduction (n=4)	2	2	-	-
Judet 2	Cast (n=2)	1	-	1	-
	Closed reduction (n=1)	1	-	-	-
Judet 3	Cast (n=1)	-	1	-	-
	Closed reduction (n=2)	1	1	-	-
	Percutaneous reduction (n=4)	4	-	-	-
Judet 4	Closed reduction (n=3)	1	2	-	-
	Percutaneous reduction (n=2)	1	-	-	1
	Open reduction (n=1)	-	-	1	-

Table 13: Correlation between outcome, fracture grade and treatment method

The correlation between outcome, fracture grade and patient age is summarized in the following table.

Fracture		Judet 1			Judet 2			Judet 3			Judet 4		
Age (years)		< 5	5-9	≥ 10	< 5	5-9	≥ 10	< 5	5-9	≥ 10	< 5	5-9	≥ 10
Outcome (restriction)	None	6	12	2	1	-	1	-	2	3	-	1	1
	Minimal	1	4	2	-	-	-	-	1	1	-	1	1
	Moderate	1	11	1	-	-	-	-	-	-	-	1	-
	Severe	-	1	-	-	-	-	-	-	-	-	-	1

Table 14: Correlation between outcome, fracture grade and patient

6.6 Radiological Outcome

By assessing the x-rays of the patients, one ectopic calcification was found in the entire study. This was found in a patient with a Judet 4b fracture who was treated with a percutaneous reduction ESIN. In his functional outcome, a flexum of 10° and a moderate restriction in pro- and supination of 20° was found. The pro- and supination recovered to a minor restriction of less than 10°. Because there was no long term follow up, it is not possible to assess if there was a complete recovery of the function of the elbow. Besides this patient, in no other patient neither ectopic calcification nor radial head malunion, residual angulation of the radial head, growth arrest or radial head necrosis was found. Summed up, in 98% of the cases there was no anomaly found in the last x-ray assessment. As expected, more radiographs were taken during the percutaneous treatment (operative) than during an immobilisation only (mean number 5.33 vs 3.6).

6.7 Immobilisation time

6.7.1 Immobilisation time classified by treatment method

Table 15 shows that the mean immobilisation time of patients treated with immobilisation only was shorter than in patients treated with percutaneous reduction and patients treated with open reduction (18,46 days vs. 24.5 days and 25,6 respectively). The immobilisation time was similar in patients treated with cast only and patients treated with closed reduction and cast. In the same way, the immobilisation time of patients treated with percutaneous reduction and open reduction was similar.

Treatment method	**Mean Immobilisation time, days (weeks)**
Cast only	18.46 (2.5)
Closed reduction and cast	18.66 (2.5)
Percutaneous Reduction	24.5 (3.5)
Open reduction	25.6 (3.6)

Table 15: Mean immobilisation time for different treatment methods

6.7.2 Immobilisation time classified by Judet's classification

Table 16 presents the mean immobilisation times according to the Judet classification. Judet 1 fractures had a shorter immobilisation time than the Judet 2 to Judet 4 fractures.

Judet classification	Mean Immobilisation time, days (weeks)
Judet 1	18,25 (2.4)
Judet 2	26 (3.7)
Judet 3	20,57 (3)
Judet 4	24 (3.4)

Table 16: Mean immobilisation time of Judet fractures

The figure 22 shows that patients with an immobilisation time of more than 3 weeks had more restriction in the functional outcome of the elbow compared to patients with less than 3 weeks of immobilisation. 91% (n=21) of the cases immobilized less than 3 weeks had an excellent or good outcome with no (n=13) or only minor restriction (n=8). In patients who were immobilized for more than 3 weeks, 8% of the cases (n=2) had severe restriction and 13% (n=3) had moderate restriction, whereas 79% had either minor (n=3) or no (n=16) restriction.

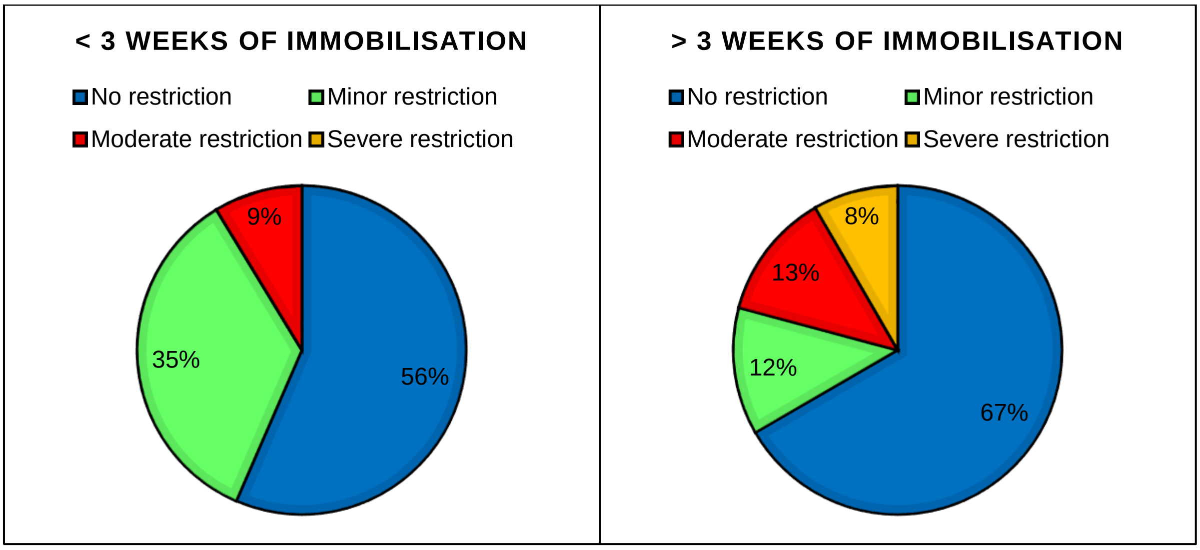

Figure 23: Outcome of patient immobilised > 3 weeks and patients immobilized < 3 weeks

7 Discussion

According to current literature, proximal radial head fractures in children are rare and can present a dilemma in terms of radiographic assessment, definitive diagnosis and therapeutic options.[3,21,23,29] This study indicates that most radial head fractures are injuries that can be treated successfully through conservative treatment as cast only was used in 64% of all cases (n=30). These results agree with the outcome of the large retrospective study of Ackerson et al.[3].

The success of a conservative treatment in non-displaced fractures is given: 85.1% of all patients with Judet 1 fractures and treated with cast only had no or minor limitation. In the study of de Mattos et al., nondisplaced fractures treated with immobilisation only had in 89.2% of the cases an excellent ROM outcome and in only 3.5% healed with poor ROM outcomes.[22]

Out of the 9 Judet 1 fractures with concomitant olecranon or epitrochlear fracture 4 patients were treated with open reduction. So, it can be said that the open reduction of these Judet 1 fractures was not carried out to treat the radial head fracture but was due to the associated fractures. 6.3% (n=3) of all patients were classified Judet 2. Out of these, two were treated with immobilisation only and one with closed reduction and cast. All of them had either an excellent outcome with no limitation or good outcomes with only minor limitation. According to this it can be said: For Judet 1 or 2 fractures a conservative treatment with brachio-antebrachial cast is effective.

In total 14.9% (n=7) of the patients were diagnosed with a Judet 3 and 12.8 % (n=6) were diagnosed Judet 4. Almost half of these radial head fractures with serious displacement and angulation (Judet 3 and 4) were treated with percutaneous reduction. And only 1 case of all Judet 3 and 4 fractures was treated with open reduction. So, the results of this study support the generally accepted opinion seen in literature that, if surgical treatment for Judet 3 and 4 fractures is required, it is recommended to prefer percutaneous reduction over open reduction.[13,22,23]

At this point an interesting result has to be mentioned: 50% of all Judet 4 fractures were treated with closed reduction and cast. Those patients had either no restriction or minor restriction in the functional outcome. This shows that every case has to be assessed individually and that a closed reduction is in 50% effective in highly angulated fractures.

Although the treatment criteria are controversial and the threshold angulations change from guidelines of the HEL[24] (<45° for conservative treatment) to guidelines found in the literature [4,5,18] (<30° or <45° for conservative treatment) finally there is the common agreement that fractures with angulation of >60° or displacement of more than 3 mm generally cause unpleasant results if not reduced and that fractures of <30° of angulation may be safely followed up conservatively.[18,22,23] This agrees with the outcome of this study: fractures with an angulation of <30°(Judet 1 and 2) were successfully treated with conservative treatment or with closed reduction. Similarly, in the present study all Judet 4 fractures analysed had either closed reduction or operative treatment with reduction.

In this study, almost one third of the radial head fracture had concomitant fractures which were not related to the degree of displacement. These results agree with the current literature: De Mattos et al.[22] recorded concomitant fractures in 34% (analysis of 193 cases), Cevik et al.[18] recorded concomitant fracture in 20% (analysis of 20 cases) and Tan et al.[16] recorded concomitant fractures in 19.4% (analysis of 108 cases) of all the cases. Girls had twice as many concomitant fractures than boys. Judet 1 fractures were more frequent in males than in females and males had less fractures with angulations >60° (Judet 4) than females. In males open reduction or percutaneous reduction was rarely used (13%) compared to females (33.5 %), which was due to a smaller percentage of fractures classified in Judet 3 or 4 in males than in females. So, males had more Judet 1 fractures which automatically leaded to less invasive treatment methods and so shorter immobilisation time than females.

In the current literature a disagreement still exists concerning the ideal treatment of displaced radial head fractures.[3,21,22] In children the entire radial head is enclosed by cartilage and its blood supply comes primarily from the metaphysis.[20] A big shift of the radial head as well as an open reduction is a risk for compromising the vascularisation of the radial head. [20,23] Closed reduction or percutaneous techniques with ESIN or K-Wire are to date favoured over open techniques because of less complications such as avascular necrosis and non-union, pseudarthrosis or infection.[1,4.13,22,23,25] Only in fractures where no percutaneous reduction is possible, and in fractures were possible functional problems may outweigh the risk of compromising the blood supply of the radial head, open reduction should be performed.[5,11,23] Not only were there more complications in open reduction techniques but the treatment method had also an influence on the final functional outcome. In this study there were 5 cases treated with open reduction, 4 of them were Judet 1 fractures with concomitant fractures, and one fracture was classified Judet 4b. This 4b fracture treated with open reduction had moderate restriction in the functional outcome. Out of 6 patients treated with percutaneous reduction 4 were Judet 3 and 2 were Judet 4b. 83,3% of the patients treated with percutaneous reduction had excellent results with no restriction. This stands in comparison to the open reduction, in which 60% of the cases had either minimal or moderate limitation and only 40% had no restriction. Comparing this result shows, that the percentage of patients with restriction is higher with open reduction than with percutaneous reduction (60% vs 16,6%). The results of this study agree that, if an operative technique is performed, percutaneous reduction with ESIN has less complications as well as a better functional outcome than open reduction.

A small subset of radial head fractures were difficult to treat and might develop significant complications. In the present study only few complications and no radial head necrosis were recorded. This result agrees with a radial head necrosis rate of 0% in the study of Tan et al.[16] (108 cases) and 0.51% in the study of De Mattos et al.[22] (193 cases).
The patient's functional capacity and the surgeon's experience are parameters that were not taken in consideration by discussing the outcome of the different treatment methods. So, the surgeon's technique in a same fracture is probably different due to experience, approach and other influences which has a unknown influence on the functional outcome.

Indications for the treatment of radial head fractures relate not only to the Judet classification with the amount of angulation but also to the fracture location, amount of translation, associated injury, the age of the patient, and the time elapsed since the injury.[18,29] The results present a big lack of data to discuss if the time elapsed since injury. The age and fracture location are important when choosing the treatment method because the ability to remodel depends on the bone involved, the patients age, the proximity to the joint, and its orientation to the joint axis. As an example, Metaizeau et al.[6] reported that 20-30° angulation in young children may be remodelled in time, but even 10-15° angulation in children over 12 years old could not be remodelled.[6,18] With an overall mean age of 7y10m, the patients of this study were of similar age than in studies of the current literature. The mean age of patients treated conservatively was lower than the mean age of patients treated with operative technique (6y10m vs 9y6m). This was mostly due to the remodelling capacity of younger children, which makes conservative treatment more sufficient in younger children than in older children. So, this study confirms the results of Monson et al.[29] and Cevik et al.[18] who reported that the age should be considered while choosing the treatment. Not only are younger children treated sufficiently with conservative methods because of higher remodelling potential but also the fractures of younger children in this study are less angulated than in older children. The mean age of children with Judet 1 was 6y11m while the mean age of children with Judet 4 fractures was 10y. Tan and Mahadev et al.[16] established the hypothesis that this higher angulated and poorer prognosis in older children is due to a higher energy involved in the injuries. Further this could be because younger children's bones are more cartilaginous and hence more cushioned.[16] Therefore, the energy form of the trauma is more efficiently absorbed, resulting in less severe fractures.[16]

The results show a link between the age, angulation of radial head, treatment method and functional outcome. Because younger children had less angulated fractures, they normally do have less surgical treatment and with less surgical treatment they have fewer poor outcomes. De Mattos et al. and Tan and Mahadev realized the same tendency: older children are more likely to have more severely displaced radial head fractures requiring surgical treatment, thus resulting in a greater risk of poor outcomes.[16,22] In the same way, the mean age of patients with moderate or severe limitation was higher (mean age 8y5m) than in patients with no limitation (mean age 7y5m). The no restriction, minor, moderate and severe restriction rate of the 47 analysed patients were similar to Badoi et al.[23] (n=67), Tan et al. [16] (n=108) and de Mattos et al. [22] (n=192). Finally, as expected, the present study shows that fractures with a lower angulation of the radial head had fewer limitations in the functional outcome.

7.1 Hypothesis

The hypothesis of this study was that at the HEL the length of immobilisation is too long, and the rate of open reduction is low, when compared to the literature.

Out of 13 Judet 3 and 4 fractures only one case is treated with open reduction. This represents 7,6% of all highly angulated fractures. With this value it can be confirmed that open reduction rate of all operatively treated cases at the HEL is lower than in other institutions.[16,22] The reason of this low rate is on one hand affected by the small number of analysed patients. On the other hand, the quality of percutaneous reduction at the HEL might be higher and therefore, open reduction as a last resource is less used.

Further, it was hypothesised, that the length of immobilisation of radial head fractures in skeletally immature patients is too long. Out of the literature and our results emerges the fact that less angulated fractures had less invasive treatment and shorter duration of immobilisation. In order to discuss this result, the treatment method of different angulated fractures and their immobilisation time was analysed. The patients treated with a cast only had an immobilisation time of 18.5 days, compared to 24.5 days in the patient group with percutaneous reduction and 25.6 days in the patient group with open reduction.

As an example, the percentage of operative treatment such as ESIN or open reduction was higher in Judet 2 fractures than the percentage of operative treatment in Judet 4 fractures. Due to this, the mean immobilisation time in patients with a Judet 4 (24 days) fracture was shorter than in patients with a Judet 2 fracture (26 days). These results show that not only less angulated fractures had shorter duration of immobilisation, but that this was mostly due to a change in treatment methods towards less invasive treatment methods, which affected the immobilisation time in an important way: Patients treated with surgical methods were longer immobilized than those treated with cast only. This corresponds to the guidelines of the literature[18,32] as well as the HEL[24], where the proposed immobilisation time of operatively treatments is longer than the immobilisation time proposed for conservative treatment.

Cosma et al.[32] suggested an immobilisation time of 10-15 days for fractures treated with percutaneous reduction. Comparing these guidelines with the mean immobilisation of all percutaneous reduced fractures in our study (mean of 25.6 days), shows that the immobilisation time of percutaneous reduced fractures in this study is too long.

Analysing the immobilisation time of conservative treatment shows that the mean immobilisation time of all fractures treated conservatively was 18.46, with 90% Judet 1 fractures and 6.7% Judet 2 and 3.3% Judet 3 fractures. Recent literature concerningly the immobilisation time in radial head fractures treated conservatively recommends an immobilisation time as short as possible. The guidelines of the HEL elaborated for radial head fractures treated conservatively and without concomitant fracture propose an immobilisation time of 2 weeks. Rockwood and Tschierne et al. suggest an immobilisation time of 7 to 14 days.[26,27] According to Von Laer et al. the immobilisation time should be even lower suggesting 8 days of immobilisation.[28] Von Laer et al. mentioned that the early functional use is important for a proper revascularisation of the radial head.[15] This shows that the immobilisation time of conservatively treated fractures in this study (mean 18.46 days) is definitively too long comparing to the guidelines of the HEL (2 weeks) but also compared to the current literature (8 days).[26,27,28] So the hypothesis that the immobilisation time performed at the HEL is too long for radial head fractures without concomitant fractures can be supported. It is important to

consider this new perception of optimal length of immobilisation to adapt the guidelines of the HEL.
In Judet 1 fractures with no concomitant fracture, the mean immobilisation time was 17 days compared to 25 days of Judet 1 fractures with a concomitant fracture. The difference of 8 days between the mean immobilisation time of Judet 1 fractures with and without concomitant fractures shows that the immobilisation time changes with presence of a concomitant fracture. It is important to analyse these two groups apart because the presence of concomitant fracture changes the treatment method and thereby, the time of immobilisation but also the functional outcome. Almost half of the Judet 1 fractures (4 out of 9) with concomitant fracture were treated with open reduction. After a thorough literature research, no guidelines for the immobilisation time of Judet fractures with concomitant fractures was found. This could be a further research topic, because concomitant fractures are not uncommon as seen in the literature as well as in this study (overall 28%).[16,18,22]
Badoi et al.[23] recorded that a longer duration of immobilisation shows poorer functional results comparing the outcome of patients with different immobilisation times (22 vs 13 days). Similarly, our results show that patients with an immobilisation time of more than 3 weeks had in 79% no or minor limitation compared to patients with less than 3 weeks of immobilisation who had no or minor restriction in 91.3% of the cases. This causality between the functional outcome and the immobilisation time was not the aim of this study, therefore a prospective study with an analysis of the outcome according to the immobilisation time should be carried out to confirm this result.

7.2 Strengths and limitations of the present study

One of the limitations is, that this study is done retrospectively. This is why it faced limitation in respect to patient data. In the same way, the lack of statistical significance was likely due to small numbers of patients.
Second, the clinical outcome with F/E and P/S of the radial head fractures was analysed by many different physicians in the HEL, which might have affected the reliability in comparing the outcomes. Third, there was not always a long-term follow up to assess the functional outcome. Many patients were treated nonoperatively who healed quickly with excellent outcomes and did not require longer follow up. Similarly, there were patients reaching a plateau in their healing: even if the function of the injured elbow was not exactly the same as the contralateral elbow, measured in degrees less than 10° of difference, this did not prevent the young patient from using their elbow normally in daily living. Those patients were told to reconsult only if needed and so a systematically follow-up was not assured.
Forth, given the number of providers whose patients were included in the study, variation of surgeon skill may have an unknowable effect on patient's outcomes.
There was a bias of selection because even with carefully chosen criterions of selection the analysed patients were inhomogeneous in the distribution of age. Yet, the percentage of males and females was identical.

A strength of this study is that it gives a deep insight into the clinical management of radial head fractures in skeletally immature children treated at the HEL. It allows a better comprehension of the perfect management of such fractures and brings light in the controversy of treatment method and immobilisation time. This paper discusses a controversial topic of paediatric orthopaedics and leads the way to an optimal care of radial head fractures in children. The outcome of this study is clear including an adequacy in the management of radial head fracture which reflect in good long-term clinical results.
The conclusions of this study are easy to apply in the management and treatment of radial head fractures in the department of paediatric surgery and orthopaedics of the HEL. Further, because of the results the guidelines of the HEL should be adapted, with new thresholds of the immobilisation time to improve the management of radial head fractures in immature patients.

8 Conclusion

Almost a third of all patients had concomitant fractures which were not related to the degree of displacement but were related to gender. Girls were twice as much at risk than boys to have a concomitant fracture. This evidence should lead physicians to research systematically concomitant fracture when confronted to radial head fractures.
Minor complications are seen in both, conservatively treated and operatively treated patients, but are more commonly seen after operative management. But regardless of which treatment method was used, it can be concluded that in the present study few complications and no radial head necrosis was recorded.
Most radial head fractures with no displacement or minor angulation (Judet 1 and 2) were successfully treated with conservative methods, whereas fractures with serious displacement and angulation (Judet 3 and 4) require reduction. Half of all Judet 4 fractures were treated with closed reduction and cast while there is no difference in the functional outcome compared to other treatments. At HEL treatment with open reduction was rarely needed which contribute to the good functional outcomes.
Finally, this study recorded that skeletally immature patients with radial head fractures were immobilised too long, presenting a 4 days excess of immobilisation time when compared to the current literature and the guidelines of the HEL. New guidelines with a diminution of the length of immobilisation should be established and applied directly in the daily routine of the management of radial head fractures.
In the end it can be said, that the management of RHF in our institution was adequate when compared to the literature. Children with simple radial head fracture treated in our institution would further benefit from a shorter immobilisation time while there is no increase of complications or functional loss.
Further prospective studies describing the effect of immobilisation interval on functional outcome in children suffering from radial head fractures would provide valuable insight into definitive clinical results and are required to confirm the results of the present study.

9 Acknowledgements

I would like to thank Dr. med. Nicolas Lutz for all his support and his explanations. Not only his medical explanations but also his encouragement and his patience were of great value to realize this master thesis. His help and knowledge in the medical field of radial head fractures in children during my analysis were essential.
I would like to thank my expert Dr. med. Frederic Vauclair for his support in the realisation of the master thesis.

10 References

1. Guyonnet C, Martins A, Marengo L, Mansour M, Rousset M, Samba A, Dimeglio A, Canavese F, Functional outcome of displaced radial head fractures in children treated by elastic stable intramedullary nailing, J Pediatr Orthop B. 2018 Jul;27(4):296-303
2. Hui Taek K, Le Viet C, Tae Young A , In Hee K, Analysis of Radiographic Parameters of the Forearm in Traumatic Radial Head Dislocation MD Clin Orthop Surg 2017;9(4):521-528
3. Ackerson R, Nguyen A, Carry PM, Pritchard B, Hadley Miller N, Scott F, Intra-articular Radial Head Fractures In the Skeletally Immature Patient: Complications and Management. J Pediatr Orthop 2015;35(5);443-448.
4. Kruppa C., Königshausen M, Schildhauer T, Dudda M, Isolated pediatric radial head and neck fractures. A rare injury. Analysis and follow up of 19 patients. Injury, Int. J. Care Injured 2015;46(S4):10-16
5. Shabtai L, Arkader A, Percutaneous Reduction of displaced radial neck fractures achieves better result compared with fractures treated by open reduction. J Pediatr Orthop 2016;36(S1):63-66
6. Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J, Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. J Pediatr Orthop 1993;13(3):355-360
7. Lascombes P, Journeau P, Haumont T, Popkov Paediatric Proximal Radial Fractures 2016;11 Musculoskeletal Medecine.
8. Tarallo L, Mugnai R, Fiacchi F, Capra F, Catani F. Management of displaced radial neck fractures in children: percutaneous pinning vs. elastic stable intramedullary nailing. J Orthop Traumatol. 2013;14(4):291–297.
9. Yao LF, Ye ZM, Li ZX, Zhong ZP, Xu RM. Treatment of radial neck fracture in children with elastic stable intramedullary nails. Zhongguo Gu Shang. 2013;26(12):1028–1031.
10. Vasilescu DE, Cosma D, Elastic stable intramedullary nailing for fractures in Children – Principles, Indications, Surgical Technique Clujul Med. 2014;87(2):91-94
11. Edgington J, Andras L, Radial Head and Neck Fractures - Paediatric 2018 Orthobullets: https://www.orthobullets.com/pediatrics/4011/radial-neck-and-head-fractures--pediatric
12. Atarraf K, Arroud M, Chater L, Afifi MA. Fractures of the radial head in children: about 66 cases. Pan Afr Med J. 2014;17:138
13. Gutierrez-de la Iglesia D, Pérez-Lopez LM, Cabrera-Gonzalez M, Knörr-Giménez J, Surgical Techniques for Displaced Radial Neck Fractures: Predicitive Factors of Functional Results, J Pediatr Orthop 2017;37(3):159-165
14. Slongo T, Audigé L, AO Pediatric Classification Group (2007), AO Pediatric Comprehensive Classification of Long-Bone Fractures (PCCF), Copyright 2010 by AO Foundation, Switzerland
15. Von Laer L, Frakturen des proximalen Radiusendes. In Von Laer et al. Frakturen und Luxationen im Wachstumsalter, 2th Ed, Georg Thieme Verlag Stuttgard, New York 1991:121-129
16. Tan BH, Mahadev A, Radial neck fractures in children, J Orthop Surg 2011;19(2):209-12
17. Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V, Radial Neck Fractures in Children: Results When Open Reduction Is Indicated J Pediatr Orthop 2014;34(8):756–762
18. Çevik N, Cansabuncu G, Akalın Y, Otuzbir A, Öztürk A, Özkan Y Functional and radiological results of percutaneous K-wire aided Métaizeau technique in the treatment of displaced radial neck fractures in children. Acta Orthop Traumatol Turc. 2018;52(6):428-434.
19. Jiang H, Wu Y, Dang Y, Qiu Y, Closed reduction using the percutaneous leverage technique and internal fixation with K-wires to treat angulated radial neck fractures in children-case report, Medicine (Baltimore) 2017;96(1):e5806

20. Zhang FY, Wang XD, Zhen YF, Guo ZX, Dai J, Zhu LQ, Treatment of severely displaced radial neck fractures in children with percutaneous K-wire leverage and closed intramedullary pinning, Medicine (Baltimore) 2016;95(1):e2346
21. Seung MR, Doo HY, Sam-Guk P, Clinical and Radiographic outcomes of pediatric radial head fractures, Indian J Orthop.2018;52(2):561-567
22. De Mattos CB, Ramski DE, Kushare IV, Angsanuntsukh C, Flynn JM, Radial Neck fractures in Children and Adolescents: An Examination of operative and nonoperative Treatment and Outcome , J Pediatr Orthop 2016;36(1):6-12
23. Badoi A, Frech-Dörfler M, Häcker FM, Mayr J, Influence of Immobilisation Time on Functional Outcome in Radial Neck Fractures in Children, Eur J Pediatr Surg 2016;26(6):514-518
24. Merckaert Sophie, Fractures, entorses et luxations en pédiatrie: Prise en charge aux urgences. Guidelines de l'HEL CHUV, Orthopédie pédiatrique, Unité pédiatrique d'orthopédie et traumatologie. Version 1.4, 23.05.2018
25. Schmittenbecher PP, Haevernick B, Herold A, Knorr P, Schmid E, Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. J of Pediatr Orthop. 2005;25(1):45-50
26. Erickson M, Frick S. Fractures of the proximal radius and ulna. In: Beaty JH, Kasser JR, et al. Rockwood and Wilkins' Fractures in children. 7th edition Philadelphia, Lippincott, Williams and Wilkins; 2010:405-444
27. Hell A, Weinberg A. Radiusköpfchen-und Radiushalsfrakturen. In: Weinberg AM, Tscherne H, et al. Unfallchirurgie im Kindesalter. Berlin, Heidelberg, Springer Verlag; 2006:313-331
28. Von Laer L, Kraus R, Linhart WE. Proximaler Vorderarm Radiusköpfchen. In: Von Laer L, Kraus R, Linhart WE, et al. Frakturen und Luxationen im Kindesalter. 6th Ed, Berlin, Heidelberg: Springer Verlag; 2012:182-191
29. Monson R, Black B, Reed M, A new closed reduction technique for the treatment of radial neck fractures in children, J Pediatr Orthop 2009;29(3):243-247
30. Wilkins KE, Principles of fracture remodelling in children, Injury, Int. J. Care Injured 2005;36Suppl 1:A3-11
31. Sahin N, Akalın Y, Türker O, Özkaya G, ESIN and K-wire fixation have similar results in pediatric both-bone diaphyseal forearm fractures. Ulus Travma Acil Cerrahi Derg 2017;23(5):415–42
32. Cosma D, Vasilescu DE, Elastic stable intramedullary nailing for fractures in children – Specific applications, Clujul Medical 2014;87(3):147-151

11 List of figures