Diploma Thesis

Retrospective Analysis of Operative Treatment after Non-Union of the Styloid Process in Pediatric Patients with Forearm Fractures and Distal Radio-ulnar Joint Instability

submitted by

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Graz, am 07.02.2014 *Ismail Khosravi*

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Abstract

Introduction

Distal forearm fractures represent one of the most common fractures in children and adolescents. A fall on the outstretched forearm can lead to distal radius fractures in combination with fractures of the ulnar styloid process. Non-unions of the ulnar styloid process can be associated with instabilities and chronic wrist pain. The aim of this study was to describe the outcome of operative treatment of painful non-unions of the ulnar styloid process.

Patients and Methods

All patients with a painful non-union of the ulnar styloid process following displaced distal radius fracture that were treated surgically were included. DASH, Mayo, grip strength, Range of Motion (ROM) of pro- and supination and the gliding test were analyzed retrospectively. To describe the incidence of non-union of the ulnar styloid process all patients who presented with displaced fractures of the radius during the time from 2008 to 2012 were analyzed and scanned for an ulnar styloid process injury.

Results

Out of 673 patients with displaced fractures of the radius 12 patients developed a non-union of the ulnar styloid process. 6 of these patients had chronic pain and therefore were treated surgically. The beneficial effect of operative treatment could be demonstrated with a significant improvement of Mayo (from a preoperative mean of 62.5 to a postoperative mean of 95.83) and DASH Score (from a preoperative mean of 32.05 to a postoperative mean of 10.94). Likewise, the ROM and grip strength significantly improved when comparing pre- to postoperative values.

Discussion

In cases with a painful non-union of the ulnar styloid process following displaced distal forearm fractures operative treatment can lead to a significant improvement of subjective complaints as well as ROM and stability.

Zusammenfassung

Einleitung

Distale Unterarmfrakturen gehören zu den häufigsten Verletzungen im Kinder- und Jugendalter. Ein Sturz auf den ausgestreckten Unterarm kann zu distalen Radiusfrakturen führen und als Begleitverletzung eine Fraktur des Processus styloideus ulnae mit sich ziehen. Ein Abriss des Proc. styloideus ulnae kann Instabilitäten und Schmerzen im distalen Radio-ulnargelenk verursachen. Ziel dieser Studie ist es das Ergebnis der operativen Versorgung des schmerzhaften Abrisses des Processus styloideus ulnae darzustellen.

Patienten und Methoden

Alle Patienten mit symptomatischer Pseudoarthrose des Proc. styloideus ulnae nach distaler Radiusfraktur, welche zwischen 2008 und 2012 operativ behandelt wurden, wurden inkludiert. Retrospektiv wurden dann Ergebnisse des DASH Score, Mayo Score, der groben Griffstärke, der Bewegungsgrade der Pronation und Supination und des „Gliding Tests“ analysiert. Zur Erfassung der Inzidenz der Pseudoarthrosen des Proc. styloideus ulnae, wurden alle Patienten mit dislozierter distalen Radiusfraktur im Studienzeitraum analysiert und die Anzahl der Verletzungen des Proc. styloideus ulnae erhoben.

Resultate

Von 673 Patienten mit einer dislozierten Radiusfraktur konnte bei 12 Patienten eine Pseudoarthrose des Proc. styloideus ulnae identifiziert werden. 6 dieser Patienten wurden aufgrund chronischer Schmerzen operativ behandelt. Der positive Effekt der operativen Behandlung zeigte sich durch eine Besserung des Mayo (Mittelwert von präoperativ 62.5 auf postoperativ 95.83) und DASH Score (Mittelwert von präoperativ 32.05 auf postoperativ 10.94). Ebenso verbesserten sich auch die Bewegungsgrade und die grobe Griffstärke.

Diskussion

Im Falle eines schmerzhaften Abrisses des Proc. styloideus ulnae, als Begleitverletzung bei dislozierten distalen Radiusfrakturen, kann die operative Versorgung zur signifikanten Besserung subjektiver Beschwerden sowie des Bewegungsausmaßes und der Stabilität führen.

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List of Abbreviations

AO	Arbeitsgemeinschaft für Osteosynthesefragen (a study group to conduct research in bone healing)
DASH	Disabilities of Arm, Shoulder and Hand
DRUL	Distal Radio-ulnar Ligament
DRUJ	Distal Radio-ulnar Joint
ECU	Extensor Carpi Ulnaris
ESIN	Elastic Stable Intramedullary Nail(-ing)
IM	Interosseous Membrane
IMN	Intramedullary Nail
MC	Meta Carpus (metacarpal)
Proc.	Processus
ROM	Range of Motion
TFC	Triangular fibrocartilage
TFCC	Triangular fibrocartilage complex

General Part

1. Development

The ossification of the radius starts in the eighth week of fetal life centrally in the shaft. Two more centres appear in the physes. While the proximal epiphysis ossifies in the fourth to fifth postnatal year, the ossification of distal epiphyses already begins in the first postnatal year, except the styloid process, which has its own centre at the age of ten. The closure of the proximal physis occurs at the age of fourteen to seventeen. The distal physis closes at the age of twenty to twenty five (1).

Ossification of the ulna also begins in the eighth week of fetal life and has two centres in each epiphysis. The two centres in the olecranon start their ossification at the same time at the age of nine to eleven. While the distal epiphysis ossifies at the age of four to seven, the centre of the styloid process starts its ossification at the age of seven to eight. At the end of the ossification the fusion in the proximal physis ends at the age of fourteen to sixteen and seventeen to eighteen in the distal physis (1).

Due to the fact that the distal physes are involved in more than 80% of the growth of radius and ulna, the right treatment of injuries in this area is very important to prevent growth disturbance of these bones (2).

At birth the carpal bones are cartilaginous although the ossification of the hamate and capitate has already started. The order of ossification of the carpal bones varies but it starts with the capitate and ends with the pisiform. Each bone ossifies from one centre starting with the capitate in the second month, the hamate in the fourth month and the triquetrum in the third year. Depending on the sex, the lunate, scaphoid, trapezium and trapezoid ossify in the fourth year in females and the fifth in males. In females the pisiform ossifies in the tenth year whereas in males in the twelfth year. According to gender, nutrition and possibly race, the order can vary in some cases (1). The development of the bones of the forearm and hand is summarized in Figure 1.

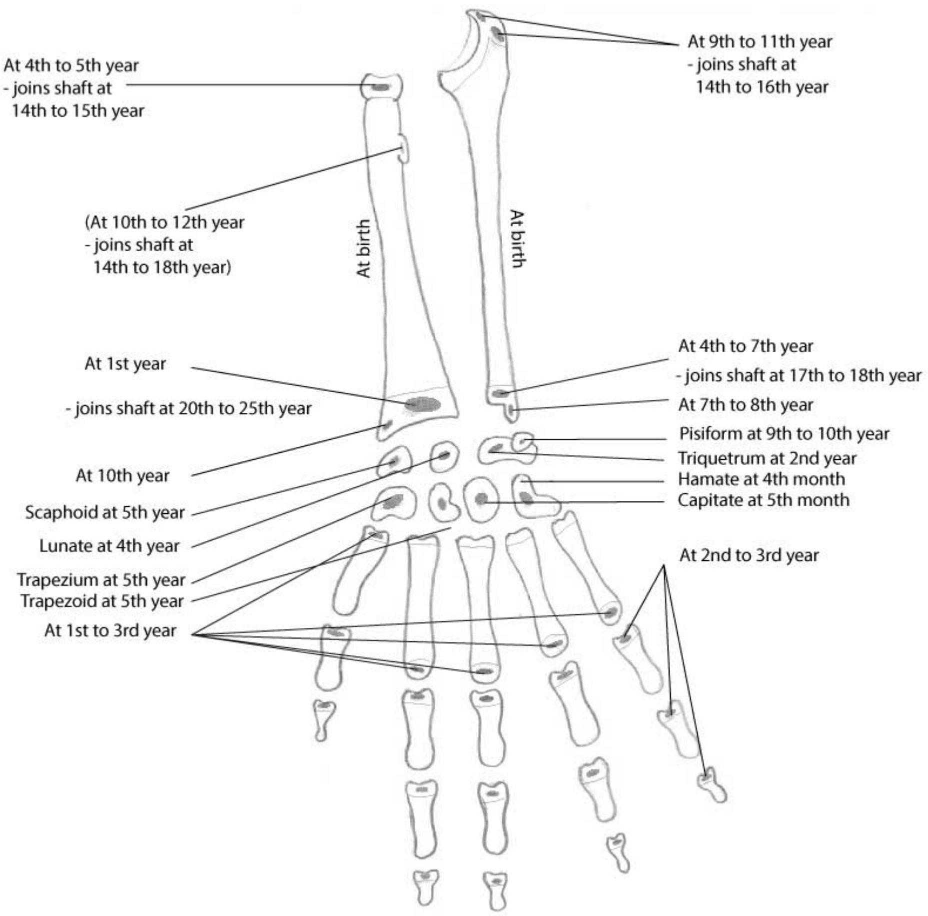


Figure 1: Development of the bones of the forearm and hand

2. Anatomy

The forearm consists of two bones, the radius and the ulna (Figure 2). These two bones are connected by the interosseous membrane and the oblique cord. Inevitably the proximal and the distal radio-ulnar joint are combined joints making the pronation and supination of the forearm possible (3).

This means that the distal radio-ulnar joint is mechanically connected to the proximal radio-ulnar joint and functionally connected to the wrist. Therefore all these joints are involved during pro- and supination (1) (3).

2.1 The radius

The lateral bone is the radius (Figure 2). Its distal part is broader than the proximal one. On the proximal part we can find the head, the neck and a tuberosity. The head is formed like a disc and has a surface that fits to the capitulum of the humerus. On the medial side of the radius lies the tuberosity. The shaft is convex on the lateral side and shows a triangular shape, while the distal part shows four sides in section. The medial part of the radius, which is the interosseous border, is sharp. Its carpal articular surface is divided in two areas, medial and lateral. The lateral area is triangular and the medial surface quadrangular. On the triangular part the apex of the triangle is built by the styloid process of the radius. The ulnar notch is located on the medial side. Its surface is smooth and concave for the articulation with the head of the ulna (1) (3).

2.2 The Ulna

When the forearm is supinated, the ulna lies medially of the radius. The interosseous membrane connects the sharp lateral border of the ulna with the medial border of the radius. Unlike the radius, the proximal part is wider than the distal part. At the distal end of the ulna a round head with a styloid process expands again. The proximal end is hook – shaped with the trochlear notch that provides the connection between the humerus and the ulna (Figure 3). While in extension, the olecranon of the ulna enters the olecranon fossa of the humerus. (1) (3).

At the proximal joint the radius articulates with the radial notch of the ulna, which is on the lateral surface of the trochlear notch (Figure 4). Distal to the radial notch the surface provides an area for the radial tuberosity. In section the shaft is triangular proximal but almost cylindrical distally. On the lateral part there is the interosseous border. The anterior surface is separated from the medial surface by the anterior border. The posterior border again separates it from the posterior surface.

The distal end of the ulna also has a styloid process. The convex articular surface of the head of the ulna fits to the ulna notch on the radius. During pronation of the forearm the head of the ulna is visible. Between the carpus and the smooth surface of the head of the ulna lies the articulation disc which is attached to the styloid process and a rough area on the articular surface (1) (3).

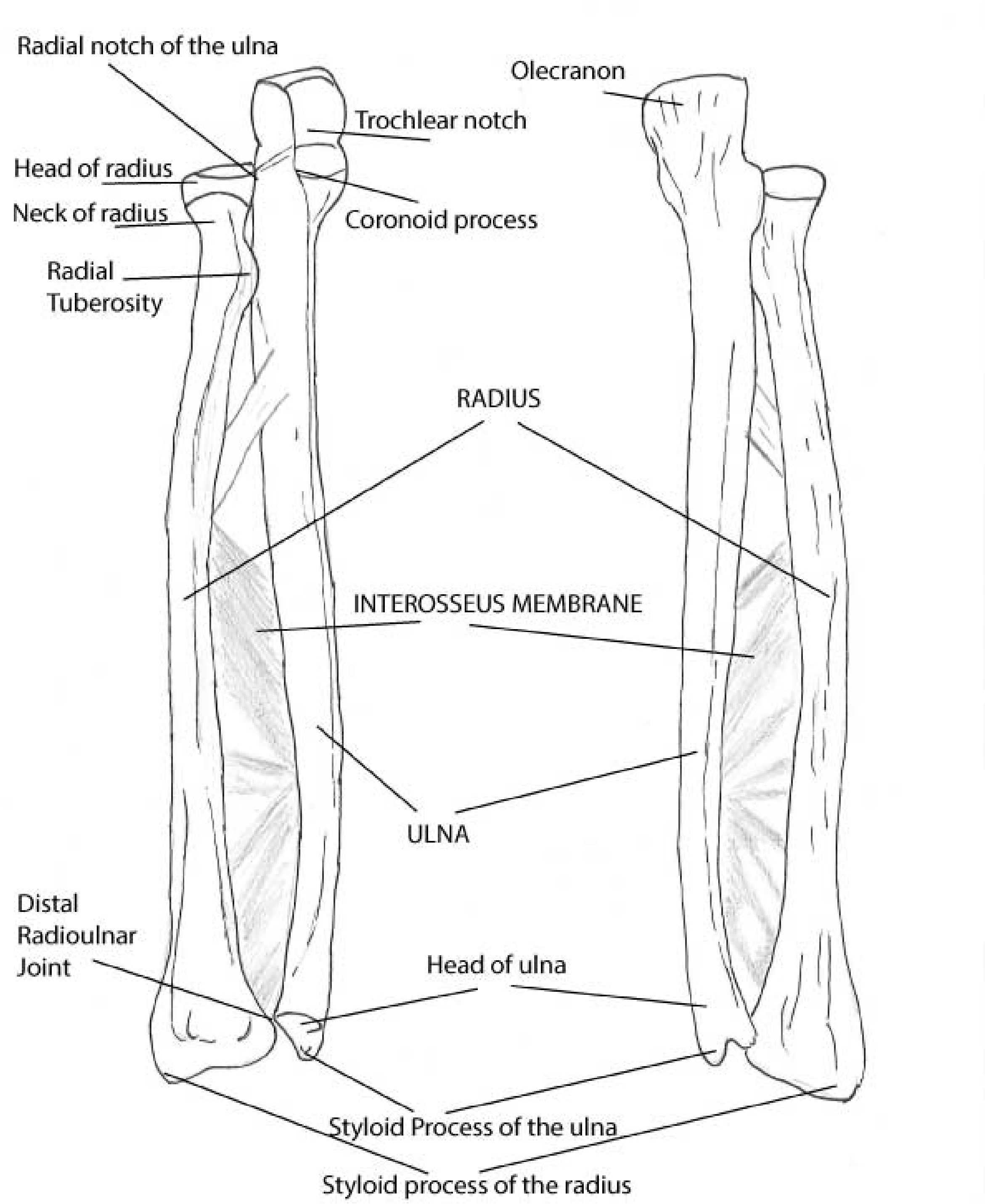


Figure 2: Anatomy of Radius and Ulna

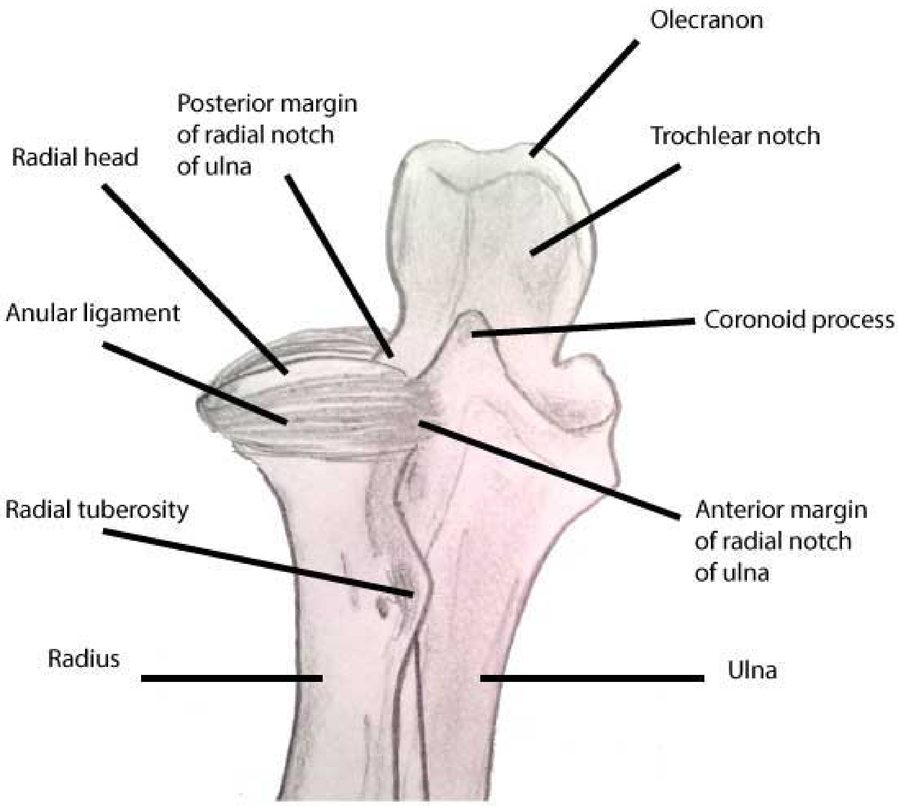


Figure 3: Proximal radio-ulnar joint frontal view

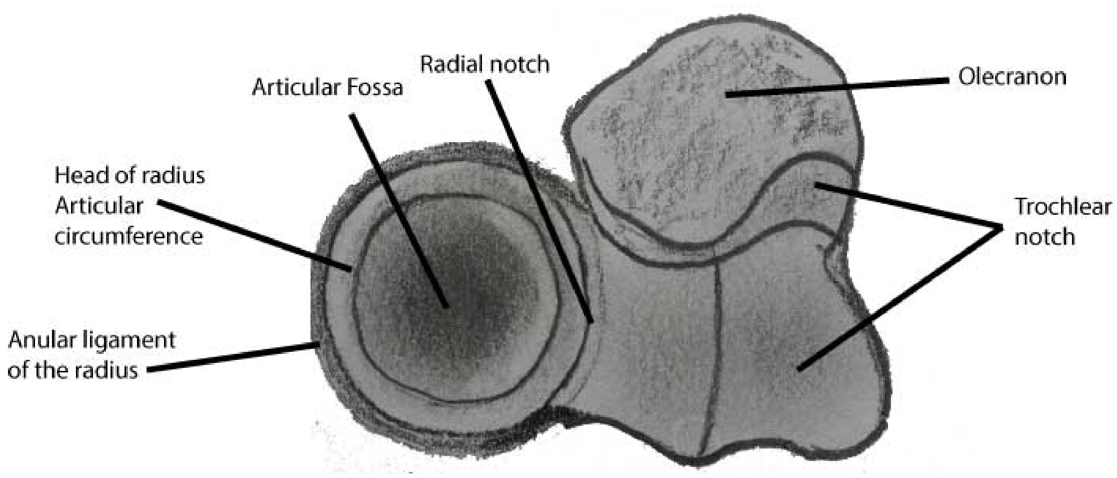


Figure 4: Proximal radio-ulnar joint transversal view

2.3 Carpal Bones

The carpus consists of eight bones that build two rows. While the proximal row, in order from radial to ulnar, is made up of the scaphoid, lunate, triquetrum and pisiform, the distal row is made up of trapezium, trapezoid, capitate and hamate (Figure 5) (1).

The carpal bones that are part of the distal radio-ulnar joint are the scaphoid, the lunate and the triquetrum. Based on the fact that tendons are attached to the non-articulating area of the pisiform on the palmar side, which is a protection to the articulation surface of the triquetrum, the pisiform serves as a sesamoid bone.

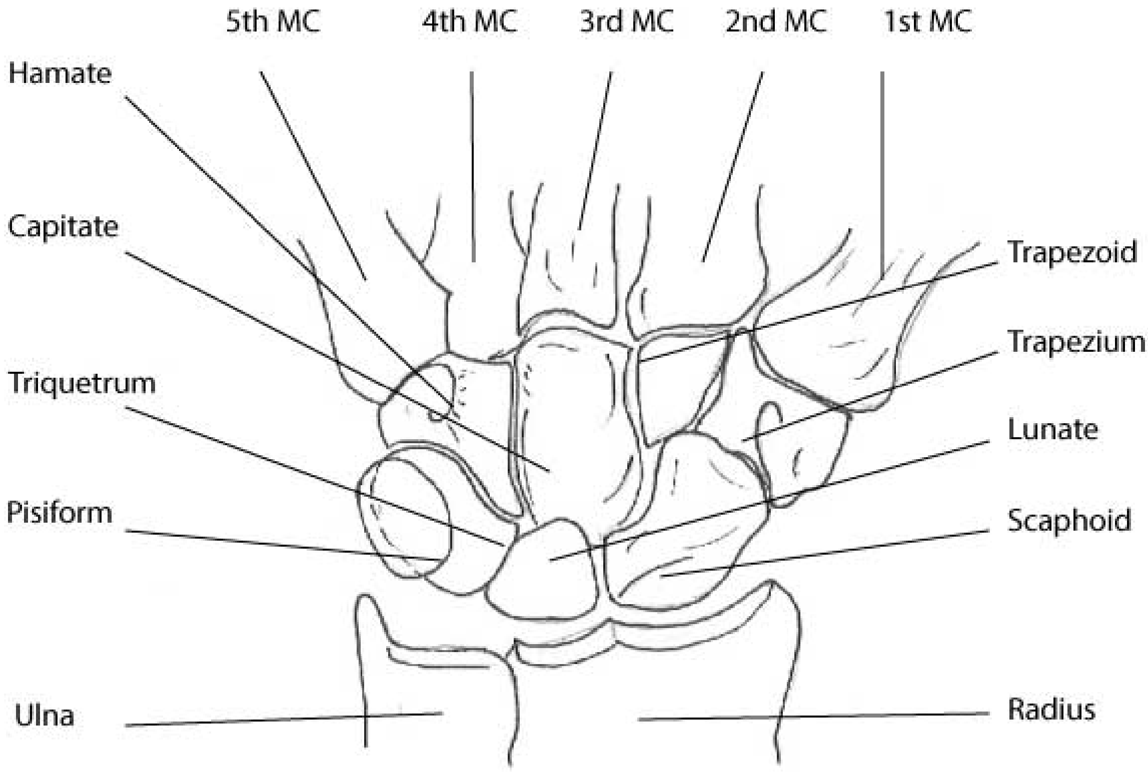


Figure 5: Anatomy of the carpal bones

2.4 Functional Anatomy

For the performance of functional tasks, the whole forearm complex is necessary. This complex is compromised of the proximal and distal radio-ulnar joint as well as the interosseous membrane. Injuries to one of these joints can adversely affect the other structures (4).

2.4.1 Proximal radio-ulnar joint (PRUJ)

As a uniaxial pivot joint, the PRUJ can make pronation and supination of the forearm possible. The proximal articulation between radius and ulna is composed of the circumference of the radial head, the ulnar radial notch and the anular ligament. The fibrous capsule is broad and thin and includes three articulations. It comprises the coronoid fossa, the radial fossa and the olecranon. Distally it is attached to the ulnar coronoid process and deep to the radial anular ligament. The epicondyles of the humerus are laterally excluded (1) (3).

2.4.2 Distal radio-ulnar joint (DRUJ)

The DRUJ is a pivot joint as well. It is inevitably combined with the PRUJ and together these joints are responsible for the pronation and supination. The cartilaginous surface of the ulnar notch of the radius turns over the ulna during supination (1).

The capsule of the distal radio-ulnar joint is wide and lax, especially at the proximal part. The reason is to build a lap for the pro- and supination. To divide the carpus from the DRUJ there is a fibrocartilage discus which is triangular and connects the distal endings of radius and ulna (Figure 6). The discus extends from the ulnar notch to the head of the ulna and is fixed to the styloid process of the ulna and in the middle of the distal articular surface of the head of ulna. Additionally the disc is attached to an edge between the ulnar notch and the carpal articular surface of the radius. The distal surface of the disc articulates with the lunate and during adduction with the triquetrum (1) (3) (5).

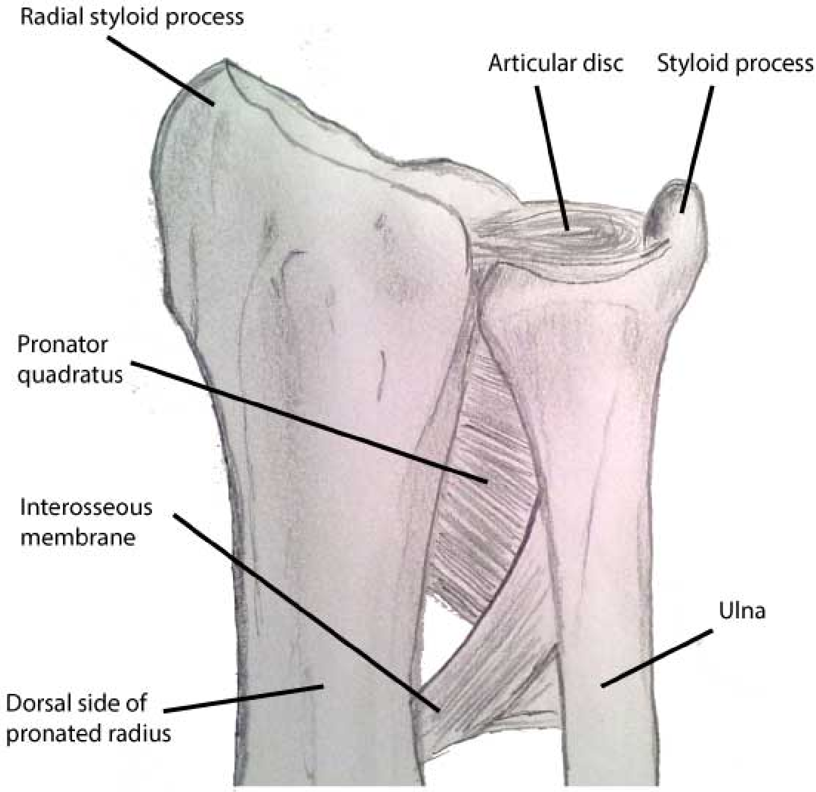


Figure 6: Distal radio-ulnar joint, frontal view

As part of the TFCC two ligaments known as the dorsal distal radio-ulnar ligament and the palmar distal radioulnar ligament contribute translational stability to the DRUJ (Figure 7). The attachment of palmar and dorsal distal radio-ulnar ligament (DRUL) is discussed controversial but by some considered to be at the base of the ulnar styloid process as well as at the ulnar fovea. The stability of the DRUJ is provided by the distal radio-ulnar ligaments in tension during forearm rotation (1) (6) (7).

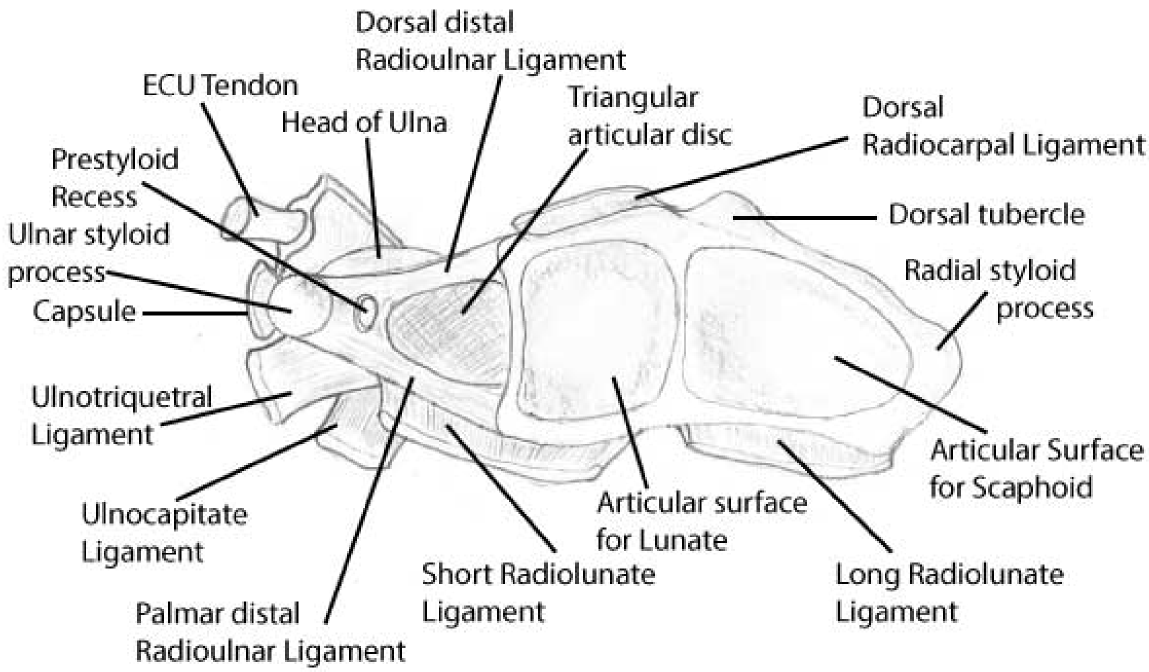


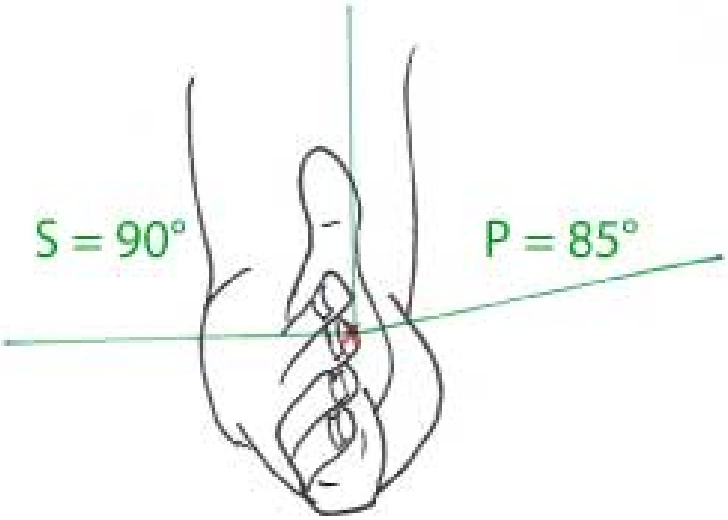
Figure 7: Distal radio-ulnar joint (transversal) shown from below

2.4.3 The interosseous membrane

The radius and the ulna are not just connected by the proximal and distal radio-ulnar joint, but also by the interosseous membrane. It starts at the insertion of the biceps and ends at the distal radio-ulnar joint. Furthermore the oblique cord is a flat band that spreads from the lateral side of the ulnar tuberosity close to the radial tuberosity. The direction of its fibres is opposite to the direction of the interosseous membrane. It seems that the interosseous membrane does not have a high importance in transmitting the force from the wrist to the humerus but its main function is to stabilize and secure the proximal and distal radio-ulnar joints. Moreover it prevents the radius and the ulna from longitudinal displacement (1) (3) (5).

2.4.4 Rotation of the forearm

Pronation and supination require an interaction of the proximal and distal radio-ulnar joint. The neutral – zero – method is used to measure the range of motion. In case of the forearm rotation, the neutral position is reached when the thumb is pointing cranially, the palm is pointing medially and the dorsum of the hand laterally. Based on this position, pronation is achieved when the thumb is pointing medially and the palm caudally at up to 85°. Beginning at the neutral position, supination is achieved when the thumb is pointing laterally and the palm cranially up to 90°. During forearm rotation, the radius turns over the ulna and rotates itself by 180° whilst the ulna does not rotate but makes an extension and lateral movement (Figure 8) (8).



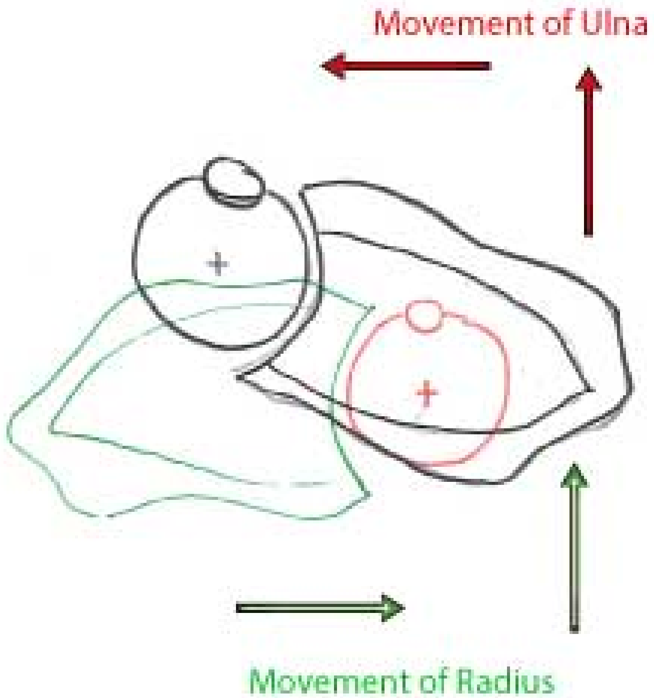


Figure 8: Rotation of the forearm

2.4.5 The wrist joint

The radiocarpal joint is a so called ellipsoid joint considering that it is a biaxial joint, including the distal radius, the triangular fibrocartilage, the scaphoid, the lunate and the triquetrum. While the scaphoid and lunate are the only carpal bones that are in contact with the radius and the articulation disc in the neutral position, a contact between triquetrum and disc is only possible in full adduction (1).

Starting in neutral position the range of motion for ulnar adduction is about 45° whereas the radial abduction is possible with 15°, considering that the axis of the forearm goes through the middle finger. The range of motion in flexion and extension is about 85° each (Figure 9) (8).

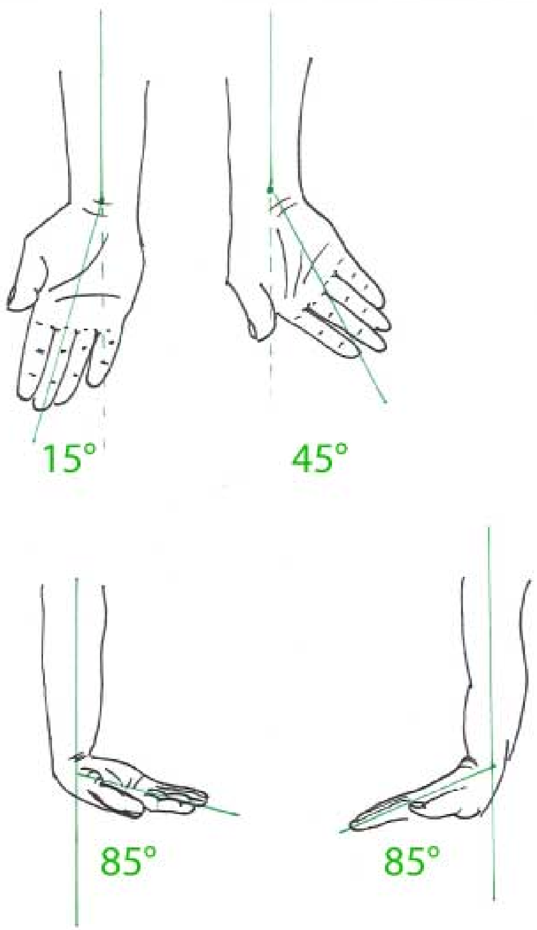


Figure 9: Wrist joint, range of motion

2.4.6 The triangular fibrocartilage complex (TFCC)

Palmar and dorsal distal radio-ulnar ligaments, together with the ulnar collateral ligament, the floor of extensor carpi ulnaris subsheath, ulnolunate and ulnotriquetral ligaments, as well as the cartilaginous disc and the meniscus homologue (Figure 10) are per definition the so called triangular fibrocartilage complex (TFCC) (5).

The triangular fibrocartilage complex is a structure that divides the distal radius and the ulnar carpus from the distal ulna. Functionally the TFCC seems to stabilize the joints, and transmit loads to the ulna and makes complicated movements in this joint possible (5).

Like other menisci and disci, the main function of the TFCC is the transmission of forces. Additionally it provides:

- a gliding surface for the radius and ulna making movements like flexion and extension as well as translational movements possible.
- a mechanism to stabilize the DRUJ and the ulnar carpus
- a solid connection between ulnar axis and palmar carpus

The fixation of the TFCC is broad in scope on the notch of the radius and has two fixation points at the ulnar styloid process. These two fixations are in first place at the base of the styloid process and secondly at the top of the styloid process. That means that in case of an injury to the head of the ulna, the discus does not have to be detached (9).

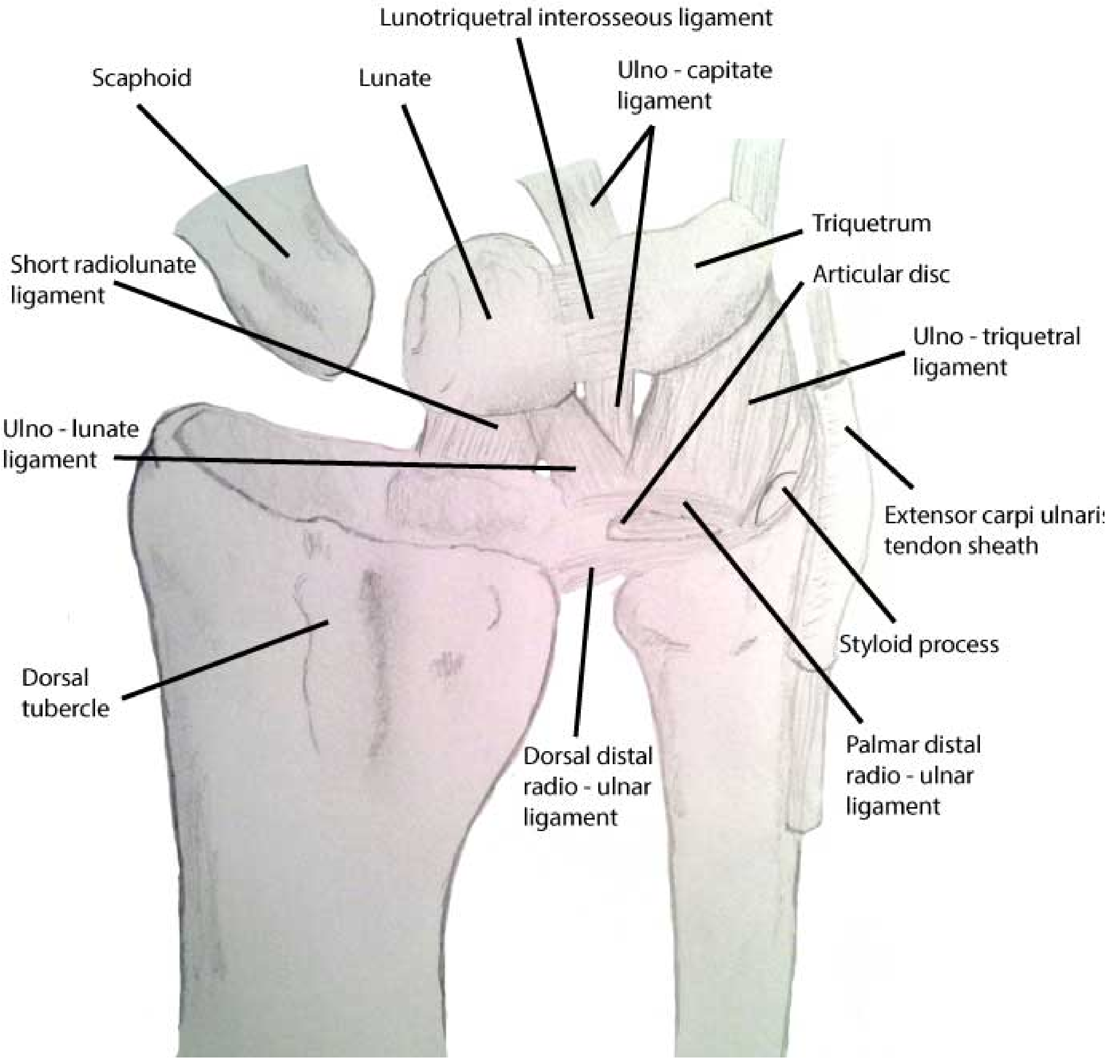


Figure 10: Distal radio-ulnar joint and triangular fibrocartilage complex

3. Definitions and Epidemiology

3.1 Definition

Fractures:

Forearm fractures are defined as complete or incomplete fractures of the radius and the ulna. (10) (11) (12).

While a complete fracture involves both cortices affection of only one cortex is described as an incomplete fracture. Furthermore incomplete fractures can be separated into “greenstick” and “buckle” or “torus” depending if the failure of the bone was caused by tension (greenstick) or compression (buckle, torus) (12).

Dislocation:

Separation of joint surfaces is termed a dislocation. Injuries with a loss of communication of the wrist joint, often lead to secondary injuries to ligaments, the joint capsule or even the muscles. Also a dislocation can be complete or partial, which is then called a subluxation (12).

Displacement:

Displacement is defined as a deviance from the normal position, in fractures it depends on the position of the distal part relatively to the proximal part. It can either be described as an anteriorly/posteriorly, or laterally/medially displacement. Also dorsal/palmar is used as well as the description of the rotation, which can be internal or external. In addition, an inclination of the distal part relatively to the proximal part is a so called angulation (12).

Impaction:

Since impaction seems to be very common in radius fractures, but not easily discovered on x-ray, a closer observation may increase the chance to find an axial compression by looking for a higher density (12).

3.2 Epidemiology

For proper treatment of fractures in pediatric and adolescent patients, a fundamental knowledge of the incidence of these injuries is crucial. The prevalence for fractures in children in Central Europe is at about 25 per 1000 children per year. It has been shown that most of the injuries occur at the age between 10 and 13. More than 60% of these fractures are related to long bones, while male patients outweigh females (13).

The largest group of fractures of all age groups, with more than 55%, is the group of forearm fractures. According to the fact that the differentiation of diaphyseal fractures and distal forearm fractures vary in different studies, the prevalence of distal forearm fractures differs from 19% to 39%. However, forearm fractures are most common in every age group and have the highest peak at the age of 13 to 14. They occur mostly in school and during sports while traffic accidents are considerably rare (13).

4. Trauma mechanism

The so called Potau – Colles fractures or “fractura loco typico” generally occur with the arm in extended position and the hand in dorsal flexion (Figure 11). In about 10% the fracture can also happen with the hand in palmar flexion (Figure 12) which is called the Goyrand – Smith fracture (14).

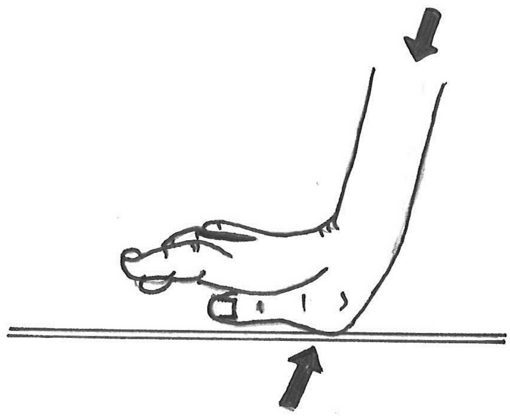


Figure 11: Fall on outstretched arm with the hand in dorsal flexion leading to Colles - fracture

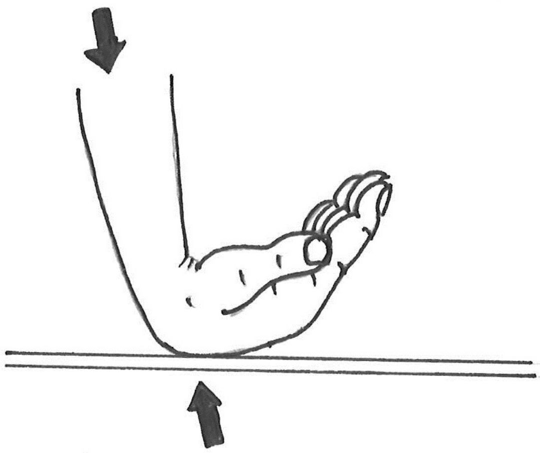


Figure 12: Fall on the outstretched arm with the hand in palmar extension leading to Smith – fracture

These injuries often happen during sports as well as in school. Forearm fractures in children and adolescents rarely are caused by traffic accidents.

5. Classification and Scoring

A proper classification of fractures is a necessary precondition for a predication of the quality of healing and the results. Therefore, it is important to choose the right classifications and scorings to obtain information for appropriate treatment.

5.1 AO – Classification

5.1.1 Localization

Based on the AO classification of fractures in adult patients, some special characteristics of pediatric fractures were added. Like in adults it is also necessary for the pediatric AO – classification to evaluate x – rays in lateral and anterior – posterior views. Each of the long bones is consecutively numbered:

- 1 Humerus
- 2 Radius/Ulna
- 3 Femur
- 4 Tibia/Fibula

It should be noted that the distal forearm and the lower leg, due to the fact that they are two pairs of bones, are considered as one long bone. Furthermore the segments are defined:

- 1 Proximal
- 2 Diaphyseal (D)
- 3 Distal

Additionally, the end segments of pediatric long bones have two subsegments which are declared as “M” for metaphysis and “E” for epiphysis. To identify the metaphysis, a square with a length the same as the widest part of the physis (growth plate) is used (Figure13). The radius and the ulna have to be included in the same square (15) (16).

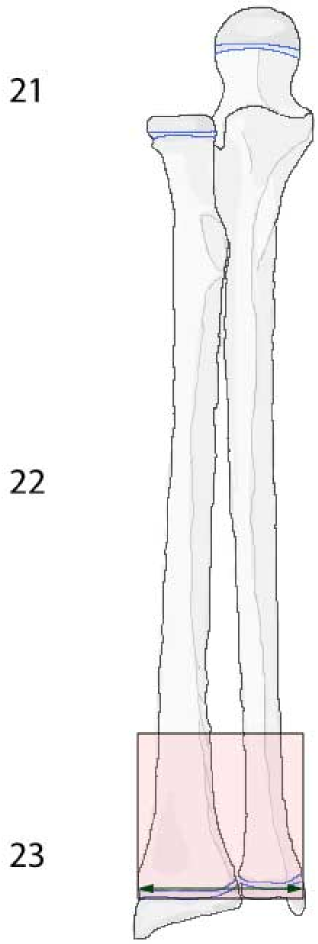


Figure 13: AO Classification for the forearm

5.1.2 Child Code

The A-B-C severity code in adults is replaced by the E-M-D (*epiphyseal, metaphyseal and diaphyseal)* code in children. In addition to the E-M-D classification a special child code has been defined. Known patterns are specifically added to each of the categories. According to Salter Harris the adequate child code E/1 to E/4 is used (Figure 14). Other child – codes from E/5 to E/8 are used to describe special fractures like Tilleaux (E/5), tri-plane (E/6), ligament avulsions (E/7) and flake fractures (E/8). The code E/9 stands for other summarized fractures (15) (16).

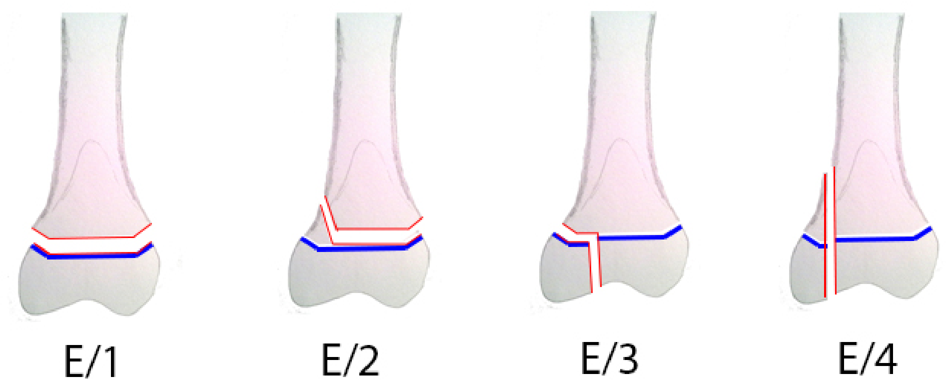


Figure 14: Child Code

Three fractures are differentiated in the metaphysis. Per definition M/2 stands for incomplete fractures like the buckle or greenstick fracture, M/3 for complete fractures and M/7 for avulsion injuries including osteo – ligamentous and musculo – ligamentous avulsions.

The patterns for the diaphysis are defined as follows: D/1 bowing fractures; D/2 greenstick fractures; D/4 complete transverse fractures with an fracture angle of less than 30°; D/5 complete oblique or spiral fractures with an fracture angle of more than 30°; D/6 for Monteggia fractures and D/7 for Galeazzi fractures (Figure 15). The code D/3 was originally used for toddler fractures. Nowadays it is not used anymore due to the fact that identifying these fractures by radiographs was found to be unreliable. The code D/8 would describe a flake fracture but does not apply to diaphyseal fractures (15) (16).

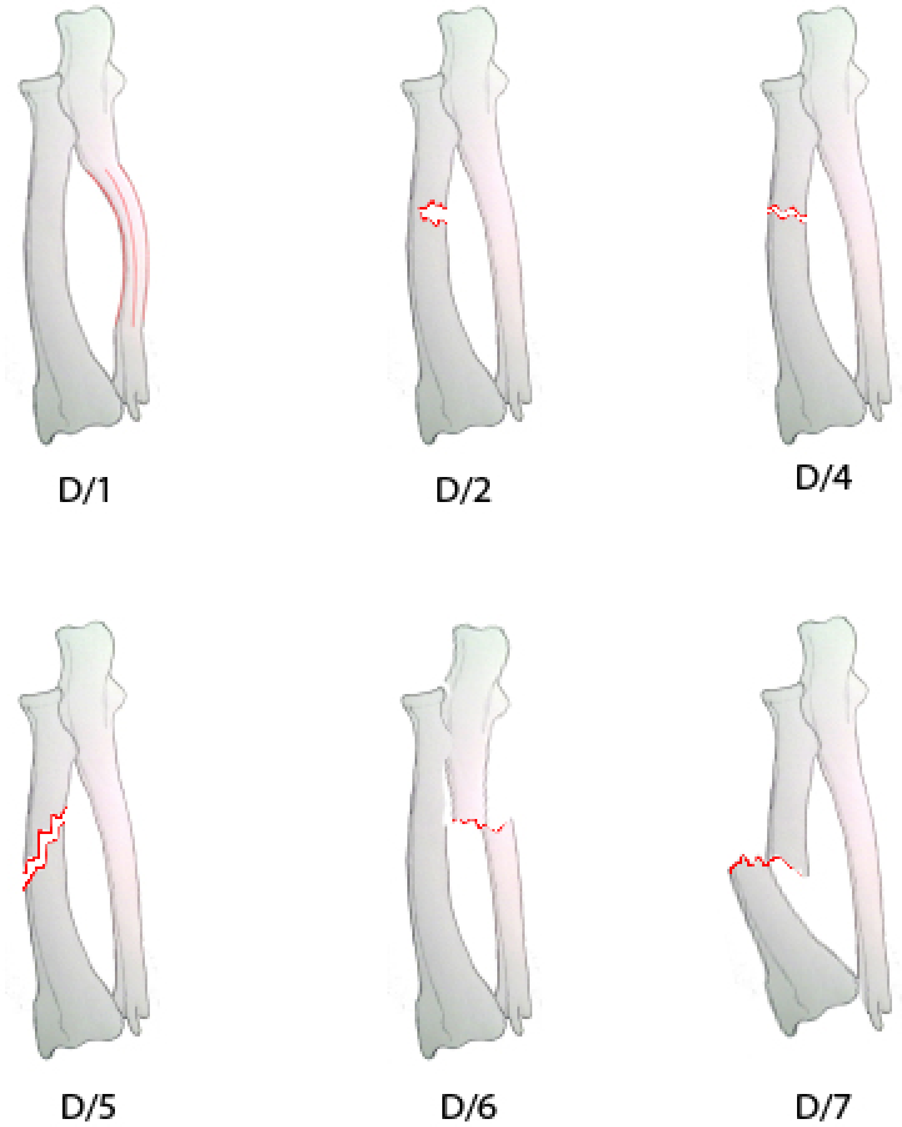


Figure 15: Child Code Diaphysis

5.1.3 Severity

For proper treatment a severity classification is inevitable. Three different severity grades can be applied (16).

- simple fracture
- wedge fracture which is partially stable and has less than three fragments including one dislocated fragment
- complex fracture which is not stable and has more than three fragments

5.1.4 Exceptions and additional codes

Due to the fact that not all fractures can be fitted in the patterns above, some additions are made for the AO classification. For supracondylar humerus fractures grades from I to IV, according to the displacement, are added.

According to the axial deviation and level of displacement in radial head fractures an addition of the codes I to III was given.

When paired bones like radius and ulna are fractured with the same pattern, a single classification is sufficient with the severity grade describing the most severely fractured bone. If the fractures in paired bones differ, the patterns should be used for each bone separately using additional letters to describe the bones. Therefore “u” is used for the ulna and “r” for the radius (16) (15).

5.2 Palmer Classification of TFCC lesions

In 1981 Palmer and Werner described the ligaments and cartilaginous structures stabilizing the DRUJ. In the year 1989 they introduced a classification of injuries to the TFCC which is nowadays used globally (12).

At first the injuries are divided into traumatic (Class 1) and degenerative (Class 2). While the traumatic classification is determined by the location of the pathology, the degenerative class follows a specific chronological order according to the repetitively transmitted forces. These affect mostly the TFCC, the ulnotriquetral ligament, the ulnar head and the lunate (17).

5.2.1 Traumatic lesions Class 1

Depending on the location, Class 1 lesions are subclassified into four subclasses A, B, C and D. Class 1A describes a lesion of the horizontal part of the TFCC. If the insertion of the TFCC to the distal ulna is affected, the lesion is classified as Class 1B, which can be accompanied by a fracture of the styloid process. Due to the fact that the TFCC serves as a stabilizing unit of the DRUJ, these injuries can lead to DRUJ instabilities.

Class 1C are avulsions of peripheral attachments of the TFCC to the lunate and triquetrum. This can lead to instabilities of the ulnar carpus and may result in palmar dislocation of the ulnar carpus. Class 1D is represented by tears of the TFCC distally from the sigmoid notch of the radius (17).

5.2.2 Degenerative lesions Class 2

Different from traumatic injuries, degenerative lesions are a result of chronic load to the TFCC. They are subdivided into 2A, 2B, 2C, 2D and 2E. A wear of the horizontal portion of the TFCC is defined as a Class 2A lesion. Class 2 B is represented by erosions of the lunate, the ulnar head or both which are subchondral. Unlike the 2C class, the first two classes do not show any perforation. A progression of this perforation can be found in Class 2D, and even the articulation surfaces are affected. A rupture of the lunotriquetal ligament can also be found here. The last stage is reached with arthritis of the distal radio-ulnar joint and complete rupture of the lunotriquetal ligament. This stage is determined as Class 2E (17).

5.3 Frykman Classification

Although there are some criticisms, like the missing recognition of displaced fractures or the lack of prognosis, the classification system which was introduced by Frykman in 1967 (Figure 16), is still used universally. Combined fractures of the distal radio-ulnar joint and the styloid process of the ulna, are classified as follows: (18)

- **TYPE I:** extraarticular fracture affecting just the distal part of the radius
- **TYPE II:** equal to Type I, including the ulnar styloid process
- **TYPE III:** intraarticular fracture which involves the carpal joint; it can lead to avulsion of the radial styloid process
- **TYPE IV:** ulnar styloid fracture in addition to Type III
- **TYPE V:** intraarticular fracture of the distal radius, with injuries to the distal radio-ulnar joint.
- **TYPE VI:** Frykman Type V including an avulsion of the ulnar styloid process
- **TYPE VII:** These fractures are a combination of Type III and Type V affecting two joints, the distal radio-ulnar joint and the carpal joint. Therefore this Type is an intraarticular fracture.
- **TYPE VIII:** equally to Type VII additionally involving the ulnar styloid process

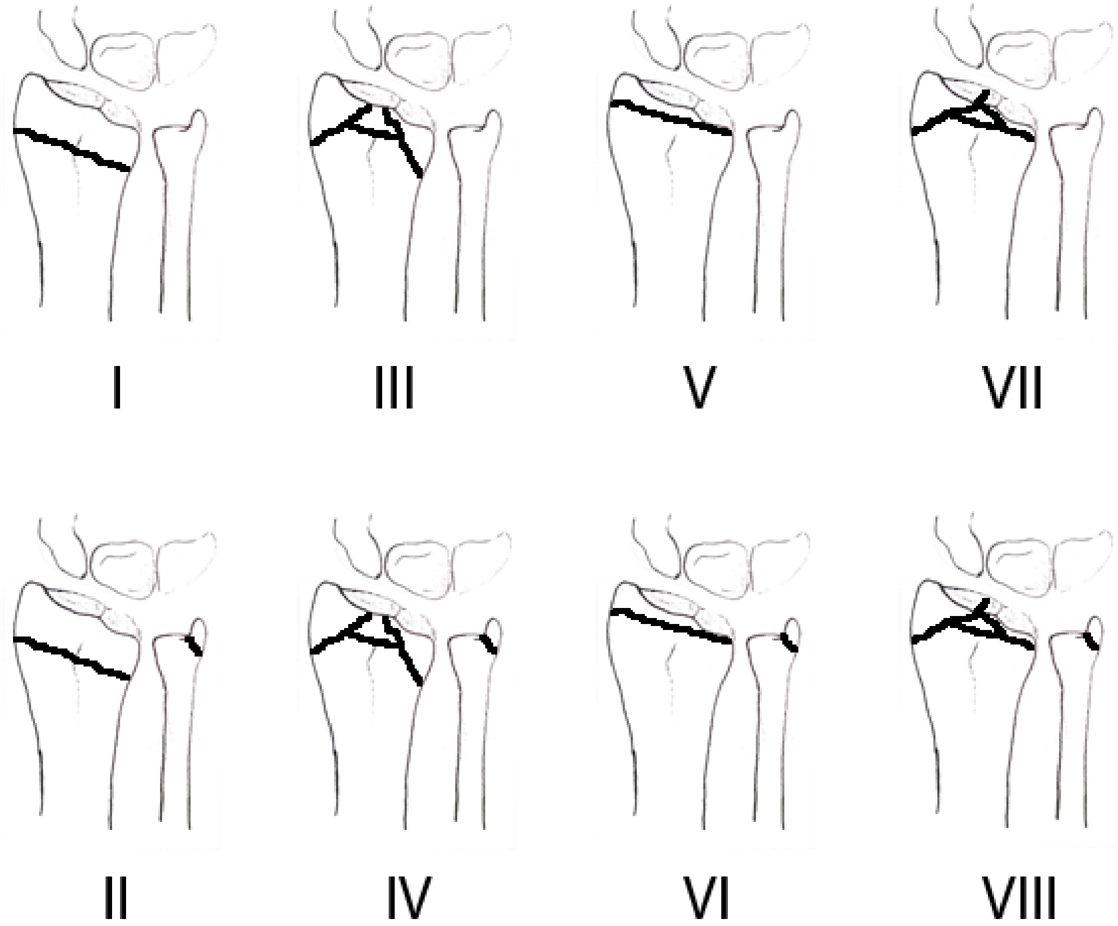


Figure 16: Frykman Classification

5.4 Salter Harris Classification

This classification is commonly used to describe fractures affecting the growth plate of immature patients. The higher the number describing the fracture, the worse can be the outcome of the injury. Epiphyseal fractures can lead to premature closure and therefore to disturbance of growth. Salter and Harris classify as follows (Figure 17): (19)

- **Type I = S** “Slipped”: The epiphysis is completely separated from the metaphysis and there is no bone fracture. This type is more common in younger patients and often a result of avulsion.
- **Type II = A** “Above”: The line of separation lies above the growth plate and extends along the growth plate for a variable distance and then exits through the metaphysis. Thus it shapes a triangle fragment of the metaphysis. This is the most common type of fractures in immature skeletons.
- **Type III = L** “Lower”: The fracture is intra – articular. It starts at the joint surface, extends to the growth plate and then to its periphery without affecting the metaphysis.
- **Type IV = T** “through – transverse – together”: This kind of fracture produces a split of the bone. It starts at the surface of the joint extends through the growth plate to the metaphysis.
- **Type V = R** “ruined – rammed”: Very uncommon fracture in joints which move in one plane only. It is a result of a severe compressing force and leads to deformity of the growing plate. Therefore a disturbance in growth can occur.
- **Type VI to IX:** Rare types of fractures which are not included in the main report

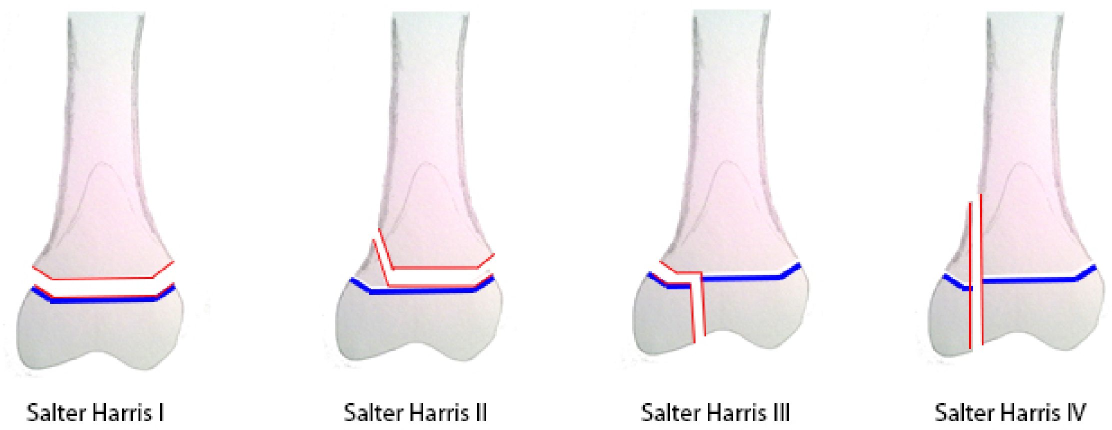


Figure 17: Salter Harris Classification

5.5 MAYO wrist Score

In 1978, Green and O'Brien proposed a scoring system, which is used by the examiner by evaluating the parameters pain, disability (according to work), impairment in flexion and tension as well as strength. Additionally the doctor has to investigate a radiograph (20).

In 1987, Cooney et al from the Mayo Clinic, modified the Green and O'Brien score, by changing the demerit items and by removing the evaluation of the radiograph. Moreover, they categorized their findings and defined a score lower than 65 as "non – satisfactory" (20) (21).

The MAYO wrist Score evaluates four parameters:

- Parameter 1: Pain intensity
- Parameter 2: Patients satisfaction
- Parameter 3: Range of Motion in % (compared to unaffected side)
- Parameter 4: Grip Strength in % (compared to unaffected side)

The patient can score up to 100 points, whereas a score of less than 65 describes a poor, 65 to 79 a satisfactory, 80 to 89 a good and 90 to 100 an excellent result. Further details are shown in Table 1 (21) (20).

Parameter	Points	Evidence
Pain Intensity	25	No pain
	20	Mild occasional pain or just with change of weather
	15	moderate or tolerable pain while performing specific activity
	5	Moderate or tolerable pain in daily life activity
	0	Severe or intolerable pain
Patients Satisfaction	25	Satisfied / able to return to regular daily life activity
	20	Moderately satisfied
	10	Not satisfied but able to manage daily life
	0	Not satisfied
Range of Motion in %	25	100 % of normal
	15	75 to 99 % of normal
	10	50 to 74 % of normal
	5	25 to 49 % of normal
	0	0 to 24 % of normal
Grip Strength in %	25	100 % of normal
	15	75 to 99 % of normal
	10	50 to 74 % of normal
	5	25 to 49 % of normal
	0	0 to 24 % of normal

Table 1: MAYO wrist score

5.6 DASH Score

The DASH Score stands for “Disabilities of the Arm, Shoulder and Hand” and is an outcome measure for patients with several pathologies of the upper limb. Hudak et al designed this self-reporting questionnaire in 1996 (22). It includes 30 items related to symptoms in daily life activities concerning the ability to perform certain activities (Figure 18). Patients can assign a score from 1 to 5 for each question. At least 27 questions have to be answered to get a score. The DASH Score is then calculated as follows, where n equals the number of answered questions:

$$DASH\ Score = \left[\frac{(sum\ of\ responses)}{n} - 1\right] * 25$$

An optional Score for the DASH Score has been added with 2 modules containing one for work and a second one for sports and music with 4 items each. For calculating the optional score, each item has to be answered. For scoring the optional modules the following formula is used:

$$Score = \left[\frac{(values\ of\ all\ 4\ items\ added\ up)}{4} - 1\right] * 25$$

A higher score describes a more disabling outcome (23). Further details of the DASH Score are shown in the Appendix. The German translation, which was used for the assessment of the patients, is shown in the Appendix.

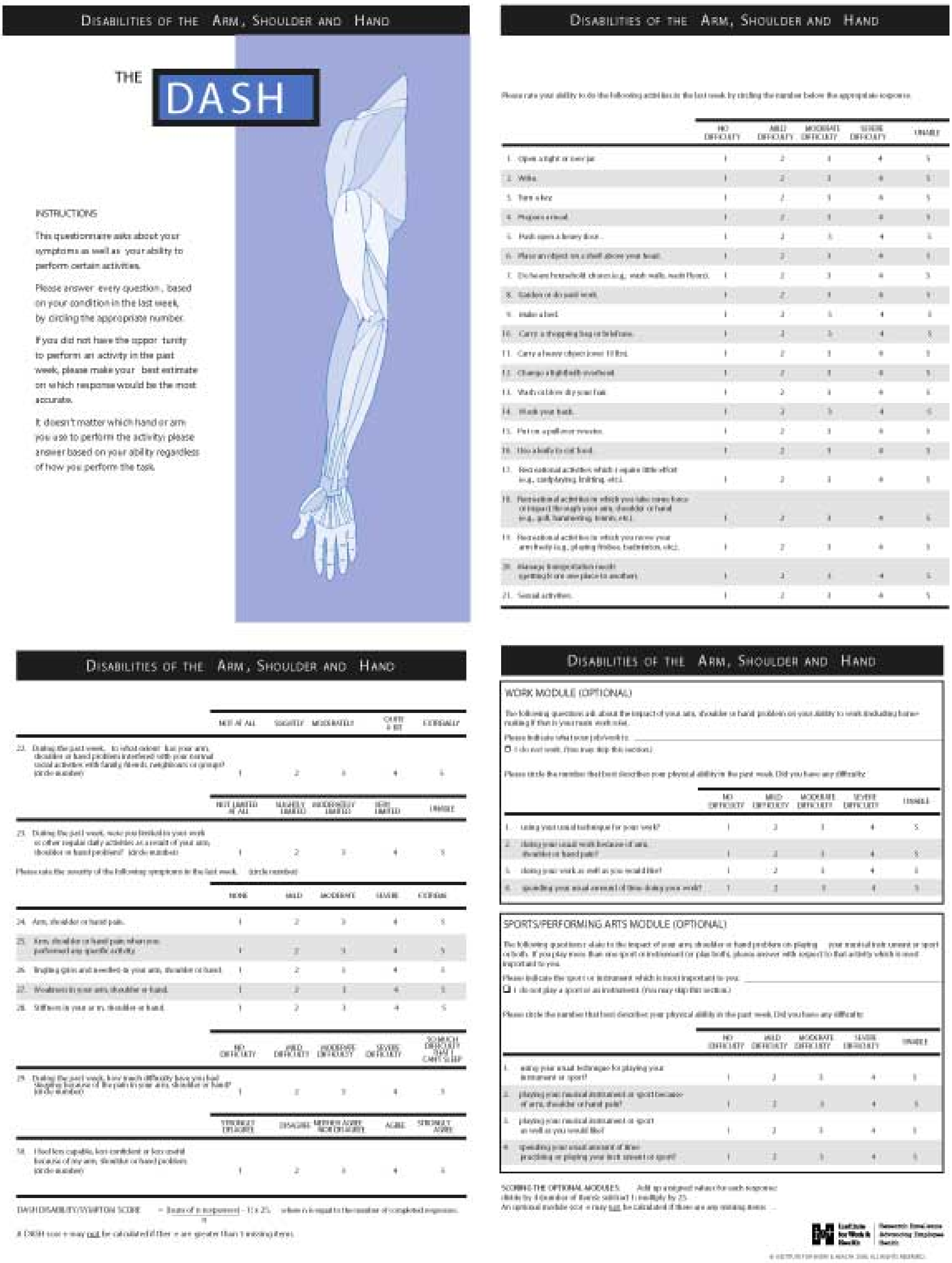


Figure 18: Dash Questionnaire

6. Diagnosis

6.1 History

Children are not just little adults. The primary problem to think about is the phenomenon of growth. Contrary to adults, injuries in a growing skeleton depend on the grade of maturity. According to this fact, the degree of maturity of the bones is far more important than the exact mechanism of injury. Secondly questioning of unnecessary facts will delay the onset of treatment. It should be kept in mind that young children often are not able to precisely describe circumstances of the injury. Nevertheless any information is important for the further treatment and should therefore be determined well (2).

6.2 Inspection

Obvious symptoms like swelling, deformation or missing parts can be judged by visual examination. Unnecessary touching of fractures will decrease the patients' will of compliance. Although it is important for further procedures to examine the injured arm, one should start at the periphery of the painful arm and work his way forward to the lesion. Because examining children always needs empathy, it is better to ask the patient if it is alright to touch the injured part. Evaluation of motor function, sensation and vascular supply are the most important results to document, although this can be difficult or even impossible, depending on the patients' age (2).

To get proper results, a comparison to the contralateral side is crucial. Thus a restriction in the ROM (range of motion) can be measured properly. The results are scored with the Mayo wrist scoring system.

After the history is taken and the injury has been inspected, temperature, swelling and possible pain can be evaluated by palpation. Also motor activity, sensation and blood flow should be evaluated. A relieving posture, axial deviations, crepitation and instabilities can be identified easily. The ROM is evaluated by active and passive movement and described with the neutral – zero method. The passive movement always shows a greater extent than the active movement. While the active movement shows the real ROM in daily life activity, the passive movement serves as an indicator for joint instabilities and restricted motions (24).

For forearm fractures following movements are usually evaluated during the follow up examinations: Pronation, Supination, Radial Abduction, Ulnar Abduction, Extension and Flexion. A goniometer should be used for proper documentation (2) (24) (25).

6.2.1 Implementation of the neutral – zero method

To measure the movement of a joint, the neutral – zero method defines a neutral position, in which the patient sits in physiological upright position, with the elbows flexed at 90° and the forearm on the examination table. In zero position the forearm lies between pronation and supination with the thumb pointing to the ceiling. The axis for rotation is a prolongation of the longitudinal axis of the third metacarpal bone and the forearm axis. For the rotation of the forearm (Figure 19 and 20), the measurement is performed with the forearm in pronation. The scale is shown in the measured angle of the movement whereas the angle is measured by a goniometer (26).

In the documentation, every movement is defined by a code, which consists of three numbers. Those are declared as the two ends of the ROM and the neutral – zero position. If the neutral position can be passed, the zero stands between the endpoint values. The code is read as follows: (26)

Flexion/Radial Abduction/Supination – 0 – Extension/Ulnar Adduction/Pronation

If the patient cannot attain the neutral position, the zero has to be written either in front of, or behind the measured results, e.g. in patients with pain or contracture of extension: (26)

0 – Flexion – Extension

For movements of the wrist following standard values have been defined (26):

- Flexion/Extension: 50° to 60° – 0 – 35° to 60°
- Radial abduction/Ulnar adduction: 20° to 30° – 0 – 30° to 40°
- Pronation/Supination: 80° to 90° – 0 – 80° to 90°

Figure 19: Neutral Zero Method: Pronation

Figure 20: Neutral Zero Method: Supination

6.2.2 Evaluation of the stability of the DRUJ

The so called “stress – tests” are two examination maneuvers for testing the palmar and dorsal radio-ulnar ligaments and for evaluating the stability of the DRUJ. The patient sits in front of the examiner with his elbows flexed in 90°. A shear force is applied between the two forearm bones by the examiner with the patients forearm in full pronation and supination. Compared to the contralateral extremity a displacement shows the condition of the ligaments. A gap between radius and ulna shows a laxity of the DRUJ and is described as snapping ulna (Figure 21) (27). This “DRUJ instability test” or “distal ulna ballottement test” must be performed in various positions of forearm rotation. In neutral position, which is provided in the middle of pronation and supination, a deviation up to 5mm is considered as normal. (28) (29) In contrary, in full rotational position like full supination and full pronation the TFCC becomes tense and decreases the possible translation of the distal forearm. In radial deviation, the ulnocarpal ligaments are also taut and together with the ECU tendon shaft tighten the joint, and make a translational movement impossible. Instability is therefore shown, when the displacement of the joint can be provoked in extreme rotation and pain reported by the patient. For a better description, a grading system was provided by Sanz L. et al. Grades are defined from 0 to 3 whereas 0 stands for no translation at all, 1 is described as one third, and 3 as full bone diameter (29).

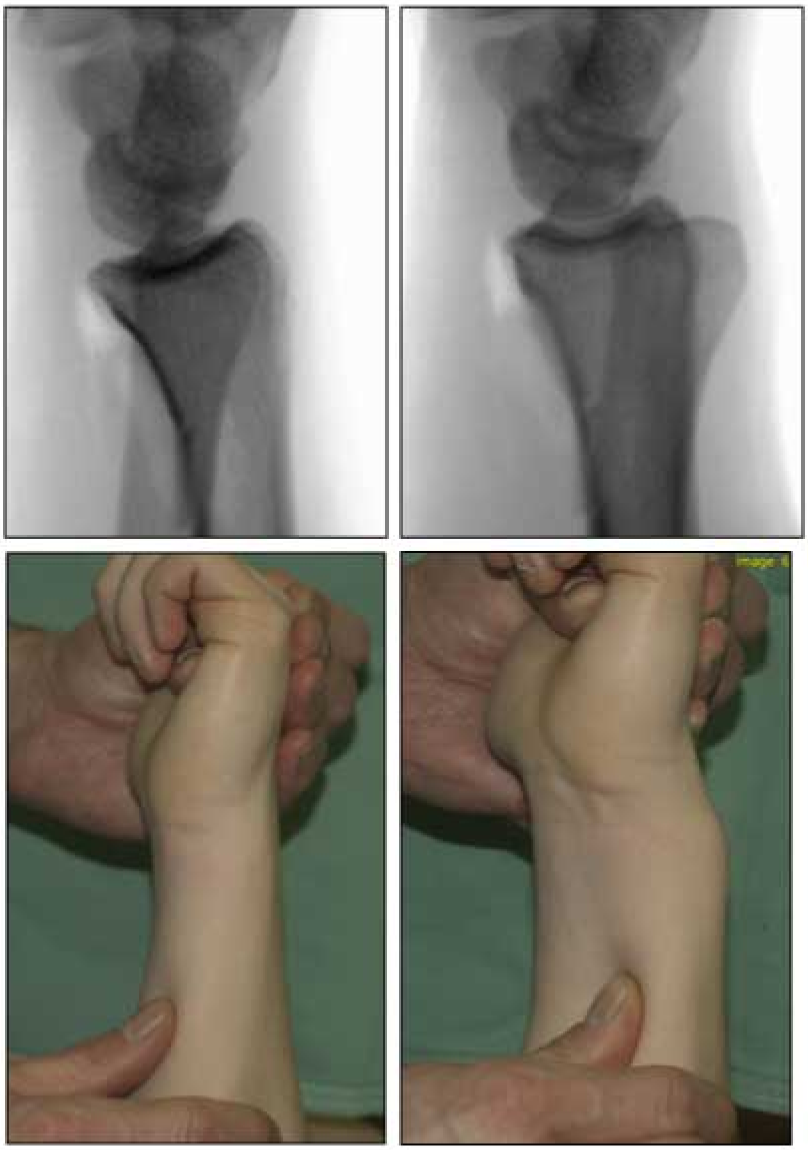


Figure 21: Stress Test “distal ulna ballottement test” or “gliding test”

The mentioned exam is used to describe a static instability of the wrist. To evaluate a dynamic instability, Lester et al. described the “Press – Test”, which provides that the patient pushes himself up from the seat by using the injured hand. Focal ulnar sided wrist pain is a positive sign for a TFCC tear (27) (30).

Furthermore a measurement of strength should be done, to evaluate if there is any limitation due to the injury. Table 2 shows the graduation of the grades of muscle strength:

Grade	Value	Movement Grade
5	Normal (100%)	Complete range of motion against gravity with full resistance
4	Good (75%)	Complete range of motion against gravity with moderate (intermediate) resistance
3	Fair (50%)	Complete range of motion against gravity
2	Poor (25%)	Complete range of motion with gravity eliminated
1	Trace (10%)	Evidence of slight contractility but no joint motion
0	Zero	No contraction palpated

Table 2: Grades of muscle strengths

Summarized, following signs indicate an instable distal radio-ulnar joint:

- Ballotteable distal ulna in extreme rotation
- More palmarly positioned ulnar styloid process
- Pain during pronation and/or supination
- Decreased grip strength

6.3 Diagnostic Radiology

Primarily it is important to protect young patients from unnecessary radiation. Radiographic images should only be taken if there is any clinical consequence drawn from it. That means basically that taking a diagnostic image has to increase the efficacy of treatment. Clinical consequence applies to:

- pain → analgesia
- non displaced fracture → immobilisation to treat the pain
- displaced fracture → reduction and retention
- luxation → reduction

Also the number of images taken depends on clinical visibility of deformation, i.e. a single plane radiograph is sufficient for determining further treatment if any displacement is clinically visible. Certainly this image should also include the two adjacent joints, because luxation fractures are more common in pediatric patients than in adults.

More often fractures are just visible in one plane. These injuries require radiographs in two planes (Figure 22), if a displacement cannot be judged clinically (2).

Figure 22: Radiographs in two planes; distal ulna presents with a ballottement sign and a fracture of the ulnar styloid process

6.4 Other Imaging Modalities

Sonography allows the investigator to ensure results of CT and MRI and collect additional information at low cost. The disadvantage of ultrasound is the requirement for an experienced examiner. Therefore this special examination still could not prevail in daily clinical use for fracture diagnosis (2).

Zimmerman R. et al. described the role of MRI in pediatric injuries of the wrist in 2007. They found out that the assessment of osseous lesions in acute injuries in children is much better in MRI than in simple radiographic images. Their conclusion was that radiographs are still first choice in examination of forearm fractures, but MRI (Figure 23) is a very important tool for the assessment of secondary injuries especially lesions of the TFCC (31).

Although there is no radiation exposure in MRI imaging, it also has the disadvantage that the patient has to be motionless to get better images. As children are always in motion, they might have to be sedated for MRI imaging. As a matter of fact anaesthesia contains its own risks.

Figure 23 MRI Images of the distal forearm, showing an injury to the ulnar styloid process and the TFCC

If plain radiographs are insufficient, e.g. in displacement of carpal bones, a CT can be made in exceptional cases. Based on the fact that the radiation exposure is very high in CT imaging, it should be avoided if possible in pediatric and adolescent patients (9).

7. Complications

Complications of pediatric forearm fractures can occur either in the acute phase or in the healing phase. In the acute phase a compartment syndrome must be considered as a possible complication. Dysaesthesia can be an acute symptom, due to compression of the nerves. Long term complications can be prevented by a fasciotomy to relief pressure.

The most common complications in the treatment of children with fractures of the forearm are malalignments. The limits for acceptable malalignment depend on the age and sex of the patient, but also on the localization of the injury (32).

Fractures in pediatric and adolescent patients can also lead to growth disturbance. Usually the kind of disturbances is stimulative growth failure leading to increased growth in length. This kind of failure can be compensated in the course of time and may have importance in injuries to the lower extremity. However, injuries to the growth plate can also lead to growth disturbance like partial or premature closure which can cause a lack or failure of growth (2). Also deformity of the injured bone is possible which can cause a loss of function. Relevant for the forearm is supination and pronation. Children younger than 10 years can recover by remodelling of the bones whereas older children can lose the function of the joint completely, because remodelling capacity decreases with age (9).

8. Therapy

It is of pivotal importance to treat pain as quickly as possible. Also restoring of the patients mobility is of high priority. Furthermore it is very important to prevent disturbances of fracture healing and also to influence growth disturbances positively. The treatment must not produce psychological sequelae and therefore achieve the best cosmetically results as well as an optimal function (2).

The potential of remodelling is very high in pediatric patients. Due to this fact, anatomic reduction is not always necessary. Still it is important for the physician to know the limits of misalignment (33). Laer states that principally axis deviations are tolerable in all three planes.

Below the age of 12 “nondisplaced” is defined as an angulation of up to 30 – 40% in the sagittal plane and 10 – 20% in the coronal plane. Above the age of 12, depending on sex and the maturity of the growth plates, an angulation of up to 20% in both planes is tolerable (2) (33).

The therapeutic options can be divided into conservative and surgical therapy.

8.1 Conservative Therapy

The majority of fractures in pediatric patients can be treated by closed reduction and cast immobilization. Von Laer states that indications for conservative treatment include all “nondisplaced” epi-, meta- and diaphyseal fractures. Depending on the age of the patient and the location of the injury, the term “non-displaced” varies a lot. Both, the occurrence of growth disturbance and spontaneous correction depend on the age of the patient and on the location of the injury, i.e. the distance to the growth plate and the functional impact. The younger the patient at the time of the injury, the more likely is the correction of displacement (2).

Conservative therapy options are either with or without anaesthesia. Treatment under anaesthesia is not necessary if there is no fracture displacement. In this case applying a split cast is the main technique. The reason for not using a circumferential cast is the post-accidental swelling. The plaster can be closed around the fourth day when the soft tissue swelling decreases (2).

Cast windowing can be made if the patient complains about pain in the cast. After inspection and adequate padding, the plaster should be closed again to prevent an oedema (2).

Secondary displacement can occur in some cases after casting. It should be treated with cast wedging. Time and location of the wedging are very important for optimal healing results. This means that the wedge has to be applied at the lowest point of the concavity and after subsiding of the soft tissue swelling (2).

Different forms of anaesthesia are used if a closed reduction is necessary. Deformities which cannot be corrected by the corrective forces or by secondary use of wedges need to be treated with reduction under anaesthesia. Closed reduction can be performed if the fracture does not include ligamentous injuries or to put displaced fragments in a stable situation for casting. Sometimes the angulation is increasing during the healing process. Applying a cast wedge can solve the problem but should be done in some kind of anaesthesia (2).

8.2 Surgical Treatment

Surgical therapy can either be performed with closed or with open reduction. Closed reduction and fixation is understood as fixation of the fragments with fixation material in a virtually stable position. These materials can be Kirschner wires, Steinmann pins, intramedullary nails or external fixators. Displaced fragments in which an appropriate stable position cannot be achieved by closed reduction are an indication for surgical fixation.

Completely displaced articular fractures are an indication for surgical treatment with open reduction. Also injuries that include ligamentous or neurovascular lesions are indications for open reduction.

In pediatric patients it is very important to avoid crossing the growth plate, when using implants. Therefore it is very important that only experienced surgeons are allowed to perform this kind of therapy.

Moreover the surgical treatment in children is usually performed in general anesthesia.

8.2.1 Elastic stable intramedullary nailing (ESIN)

This minimally invasive technique was designed to treat long bone fractures without the necessity of surgically opening the fracture. In pediatric patients the intramedullary nails are preformed to provide some flexibility, while still providing axial, rotational and translational stability. The flexible characteristics of the nails support the children's healing properties by preserving the periosteum and stimulating various kinds of callus formation (34).

ESIN is usually an effective method of osteosynthesis for transverse, spiral and oblique diaphyseal fractures, but can also be used for the treatment of metaphyseal fractures like the radial neck fracture, proximal and distal metaphyseal – epiphyseal fractures of the humerus and the femur (34).

For the diagnosis an x-ray imaging in 2 planes is sufficient. A second imaging of the contralateral side is not necessary. A non-displaced fracture or a detachment of the epiphysis after spontaneous reduction can lead to misdiagnosis in radiology. These patients need to be diagnosed clinically (35).

8.2.2 Kirschner wire (K – wire) osteosynthesis

This operative method is an adaptation osteosynthesis. Other than in the ESIN therapy, this therapy provides stability of the forearm to movements but not to heavy loading. The wires are inserted percutaneously which means that there is no requirement for surgically exposing the fracture. In pediatric patients with forearm fractures, K – wires are often used in metaphyseal fractures. Because of the thin wires, the fracture can be stabilized adequately, while the growth plate is not affected. To avoid wire movements, the wires are bent, and the forearm immobilized in a plaster cast (14) (21) (36) (37) (38).

8.2.3 Plate osteosynthesis

Due to the fact, that a secondary intervention for the implant removal can lead to re-fractures, inconsiderable scars and, far most important, to nerve injuries, this method is just indicated in exceptional cases, particularly for growing children, e.g. in Monteggia fractures, where the length of the ulna needs to be restored, and it cannot be achieved by the ESIN method (39). An indication is therefore only given for fractures of the distal third of the radius, where an intramedullary nail would just fix the shaft of the radius but not the distal fragment anymore (40).

The fracture is stabilized by a fixation of a plate after open reduction, thus fulfilling the principle of an extra medullary splint. With a sufficiently reduced forearm, the plate fixes the forearm in a stable position, even during heavy loads or forces like bending, compression or torsion (36) (40).

8.2.4 Fixateur externe

If fracture reduction cannot be obtained with ESIN, the fixateur externe can be used as an alternative technique should be used. Completely unstable fractures with more fragments especially of the femur, tibia and forearm are the main indications for this method. This technique is particularly suitable for older children and adolescents. Laer states that oblique-, wedge- or more fragment fractures, as well as fractures with soft tissue injuries are the most common injuries for a treatment with a fixateur externe (2) (39).

Specific Part

1. Introduction

Distal forearm fractures are one of the most common fractures in pediatric and adolescent patients (10). Most of these injuries in children are incomplete fractures which do not cause long – term problems. Adolescents rather sustain complete fractures, which have the potential to lead to complications like rotation disabilities, due to dislocation of the bones of the forearm, as well as forearm shaft drifts and re-fractures (11).

Fractures in adults are managed differently than in children. While the primary treatment of children and adolescents is non - operative, adults are often treated by open reduction and internal fixation. Operative treatment of pediatric distal forearm fractures is rarely necessary, except of some indications including instability of the distal radio-ulnar joint (DRUJ) (33). Injuries of the TFCC are the most common secondary injuries of these fractures. Intact anatomical structures of the TFCC are responsible for function and stability of the DRUJ. An impaired joint function is usually caused by an injury of the radius and simultaneous fracture of the ulnar styloid process with rupture of the capsule and ligaments including a dorsal dislocation or subluxation of the ulna.

Non-union of the ulnar styloid process is a common secondary injury of distal radius fractures. At its base, the ulnar styloid process acts as an anchor for the TFCC. Therefore, an injury of the styloid process may impair the outcome of an otherwise correctly treated forearm fracture. According to some studies, a non-union of the ulnar styloid process can lead to tears in the TFCC and therefore to instabilities, wrist pain and decreased range of motion (41).

A combination of radius fracture and non-union of the styloid process seems to be less frequent in children and adolescent. Nevertheless, a recent study showed that injuries of the base of the styloid process lead to tears of the TFCC and therefore to the described symptoms (42).

Reconstructive surgery with re-fixation of the ulnar styloid process and simultaneous tightening of the capsule may restore the joint function.

The aim of this thesis is to retrospectively analyse the treatment of pediatric patients with non-union of the ulnar styloid process and complaints about instabilities and pain.

2. Patients and Methods

2.1 Patients

The present study was approved by the Ethics Committee of the Medical University of Graz (EK number: 26-105 ex 13/14) and fulfills the declaration of Helsinki.

In a retrospective analysis, medical histories of surgically treated children with a painful non-union of the ulnar styloid process following displaced distal radius fractures and fractures of the ulnar styloid process, in a five years period from 2008 to 2012, were investigated. Only patients, with open growth plates at the time of the injury were included.

The patients were determined and following parameters were recorded: gender, age at the time of injury, cause of accident, type of fracture of the distal radius and the associated ulnar styloid process injury, pre- and postoperatively measured DASH and Mayo Score as well as grip strength, ROM of pro- and supination and Gliding – Test Score before and after surgical treatment.

To describe the incidence of non-union of the ulnar styloid process, all patients who presented with displaced fractures of the radius during the time from 2008 to 2012, were analyzed and scanned for an ulnar styloid process injury. Medical histories and radiographs of these patients were then reviewed to determine the rate of non-union of the styloid process of the ulna.

2.2 Operative technique

In cases of non-union of the styloid process of the ulna accompanied with instability of the DRUJ associated with pain, an operative intervention was discussed with the patient. A careful clinical examination of the wrist including measurement of the dorso – palmar translation of the distal ulna related to the distal radius was performed and compared to the unaffected contralateral side. Conventional X-rays in 2 planes (Figure 24) were taken to exclude growth disturbances concerning the length of the ulna.

Reconstructive surgery was performed dorso-ulnar with a curved incision of 4 to 5 cm addressing the DRUJ (Figure 25). A tourniquet was applied with 250 mmHg. After dissecting the subcutaneous tissue the elongated capsule was identified and incised close to the styloid process. The discus was inspected carefully and detached as far as necessary to reach the area of non-union of the styloid process. The next step was to refresh the bone at the base by removing scar tissue, and if needed, bring cancellous bone harvested from the distal radius by a separate incision to the non-union (Figure 26). The styloid process was stabilized in a next step with a cerclage in a figure of eight technique using K-wires with 0.8 mm diameter (Figure 27). The elongated capsule was doubled and sutured with resorbable material. To guarantee adequate healing of the bone, a temporary radio-ulnar transfixation (Figure 28) with two 2.0 mm K-wires was performed.

Figure 24: Radiographs in two planes preoperatively

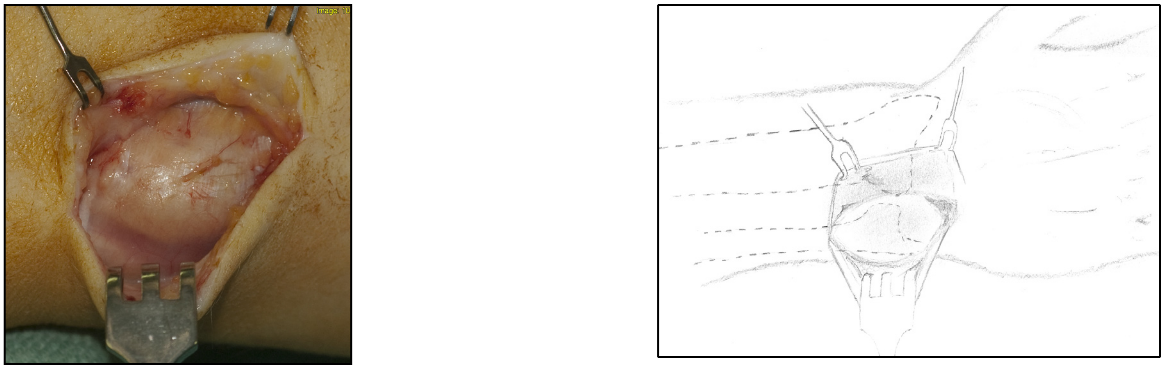


Figure 25: Skin incision, facing the elongated capsule

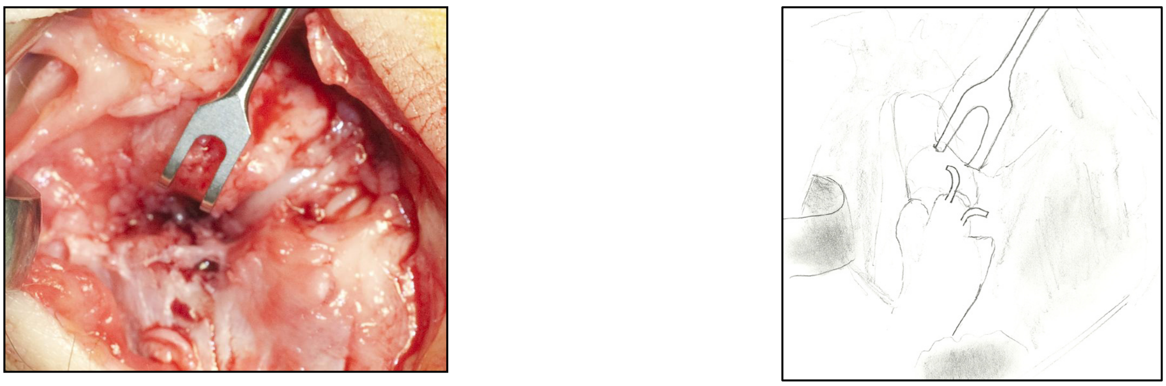


Figure 26: Bringing cancellous bone to the non – union

Figure 27: Fixed styloid process

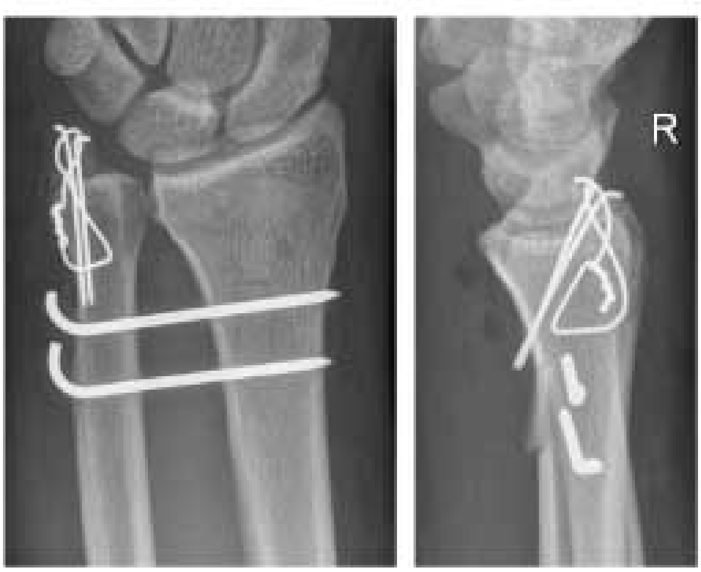


Figure 28: Radiograph in two planes postoperatively

2.3 Statistical Analysis

Data are reported as mean and standard deviation (SD). The Wilcoxon signed-rank test was used to compare the preoperative and postoperative DASH and Mayo scores as well as the ballottement test score and the ROM (range of motion) A p value of <0.05 was considered significant.

3 Results

Of 673 patients presenting with a displaced fracture of the distal radius from 2008 to 2012, 10.7% (n=72) sustained an associated ulnar styloid process injury.

Out of these, 12 patients (80.8%) developed a non-union. All fractures with resulting non-union of the ulnar styloid process were located at the base.

Six patients had complaints and instabilities and therefore surgical treatment was performed. Four of these patients were male with a mean age of 16.5 years (range 15 to 19), and two were female with a mean age of 16 years (range 15 to 17), at the time of operation. The surgery was performed on the right side in 3 cases and on the left side in the other 3 cases.

Among these six patients, three presented with a Salter Harris Type III, two with a Salter Harris Type II, and one patient with a Salter Harris Type IV radial fracture. The fractures of the radius were also classified according to Frykman. Four patients were classified as Type VIII, and one patient each with Type II and Type IV.

All patients reported a fall on the outstretched pronated forearm. In five cases the fracture occurred during sports activities, i.e. snowboarding, physical education in school and playing football during free time. One case was related to a traffic accident while driving a motorcycle.

The mean time between operation and follow up was 19 months (range 7 to 39). The transfixation was removed after 6 weeks in all patients, whereas the K – wires and the cerclage remained for a mean of 15 months (range 5 to 38).

Both, DASH and Mayo Score, significantly improved from the preoperative assessment to the final follow-up. The mean value of the preoperative DASH was 32.05 (range 25.9 to 35.2 SD 3.45) and significantly ($p = 0.028$) improved to 10.94 (range 5 to 22.5 SD 6.41).

The optional DASH score questionnaire for sportive activity was answered postoperatively by 3 patients only and was scored with 0. The second optional module, which includes questions about the ability to work, was also postoperatively answered by six patients. The mean score was 14.58, (range 0 to 25).

To evaluate the outcome of the operative treatment, the Mayo Score was assessed. All six patients showed a significant improvement, with a mean score of 62.5 (range 55 to 75, SD 8.5) preoperatively and 95.83 (range 85 to 100, SD 5.85) postoperatively.

Grip strength averaged 60% (50 – 75) of the opposite hand before treatment, and improved to an average of 97% (90 – 100) after operation and physical therapy.

Moreover the range of motion was evaluated before the operation and during the follow up examination. Since a stable DRUJ is shown in a proper pro- and supination, only this movement was evaluated in this study (43). All patients presented with a preoperative restriction of the ROM. The average ROM was 90° (range 60° to 120°) before operative treatment, and improved to a mean of 164° (range 160° to 170°) postoperatively (Table 3). For further details of the improvement in the ROM see also Table 4 and Table 5 below.

	Preoperatively	Final follow up	p Value
DASH	32.05 ± 3.45	10.94 ± 6.41	0.028
Mayo	62.50 ± 8.50	95.83 ± 5.85	0.027
ROM in °	90 ± 25.30	164 ± 4.90	0.028
Grip strength in %	60 ± 12.25	96.66 ± 4.08	0.027
Gliding test	2.16 ± 0.75	0 ± 0	0.026

Table 3: Results analyzed with the Wilcoxon signed rank test

Only one patient showed a restriction in his ROM, which was fully compensated in the wrist. Patient 4 presented with a ROM of 90 – 0 – 50 without compensation in the wrist which could be extended to 90 – 0 – 80 when compensated.

All patients presented with instability and pain of the wrist preoperatively, the gliding test showed an average of 2+ (range 1 to 3). When the stress test was performed at follow-up, no translational movement was recognized. Additionally the ulnar stress test at follow-up scored with 0 in all cases.

Nr	Age	Gender	Side	P/S pre OP	P/S post OP
1	16	M	L	**50/0/50**	**90/0/80**
2	17	F	R	**30/0/30**	**80/0/80**
3	16	M	L	**90/20/0**	**90/0/70**
4	19	M	R	**90/0/0**	**90/0/80**
5	15	M	L	**20/0/40**	**75/0/90**
6	17	F	R	**60/0/60**	**70/0/90**

Table 4: Range of motion: Pronation - Supination

Nr	Timespan between Accident and operative Treatment (months)	ROM (Range of Motiion)° pre – OP	ROM ° post - OP	Mayo pre - OP	Mayo post - OP	Grip Strength in % pre OP	Grip Strength in % post OP
1	4	100	170	55	95	50	100
2	36,5	60	160	55	85	60	100
3	1	110	160	70	100	75	95
4	23	90	170	65	100	50	90
5	0	60	165	55	95	50	95
6	11	120	160	75	100	75	100
Mean	12,58	90	164,17	62,5	95,83	60	96,66

Table 5 Range of Motion Mayo Score and Grip Strength

4 Discussion

The present study focused on operative treatment of non-union of the ulnar styloid process following distal radius fractures in association with ulnar styloid fractures. This type of injury is often underestimated in children and adolescents. Our retrospective analysis revealed that the DASH score assessed pre- and postoperatively, improved from a mean of 32.05 to a mean of 10.94. Likewise the Mayo Score improved from a mean of 62.5 to 95.83. Moreover, an improvement in ROM, grip strength and stability could be demonstrated as well. This leads to the assumption, that restoration of the TFCC to its anatomical position can avoid pain and instability in cases with posttraumatic painful non-union of the styloid process of the ulna.

Distal forearm fractures are one of the most common injuries in children and adolescents (9). In contrary to other reports that determined that up to 70% of distal radius fractures in adults are associated with ulnar styloid process fractures Stansberry et al. found that out of 222 pediatric patients with distal radius fractures only 45 (33%) had a concomitant ulnar styloid fracture (41) (44) (45). In the present study only 10.7% of the patients presented with this combination of fractures. In contrast, 40-70% of distal radius fractures in adults are associated with an ulnar styloid fracture (41) (44) (46). This difference of the prevalence between children and adults may be due to the fact that the ulnar styloid process starts its ossification at the age of 7 years in girls to 9 years in boys (1) (47). Therefore, a certain number of fractures of the ulnar styloid process occurring prior to the ossification of the process may be missed causing an underestimation of the true incidence. Abid et al. reported two cases where the missing appearance of the ossification center led to a misdiagnosis (48).

Because of its close relation to the TFCC, an injury of the styloid process of the ulna may affect DRUJ stability (41). Abid et al. stated that up to 86% of the associated ulnar styloid fractures are tip fractures and only a minor part of the injuries represents injuries of the base of the ulnar styloid process (48). In the present study 12 out of 72 (16.7%) patients with a combined injury were confirmed with a fracture of the base of the ulnar styloid process and developed a non – union, which almost mirrors the findings of Abid et al.

The function and stability of the DRUJ are fundamentally based on correct anatomical conditions (49). Due to the fact that the radial sigmoid notch shows a 50% greater radius than the articulating head of the ulna, the surfaces show a contact of 60% in neutral position and less than 10% in full pronation and supination (50). Accordingly, soft tissues, implying ligaments of the DRUJ as well as the TFCC, seem to be an important factor for stabilization of the DRUJ. As mentioned above, the TFCC consists of palmar and dorsal distal radio-ulnar ligaments, the ulnar collateral ligament, the floor of extensor carpi ulnaris subsheath, ulnolunate and ulnotriquetral ligaments and the cartilaginous disc. As the discus is fixed to the base of the styloid process of the ulna, a fracture of the ulnar styloid process can be linked to injuries of the articular disc and therefore of the TFCC. In contrary, in patients with a non-union located at the tip of the ulnar styloid process, the TFCC should remain unharmed (51).

In cases of treatment of displaced radial fractures with reduction and cast immobilization in pediatric patients, the unstable DRUJ is often not identified properly. In 1998 Terry and coworkers analyzed 29 pediatric and adolescent patients with a surgically documented TFCC tear. In 12 cases non-union of the ulnar styloid process as well as DRUJ instability were found and operatively treated by ulnar styloid non-union excision, distal radio-ulnar joint stabilization, ulnar shortening, radius corrective osteotomy, and intercarpal ligament debridement. These findings indicate that a non-union of the ulnar styloid process may have a relationship to instability in the wrist. The postoperative outcomes in a mean follow-up of 21 months were graded by the Mayo wrist score which averaged 79.5 preoperatively for all 29 patients, where the upper range for a fair surgical result would be 71 to 80, and improved to a mean of 97.5 postoperatively. They found that the lack of recognition is based on the fact that the majority of patients do not have severe symptoms and are only mildly disabled (52). In our study the Mayo score preoperatively showed a mean of 62.5 which does not mirror the findings of Terry et al. This might be due to the fact that the present review included the scores of patients with a non-union of the styloid process only. Although the patients presented with a mild disability Terry et al. recommend that the TFCC should be repaired and coexisting pathologies treated to restore stability (52).

A recent study showed that children with a displaced distal radius fracture accompanied by a non-union of the ulnar styloid process have a worse DASH Score compared to patients with an isolated distal radius fracture. Among 46 patients, 7 patients were identified with a non-union of the ulnar styloid process. Those patients who complained about remaining intermittent pain sustained a fracture at the base of the styloid process of the ulna and furthermore showed instability of the DRUJ (42).

Another study, in contrary, showed no significant association between a non-union of the ulnar styloid process and wrist function or instabilities. 36 patients with a distal radius fracture and an associated fracture of the proximal half of the ulnar styloid process were treated with palmar plate fixation of the radius. The stability was assessed at surgery after internal fixation with the gliding test and dislocation during forearm rotation. The patients were randomly divided into two study groups which consisted of patients with cast immobilization in one group and patients with a removable splint in the second group. Both groups were asked to fill out a DASH questionnaire 2 weeks after surgery and at a follow-up after 6 months. The results showed no differences in motion, strength, DASH, Mayo or pain between the two groups (53). However, the findings of this study are limited by the short follow-up of 6 months and a patients' mean age of 54 years. The results are therefore to be compared cautiously.

In the present study we reviewed the outcome of patients that developed a painful non-union after conservative treatment of displaced distal radius fractures. The styloid process was reduced, the joint capsule reconstructed and the patients were evaluated in a follow-up examination. Because this study is retrospective, it has several limitations. The patients were treated by multiple surgeons and DASH and Mayo Score are subjective outcome scores which were developed for adults. However no valid scores for measuring the outcome of children sustaining injuries of the upper limb are available.

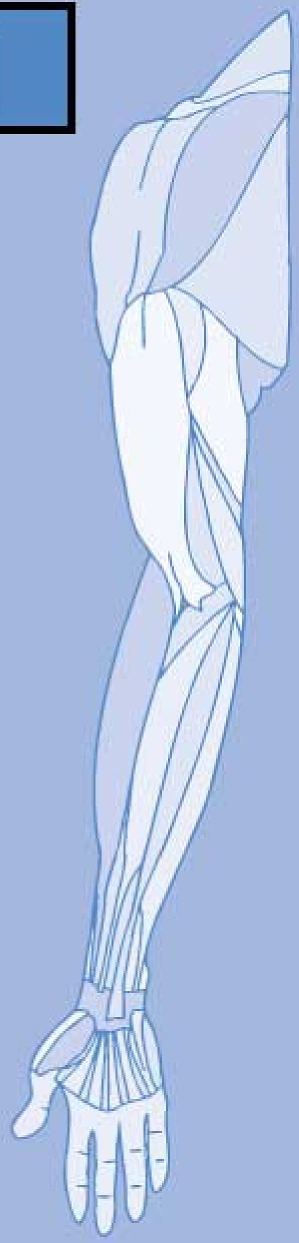
In conclusion, the results of the present study show that in cases with a painful non-union of the ulnar styloid process following displaced distal radius fractures operative treatment can lead to a significant improvement of subjective complaints as well as ROM and stability. In children and adolescents with distal radius fractures in combination with a fracture of the base of the ulnar styloid process, we suggest to treat the distal radial fracture and to follow the patients until union of the radius and ulnar styloid process is observed and/or the patient is asymptomatic. In cases with a painful non-union of the ulnar styloid process operative reconstruction may be a suitable treatment protocol.

Appendix

DASH Questionnaire (English)

DISABILITIES OF THE ARM, SHOULDER AND HAND

THE **DASH**



INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer every question, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your best estimate on which response would be the most accurate.

It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.

Disabilities of the Arm, Shoulder and Hand

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Write.	1	2	3	4	5
3. Turn a key.	1	2	3	4	5
4. Prepare a meal.	1	2	3	4	5
5. Push open a heavy door .	1	2	3	4	5
6. Place an object on a shelf above your head.	1	2	3	4	5
7. Do heavy household chores (e.g., wash walls, wash floors).	1	2	3	4	5
8. Garden or do yard work.	1	2	3	4	5
9. Make a bed.	1	2	3	4	5
10. Carry a shopping bag or briefcase.	1	2	3	4	5
11. Carry a heavy object (over 10 lbs).	1	2	3	4	5
12. Change a lightbulb overhead.	1	2	3	4	5
13. Wash or blow dry your hair.	1	2	3	4	5
14. Wash your back.	1	2	3	4	5
15. Put on a pullover sweater.	1	2	3	4	5
16. Use a knife to cut food.	1	2	3	4	5
17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.).	1	2	3	4	5
18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5
19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.).	1	2	3	4	5
20. Manage transportation needs (getting from one place to another).	1	2	3	4	5
21. Sexual activities.	1	2	3	4	5

DISABILITIES OF THE ARM, SHOULDER AND HAND

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
22. During the past week, to what extent has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? (circle number)	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? (circle number)	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. (circle number)

	NONE	MILD	MODERATE	SEVERE	EXTREME
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your ar m, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (circle number)	1	2	3	4	5

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. (circle number)	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE $= \left[\frac{\text{sum of n responses}}{n} - 1\right] \times 25$, where n is equal to the number of completed responses.

A DASH scor e may <u>not</u> be calculated if ther e are greater than 3 missing items.

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including home-making if that is your main work role).

Please indicate what your job/work is: ____________________

❒ I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions r elate to the impact of your arm, shoulder or hand problem on playing your musical instr ument or sport or both. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the spor t or instrument which is most important to you: ____________________

❒ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of ar m, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instr ument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module scor e may <u>not</u> be calculated if there are any missing items .

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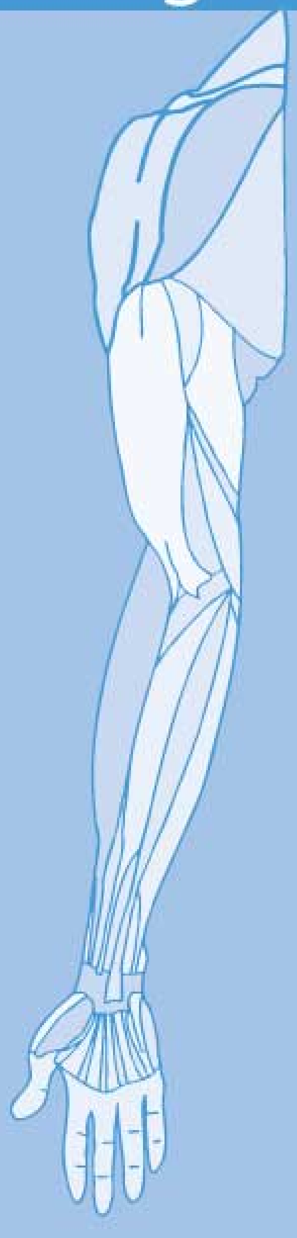
DASH Questionnaire (German)

DISABILITIES OF THE ARM, SHOULDER AND HAND

DER DASH-Fragebogen



ANLEITUNG

Dieser Fragebogen beschäftigt sich sowohl mit Ihren Beschwerden als auch mit Ihren Fähigkeiten, bestimmte Tätigkeiten auszuführen.

Bitte beantworten Sie alle Fragen gemäß Ihrem Zustand in der vergangenen Woche, indem Sie einfach die entsprechende Zahl ankreuzen.

Wenn Sie in der vergangenen Woche keine Gelegenheit gehabt haben, eine der unten aufgeführten Tätigkeiten durchzuführen, so wählen Sie die Antwort aus, die Ihrer Meinung nach am ehesten zutreffen würde.

Es ist nicht entscheidend, mit welchem Arm oder welcher Hand Sie diese Tätigkeiten ausüben. Antworten Sie Ihrer Fähigkeit entsprechend, ungeachtet, wie Sie die Aufgaben durchführen konnten.

Disabilities of the Arm, Shoulder and Hand

Bitte schätzen Sie Ihre Fähigkeit ein, wie Sie folgende Tätigkeiten in der vergangenen Woche durchgeführt haben, indem Sie die entsprechende Zahl ankreuzen.

	Keine Schwierig-keiten	Geringe Schwierig-keiten	Mäßige Schwierig-keiten	Erhebliche Schwierig-keiten	Nicht möglich
1. Ein neues oder festverschlossenes Glas öffnen	1	2	3	4	5
2. Schreiben	1	2	3	4	5
3. Einen Schlüssel umdrehen	1	2	3	4	5
4. Eine Mahlzeit zubereiten	1	2	3	4	5
5. Eine schwere Tür aufstoßen	1	2	3	4	5
6. Einen Gegenstand über Kopfhöhe auf ein Regal stellen	1	2	3	4	5
7. Schwere Hausarbeit (z. B Wände abwaschen, Boden putzen)	1	2	3	4	5
8. Garten- oder Hofarbeit	1	2	3	4	5
9. Betten machen	1	2	3	4	5
10. Eine Einkaufstasche oder einen Aktenkoffer tragen	1	2	3	4	5
11. Einen schweren Gegenstand tragen (über 5kg)	1	2	3	4	5
12. Eine Glühbirne über Ihrem Kopf auswechseln	1	2	3	4	5
13. Ihre Haare waschen oder fönen	1	2	3	4	5
14. Ihren Rücken waschen	1	2	3	4	5
15. Einen Pullover anziehen	1	2	3	4	5
16. Ein Messer benutzen, um Lebensmittel zu schneiden	1	2	3	4	5
17. Freizeitaktivitäten, die wenig körperliche Anstrengung verlangen (z. B. Karten spielen, Stricken, usw.)	1	2	3	4	5
18. Freizeitaktivitäten, bei denen auf Ihren Arm, Schulter oder Hand Druck oder Stoß ausgeübt wird (z.B. Golf, Hämmern, Tennis, usw.)	1	2	3	4	5
19. Freizeitaktivitäten, bei denen Sie Ihren Arm frei bewegen (z. B. Badminton, Frisbee)	1	2	3	4	5
20. Mit For tbewegungsmitteln zurecht zukommen (um von einem Platz zum anderen zu gelangen)	1	2	3	4	5
21. Sexuelle Aktivität	1	2	3	4	5

22. In welchem Ausmaß haben Ihre Schulter-, Arm- oder Handprobleme Ihre normalen sozialen Aktivitäten mit Familie, Freunden, Nachbarn oder anderen Gruppen während der vergangenen Woche beeinträchtigt? *(Bitte kreuzen Sie die entsprechende Zahl an)*

Überhaupt nicht	Ein wenig	Mäßig	Ziemlich	Sehr
1	2	3	4	5

23. Waren Sie in der vergangenen Woche durch Ihre Schulter-, Arm- oder Handprobleme in Ihrer Arbeit oder anderen alltäglichen Aktivitäten eingeschränkt? *(Bitte kreuzen Sie die entsprechende Zahl an)*

Überhaupt nicht eingeschränkt	Ein wenig eingeschränkt	Mäßig eingeschränkt	Sehr eingeschränkt	Nicht möglich
1	2	3	4	5

Bitte schätzen Sie die Schwere der folgenden Symptome während der letzten W oche ein. *(Bitte kreuzen Sie in jeder Zeile die entsprechende Zahl an)*

	Keine	Leichte	Mäßige	Starke	Sehr starke
24. Schmerzen in Schulter, Arm oder Hand	1	2	3	4	5
25. Schmerzen in Schulter, Arm oder Hand während der Ausführung einer bestimmten Tätigkeit	1	2	3	4	5
26. Kribbeln (Nadelstiche) in Schulter, Arm oder Hand	1	2	3	4	5
27. Schwächegefühl in Schulter, Arm oder Hand	1	2	3	4	5
28. Steifheit in Schulter, Arm oder Hand	1	2	3	4	5

29. Wie groß waren Ihre Schlafstörungen in der letzten Woche aufgrund von Schmerzen im Schulter-, Arm- oder Handbereich? *(Bitte kreuzen Sie die entsprechende Zahl an)*

Keine Schwierigkeiten	Geringe Schwierigkeiten	Mäßige Schwierigkeiten	Erhebliche Schwierigkeiten	Nicht möglich
1	2	3	4	5

30. Aufgrund meiner Probleme im Schulter-, Arm- oder Handbereich empfinde ich meine Fähigkeiten als eingeschränkt, ich habe weniger Selbstvertrauen oder ich fühle, dass ich mich weniger nützlich machen kann. *(Bitte kreuzen Sie die entsprechende Zahl an)*

Stimme überhaupt nicht zu	Stimme nicht zu	Weder Zustimmung noch Ablehnung	Stimme zu	Stimme sehr zu
1	2	3	4	5

DASH Wert für Behinderung/Symptome = [(Summe der n Antwortpunkte) - 1] x 25,
n
wobei n der Anzahl der beantworteten Fragen entspricht

Wurden mehr als 3 Fragen nicht beantwortet, so darf ein DASH Wert nicht berechnet werden.

DISABILITIES OF THE ARM, SHOULDER AND HAND

SPORT- UND MUSIK-MODUL (OPTIONAL)

Die folgenden Fragen beziehen sich auf den Einfluss Ihr es Schulter-, Arm- oder Handpr oblems auf das Spielen Ihr es Musikinstrumentes oder auf das Ausüben Ihres Sports oder auf beides.
Wenn Sie mehr als ein Instrument spielen oder mehr als eine Sportar t ausüben (oder beides), so beantworten Sie bitte die Fragen in bezug auf das Instrument oder die Sportart, die für Sie am wichtigsten ist.
Bitte geben Sie dieses Instrument bzw. diese Sportart hier an:

☐ Ich treibe keinen Sport oder spiele kein Instrument (Sie können diesen Ber eich auslassen).

Bitte kreuzen Sie die Zahl an, die Ihre körperlichen Fähigkeiten in der vergangenen Woche am besten beschreibt.
Hatten Sie irgendwelche Schwierigkeiten:

	Keine Schwierig-keiten	Geringe Schwierig-keiten	Mäßige Schwierig-keiten	Erhebliche Schwierig-keiten	Nicht möglich
1. In der üblichen Art und Weise Ihr Musikinstrument zu spielen oder Sport zu treiben?	1	2	3	4	5
2. Aufgrund der Schmerzen in Schulter, Arm oder Hand Ihr Musikinstrument zu spielen oder Sport zu treiben?	1	2	3	4	5
3. So gut Ihr Musikinstrument zu spielen oder Sport zu treiben wie Sie es möchten?	1	2	3	4	5
4. Die bisher gewohnte Zeit mit dem Spielen Ihres Musikinstru-mentes oder mit Sporttreiben zu verbringen?	1	2	3	4	5

ARBEITS- UND BERUFS-MODUL (OPTIONAL)

Die folgenden Fragen beziehen sich auf den Einfluss Ihr es Schulter-, Arm- oder Handproblems auf Ihre Arbeit (einschließlich Haushaltsführung, falls dies Ihre Hauptbeschäftigung ist).
Bitte geben Sie Ihre/n Arbeit/Beruf hier an:

☐ Ich bin nicht berufstätig (Sie können diesen Ber eich auslassen).

Bitte kreuzen Sie die Zahl an, die Ihre körperlichen Fähigkeiten in der vergangenen Woche am besten beschreibt.
Hatten Sie irgendwelche Schwierigkeiten:

	Keine Schwierig-keiten	Geringe Schwierig-keiten	Mäßige Schwierig-keiten	Erhebliche Schwierig-keiten	Nicht möglich
1. In der üblichen Art und Weise zu arbeiten?	1	2	3	4	5
2. Aufgrund der Schmerzen in Schulter, Arm oder Hand Ihre übliche Arbeit zu erledigen?	1	2	3	4	5
3. So gut zu arbeiten wie Sie es möchten?	1	2	3	4	5
4. Die bisher gewohnte Zeit mit Ihrer Arbeit zu verbringen?	1	2	3	4	5

Auswertung der optionalen Module : Die Antwortpunkte der Fragen werden summiert; durch 4 (Anzahl der Fragen) dividiert; 1 wird subtrahiert und danach mit 25 multipliziert.
Für die Auswertung eines optionalen Moduls dürfen keine Antworten fehlen.

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The Dash Questionnaire was downloaded from the website of the Institute of work and health http://www.dash.iwh.on.ca/ (23).

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