Grip on prognostic factors after forearm fractures
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Chapter 11
General discussion
The subject of this thesis is the evaluation of classification systems for forearm fractures and their relation to the functional outcome.

Many classification systems for forearm fractures can be found in literature, although the intraobserver and interobserver reliability is usually not reported, and neither its relation with optimal treatment and likely prognosis. A classification would ideally be practical in use, comprehensive, reliable and be able to guide treatment and predict prognosis.\textsuperscript{1,2}

Normative data of isokinetic grip strength and forearm rotation is not widely available in literature,\textsuperscript{3-7} and especially in children strength has a strong relationship with age and sex. Loss of posttrauma isokinetic strength may be an indication of severity of soft tissue damage after forearm fractures. Hence the interest in this data, which could be of potential value to assess rehabilitation programs as well as improve prediction of prognosis after forearm fractures in children. Ideally, it would even be an extra tool to guide postoperative treatment of forearm fractures and even an aid in establishing indications for surgery.

I Classifying forearm fractures (Chapter 2)

In literature 27 different classification systems can be found.\textsuperscript{appendix} The problem with the use of these classification systems, based on plain radiographs, is the poor observer reliability. These systems were most commonly evaluated using a limited number of observers, while testing a large number of cases.\textsuperscript{1, 8-12} Using numerous cases in testing, bypasses a test's learning curve. In fact testing few observers (mostly experts in the field) results in measuring the observer's interpretation of a specific classification introducing experience bias.

In this study we used a large observer panel for the qualification of four different classification systems. We studied the interobserver and intraobserver reliability of four frequently used classification systems (Older, Fernandez, Frykman, AO/ASIF).\textsuperscript{1, 8, 13-16} A large panel of trauma interested physicians was asked to apply all four classification systems on a limited series of radiographs, in order to assess reliability of these systems for use in general hospitals.

Our results show that the distal radius classification systems used in this thesis are characterised by poor interobserver and intraobserver reliability. This is in agreement with other reports in literature.\textsuperscript{8} In our study, both junior and senior trauma surgeons performed observations twice, with a two months interval. We did not find a correlation between experience and interobserver reliability.

Using radiographs instead of CT scans was considered to be a potential cause of these poor results. Most classifications are based upon plain radiographic imaging,\textsuperscript{17} and one would expect, by adding advanced imaging (CT-scan) more insight would be obtained with regard to the fracture pattern. Surprisingly according to literature, adding a CT-scan to the radiographs for classification purposes, does not seem to help improve inter- intraobserver agreement.\textsuperscript{18-20}

A shortcoming of this research is that we did not study the trainability of participants for each
classification system separately, in order to establish whether specialised physicians could more reproducibly use them. Second we asked to fill out four pre-selected classifications to be tested. This selection took away the possibility of using a more suitable classification per case. The suggestion that different classifications serve different fractures better, would severely hamper comparability in literature of possible candidates for the ideal classification of forearm fractures. We conclude that tested classifications do not suffice the criteria for a universal forearm classification in daily practise. There are too many variables in wrist fractures to make one classification workable for each wrist fracture.

II a  Normal forearm function represented in normative isokinetic strength measurements (Chapter 3,4,5)

The purpose of treating forearm fractures in children is to restore function. Restoration of anatomy and alignment by observing radiography for consolidation after fracture treatment of the forearm in children, does not predict functional recovery. Additionally range of motion should give an impression of functional results. Isokinetic strength measurements, which are frequently used in adults, can be used to complement the range of motion assessment to obtain a more comprehensive idea of the child's functional forearm status. For correct interpretation of measurement data, the normative values in a healthy representative population have to be known first.

In literature we found several studies measuring grip strength in children. There were encountered during our literature study. The first problem is that the results of these studies were difficult to compare, since most studies did not use a standardised measurement method. The JAMAR grip strength dynamometer was used in various ways, and the setup with regard to positioning of the shoulder, elbow and forearm was also different for each study. The second problem is that these study groups were relatively small and lacking in detailed subgroup characteristics (age, weight, length, sport activity and hand dominance), which we consider of paramount importance for correct interpretation when comparing these measurements with post injury values.

To solve all the aforementioned issues, we undertook a large study including 200 children per age group, in a standardized position (as advocated by the JAMAR device), giving a representative insight in the strength per age group resulting in normative data. The results of our study provided unique normative data for the younger age groups (4-15 years) linking age; sexe; height; and weight to grip strength. Weight and height also have a strong positive association with grip strength in children and adolescents, particularly noticeable during growth spurt in girls.

Comparing measurement values of the injured arm to the contralateral healthy side is potentially even better than comparing with normative data. Although not always possible (e.g. bilateral injuries), it would negate any possible confounders and effect modifying variables by 'perfect matching' of the subject with oneself.
However we have to bear in mind that despite the similarity in functional anatomy, hand dominance, as well as cognitive dominance may cause differences in performance or strength between the dominant and non-dominant arm. For adults there is a rough 10% strength deficit between grip strength of the dominant and the non-dominant forearm. Extrapolation of these data to children seems premature. This is underlined by literature, which states that in children under the age of four, hand preference is hard to tell. In chapter three we showed that grip strength in children in a developing phase is particularly influenced by age, sex, height and weight. In our study we analysed the difference in strength of the dominant and the non-dominant hand in children.

Our results showed that, in children who are right hand dominant, the right hand is 10% stronger than the left hand, while this difference is maintained over age, thus mirroring the known values for adult populations. However in children who are left hand dominant the difference in strength compared to the right was in general comparable. This can be extrapolated to the adult situation in which strength difference for right hand dominance is 10%, for left hand dominance less data is present with no significant difference.

In trauma the juvenile bone absorbs most of the energy, sparing the relative elastic soft tissues. In adults the capsuloligamentous and tendinous structures have become more rigid and are therefore more prone to injury when sustaining a fracture. It would be reasonable to assume that these soft tissue injuries in the forearm of adults may have an additional negative impact on supination and pronation strength. This association has indeed been confirmed in previously published papers. These reports unfortunately lack a standardised approach to measure pronation and supination strength.

In order to find the preferred way of testing, we undertook a study measuring isokinetic function (grip strength and pronation supination strength) in different forearm positions from 60° pronation to 60° supination. Our subjects were young adolescents, and we adapted elbow posture to rule out upper arm muscle strength for an optimum representation of forearm strength.

The pronation and supination strength curves had a very consistent relation with each other. We established that in the 20° supination position, the pronation curve bisects the supination curve, meaning that in this rotational position supination strength is similar to pronation strength.

The gathered isokinetic normative data resulting from the studies described in chapter 3, 4 and 5 opens the opportunity to learn what is to be considered (ab)normal. These strength curves could be used to assess severity of functional deficit or to monitor recovery of function after forearm injury. Though future studies comparing the results of strength curves of injured individuals with the consistent normative data curves are needed, they potentially can be used as a qualitative diagnostic tool for function.

Future studies are needed to assess other potential uses of these measurements, such as its use as a diagnostic tool to identify specific injuries.
II b  Isokinetic pronation and supination strength measurements after forearm injury
(Chapter 6,7)

Posttraumatic sequelae of forearm injuries can lead to a significant decrease in function. Imaging of bony structures using conventional x rays and additional imaging techniques are standard tools to objectify the skeletal role in functional impairment. Although it is not evident in all cases, certain forearm fractures come in a specific fracture pattern, which is associated with gross ligament disruption. However, there is no standard tool to assess the soft tissue components after these type of injuries. MRI or ultrasound could be used to visualise these, but a more functional assessment using rotational strength measurements was hypothesized to be able to detect injury in a quantitative manner.

In chapter 6 isokinetic strength tests were performed in a cohort of patients that had sustained a Galeazzi fracture and were assumed to have fully recovered. We assumed that the direction of ulnar dislocation during DRUJ trauma would disrupt function in a specific direction and sparing function in the other.

Interestingly overall strength diminished after Galeazzi’s fracture. The strength curves therefore are promising for monitoring post trauma functional recovery, and assessment of persistent injury. Apparently the Galeazzi’s fracture mechanism does not seem to result in a posture specific, or direction specific decrease of rotational strength, but rather an overall decrease of strength.

In chapter 7 pronation and supination was investigated in a cohort of female patients, that sustained a Frykman type II fracture. The analysis showed that middle aged female subjects with anatomically healed extra articular distal radius fractures associated with a basal ulnar styloid fracture have persistent loss of isometric supination and pronation strength at 2-4 years after surgery. While overall strength in supination position was less, a remarkable curve dimple was observed at 60° degrees of supination. This could be explained as a “position specific” giving way, caused by an isolated soft tissue injury such as disruption of the triangular fibrocartilaginous complex that stabilises the radioulnar joint. This specific loss of rotational strength correlated with lower functional scores (PRWE), highlighting the importance of supination function in daily life.

A limitation of this study is that no advanced imaging or arthroscopic information was available to assess the exact nature of DRUJ pathology accounting for the subjective and objective wrist deficits. However the studies of chapter 6 and 7 are pilot studies testing the forearm torque testing protocol. Future research should focus on prospective studies with larger cohorts and additional imaging to correlate deviations in strength measurements with specific types of soft tissue injuries.

Besides rotational strength measurements, we also tested grip strength in the cohorts studied in chapter 6 and 7. Comparing our measurement values with the normative data from chapter 5 revealed that sustaining a Galeazzi’s fracture grip strength in both supination and pronation was considerably decreased. Frykman type 2 fractures on the other hand resulted in a more
specific decrease in grip strength in the supination position. These strength deficits were even more pronounced when using the uninjured side as a comparison. Wrist function and stability is a complex interplay between several ligaments and bony structures. The more specific loss of both grip and rotational strength in the supinated position for Frykman type 2 fracture patients fit the expectation that soft tissue injuries are more specific and limited when compared to the more gross disruption that follows a Galeazzi fracture. The demographic differences between the groups support this hypothesis: Galeazzi fractures were sustained by younger males after a high energy trauma, while the Frykman type 2 fractures were sustained by older females after a low energy trauma.

III Predicting outcome after paediatric forearm fractures
(Chapter 8,9,10)

In order to obtain the best available evidence with regard to acceptable versus unacceptable angulation and malalignment after forearm fractures, we collected all available literature, as well as opinions of 17 international experts on this subject (Chapter 8). This resulted in 8 graphs (Isala graphs) each with two curves (one according to literature and one according to the experts) of different forearm fractures representing an acceptable angulation at certain age of a traumatic angular deformation. With these acceptable advisable angulations for different forearm fractures and given potency of remodelling, we could collect data with this evidence for a proposed conservative treatment.

Following these results a prospective study (Chapter 9) was designed to assess functional outcome in relation to angulation and residual malposition. Therefore range of motion isokinetic grip strength; initial angulation and malposition were measured in time, in order to further explore the value of these measurements.

This study confirmed some of the conclusions that were drawn from the existing literature and expert opinions, and provided additional insight. The inclusion criteria regarding angular deformation were broad; hence subtle deformations were also accepted. Accounting for paediatric healing potential, wrist function was followed one year after paediatric trauma, and directly compared to the normal situation of the non-index arm and gathered normative data (from chapter 3). In this study the hypothesis of functional recovery sustained, range of motion and grip strength after one year of trauma approaches 100% compared with normative data. Few did show rest angulation and no functional problems occurred in time. Though functional deficits could be observed in patients with a more profound angulation, a subtle rest angulation after one year did not affect grip strength (grip strength approached 100% compared to the non affected side). Unfortunately numbers for subgroup analysis were too low to state this observation.

There still are answers to questions that remain obscure. For example, we still do not know in which phase most reangulation takes place: in the period of callus formation, is there a maximum for physisal angular correction? During reangulation the physisal growth seems to be redirected
preceeding the cortical drift on the level of the fracture, and remodelling follows patterns of normal bone physiology.\textsuperscript{51-53} Frost\textsuperscript{??}

Future studies may increase our understanding of fracture-physiology and remodelling on different levels in the bone and may help us to more accurately guide treatment after forearm fractures in children.\textsuperscript{51-55}

As stated in the introduction of this thesis most paediatric forearm fractures are believed to have a favourable prognosis; the general thought is that children will overcome their initial restrictions during growth. Previous 2 chapters confirm, for observed fractures and malalignment, this statement. Unfortunately there are specific fracture patterns which do end up giving complaints, restriction in range of motion, instability and pain.\textsuperscript{54} This subgroup deserves our attention, while being overlooked, effort should be taken to identify and prevent these adverse effects in an early stage.

Loss of initial successful reduction after forearm fractures is another unfavourable outcome that clinicians try to detect early. Stability is the most important factor in predicting redisplacement that may result in malalignment and rotational limitations. We explored radiographic variables that were associated with instability in chapter 10. In this study we explored the value of initial imaging to get an early indication of prognosis after sustaining these fractures in combination with the data from chapter 8.

For this study we selected malaligned both bone forearm fractures, which successfully were repositioned but failed to hold their position, and compared these fractures with a selected cohort of successfully reduced fractures that maintained their position.

Both complete fracture displacement and shortening of the ulna were found to be independent determinants associated with an increased risk of redislocation. This important role of malalignment of the ulna has not been reported before in literature.\textsuperscript{57-63} Beside fracture displacement, incomplete reduced fractures are 5 times more susceptible to redisplace, than those in which anatomic reduction was obtained.\textsuperscript{59, 60, 64-67} Differences in casting were not found to be associated with increased risk of redislocation.

We recommend careful inspection of both initial radiographs as well as post-reduction radiographs for these signs of instability. If present, close monitoring or even prompt surgical intervention is indicated.

\section*{IV Recommendations and future perspectives}

Both pediatric and adult forearm and wrist fractures can be difficult to treat with varying results. The wide variety in fracture patterns, concomitant soft tissue injuries and patient characteristics can be confusing for the treating clinician. In this PhD thesis we have attempted to assess a multitude of methods aiming to guide treatment and predicting outcome. All methods described in this thesis were either radiologic classification systems or strength measurements.
Eponyms have been used to the purpose of easy communication and classifying injuries for many years. They are easily adopted in general medical jargon, but they lack a comprehensive view of complexity due to a consciously simplification.

Distal radius fractures are complex injuries with considerable variation in fracture pattern and soft tissue involvement, making it difficult to design a classification system that takes all of these relevant variables into account. Existing classifications that attempt to do so by including many subgroups, become more cumbersome to use in daily practice and lack good inter and intra observer reliability. Furthermore, they cannot be fully relied on to reliably guide treatment nor indicate prognosis following treatment. The exact treatment and rehabilitation is in certain cases also influence by certain intraoperative findings (successful restoration of anatomy, achieving stability etc), which cannot be predicted beforehand. Predicting final outcome is even harder, since it does not always correlate well with radiographic results and other quantifiable variables. None of the classifications studied in this thesis was able to fulfil all of these criteria.

It may be more feasible to develop algorithms based on flowcharts to guide decision-making and perhaps to aid in predicting prognosis. This would allow for implementation of several variables only relevant at a specific decision point, and updating the decision tree with the use of necessary input at every next step in the process. Automated processes as well as integrating patient individual as well as big data implemented in widely available apps may contribute to ease and precision of such future solutions.

Another approach to optimising treatment and prognosis in general, is to concentrate specific injuries in specialised centres. This would not just be a dedicated surgical specialist, but also pertains to other key members of his team, such as the radiologist, hand and occupational therapists and rehabilitation physicians.

A second recommendation in our search in order to improve function and rehabilitation, is to consider isokinetic testing as a diagnostic tool. In this way it might be possible to diagnose a solitary ligament injury. By studying the isokinetic strength diagram, in combination with ROM and function a more precise diagnosis could then be made.

We have measured isokinetic strength of the hand and forearm in several post injury cohorts. The exact value of the measurements remains to be elucidated in future research, but it seems reasonable to state that it is of added value to monitor recovery or final results of treatment of forearm and wrist injuries. Extensive normative data would allow for subgroup analysis (e.g. sex, age, hand dominance) for specific patient groups. Again, collection of more data in specific post injury cohorts (before and after treatment) would then allow us to extricate more specific data to aid in decision-making and to provide both clinician and patient with better data to predict final outcome. Perhaps this could even guide the development of specific strength test measurements to identify more specific injuries, turning these measurements into a diagnostic tool rather than a post treatment assessment instrument. Pooling of data into a central database would be necessary to get sufficient numbers, especially for the more rare kind of injury patterns.
We have come a long way to appreciate forearm fractures for the complex injuries that they are, with variable outcome depending on different trauma mechanisms. Recognising these injuries, treating them in an optimal way and guiding rehabilitation in an individually tailored manner in all age groups, as well as different patients with different characteristics can be optimised as aforementioned. I hope this thesis has made a contribution in this fascinating area.
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