Grip on recovery after paediatric forearm fractures

Hepping, Ann Marjolein

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CHAPTER 7

General Discussion

This thesis focuses on functional outcome during the recovery of angulated fractures of the forearm and hand in children and adolescents. With an overall goal to offer a better substantiated and more standardised set of outcome measures to be incorporated into future research, the first part of this thesis **(Chapters 2 and 3)** aims to provide interpersonal and intrapersonal reference values for one of the most important outcome measures reflecting hand function: grip strength. The second part of this thesis **(Chapters 4, 5 and 6)** investigates prospectively how grip strength and other outcome measures, such as mobility and dexterity, recover after increasingly invasive courses of treatment have been followed.

GRIP STRENGTH

Grip strength measurements have a well-established role in the assessment of hand function in adults, and are thus extensively used.[1-5] They have a high inter-rater and test-retest reliability and are quickly obtainable.[6-8] However, for the paediatric population representative normative data have not been readily available in the past. **Chapter 2** addresses this hiatus by providing interpersonal reference values based on a large, random sample obtained according to current standardised testing procedures.

On a day-to-day (or clinical) basis though, especially for children with unilateral fractures, it might be better to utilise an intrapersonal difference in grip strength between the dominant and the non-dominant hand. Intrapersonal reference values automatically take the individual characteristics that determine strength into account. After all, as shown in **Chapter 2**, the most important personal factors associated with strength comprise age, height, weight and male gender. These variables are all likely to sort a similar attributing effect on the strength of both hands rather than one. The outcome of the regression analysis from **Chapter 2** boosts this hypothesis, as the results for the factors correlated with strength prove to be very similar for either hand.

Chapter 3 investigates whether a strength difference in favour of the dominant hand exists in children, and whether such an advantage is different for left- and right-dominant boys and girls. Results bring forward another advantage of the use of intrapersonal reference values, namely that they do more justice to the minority of left-dominant children. As shown in **Chapter 3**, the strength difference in favour of the dominant hand for left-dominant boys and girls only amounts to 0% and 3%, respectively. By contrast, this difference amounts to 10% in both right-dominant boys and girls. Several studies measuring grip strength in adults have reported similar findings with respect to the '10% rule' of hand dominance only being applicable to right-dominant males and females.[9-11] One study from 2001 performed in minors even reported trends almost identical to our findings from **Chapter 3**, but when broken down by gender, age and hand dominance their subgroups were way too small to allow for statistical differences or conclusions.[12] The latter argument unfortunately also holds true for other studies performed in minors.[13-16] Two studies that appeared after the publication of **Chapter 3** stated that hand dominance does not influence grip strength, but these studies either did not analyse children of a different hand dominance separately or compared interpersonal instead of intrapersonal results.[17,18] In **Chapter 3** a large number of left-dominant children were included in each subgroup by age and gender, enabling us to draw new conclusions about this minority of children and to examine differences between left-dominant boys and girls in more detail. By sheer coincidence, the results make it relatively easy to calculate the expected grip strength value of the affected hand based on the value of the unaffected hand quickly by head, as long as your patient is not a left-dominant girl. But even in the latter case, such a calculation would be much less time-consuming than having to fill in patients' data into normative data graphs.

In conclusion, when possible, intrapersonal instead of interpersonal reference data on grip strength should be used, as the former are more accurate plus easier to obtain. Our advice thereby follows that of the American Medical Association and the American Association of Hand Therapists, although the mentioned lack of representative normative data also played an important role in recommending intrapersonal data.[19,20]

STRENGTH MEASUREMENTS

The way strength recovers after sustaining angulated paediatric fractures of the upper extremity has not previously been the specific scope of research. Strength measurements are used predominantly as an outcome parameter to either compare the affected hands between two different types of treatment groups or to compare the affected to the unaffected hand in the setting of a long-term follow-up evaluation.[21-24] However, neither comparison gives any actual information about the recovery process of strength itself, as strength could very well be diminished in both treatment groups or be severely affected in the first months (or years) post-injury. In this thesis, recovery of grip strength is evaluated prospectively for both non-reduced fractures in **Chapter 4** and reduced fractures in **Chapter 5**. Results show that for non-reduced fractures grip strength is significantly affected up to 6 months post-injury. By that point strength of the affected hand already amounted to 97% of that of the unaffected hand, and this remained unchanged one year post-injury. This difference could very well be attributed to hand dominance, which was not taken into account as an additional factor due the relatively small study population. The difference in grip strength between both hands up to 6 months post-injury is nonetheless evident. Moreover, **Chapter 4** shows that grip strength is associated with extent of angulation. We have not found any other studies assessing this connection.

Chapter 5 further examines the recovery of grip strength for reduced fractures by increasingly invasive types of treatments. Results show that grip strength is more impaired the more invasive the course of treatment given – in other words, most extensive for open reduction with internal fixation (ORIF), intermediate for closed reduction with percutaneous pinning (CRIF), and least extensive for closed reduction without internal fixation (CR). Grip strength was still significantly diminished at six months post-injury in the ORIF group, while this did not hold true for the CRIF and CR groups.

Chapter 5 additionally investigates recovery of strength of the key grip and three-jaw-chuck grip, showing similar results for the inverse relation between recovery of strength and treatment invasiveness described for grip strength. For all strength measurements, both extent and duration of muscle strength loss were more prominent the more invasive the treatment chosen. However, key grip normalised at 3 months for the CR group, and the three-jaw chuck normalised at 3 months for both the CR group and the CRIF group. In other words, it seems these measurements can be used in conjunction with each other with the three-jaw chuck normalising the earliest, followed by key grip and lastly grip strength. This is a new finding, as no other studies have assessed how these outcome measures recover over time. It would be worthwhile to further examine this finding in future studies (and perhaps even different types of pathologies). For angulated fractures of the forearm though, the three-jaw chuck grip will not likely differentiate between treatment groups beyond 6 weeks post-injury. Its use as an outcome measure in the recovery after angulated forearm fractures is therefore less suited.

Finally, for those who are wondering why tip-to-tip pinch strength was not evaluated in any of the chapters of this thesis, it proved to be a very complex grip. We were not able to obtain a reliable measurement in a vast number of younger children, so we decided to remove it as outcome parameter. Other studies investigating strength measurements in children under the age of 6 have reported similar problems with tip-to-tip pinch strength, choosing to only measure grip strength and key grip.[14,25] Hence we logically advise against incorporating tip-to-tip pinch in future studies that include children younger than 6 years; its value in recovery after paediatric forearm fractures in older children is not established. In conclusion, incorporating grip strength as an outcome measure, possibly in combination with key grip, has the highest sensitivity to change and will provide the most important information in the recovery after angulated fractures.

MOBILITY MEASUREMENTS

Recovery of mobility of the elbow, forearm and wrist was also evaluated prospectively for both non-reduced **(Chapter 4)** and reduced **(Chapter 6)** angulated forearm fractures. Six weeks post-injury both studies found all movements distal from the elbow to be significantly diminished compared to the unaffected hand. Most affected fractures after non-reduction were supination and pronation, followed by palmar flexion, all with a maximum limitation of 10°. For fractures treated by means of reduction, supination and palmar flexion were the most affected (18° limitation), followed by dorsal flexion and pronation with 15 and 13° limitation, respectively. **Chapter 6** shows that 3 months post-injury, pronation and palmar flexion are still significantly diminished after reduced fractures, although by then the limitation had decreased below 10° for both movements. Pronation and palmar flexion are the only movements significantly influenced by the course of treatment chosen (the ORIF group was associated with the worst outcome). Six months post-injury no significant differences in favour of the unaffected hand were found. **Chapter 4** shows that for non-reduced fractures pronation and supination are still significantly diminished 6 months post-injury, although only by 4.1 and 2.5°, respectively. Most likely, the reason why such a small difference turned into a significant result in the non-reduced study as opposed to the reduced study is the fact that pronation and supination were measured with a goniometer in the non-reduced study of **Chapter 4** and with an inclinometer in the study of **Chapter 6**, which was performed later. The standard deviations in the first study with respect to these two measurements were specifically more than twice as low as in the second study, which probably caused these small differences to become significant. Perhaps arbitrarily, we feel that such small limitations (below 5°) should not be considered clinically relevant.

Reason for the introduction of the grip inclinometer to measure forearm rotations was an attempt to obtain more reliable results. Pronation and supination assessment by goniometer are more challenging than assessment of the other measurements, since a bony landmark between the levers is absent and the distance over which the lever can be positioned is small. This challenge is reflected in the literature, with multiple studies examining which of several goniometry methods is most reliable, as well as testing the reliability of smartphone applications, visual estimation, or measurement of a pencil held in the subject's hand.[26-29] Two of these studies show that goniometry is more reliable than visual estimation or the handheld pencil method.[26,29] Interestingly, another study showed that a mobile phone held in a selfie stick had both higher test-retest and inter-rater reliability than goniometry and the handheld pencil method.[28] Not only that: the setup used in that study was almost identical to the use of our inclinometer. We observed that children quickly find out that the device can be rotated slightly further by lowering the grip of their fifth digit, but when comparing the mean supination scores of the unaffected hands from **Chapter 4** (94.5°) and **Chapter 6** (95.6°), the difference was only marginal. In conclusion, based on existing literature and the current thesis we cannot give a clear answer as to which of these two methods is most reliable.

In conclusion, the extent of mobility impairment is slightly larger in the reduced than in the non-reduced study. Limitations can be considered mild for both groups 3 months post-injury, and no clinical or other meaningful limitations could be assessed 6 months post-injury. Moreover, unlike grip strength, mobility did not show an association with degree of fracture angulation. Measurements of pronation and palmar flexion will differentiate the best on functional recovery of mobility between different courses of treatment, but most likely only up to 3 months post-injury.

Comparison of these findings to other studies is difficult, as they are very scarce. Retrospective studies on reduced fractures have shown mild limitations in pronation and supination of less than 10° and negligible restrictions in dorsal and palmar flexion of the wrist over one year post-injury.[22,24] One prospective study conducted specifically on angulated both-bone fractures described that limitations of 20° in the pronation-to-supination range of motion do exist 6 months post-injury.[30] Results showed that both re-fractures and diaphyseally located fractures were associated with these increased limitations. In our study no re-fractures occurred in reduced fractures, and no significant differences exist in either pronation or supination between distal metaphyseal and diaphyseal fractures 6 months post-injury.

OTHER OUTCOME PARAMETERS

Lastly, **Chapter 6** prospectively evaluates the recovery of dexterity and a pre-defined set of post-traumatic symptoms, namely pain, swelling, redness, hypertrichosis, temperature asymmetry, reduced sensitivity and allodynia. For post-traumatic symptoms no significant differences were found between the treatment groups, probably due to the low number of children in the ORIF group. The incidence of pain and reduced sensitivity did seem to show a trend corresponding with treatment invasiveness, and pain and hypertrichosis showed to be common symptoms in children that persist over time. We consider it worthwhile for future studies to further investigate these three symptoms in more detail. By contrast, dexterity – as tested by means of the nine-hole peg test – seems to be an unsuitable test for recovery of hand function after fractures. Scores of both hands improved significantly over time (suggesting a learning effect), no significant differences between affected and unaffected hand were found beyond 6 weeks post-injury, and no association between test score and course of treatment was found.

STRENGTHS AND LIMITATIONS

In research strengths and limitations are often determined by power, and **Chapter 2** and **Chapter 3** ambiguously take the saying 'strength lies in numbers' to a new level. To our knowledge, we have conducted the largest study ever on the obtainment of normative data on grip strength in children, ensuring that each subgroup when broken down by age and gender included a sufficient number of children. Results are presented in similar fashion as children's growth curves. The plotted percentiles facilitate an at-a-glance determination of what can or cannot still be considered as normal. Because results are shown by gender, hand-dominance and age, adequate comparison over longer periods of time is made possible. These graphics can be of particular use for comparison to children who endured a complication or children with bilateral fractures, although the curves can of course be used for a much broader range of conditions. With over 2200 children participating, more substantiated statements for the minority of left-dominant boys and girls could be made, and the 10% rule of had dominance could be challenged for children for the first time.

Another strength of this thesis is that all studies on recovery after paediatric fractures were conducted prospectively. Although this might seem like a small step, when it comes to research on angulated paediatric fractures of the upper extremity this can be considered as somewhat of a leap. Prospective studies on this topic are simply extremely rare, let alone those that take functional recovery into account. Children in our studies were measured at pre-defined moments in time, according to the same protocols and by the same researchers, thereby minimizing intra-rater and inter-rater differences.

Finally, this thesis contains several novelties. **Chapter 4** is to our knowledge the first study to prospectively investigate fracture remodelling in paediatric non-reduced angulated forearm fractures for functional outcome. **Chapter 5** is the first study to prospectively focus on recovery of strength after reduced fractures of the forearm, wrist or hand, and **Chapter 6** is the first study to evaluate a pre-defined set of post-traumatic symptoms, dexterity and a broad set of mobility measurements according to increasingly invasive courses of treatment followed.

When strength lies in numbers, weaknesses will often lie in the lack thereof. While heterogeneity was a close friend in those studies focusing on normative data, it became our foe in the fracture studies. As stated in the introduction of this thesis, reaching numbers with power is difficult when measuring boys and girls with diverging growth potentials, at different ages, with different fractures and varying angulations, and undergoing different treatments initiated by different physicians. Hence the study population for both the non-reduced fractures from **Chapter 4** (N = 26) and the reduced fractures when broken down into subgroups by treatment from **Chapter 5** (N = 12-36) and **Chapter 6** (N = 9-23) can be considered small and heterogeneous. However, as stated before, prospective studies on functional recovery after reduced paediatric forearm fractures are extremely rare, and the results from these three studies provide not only new information but also better guidance for future research.

Another limitation is that all studies in this thesis are descriptive by nature, hence no treatment alterations or allocations were made. Suiting several aims of this thesis, namely to provide insight into how commonly used outcome measures actually recover in children, and to provide an easy and quickly obtainable yet substantiated and standardised set of outcome measures, there is a pitfall. Correlation does not equal causation – *cum hoc ergo propter hoc*: worse outcome is not necessarily caused by a more invasive course of treatment. One could very well argue that the inverse relation found between several outcome measures and treatment invasiveness is simply a reflection of the severity of the injury sustained. After all, more extensive injuries are more likely to cause functional limitations and thus warrant more invasive treatments. The current thesis cannot provide a definitive answer for this chicken-and-egg paradox, as the descriptive nature of the various studies is not suited to investigate causality. On the other hand, in order to actually investigate causality properly in future studies, one first has to know what should be measured, when it should be measured, and what it should be compared to – and this is where the present thesis comes into play. Still, we can, and will, provide an educated guess by stating that treatment invasiveness is at least partially to blame for poorer functional outcome. First, because no treatment allocations were made there will irrevocably be overlap in severity of fractures between treatment groups. In other words, the fractures included in the different studies and subgroups form a continuum rather than distinct ordinal groups. It is thus not unlikely for differences in outcome between these groups to be at least partially caused by the severity of the treatment undergone. Treading even more carefully, functional results from this thesis at least do not advocate for a more invasive course of treatment.

RECOMMENDATIONS

When working towards a standardisation of testing procedures we suggest measuring children at 6 weeks, 3 months and 6 months post-injury, and additionally at 1 year if treatment by ORIF falls within the scope of the study. For grip strength we advise use of a handheld dynamometer and the testing position as advocated by the American Society of Hand Therapists. This position comprises a seated subject with shoulders adducted and neutrally rotated, elbow flexed at 90°, and wrist between 0 and 30° extension and 0 and 15° ulnar variation.[20] Additionally, as elaborated in **Chapter 2** and **Chapter 3** we recommend using the mean of two instead of three attempts when working with children. Studies have shown that this does not lead to significant differences in results, plus it is less time-consuming for the researcher and less burdensome for the child.[9,31,32] It proved to be a challenge to keep children focussed on a rather repetitive task, especially when a broader set of measurements was being obtained. For children aged 4 and 5, we furthermore advise setting the handlebar to the first instead of the second position, since they have smaller hands and have trouble reaching the second setting (as has also been described by others[14,17]). We feel that verbal encouragement should be given, not only to motivate children to do their best but also because this simply makes them feel more comfortable. Hand dominance should be taken into account. For studies evaluating children in the first 3 months post-injury, key grip could be added as an outcome measure. For measurements of mobility we deem the incorporation of pronation, supination and palmar flexion as sufficient. Lastly, we would advise further investigating the association of pain, reduced sensitivity and hypertrichosis with treatment invasiveness.

FUTURE PERSPECTIVES

Results of this thesis, carefully treading towards a less invasive treatment rather than a more invasive one, are consistent with the very few other existing studies that examine related topics. Eismann et al. (2013) reviewed abstracts on paediatric upper extremity fractures presented at the Pediatric Orthopaedic Society of North America and the American Academy of Orthopaedic Surgeons between 1993 and 2013.[33] Results showed that the vast majority of level I and II studies (91%) advised less invasive or at most neutral treatments rather than more aggressive ones. The authors concluded that 'research fails to support the trend towards increasingly aggressive treatment of paediatric upper extremity fractures', as also described in the introduction of this thesis.[33] Thereafter, Roth et al. (2014) found that re-manipulation of re-angulated distal forearm fractures in children under age 12 did not improve outcome on angulation, grip strength, mobility or pain in a long-term functional and radiographic assessment. Authors deemed re-manipulations in children younger than 12 as unnecessary, and moreover concluded that current guidelines on acceptable angulations for children over 12 are too strict.[22] Unfortunately, most other studies that included functional outcome are retrospective, comparing or focussing on different stabilisation methods in children undergoing the most invasive treatment, namely open reduction with internal fixation.[34]

Back to the future is back to the drawing board. When to accept, reduce or operate (and how) remains the question at hand, almost literally. Future research should focus more on the effects on functional recovery when moving the dividing (arbitrary) lines between two successive treatments towards the least invasive option, rather than comparing outcome between different surgical stabilisation methods after performing an open reduction. Examples are expansion of the acceptable angulations previous to performing a reduction, as well as limits on acceptable re-angulation before reverting to internal fixation. Either way, from a clinical perspective as soon as ORIF is on the table more extensive and prolonged limitations can or rather should be expected, and in our opinion referral to a hand therapist should be seriously considered.

CONCLUSIONS

Grip strength measurements are a well-established outcome measure in the assessment of hand function. Known to have a high intra-rater and inter-rater reliability, they are also easily and quickly obtainable in children. This thesis provides both interpersonal and intrapersonal reference values of grip strength for children and adolescents. Intrapersonal data is easier to obtain and, more important, has higher accuracy, as it automatically takes the individual characteristics that determine strength into account. Compared to other strength measurements, namely key grip and three-jaw chuck, grip strength is more sensitive to change. The extent as well as the duration of strength loss is more prominent the more invasive the treatment and, lastly, grip strength is associated with fracture angulation whereas range of motion is not. Hence the role of grip strength measurements in the evaluation of recovery after angulated paediatric fractures seems to be undervalued in comparison to mobility measurements.

Loss of mobility of elbow, forearm and wrist can be considered mild with an overall average below 20° in the reduced study and below 10° in the non-reduced study at 6 weeks post-injury. Measurements of pronation and palmar flexion can be of value, as they are significantly impaired up to 3 months post-injury and show to be associated with the undergone treatment. Similarly to strength, an inverse relation was seen between extent of impairment and invasiveness of treatment.

The recovery of the post-traumatic symptoms of pain, reduced sensitivity and hypertrichosis warrants further investigation. Although a trend was observed in relation to treatment invasiveness, the number of children in the ORIF group was too small to yield significant differences between treatment groups. We consider the nine-hole peg test to be an unsuitable test for recovery of hand function after fractures.

Results of this thesis advocate towards a less invasive treatment rather than a more invasive one, or at least cannot support the trend towards more aggressive treatments. Future research should focus more on the effects on functional recovery when moving the dividing (arbitrary) lines between two successive treatments towards the least invasive one.

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