Summary
Distal radius fractures are one of the most common types of fractures, accounting for around a quarter of fractures in the paediatric population and up to a fifth of all fractures in the elderly aged population. These fractures are substantially represented throughout different age groups. Different peak incidences can be observed, but are not as age specific as for the proximal femoral fracture. Fractures of the wrist come in a wide variety, this is probably due to the anatomy: two long bones (radius and ulna), and carpalia forming three joints, interconnected with each other by a complex of ligaments. The toughness of these structures and their relation differ during life: as a child ligaments seem to be stronger than bone and bone is far more elastic (even plastic deformable), as in the geriatric situation bone becomes more brittle due to higher mineral density and less trabeculae.

To accurately treat patients with a distal radius fracture it is of prerequisite to analyse trauma radiograph in order to decide upon what treatment would suffice long term prognosis best. Naturally specific fracture characteristics benefit specific treatment. Historically eponyms described fracture characteristics, which later made place for classifications to signify the severity of fracture and serve the injury for adequate treatment. Four popular and widely used classifications based on radiography were used in Chapter 2 in order to study their use in a general traumatologic population for reliability.

Forty-five observers (trauma surgeons and residents) classified five different radiographs of distal radial fractures according to the AO/ASIF, Frykman, Fernandez and Older classifications. Four months later, the same panel classified the same radiographs in a different order. Mean correlation between observers for all cases was fair to moderate, and poor with the gold standard as classified by the senior author (DP). Observer agreement after 4 months, was demonstrated to be moderate for the AO/ASIF classification and fair for the Frykman, Fernandez, and Older classifications. When the group was divided based on years of clinical experience (< 6 years; ≥ 6 years), there was still poor correlation between experience and consistency among all four classifications.

It was concluded that based on these findings, the different radius classification systems are not workable for the general traumatologist. Due to their questionable reproducibility and reliability it would be of ill advise to couple treatment modalities let alone predict prognosis after injury. There could however be a role for these classifications in specialised centres and for research purposes.

Fortunately there are different options to portend prognosis, that is each with it's own limitation. For example grip strength measurement is considered a sufficient way to observe restoration of normal function of the forearm after trauma. A successful treatment can be considered successful when function is restored, but also if a functional deficit can be expected due to primary trauma. Bearing this in mind it would be a potential tool to follow-up patients after forearm fracture. Fact is that after an injury hand function cannot be considered normal, and people have a preference for one hand with one being stronger than the other.

In Chapter 3 the largest to our knowledge heterogeneous population of children was studied with normal function of both hands, for reference values of grip strength. Though injury and hand preference are variables for function, age, sex, weight and height are considerable contributors to grip strength and were measured.
The study included healthy children (N = 2241) and adolescents ranging in age from 4-15 years. All children had their height (cm) and weight (kg) measured and allowed a total of four attempts using the JAMAR hand dynamometer: twice with each hand. Scores (kg) were noted according to dominance. Reference values for boys and girls are provided according to age and dominance. We were able to show grip strength has a linear and parallel progression for both sexes until the age of 11-12 years, after which grip strength development showed an acceleration, more prominent for boys. There is a significant difference in grip strength with each ascending year of age in favour of the older group, as well as a trend for boys to be stronger than girls in all measured age groups. Weight and especially height had a strong correlation with grip strength in children.

In Chapter 4 the effect of hand preference influencing grip strength in children and adolescents was further determined. The study population comprised 2284 children and adolescents. Right-preferent boys and girls scored significantly higher with their dominant hand, with a difference of 9.5 and 10.1% respectively. Left-preferent girls scored significantly higher with their dominant hand, but this difference was only 3.0%. For left-preferent boys no significant difference was found. It seems to be more common for left-preferent individuals to be stronger with the non-preferent hand, or be as strong in both hands, than it would be for right-preferent children. There is a 10%-rule in adults for grip strength in which the dominant hand is 10% stronger, this is also applicable for right-preferent children ranging in age from 4–17 years, though it does not account for left-preferent children. In contrast to left-preferent boys, left-preferent girls are overall still significantly stronger with their preferent hand.

In our understanding of forearm fractures in relation to age, absorbed energy during trauma causes different structures being injured between age groups. In the paediatric situation it is less likely that tendons, ligaments and capsule are being ruptured, mostly the osseous structures absorb all the energy. Accessory soft tissue injury is more likely to occur in the adult situation. Grip strength alone covers only gross forearm function, though would not foresee in function limited by giving way or instability. In Chapter 5 the pattern of pronation and supination strength as well as grip strength was being evaluated. In varying positions of forearm orientation, normative data could be retrieved from healthy volunteers, in order to observe how pronation, supination and grip strength would relate in these positions. Both forearms were assessed with a baseline dynamometer (pronosupination strength) and Jamar dynamometer (grip strength) to measure isometric peak strength in different forearm positions, varying from 60º pronation to 60º supination. This resulted in 142 strength graphs of 71 healthy volunteers (22 years ± 3.6 (SD)), with a consistent general linear effect of pronosupination and grip strength on forearm orientation in the healthy population. A remarkable finding is the bisection at 20º supination of pronosupination strength curve which could provide clinicians an easy obtainable and sensitive, however, non-specific indicative measure of forearm pathology. This normative data suffices as the backbone when studying function after an injury.

To test aforementioned hypothesis of accessory ligament injury in the adult situation we poses normative grip strength and pronosupination strength curves in different pronosupination
positions of the forearm. These could be used as a new diagnostic tool instead of imaging techniques. This isometric strength testing in variable angles would be wise first to compare with a known pathologic situation of the forearm. Therefore we performed a pilot study (Chapter 6) identifying patients with a distal radial ulnar joint dislocation due to trauma. The dislocation sporadically is being presented isolated, and mostly part of a distal radius fracture. A known example is a Galeazzi’s fracture, in which treatment exists in open reposition and internal fixation of the radius fracture, while leaving ruptured ligaments caused by the dislocation untreated (which are assumed to (partially) heal while alignment is restored). With this known traumatic ligamentous injury of the wrist, patients were tested for isokinetic grip strength and pronosupination strength in different pronation and supination positions of the forearm (making use of the same protocol used, while gaining normative data). Scope of this study was to find a significant decrease after trauma treatment in pronosupination strength curve due to expected rest instability. Comparing the curves of healthy uninjured individuals with the curves of traumatized DRUJoints, there seem to be a significant difference in strength, and a similar trend toward the shape of the curve intersecting at 20° supination.

In Chapter 7 we used the same principal however for a different classified forearm fracture. Instead using Galeazzi’s fracture, used was an extra articular distal radius fracture combined with an ulnar styloid fracture at the base. This fracture described as a Frykman type II fracture is potentially, like Galeazzi’s fracture, causative for DRUJ disruption. Concerning the styloid component, part of the energy after the fracture of the radius should pass through the DRUJ in order to have a styloid fracture. This makes the injury more complex than a sole distal radius fracture in relation to post trauma stability. The objective of this study was to define pronation and supination strength profiles tested through the range of forearm rotation in normal individuals, and to evaluate the torque profiles and torque deficits across the testing range in a cohort of patients treated for a Frykman type II fracture.

Twelve subjects were evaluated 2-4 years after anatomical open reduction and volar plate fixation of a distal radius fracture in comparison to the normative data. The injured wrist was consistently weaker (corrected for hand dominance) in both supination and pronation strength in all testing positions, with the greatest loss in 60° supination. Mean supination strength loss across all testing positions was significantly correlated with worse functional scores (PRWE), highlighting the importance of supination in wrist function. Unfortunately we did not find a specific position dependant decrease in our strength curve, explanatory for giving way of a specific ligament.

Different from isokinetic devices in observing rehabilitation and predicting functional outcome, is the primary purpose of radiography; it’s diagnostic use. But when a correct diagnosis has been made and a treatment is set accordingly, specific factors can be observed from radiographs determining chance of failure of stability and therefore prognosis. Few rare entities exist with a strong advise for surgical intervention (e.g. Monteggia dislocation fracture). Manipulation or open reduction with internal fixation is often being advocated for malaligned fractures, while conservative regimes can be optional. Deciding to opt between one or another depends on the risk of potential complications (infection/anaesthesia/post traumatic experience) or failure of immobilisation. There are some specific factors in these forearm fractures to bare in mind and
important, while considering the effect of treatment. The next chapters in this thesis highlight the potency of remodelling (derived from growth) and fracture's stability, as subject of radiographic predictable factors for success of conservative treatment.

The forgiving character of the juvenile skeleton makes it possible to cope well with traumatic deformities like angulation, and displacement compared with the adult situation. While making use of remodelling as a characteristic of the juvenile bone, the effect is more or less known/predictable. This experience is used in most conservative forearm treatment modalities, but the exact mechanism and degree of remodelling remains obscure.

Different types of forearm fractures require specific treatment options, with their own limitations of angulation during remodelling. In Chapter 8 we show the results of a meta-analysis of literature together with the opinions of eighteen international experts. This effort was made to provide insight in the limitation of acceptance of angular deformation in the non-operative treatment of eight different paediatric forearm fractures. With this information we constructed graphs (age versus angulation) for each of these fractures, providing useful support in the decision-making process of acceptance of angular deformities in paediatric forearm fractures. (Isala-graphs)

Following the results of this meta-analysis with expert opinion and advising on angular acceptability in the conservatively treated forearm fractures, a clinical relevant question has been answered. Unfortunately basic scientific questions remain in order to understand tolerability of the juvenile skeleton on angular deformities. While remodelling is key in the long process of conservative treatment, the effect on function is essential. As we know from literature remodelling and function interact and develop dependent on each other. If function cannot be maintained caused by for example an extreme angulation during trauma, remodelling cannot continue its normal favourable fashion and the result is unpredictable.

The remodelling potential in relation to function of angulated traumatic deformities in children was base for a prospective study Chapter 9. Secondary to this study is the predictability of predefined maximum acceptance of angulation in forearm fractures with at least 2 years of growth. (Derived from the Isala-graphs)

As radiographic angular deformation has been subject to predict the outcome of remodelling and the functional success of a conservative treatment, after the necessity of reduction other factors influences the conservative treatment. Not remodelling and function but alignment loss after reduction and cast-immobilisation of angulated and/or complete displaced forearm fractures are most common and subject of the study in Chapter 10. Our concern is the potential risk for losing alignment of the fracture (in the period after reduction during immobilisation), which could be observed by signs on initial radiograph. The goals were to indicate fractures that are prone to losing their alignment during treatment, based on initial radiographs.

Performed was a retrospective case-control study included children sustaining both-bone forearm fracture, treated by closed reduction, and cast immobilization. Displacement, angulation, before and after reduction; cast index and padding index were measured.

(initial angulation; initial complete displaced (and shortening); lack of anatomic reduction; cast and padding index)

This resulted in 2 groups: group A considered 22 patients in whom > 5º loss of reduction was seen during cast-immobilisation, and group B consisted of 16 patients with < 5º reduction loss.
Group A consisted of more broken cortices, with a statistically significant higher number of initial displaced fractures ($p<0.001$ and $p=0.010$), and residual displacement ($p=0.022$). The cast and padding index didn't differ significantly between groups ($p= 0.77$ and $0.15$ respectively). As a predictor of losing alignment cast- and padding index didn't correlate well with alignment loss, though cortical stability seemed of more importance in predicting alignment loss in this study.

The aim of this thesis was to create a scientific foundation for studying the outcome of regular trauma treatment of forearm fractures, and study measurements contributing to improve its prognosis. A common theme in all our studies was to find possibilities to make those characteristics objective responsible for a less favourable outcome. The results of these studies can easily be adapted in a normal clinical setting improving awareness and possibly preventing under treatment.

We conclude that:

1. We filled in a lacuna of normative data, for isometric strength tests of the forearm, important for the evaluation of function after trauma.
2. In our study isometric strength testing reflects function of the forearm, however after trauma we cannot specify injured structures where we hoped for.
3. We can predict the remodelling of paediatric forearm fractures more accurate as their initial stability.