Chapter 1
General introduction and aims
Introduction
Forearm fractures account for a substantial proportion of presented trauma on emergency departments worldwide, representing an estimated 16% of all fractures. Of all upper limb fractures in children 20-33% are localized in the forearm. Overall forearm fractures are, in prevalence, the most common fractures. A close analysis of these long bone injuries shows that the distribution is sex- and age-specific, depending on different characteristics.

Biology
On a histological level bone has a unique age-specific skeletal property. The unique juvenile properties of bone fade when epiphyseal growth plates (physes) start to ossify in the adolescent. The absorption of energy in the juvenile bone, before the physis starts to ossify, results in a biomechanical situation that is distinct from that in the adult. This can be attributed to differences in osseal composition (less mineralized, high in collagen but a less dense matrix with high cellularity) and differences in osseal structure (highly vascularized and spongious) compared to adults. The juvenile forearm has a firm periosteal sleeve containing the bone, and a weak unique epiphyseal growth plate. This thicker periosteal sleeve in the immature skeleton has a distinct effect not just on impact absorption during injury but also on healing. Even after a malunited fracture, the juvenile bone has the potency to correct and remodel. Hence certain fracture malalignment in children can be accepted, which could not be the case in the adult situation. All of these different biological properties make the juvenile bone, during its growth period, absorb energy during trauma in a manner that is very different compared to the adult bone. This results in treatment of paediatric fractures determined by juvenile pathophysiology rather than adult.

Incidence
A second observation is that lifestyle differences between the sexes during the course of time influence forearm fractures. Generally speaking, there are three peaks in incidence. The first is during childhood when there is a peak of forearm trauma at the age of 5-14 years (with a slight predilection for boys), there is another later in life in adult males under the age of 50 years, followed by an increase in females sustaining especially wrist fractures over the age of 40 years. The activity level and biological hormonal differences between young adult and geriatric bone, periosteum, and muscles seem to influence the statistics and incidence, thereby influencing the type of fracture. In the 5-14 year age group, trauma is inflicted mostly by a fall on an outstretched hand and not by a high impact, although motor vehicle injuries in children have increased. The fractures in the adult male group are caused by a high-energy impact due to injury, caused by traffic or sports, which results in an increased incidence of intra-articular fractures. In the elderly female population, decreased bone mass and density causes the forearm to be at risk for extra-articular fractures when sustaining a fall.

History
The fact that forearm fractures are so common throughout all ages explains why there is a lot of literature concerning their diagnoses and treatment. The risk of fracturing the radius was significantly increased by the transition to bipedal ambulation. Treatment of radius fractures predates the written word as reports of splinting techniques for wrist fractures have been dated back to 5000 years ago in ancient Egyptian hieroglyphics. Around 400 BC, notes were
found from Hippocrates describing treatment of forearm fractures and dislocations by manual reduction and bandaging.\textsuperscript{25} After Abraham Colles and Guillaume Dupuytren had published their insight into the treatment modality of radius fractures, treatment changed little - even with the introduction of plaster of Paris (1850). Physicians struggled to diagnose fractures, although they also realised the existence of different patterns of fracture. A few tried to categorise them to point out the importance of prognosis during (different) treatment regimes. Hence eponyms followed from the pioneers, who first observed, described and published common fracture types. These typical fractures were coupled to a treatment or sometimes a warning for prognostically unfavourable results at a time when there were no radiographs (Pouteau\textsuperscript{1783}, Colles\textsuperscript{1814}, Monteggia\textsuperscript{1814}, Cooper\textsuperscript{1826}, Dupuytren\textsuperscript{1832}, Hutchinson\textsuperscript{18}, Barton\textsuperscript{1838}, Goyrand\textsuperscript{1832}, Smith\textsuperscript{1847}), and even when there were (Galeazzi\textsuperscript{1934}, Essex-Lopresti\textsuperscript{1951}, Hume\textsuperscript{1957}).

In the second part of the nineteenth century, x-ray became available for diagnostic purposes. From that time adequate fracture diagnosis could be made, resulting in the publication of large numbers of papers based on radiographic diagnoses (although also based on anatomical dissections and experiments) to assess the different trauma types and fracture patterns, which were described using eponyms. These eponyms could be considered as the predecessors of later classifications. Whilst the eponyms still serve a certain purpose, it became clear that a more detailed and structured distinction, even within the same injury type, was needed to try to understand the differences in outcome between patients, and to perhaps guide treatment in an individually tailored manner.

**Classifications**

Classically, classifications serve the purpose of processing radial fracture into universal medical code. However the usefulness, and more importantly the aim, depends on how practically a classification can be used. Ideally, it should be practical in use, analytic, reliable (intra-observer reliability and intra-observer variability) and discriminate in treatment and prognosis. Practically, a classification should yield a platform for communication research, give direction to a clinician to make a thorough treatment decision, and provide information to the patient with a reliable rehabilitation phase and treatment outcome.

About 27 different distal forearm fracture classifications have been developed. Most of them give an understanding of the trauma mechanism with a treatment advice, some stress a detail or feature of the fracture from a specialist point of view, and others have been built systematically. These different characteristics lead to different outcomes, for example a systematic classification is often easy to use, and could therefore improve variability. However not all fracture types can be posted in this classification and there is no clear treatment direction, which can predict rehabilitation or prognosis.

Hence Kreder’s statement/proclamation: “In general we feel that treatment should be based on sound basic principles of fracture care and anatomy as well as consideration of the patient and his circumstances, rather than relying on a specific fracture classification system”.\textsuperscript{26} On the other hand, a classification that is based on a specific trauma mechanism is often too complex, resulting in increased inter-observer variability and intra-observer reliability.

Apparently the variation in forearm fractures is complex, making it a difficult subject to contain in a universal classification that provides satisfactory guidance for treatment and predicted prognosis.\textsuperscript{27}
**Function**
The restoration of function after a fracture is clearly the most important outcome parameter. Measuring grip strength is historically considered to be a reliable functional score that represents gross forearm function and there is reasonable evidence in adults to support this. Grip strength has been used extensively as a parameter in the assessment of hand function, as both neuromuscular and generalized bone diseases directly affect it. It has been used as an indicator in the evaluation of patients with a large variety of pathologies that impair the upper extremities, including rheumatoid arthritis, osteoarthritis, muscle dystrophy, tenosynovitis, strokes, and congenital malformations.

Grip strength measurements also have an established role in determining treatment efficiency, for example in the evaluation of different wrist orthoses, the effect of hand exercises in rheumatoid arthritis, and recovery after trauma. Finally, grip strength measurements are used as outcome parameters in many different surgical interventions. Grip strength measurements provide a well-established and objective score, reflecting mobility of different wrist joints and therefore function of the hand and are easily and quickly obtainable by a range of different professionals.

These measurements of the post-injured forearm are usually compared with the contralateral side as best comparable parameter, although normative data can be used as an important indicator as well. Comparison to normative data is important when making statements about specific patient groups or treatment regimes. Obtaining normative data for grip strength in adults has been the subject of many studies; results are widely available from investigations when the forearm is positioned in the neutral position, and also from those related to hand-dominance. For grip strength in children and in different forearm positions in adults there remains a lacuna in data.

The situation for grip strength in children is different compared to that in adults. Although more or less the same structures are being stressed in normal use, ligament injury is usually less of a problem in children and more common in adult forearm fractures. Therefore grip strength in the neutral position gives a good indication of general hand function after forearm trauma in children. However during pronation and supination of the forearm, different anatomic structures become taut or relaxed, so measurement of grip strength in a neutral position would miss these problems in adults. In other words, testing the forearm in only a neutral position would not stress specific ligament injuries and therefore would not adequately test function. The same applies for pronation and supination strength measurements in only the neutral position. In different pronation and supination positions, different ligaments are taut and relaxed and different muscles are being used. Therefore pronation and supination tests in different forearm positions are more specific and complementary when examining ligament and muscular injury in the forearm after injury.

**Remodelling in children**
Forearm fractures in adults encompass intra-articular structures and firm ligament complexes as part of a complex injury, which eventually are predictive for the traumatised limb's function. In children most fractures involve the epiphyseal and diaphyseal bone and therefore prognosis of function depends merely on growth and the remodelling capacity of bone. Fractures, especially of the long bones, can correct if malaligned and remodel during time because of the child's growth potential executed by the growth plate (physis). The compensatory
remodelling capacity is influenced by both intrinsic and extrinsic factors. Important intrinsic factors include the remaining growth period, which is influenced by sex. Boys tend to have a more or less 2 year longer growth period than girls. The proximity of the fracture to the epiphyseal growth plate, and apparently the thick periosteal sleeve in the immature skeleton have a distinct effect on injury healing.

Extrinsic factors for remodelling are the amount of angular deformation and the direction of deformation in relation to the plane of movement, e.g. a rotational deformity or the presence of complete fracture displacement.  

During healing there is a very complex system of mechanotransduction, a process through which forces or other mechanical signals are converted to biomechanical signals and are transduced to a cellular response. Without attempting to completely understand the intricacies of such a highly complex regulatory system, we do need to gain clinical insight to know when to call an angular deformation acceptable and when not.

**Scope, objective and goal of the thesis**

The scope of this thesis encompasses predicting functional recovery after forearm fracture. The objective is to obtain data for evaluating the forearm as such, focused on radiographs and kinematic tests as tools for prognosis. Therefore the reliability of radiographic forearm fracture classifications is tested and the acceptable angular deformation for a conservative treatment is studied, making use of international literature and empiric data. Data on normative grip strength and pronation-supination strength in different positions are obtained using dynamometer tests to evaluate normal forearm function.

The final goal is to use this information from radiographs (classification and acceptable angular deformation), and normative kinematic data (grip strength and pronation-supination strength) to predict functional outcome during rehabilitation after sustained forearm fracture.

**General outline summary**

Although there are many radiological classification systems for forearm fractures, it remains unclear which of these systems are most reliable and reproducible. Therefore in this thesis we selected four of the most popular classification systems and measured the inter-observer variability and the intra-observer reliability/reproducibility. (Chapter 2)

Grip strength is regarded as a reliable and objective score for forearm function in adults. Because fracture of the forearm in children generally does not affect the ligamentous structures, grip strength measured in neutral rotation of the forearm is regarded as a useful tool to test the gross forearm function. To sample normative grip strength values for children, we studied a Dutch cohort of normal healthy children, measuring grip strength in relation to sex, height and weight. The primary aim of this study was to provide reference values for grip strength in children and to present this data in a graphical representation that allows easy comparison. (Chapter 3)

In the literature it is suggested that factors such as hand dominance, sex and age might influence grip strength in children. No quantitative data are available however. Therefore in this study, a multivariate analysis was performed to quantify differences in grip strength due to differences in hand dominance, sex and age. It was found that age-related changes in strength between sex exist and that strength differences vary between left- and right-handed children. As mentioned before, grip strength measured in a neutral position is regarded as a useful tool to
observe forearm function after forearm fractures (without ligamentous disruption). (Chapter 4)
Because ligamentous disruption occurs in adults sustaining a forearm fracture, but rarely in children (Monteggia), it is of interest to measure grip strength not only in a neutral forearm position after adults fractured their forearm. Different ligament complexes can only be tested when they are taut, which is in specific forearm positions (pro- and supination of the forearm). In order to get normative values for grip strength in pro- and supination we therefore measured in this study grip strength in pro- and supination positions. (Chapter 5)
Using the selected radiological classification system from Chapter 2, patients were identified who had sustained a forearm fracture in correlation with ligamentous injury. With this selected fracture with ligament injury, the hypothesis was to identify by kinematic testing in different positions the functional deficit when the injured ligament would give way compared to the normative data from Chapter 5. This would be of value and give possibilities for a reliable predicted initial outcome and prognosis after a forearm fracture.
Two adult forearm fracture dislocation injuries were selected, notorious for instability in the distal radial ulnar joint, and compared with the normative data. The prognostic value and functional results after a Galeazzi's dislocation fracture cohort are described in Chapter 6, the results of a cohort of Frykman's type two fractures are described in Chapter 7.
The goal of another study was to clarify the extent of angulation that can be accepted and thus for which fractures conservative treatment without reposition can be accepted. The results show that multiple factors have to be taken into account, such as gender, age, apposition, etc. Therefore no clear uniform border for acceptance of angulation can be given for these type of fractures (Chapter 8). Using criteria and advice from experts and literature from chapter eight, combined with the normative grip strength data in children, the angular deformity and forearm function was measured prospectively in time in Chapter 9.
Loss of position in the conservatively treated and not reduced forearm fracture in children is a considerable risk. The effect of accepted alignment loss after comminutive treatment may have considerable impact on the function of the forearm. In this chapter we studied two groups of patients with forearm fractures with the same initial angular deformity who were treated conservatively. In one group the initial position was maintained and in the other group the initial alignment was lost. In order to predict reduction loss, radiological parameters were postulated which a priori have a negative influence on stability. (Chapter 10)

**Closing statement**
The subject of this thesis represents the vision of our Orthopaedic Department in the University Medical Centre on the subject of healthy ageing and developing. Our approach, besides the classical approach of treatment and cure, is a concept representing prevention and education in health and quality of life with regard to function and mobility.
As such the thesis forms part of a broader Public Health Research (PHR) program, which contributes research on the prediction and (early) detection of adverse health and disease, and on social participation in case of health problems. These research themes are part of the broader areas of prevention and societal participation, that is, of core domains of public health. They are also pivotal parts of the mission of the Research Institute SHARE and of the University Medical Center Groningen.
REFERENCES

23. Nellans KW, Kowalski E, Chung KC. The Epidemiology of Distal Radius Fractures. Hand Clin. Author manuscript; available in PMC 2013;May 1.


