Distal Radius Fractures

Aspects on radiological and clinical outcome and evaluation of a new classification system

Thesis for doctoral degree

Mats Wadsten

Main supervisor:
Associate professor Göran Sjödén
Umeå University
Department of surgical and perioperative sciences

Co-supervisor:
Associate professor Arkan Sayed-Noor
Umeå University
Department of surgical and perioperative sciences

Department of Surgical and Perioperative Sciences
Umeå 2016
Till familjen

“I hear and I forget. I see and I remember. I do and I understand.”

Confucius (551BC-479BC)
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table of Contents</strong></td>
<td>i</td>
</tr>
<tr>
<td><strong>Abstract</strong></td>
<td>iii</td>
</tr>
<tr>
<td><strong>List of publications</strong></td>
<td>vi</td>
</tr>
<tr>
<td><strong>List of abbreviations</strong></td>
<td>vii</td>
</tr>
<tr>
<td><strong>Definitions</strong></td>
<td>viii</td>
</tr>
<tr>
<td><strong>Sammanfattning (summary in Swedish)</strong></td>
<td>ix</td>
</tr>
<tr>
<td><strong>Introduction</strong></td>
<td>1</td>
</tr>
<tr>
<td>Background</td>
<td>1</td>
</tr>
<tr>
<td>Fracture of the distal radius - a historical perspective</td>
<td>1</td>
</tr>
<tr>
<td>Epidemiology</td>
<td>2</td>
</tr>
<tr>
<td>Treatment of Distal Radius Fractures</td>
<td>2</td>
</tr>
<tr>
<td>Conservative treatment</td>
<td>2</td>
</tr>
<tr>
<td>Pinning</td>
<td>3</td>
</tr>
<tr>
<td>External fixation</td>
<td>3</td>
</tr>
<tr>
<td>Open reduction and internal fixation (ORIF)</td>
<td>4</td>
</tr>
<tr>
<td>Radiological Outcome</td>
<td>4</td>
</tr>
<tr>
<td>Views and measurements</td>
<td>4</td>
</tr>
<tr>
<td>Issues when measuring radiological outcome</td>
<td>8</td>
</tr>
<tr>
<td>Factors predicting radiological outcome after DRF</td>
<td>10</td>
</tr>
<tr>
<td>Clinical outcome</td>
<td>10</td>
</tr>
<tr>
<td>Objective assessment</td>
<td>11</td>
</tr>
<tr>
<td>Patient reported assessment</td>
<td>11</td>
</tr>
<tr>
<td>Factors predicting clinical outcome</td>
<td>12</td>
</tr>
<tr>
<td>When should a DRF be treated with surgical intervention?</td>
<td>12</td>
</tr>
<tr>
<td>Classifications</td>
<td>14</td>
</tr>
<tr>
<td>The Older classification 1965</td>
<td>14</td>
</tr>
<tr>
<td>The Frykman classification 1967</td>
<td>16</td>
</tr>
<tr>
<td>The Melone classification 1984</td>
<td>17</td>
</tr>
<tr>
<td>The Comprehensive classification-AO</td>
<td>18</td>
</tr>
<tr>
<td>The Universal Classification (Rayhack, Cooney)</td>
<td>18</td>
</tr>
<tr>
<td>The Mayo Clinic classification</td>
<td>19</td>
</tr>
<tr>
<td>The Fernandez classification</td>
<td>20</td>
</tr>
<tr>
<td>Issues using fracture classifications</td>
<td>20</td>
</tr>
<tr>
<td>The development of a new classification</td>
<td>22</td>
</tr>
<tr>
<td>The Buttazzoni Classification</td>
<td>22</td>
</tr>
<tr>
<td>Presentation of the new classification:</td>
<td>24</td>
</tr>
<tr>
<td><strong>Aims of the thesis</strong></td>
<td>28</td>
</tr>
<tr>
<td><strong>Hypotheses of the studies</strong></td>
<td>29</td>
</tr>
<tr>
<td><strong>Materials and methods</strong></td>
<td>30</td>
</tr>
<tr>
<td>Patients</td>
<td>30</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Methods</td>
<td>32</td>
</tr>
<tr>
<td>Statistics</td>
<td>36</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td>39</td>
</tr>
<tr>
<td>Study I</td>
<td>39</td>
</tr>
<tr>
<td>Interobserver Reliability</td>
<td>39</td>
</tr>
<tr>
<td>Intraobserver Reliability</td>
<td>39</td>
</tr>
<tr>
<td>Study II</td>
<td>40</td>
</tr>
<tr>
<td>Outcome according to fracture class</td>
<td>41</td>
</tr>
<tr>
<td>Outcome according to fracture patterns regardless of fracture class</td>
<td>46</td>
</tr>
<tr>
<td>Study III</td>
<td>48</td>
</tr>
<tr>
<td>Outcome according to fracture class</td>
<td>48</td>
</tr>
<tr>
<td>Outcome according to fracture patterns</td>
<td>51</td>
</tr>
<tr>
<td>Study IV</td>
<td>54</td>
</tr>
<tr>
<td><strong>General discussion</strong></td>
<td>57</td>
</tr>
<tr>
<td>Discussion on radiological evaluation and results</td>
<td>58</td>
</tr>
<tr>
<td>Assessment of stability in DRF</td>
<td>59</td>
</tr>
<tr>
<td>Age</td>
<td>60</td>
</tr>
<tr>
<td>Initial degree of displacement</td>
<td>60</td>
</tr>
<tr>
<td>Comminution</td>
<td>61</td>
</tr>
<tr>
<td>Late instability</td>
<td>64</td>
</tr>
<tr>
<td>Discussion on clinical evaluation and results</td>
<td>65</td>
</tr>
<tr>
<td>Factors predicting clinical outcome</td>
<td>65</td>
</tr>
<tr>
<td>Age</td>
<td>65</td>
</tr>
<tr>
<td>Initial degree of displacement</td>
<td>66</td>
</tr>
<tr>
<td>Comminution</td>
<td>66</td>
</tr>
<tr>
<td>Fracture class</td>
<td>67</td>
</tr>
<tr>
<td>The correlation between objective and subjective outcome</td>
<td>68</td>
</tr>
<tr>
<td>Clinical outcome in relation to radiological outcome</td>
<td>69</td>
</tr>
<tr>
<td>Strengths and weaknesses of the thesis</td>
<td>71</td>
</tr>
<tr>
<td><strong>Conclusions</strong></td>
<td>74</td>
</tr>
<tr>
<td><strong>Implications for future research</strong></td>
<td>75</td>
</tr>
<tr>
<td><strong>Acknowledgements</strong></td>
<td>76</td>
</tr>
<tr>
<td>References</td>
<td>78</td>
</tr>
<tr>
<td>Appendix</td>
<td>92</td>
</tr>
</tbody>
</table>
Abstract

Distal radius fracture (DRF) is the most common fracture encountered in clinical practice. Every year, more than 20,000 people in Sweden suffer from this injury. It has been shown that there is a correlation between malalignment and function following distal radial fractures and malunion may cause persistent pain and disability.

A problem has been in making a correct initial assessment of the fracture. Many fractures are unstable despite an acceptable position on the initial radiographic examination or following a successful closed fracture reduction.

Numerous classification systems have been developed for evaluation of DRF in order to predict the outcome. However, the values of these are limited since they have not shown satisfactory reliability. Furthermore, the utility of these systems to predict radiographic or clinical outcome is not yet proven. These shortcomings may be one reason why optimal DRF management is still controversial. Requests for a new classification system of DRF, predictive of outcome and easy to use, have been made.

Improvement in initial assessment of DRF will benefit a large group of patients, as well as the society, by reducing persistent symptoms and disability.

**Study I:** In this study we evaluated the interobserver and intraobserver reliability of a new classification system (the Buttazzoni classification). Two hundred and thirty-two patients with acute DRF were blindly evaluated using the new classification by three orthopaedic surgeons twice with a 1-year interval. The new classification showed fair to substantial interobserver and intraobserver reliability, i.e., results comparable with other commonly used classification systems.

**Study II:** This was a prospective multicenter study of fracture stability in 428 DRF. The study investigated whether cortical comminution and intra-articular involvement, as well as the new classification system, could predict displacement in DRF. Logistic regression analysis showed that initial position of the fracture and volar or dorsal comminution predicted later displacement, while intra-articular involvement did not. Volar comminution was the strongest predictor of displacement. The new
classification system, which is the first to include volar comminution as a separate parameter, was highly predictive of fracture instability. Furthermore we found that it is quite common for non-operatively treated fractures to displace at a later stage than two weeks.

**Study III:** This was a prospective multicenter study on clinical outcome in 406 patients with DRF. The patients followed a conservative treatment algorithm so no fracture was operated on if proven stable in the cast. Three hundred and thirty four patients had clinical follow up at one year. Initial displacement was associated with a worse quickDASH score, worse EQ-5D score, reduced grip strength and reduced total ROM. Dorsal comminution was associated with a worse quickDASH score, reduced flexion and reduced pronation-supination ability. Volar comminution was associated with loss of extension. Intra-articular involvement was associated with a reduced flexion-extension arc and a worse EQ-5D score. There was a significant difference in ROM between non-comminuted and comminuted Buttazzoni classes. QuickDASH, EQ-5D, pain VAS, grip strength and complications were comparable among Buttazzoni classes.

**Study IV:** In study II it was found that late displacement of DRF, still in acceptable radiologic position after 10-14 days, occurred in approximately 1/3 of cases. Despite this, we have not been able to find any study focusing on evaluating the clinical outcome in patients with late displacement. Two hundred and nine unilateral DRF from study II were still in good position after 10-14 days and were included in the study. One hundred and seventy five patients had radiographs taken at a minimum of 3 months and a clinical examination 1 year after the fracture. Late displaced distal radius fractures had significantly higher loss of ROM and grip strength compared to fractures that didn’t displace. No significant differences were seen in subjective outcome.

In conclusion, initial position of the fracture predicted later displacement and was the most important parameter in predicting clinical outcome. Comminution of the fracture also affected radiological stability and clinical outcome. Volar comminuted fractures are highly unstable and need surgical intervention if displacement is to be avoided. Intra-articular involvement affected clinical outcome. Late displacement is common in DRF and may result in loss of range of motion and grip strength. To detect late displacement, DRF should be followed for more than 2 weeks.
The new classification system had a moderate reliability and reproducibility. The classification was found predictive of radiologic and objective clinical outcome. However, it was not predictive of subjective outcome. The classification system was also predictive of fractures at risk for late displacement.

**Keywords**

Distal radius fracture; reliability; radiographic outcome; clinical outcome; late displacement
List of publications

I. The Buttazzoni classification of distal radius fractures in adults: interobserver and intraobserver reliability.
   Wadsten MA, Sayed-Noor AS, Sjödén GO, Svensson O, Buttazzoni GG.

II. Cortical comminution in distal radial fractures can predict the radiological outcome: a cohort multicentre study.
    Wadsten MÅ, Sayed-Noor AS, Englund E, Buttazzoni GG, Sjödén GO.

III. Cortical comminution and intra-articular involvement in distal radial fractures.
     Clinical Outcome at 1 Year, using a conservative treatment algorithm.
     Wadsten MÅ, Buttazzoni GG, Sjödén GO, Englund E, Sayed-Noor AS.
     Submitted

IV. The Influence of Late Displacement in Distal Radius Fractures on Function, Grip Strength, Range of Motion and Quality of Life.
    Wadsten MÅ, Sjödén GO, Buttazzoni GG, Englund E, Sayed-Noor AS
    Submitted

Permission to reprint article I has been given by Springer.
Article II in its unedited, pre-publication draft is reproduced with permission and copyright © of the British Editorial Society of Bone and Joint Surgery.
## List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAOS</td>
<td>American Academy of Orthopaedic Surgeons</td>
</tr>
<tr>
<td>ADL</td>
<td>Activities of daily living</td>
</tr>
<tr>
<td>AO</td>
<td>Arbeitsgemeinschaft für Osteosynthesfragen</td>
</tr>
<tr>
<td>CRPS</td>
<td>Complex Regional Pain Syndrome</td>
</tr>
<tr>
<td>CT</td>
<td>Computed tomography</td>
</tr>
<tr>
<td>CTS</td>
<td>Carpal Tunnel Syndrome</td>
</tr>
<tr>
<td>DASH</td>
<td>Disability of the Arm, Shoulder and Hand</td>
</tr>
<tr>
<td>DRF</td>
<td>Distal Radius Fracture</td>
</tr>
<tr>
<td>DRUJ</td>
<td>Distal radioulnar joint</td>
</tr>
<tr>
<td>EPL</td>
<td>Extensor Pollicis Longus tendon</td>
</tr>
<tr>
<td>EQ-5D</td>
<td>The European five-dimensional self-assessment instrument</td>
</tr>
<tr>
<td>GLM</td>
<td>General Linear Model</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>ORIF</td>
<td>Open Reduction and Internal Fixation</td>
</tr>
<tr>
<td>PRWE</td>
<td>Patient Rated Wrist Evaluation.</td>
</tr>
<tr>
<td>ROM</td>
<td>Range Of Motion</td>
</tr>
<tr>
<td>TFCC</td>
<td>Triangular fibrocartilage complex</td>
</tr>
<tr>
<td>UV</td>
<td>Ulnar Variance</td>
</tr>
</tbody>
</table>
Definitions

AO: The AO Foundation is a non-profit organization led by an international group of orthopaedic surgeons dedicated to improving the care of patients with musculoskeletal injuries.

CPRS: Complex regional pain syndrome (CRPS), formerly known as reflex sympathetic dystrophy (RSD), is a chronic pain condition that may result in extreme sensitivity and pain.

DASH: A regional outcome questionnaire that measures pain and disability in the upper extremities.

EQ-5D: A 5-dimensional standardized instrument used as a measure of health outcome.

General Linear Model (GLM): The General Linear Model is mathematically identical to a multiple regression analysis but stresses its suitability for both multiple qualitative and multiple quantitative variables.

Instability: In this thesis a DRF that will not maintain its position with conservative treatment in a short arm cast.

Malunion: When a fracture heals with an anatomic deformity.

Minimal displacement: In this thesis a common expression both for fractures without displacement and fractures with minimal displacement according to criteria in studies II, III and IV.

Reduction: The manipulation of a displaced fracture to a more anatomical position.

Reliability: The internal consistency and reproducibility of an instrument.

Responsiveness: An instrument’s responsiveness to clinical change.

Ulnar variance: Axial shortening, the loss of length of the distal radius after a fracture
Sammanfattning (summary in Swedish)

Handlefsfraktur, eller distal radiusfraktur (DRF), är den vanligaste frakturerna. Varje år drabbas fler än 20 000 personer i Sverige. Flera studier har visat ett samband mellan anatomisk felställning och funktion efter handledsfraktur och en felläkning kan leda till smärta och funktionsnedsättning.

En svårighet är att vid första undersökningen korrekt bedöma stabiliteten efter handledsfraktur. Många frakturer förlorar sitt anatomiska läge vid uppföljning trots ett bra initialt frakturläge eller ett framgångsrikt tillrättaläggande (reposition) av brottet.

Ett flertal bedömningssystem (klassifikationer) för utvärdering av handledsfrakturer har föreslagits för att kunna förutse slutresultat. Värdet av dessa har dock varit tveksamt då man inte kunnat påvisa en bra tillförlitlighet. Klassifikationerna har heller inte kunnat påvisa betydelse för radiologiskt eller kliniskt utfall. Dessa brister kan vara en av förklaringarna till att behandling av handledsfrakturer fortfarande är omtvistad. Önskemål om ett nytt lättanvändt klassifikationssystem, med bra tillförlitlighet och betydelse för radiologiskt och kliniskt utfall, har framförts.

En förbättrad initial bedömning av handledsfrakturer kommer att gynna ett stort antal patienter.

**Artikel I:** I första studien presenterades och utvärderades tillförlitligheten och reproducerbarheten hos ett nytt klassifikationssystem (Buttazzonis klassifikation) för bedömning av DRF. Trehundra trettiofem patienter med akut DRF utvärderades med det nya klassifikationssystemet av tre ortopeder 2 gånger med 1 års mellanrum. Den nya klassifikationen visade en måttlig tillförlitlighet och reproducierbarhet hos granskarna, vilket är jämförd med några av de bättre resultaten i tidigare studier.

**Artikel II:** Detta är en prospektiv multicenter studie om frakturstabilitet hos 428 DRF. Patienterna följde en konservativ behandlingsalgoritm som innebär att ingen fraktur opererades så länge den var stabil i gips.
Studien utvärderar om kortikal splittring och ledengagemang, liksom den nya klassifikationen, kan förutsäga dislokation av fraktur. Logistisk regressionsanalys visade att initialt frakturläge och volar (handflatesidan) eller dorsal (handryggsidan) splittring var riskfaktorer för dislokation, medan ledengagemang inte påverkade stabiliteten. Volar splittring var den stärkaste riskfaktorn för dislokation. Det nya klassifikationssystemet, vilket är det första som inkluderar volar splittring som en separat parameter, var höggradigt prediktivt för radiologiskt utfall.


**Artikel IV:** I studie 2 konstaterades att sena haverier av DRF, med kvarstående bra läge efter 10-14 dagar, inträffade i cirka 1/3 av fallen. Trots detta har vi inte kunnat finna någon studie som utvärderar det kliniska resultatet hos dessa patienter. Tvåhundranio patienter med ensidig DRF från studie 2 hade acceptabelt frakturläge vid 10-14 dagars kontrol och inkluderedes i studien. Etthundrasjuttiofem av dessa kunde följas upp både radiologiskt efter minst 3 månader och kliniskt ett år efter frakturen. Sent havererade frakturer hade sämre rörlighet och styrka jämfört med frakturer läkta i bra läge. Ingen säker skillnad kunde ses i subjektiva besvär.

Sena haverier är vanligt vid DRF och kan resultera i förlust av rörlighet och greppstyrka. För att upptäcka sena haverier behöver DRF följas mer än 2 veckor.

Introduction

Background

Fracture of the distal radius - a historical perspective

The Greek physician Hippocrates is often referred to as “the father of western medicine”. Even though distal radius fracture (DRF) incidence has increased in the last decades, we may assume that the injury was quite common also during antiquity. Therefore, it is not surprising that the work of Hippocrates includes a description of the most common fracture known to us. The old scriptures actually described variants of carpal dislocations and maybe we can call this the first classification of the injury. In 1705 Jean-Louis Petit was the first physician who suggested the possibility that the injury sometimes may be fractures of the distal radius rather than carpal dislocations. Later in the same century Claude Poteau’s work published in 1783 clearly recognizes the injury as a fracture. Even though Poteau’s article predates Abraham Colles’ famous article of 1814 by 30 years, Colles’ work is widely regarded as the definitive description of the fracture. The eponym “Colles’ fracture” is still commonly used and may be considered a “single-class” classification as it refers to a dorsally displaced DRF. Other famous “single-class” classifications or eponyms still in clinical use are the shearing fracture or “Barton’s fracture” described by John Lea Barton in 1838 and the volarly displaced “Smith’s fracture” described by Robert William Smith in 1847. The “chauffeur fracture” originates from the time when cars were started with a hand-crank. Sometimes the car backfired and the starting hand-crank was forced backwards into the chauffeur’s palm, resulting in a typical styloid fracture.

Guillaume Dupuytren (1774-1835) made post mortem examinations of a large number of DRF. He divided the fractures into simple and comminuted. This is the first “classification”, in our view, with a precise definition. His observation actually echoes through time all the way to this thesis, where the type of comminution of the fracture plays a most important role.
**Epidemiology**

DRF is the most common fracture encountered in clinical practice\(^6\) and has been estimated to account for more than one sixth of all fractures treated in emergency rooms. The incidence is 20-40 per 10000 person-years.\(^7,8\) The age-distribution of DRF is bimodal, peaking in up to epiphyseal closure and elderly populations. Most fractures in adolescents and young adults are the result of a high-energy trauma such as sports injuries, fall from heights or traffic accidents, in contrast to the elderly population were the fracture usually is an osteoporotic low-energy fracture.\(^9\) Below 50 years of age the incidence of DRF is similar among women and men.\(^7\) The women to men ratio then increases up to 4:1 \(^7,10\) and women over 80 years reach the highest incidence of 120 DRF per 10000 person years.\(^7\) The incidence has been increasing from the 1950’s to the 1980’s but in a Swedish study from 2007 this upward trend seems to have stopped.\(^7\) In Nordic countries seasonal variations show an increase in the number of fractures during winter months.\(^11\)

**Treatment of Distal Radius Fractures**

The management of DRF is still controversial\(^12,13\). Non-displaced fractures are usually treated in a cast for 4-6 weeks while displaced fractures are reduced and then treated in the same way. If the fracture is considered unstable operative intervention is an alternative. Several surgical techniques are available. External fixation\(^14\) or pinning percutaneously\(^15\) have been used for a long time. During the last 2 decades open reduction and internal fixation with dorsal plates\(^16\) or volar plates and angle stable screws\(^17\) have gained popularity.\(^8,18\)

A difficulty has been to make a correct assessment of the stability at the time of injury. Fractures unable to be reduced are detected immediately, but many fractures displace later despite a successful reduction and casting.

**Conservative treatment**

Closed reduction and casting have historically been the treatment of choice. Loss of reduction and redisplacement are common and occur more frequently in patients who initially required manipulation.\(^19\) Rereduction,
especially in the elderly, is usually of no use.\textsuperscript{20} When the fracture displaces this may be an indication for surgery.\textsuperscript{21} Among low-demanding patients treated with a cast, good subjective outcome has been reported despite displacement of the fracture.\textsuperscript{22} A systematic review of 37 studies concluded that insufficient evidence exists to suggest the best casting technique and duration of immobilization during treatment of distal radius fractures.\textsuperscript{23} Bong et al prospectively randomized a series of patients to a short-arm cast or a sugar tong splint. They identified no difference in fracture reduction maintenance, however the patients tolerated the short-arm cast better.\textsuperscript{24}

**Pinning**

Percutaneous pinning may be an effective method for treating certain DRF.\textsuperscript{25} It is usually performed with two or three Kirschner wires. The Kapandji method\textsuperscript{15} was compared with transstyloidal pinning as described by Willenegger in a randomized trial.\textsuperscript{26} Functional and radiographic outcomes at 10-month follow-up were significantly better in those fractures treated with the Kapandji method. The Kapandji method uses dorsal and radial intrafocal pins for reduction and fixation of DRF. One feared complication is over-reduction. Additional support may be achieved with an intramedullary styloid pin (Benoist).\textsuperscript{27} For this procedure the fracture must be without any major volar comminution and volar cortical continuity must be restored.\textsuperscript{28} If the volar cortex is poor, consideration should be given to more stable surgical options. Compared to ORIF percutaneous pinning offers the advantage of a minimally invasive procedure. Simultaneously, it provides better maintenance of volar tilt compared to cast treatment of DRF.\textsuperscript{29}

**External fixation**

Treating DRF with external fixation has two main concepts, bridging and non-bridging construct.\textsuperscript{30} The non-bridging technique enables early motion of the wrist. The bridging technique does not always guarantee radial length because the capsule and extrinsic ligaments of the wrist joint are mostly oblique and tend to elongate with ligamentotaxis. This can lead to stretching of the wrist joint and shortening of the fracture if there is comminution or less than perfect apposition of the volar cortex. The non-bridging technique, as advocated by Margaret McQueen, does not have this disadvantage but is not widespread, possibly due to technical difficulties. A review of nine
studies did not demonstrate evidence enough to determine the most favourable technique of the different methods of external fixation. The use of external fixation in Sweden has decreased during the last decade in favour of internal fixation.

Open reduction and internal fixation (ORIF)

Open reduction and internal fixation of distal radius fractures is often used to treat unstable fractures. It includes volar plating, radial plates, dorsal plates and fragment specific fixation. Rikli and Regazzoni introduced dorsal plates placed on the lateral and the intermediate columns of the wrist. Later, the introduction of angular stable locking screws enabled volar fixation for dorsally displaced DRF. Locked volar plating has become increasingly common for surgical intervention in unstable distal radius fractures during the last decade. When prospectively evaluated, locked volar plating has improved postoperative radiographs, strength and ROM better than external fixation. The use of a volar locking plate also has resulted in a faster early recovery of function compared with use of percutaneous methods. In a randomised study, palmar plating demonstrated significantly better results than dorsal plating when ROM, grip strength and pain were evaluated. However, the difference in PRWE, DASH and quickDASH scores have not been significant after one year or more. In a meta-analysis the DASH was significantly better for volar locked plates than external fixation but the difference was smaller than the minimal clinically important difference estimated for the DASH score.

Radiological Outcome

Views and measurements

Most DRF are diagnosed by conventional radiography. The description of DRF is commonly based on distal radial angulation and displacement, intra-articular or extra-articular involvement, and associated injuries of ulna and the carpal bones. Because the initial presentation of the distal radius fractures on the radiographs has such a profound impact on the treatment of these injuries, accurate imaging and assessment of the radiographs is essential for appropriate management.
Radiographic evaluation of the distal radius normally includes a posteroanterior (PA) and lateral view of both bones in neutral rotation. In neutral rotation, the frontal view of the distal radius is accompanied with a lateral view of the ulna. To achieve this, a PA view of the radius should be taken with the wrist, elbow and shoulder in the transverse plane, perpendicular to the X-ray beam. The elbow is flexed at 90 degrees to guarantee neutral rotation. In neutral rotation the PA view of the wrist should profile the extensor carpi ulnaris tendon groove, which should be at the level of or radial to the base of the ulnar styloid. Simultaneously the ulnar styloid is at the ulnar border of the bone. If the forearm pronates from neutral rotation the radius crosses the ulna and becomes relatively shorter resulting in improper measurement of the length of the bones. In supination the radius and ulna are parallel and thus the relative length of the radius is longer. The supinated position is in some literature referred to as the anteroposterior (AP) view. This view may give a better view of the scaphoid and the scapholunate distance.

Consequently, the lateral view is taken with the arm hanging adducted to the body. Shoulder, elbow and wrist are in the sagittal plane with the elbow flexed at 90 degrees. In this position, the lateral view will be perpendicular to the PA view. On a standard lateral view, the palmar cortex of the pisiform bone should overlie the central third of the interval between the palmar cortices of the distal scaphoid pole and the capitate head.

The 15° lateral projection positions the articular surface in profile. This projection is performed simply by elevating the distal forearm 15° from horizontal or by aligning the beam 15° proximally.

Oblique radiographs sometimes are included as a supplemental view. Oblique views may reveal intra-articular involvement that is not apparent on the other views.

CT scans are sometimes used to assess DRF. CT scans have been proven to be better at evaluating joint involvement and amount of comminution. Usually CT scan is used as a complement in patients undergoing surgery for complex intra-articular fractures or when more information about comminution and joint depression is needed. However, no validated studies have shown better functional outcomes with CT imaging before surgical intervention.
The most commonly used measurements are presented below:

Volar inclination

The volar inclination is measured on the lateral view and is a measure of the volar angle. A line perpendicular to the long axis of the radius is drawn; this line goes parallel to the mid part of the volar cortex of the radius and goes under the name of the Volar Line of Lewis. A second line is drawn from the dorsal rim to the volar rim of the articular surface. The normal volar tilt averages 11° and has a range of 2°–20°. A negative volar tilt indicates dorsal angulation of the distal, radial articular surface.
Radial inclination

Radial inclination is assessed on the PA view and is a measurement of the radial angle. This parameter is described as the angle between the long axis of the radial shaft and a line connecting the tip of the radial styloid with the ulnar corner of the distal radius. The normal radial inclination is 24° and ranges between 19° and 29°.

Radial height

Radial height is measured on the PA view. It is a measurement between 2 parallel lines that are perpendicular to the long axis of the radius. One line is drawn over the volar ulnar corner of the articular surface of the radius and the other is drawn at the tip of the radial styloid. This measurement has a mean of 10 –13 mm.

Ulnar variance

Ulnar variance (UV) is measured on the PA view. In this study we used the method of perpendiculars, in which 2 lines are drawn perpendicular to the long axis of the radius. One line is drawn over the volar ulnar corner of the articular surface of the radius and the other is drawn on the distal surface of the ulna. UV is described as being zero, minus, or plus. Normal mean UV is between -1 and 1 mm, with a range from -3 to 4. Note that UV depends on the rotation of the forearm, as well as on the radiographic technique. Due to the widespread variation in a normal population, the variance of the fractured wrist should be compared with the variance on the contralateral normal wrist in doubtful cases.

Intraarticular step off

A fracture involving the articular surface may cause a gap or a step-off when displaced. The step-off will affect the continuity of the articular surface and may lead to posttraumatic arthritis. Fractures with an articular gap or step-off occur in less than 5% of distal radius fractures.
Issues when measuring radiological outcome

Plain X-rays are two-dimensional investigations of a three-dimensional reality. This causes some issues in the assessment of the images.

In the normal radius, the articular surface can be seen as the projection of the volar rim of the lunate facet. This structure is normally proximal to the distal margin of the radius, because the normal volar tilt of the articular surface of the distal radius places the volar rim more proximally than the dorsal rim. Its projection on the radiograph is radiodense, because the subcortical bone of the volar rim of the lunate facet is aligned parallel to the radiographic beam.

The relationship of the articular surface is reversed in a fracture or malunion in which there is dorsal angulation of the distal fragment. When the fracture is angulated dorsally, the dorsal edge of the most distal part of the radius is seen proximally and the volar edge is seen distally on the PA view.

Because the most radiodense part of the articular surface can represent two different anatomic structures depending on the angulation of the fracture, it is essential to always correlate the PA view with the lateral view for evaluating displacements of the articular surface.

The landmark on the ulnar border of the radius is used to measure radial height, radial inclination and ulnar variance. Therefore the consistency of locating this reference point is essential.

During appraisal of the research by others included in this thesis, the impression is that most published studies on DRF do not consider or define if the radial inclination, radial height and ulnar variance were measured on the volar or dorsal rim of the radius. In many of these we believe that there may have been a change in the reference points on pre- and post-reduction films. Ando et al. made the same assumption in their study on ulnar variance and suspected that different landmarks often are used in the UV assessment. They suggested that in severely displaced DRF, the true central reference point could be calculated from the dorsal UV and the volar UV by using a mathematical formula (UVc=UVd-(UVd-UVv)/2-DcosA). However, this management seems impractical and far too complicated to use in the emergency room.

An alternative measurement was presented by Medoff et al. suggesting that this measurement should use a reference point midway between the volar
and dorsal ulnar corners of the radius to eliminate variation caused by dorsal angulation. This central reference point is defined as the CRP.

In both hospitals included in the studies the ulnar variance is measured using the method of perpendiculars, which has been the most reliable. The most radiodense landmark (the volar rim) has been the point of reference in the wrist in anatomical position. Therefore, before initiating the studies, a consensus was taken to always use the volar rim as a reference point in measuring UV as we consider it important to identify the same landmarks in all DRF regardless of the degree of displacement. All physicians taking care of patients with DRF were informed and the technique was described in the checklist used in the emergency room evaluating the X-rays (appendix 1). Because the most radiodense part of the ulnar corner may be a different anatomic structure with volar and dorsal angulation of the distal articular surface, again, the PA view must be correlated with the lateral view for evaluating the volar and dorsal rim of the radius. A phenomenon when measuring UV this way is that the volar rim of the radius, during dorsal tilting, will describe a movement in the form of an arch distally. This means that it will reach its most distal point at about 20° of dorsal tilt (assuming there is no real shortening, i.e. no volar comminution and perfect apposition of the volar cortex). However, since lengthening of the UV is not defined as displacement in the studies, we did not consider this a major problem.

Another issue is the consistency of the assessment of the images. Evaluating the reliability for a finding usually tests this. Reliability is the degree of agreement among different viewers. It gives a score of how much homogeneity there is in the assessment by observers.

**Intraobserver reliability**

The intraobserver reliability or “reproducibility” is the degree of agreement for an observer at different periods of time. The intraobserver reliability in this thesis was measured using the Cohen’s kappa coefficient. Cohen’s kappa takes into account the amount of agreement that could be expected to occur through chance.
Interobserver reliability

The interobserver reliability is the agreement among two or more observers at a specific time, evaluating the material under the same conditions. The interobserver reliability in this thesis was measured using the Fleiss kappa coefficient.

The kappa values range from −1.0 (complete disagreement) through 0.0 (chance agreement) to 1.0 (complete agreement).

Factors predicting radiological outcome after DRF

A major difficulty has been to make an initial assessment of the stability of the fracture, and the concept of stability has been debated. Fractures that are not possible to reduce or displace immediately upon reduction are of course detected directly, but many DRF displace later, despite an initially acceptable fracture reduction.

Supposed risk factors for instability with malunion include age, initial degree of displacement, comminuted fracture, simultaneous fracture of the ulna, and intra-articular involvement. Scoring systems using mathematical formulas for the evaluation of fracture stability have also been developed. These have to some extent been able to predict instability, but they can be difficult to use in clinical practice and repeated studies have shown a tendency for them to underestimate the degree of fracture instability.

Clinical outcome

Commonly the methods for evaluating wrist and hand function following a fracture consist of measuring grip strength and assessing the range of motion (ROM). Subjective evaluation usually includes validated questionnaires.
Objective assessment

ROM is measured in the radiocarpal joint by testing the flexion and extension of the wrist as well as the radial and ulnar deviation. Forearm rotation is tested by supination and pronation and represents the motion in the proximal and distal radioulnar joints. A standard goniometer is used to measure the angle in degrees.63

Grip strength can be measured using a JAMAR dynamometer64. The patient is sitting. The arm should be adducted to the body. The elbow is flexed in 90 degrees with the forearm in neutral rotation and wrist in 0-30° extension. To prevent it from falling, the examiner may support the JAMAR dynamometer. Both hands are examined, starting with the uninjured side. Each measure is attempted 3 times and the mean value in Kilograms is used.65

Patient reported assessment

A wide variety of outcome measures have been proposed to assess recovery after a DRF. Some of these are generic instruments, such as the Short Form SF-3666 and the EQ-5D67 analysing multiple aspects of health. The disability of arm shoulder and hand (DASH)68 is a tool covering the function of the upper extremity as one entity. More specific outcome instruments for DRF includes the patient-rated wrist evaluation score (PRWE)69 and the Michigan Hand Outcomes Questionnaire (MHQ)70. There are also combined objective and subjective measurements such as the Gartland and Werley score71.

In this thesis we used EQ-5D and the shorter version of DASH, called quickDASH, to evaluate the patients.

DASH

The DASH outcome measure is a questionnaire evaluation of the upper extremity scored in two components: the disability/symptom section (30 items, scored 1-5) and the optional high performance sport/music or work section (4 items, scored 1-5). DASH yields a score from 0 to 100, where higher scores represent a worse outcome. The QuickDASH score is an 11 item, self-administered questionnaire and a shorter version of DASH.
QuickDASH can be used instead of the full DASH. The minimal clinically important difference estimated for the DASH score is approximately 10 points.

**EQ-5D**

EQ-5D measures health related quality of life and has two parts. The first is a questionnaire with 5 questions that evaluates health from 5 dimensions; mobility, self-care, usual activities, pain/discomfort and anxiety/depression. Each dimension has 3 levels: no problems, some problems, extreme problems. The weighted average score for EQ-5D represents 1.0 for full health and 0 for death; negative values (worse than death) are possible for some combinations of questionnaire answers. The other part is a health VAS graded from 0 to 100. The value 100 represents the best possible health and 0 represents the worst possible health.

**Factors predicting clinical outcome**

Several studies have shown a correlation between anatomical reduction and function after DRF, although this relationship has been questioned in the elderly. Furthermore associated ligament injuries, fracture comminution, age, patient education level, socioeconomic status and injury compensation affect outcome.

**When should a DRF be treated with surgical intervention?**

There are definitely controversies in choosing optimal treatment for patients with a DRF. The American Association for Orthopaedic Surgeons found “moderate” evidence for benefit from operative treatment in fractures with post-reduction dorsal tilt >10°, radial shortening >3mm and intraarticular step of > 2mm. However, they were unable to recommend for or against operative treatment for patients over 55 years and unable to recommend for or against any one specific operative method for fixation of distal radius fractures. Moreover, they were unable to recommend for or against concurrent surgical treatment of distal radioulnar joint instability and ulnar styloid fractures in patients with operatively treated distal radius fractures.
The controversies among patients above 50-60 years of age is partly a result of few and inconclusive studies. Young et al\(^2\) concluded that there were no significant clinical differences in outcome in conservatively treated low demanding elderly patients with a “good” versus a “poor” radiological outcome. A closer view of the study however reveals that most patients with “excellent” radiological outcome have “excellent” clinical outcome and patients with “poor” radiological outcome had “poor” clinical outcome more often. The study however only included 25 patients, which may be a reason why the differences were not significant. Furthermore, it was pointed out that the study population did not represent elderly people but low demanding people. Anzarut et al\(^8\) found no correlation between radiologic outcome and the DASH questionnaire in 74 patients above 50 years of age. A review article by Diaz-Garcia et al\(^8\) suggests that despite worse radiographic outcome associated with cast immobilization, functional outcome was no different than surgically treated groups for patients 60 years and over. They conclude that further prospective comparative outcomes studies are necessary.

With today’s lack of evidence, the treatment of a DRF must still be discussed with each patient and the patient’s preference should have an influencing role. If surgery is chosen, the surgeon’s technical experience is probably still the best way to decide treatment.
Classifications

The introduction of radiology by Wilhelm Conrad Röntgen provided investigators with a more detailed description of the fracture. Presence or absence of articular involvement and comminution as well as the degree of displacement resulted in the first classification systems. During the 20th century numerous classification systems have been suggested for evaluation of DRF. Most of them are of a historical interest and are seldom used in clinical practice. The Nissen-Lie classification\(^9\) from 1939 and the Gartland and Werley classification\(^7\) from 1951 still sometimes appear in current literature on DRF. The most commonly cited classifications are the Older, Frykman, Melone, AO/OTA, Universal, Mayo and Fernandez classifications.

The purpose of a classification is to guide management and predict prognosis. Furthermore, a common language among clinicians is created to communicate and compare results published in different studies. To achieve this, the classification system should be simple, reliable, clinically relevant, and all-inclusive and with as few subtypes as possible.\(^90,91\)

The Older classification 1965

Older et al.\(^92\), in 1965 divided DRF into four fracture types. He graded the fractures according to the amount of dorsal angulation, degree of comminution, direction and extent of displacement, and added the presence of shortening of the distal fragment in relation to the distal ulna (Table 1). The published article included both anatomical and functional results at 4 months after the fracture. Even though no statistical analysis was presented, they concluded that the classification was an aid for the beginning resident in selecting treatment and also predictive of final results.

The classification was slightly modified by Solgaard (Table 2) and has been evaluated for radiological outcome\(^21,53,59\), functional outcome\(^93\) and reliability\(^94\).

Regarding the radiological outcome, Solgaard et al. found that Older’s system gave the best information about the radiographical prognosis of a fracture and that the prognostic value of the Nissen-Lie\(^8\), Gartland & Werley\(^7\), Lidström\(^95\) and Frykman\(^96\) classification systems were of less value. They also found the system predictive of final function when evaluated using a modification of the Gartland and Werley score\(^93\). Finally, they found high
agreement for observers using the classification when evaluated for interobserver and intraobserver reliability. Wilcke et al. found no statistically significant relation between Older’s classification and the DASH score at follow-up.

<table>
<thead>
<tr>
<th>Older’s classification of distal radial fractures (Older 1965)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type I: Non-displaced.</strong></td>
</tr>
<tr>
<td>• Loss of some volar angulation, and up to 5 degrees of dorsal</td>
</tr>
<tr>
<td>angulation</td>
</tr>
<tr>
<td>• No significant radial shortening -2 mm or above the distal</td>
</tr>
<tr>
<td>ulna</td>
</tr>
<tr>
<td><strong>Type II: Displaced with minimal comminution.</strong></td>
</tr>
<tr>
<td>• Loss of volar angulation or dorsal displacement of distal</td>
</tr>
<tr>
<td>fragment</td>
</tr>
<tr>
<td>• Shortening- usually not below the distal ulna, but occasionally</td>
</tr>
<tr>
<td>up to 3mm below it.</td>
</tr>
<tr>
<td>• Minimal comminution of dorsal radius</td>
</tr>
<tr>
<td><strong>Type III: Displaced with comminution of the dorsal radius.</strong></td>
</tr>
<tr>
<td>• Comminution of dorsal radius</td>
</tr>
<tr>
<td>• Shortening- usually below the distal ulna</td>
</tr>
<tr>
<td>• Comminution of distal radial fragment- usually not marked and</td>
</tr>
<tr>
<td>often characterized by large pieces</td>
</tr>
<tr>
<td><strong>Type IV: Displaced with severe comminution of radial head</strong></td>
</tr>
<tr>
<td>• Comminution of dorsal radius marked</td>
</tr>
<tr>
<td>• Comminution of distal radial fragment- shattered</td>
</tr>
<tr>
<td>• Shortening- usually 2 to 8 mm below the distal ulna</td>
</tr>
<tr>
<td>• Poor volar cortex in some cases</td>
</tr>
</tbody>
</table>

Table 1. The original classification as described by Older.
Older's classification of distal radial fractures, modified (Solgaard 1985).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Non-displaced, length of radial styloid ≥ 7 mm, dorsal angulation ≤ 5°.</td>
</tr>
<tr>
<td>II</td>
<td>Displaced with minimal comminution of dorsal radius, length of radial styloid &lt; 7 mm and ≥ 1 mm, dorsal angulation &gt; 5°.</td>
</tr>
<tr>
<td>III</td>
<td>Displaced with slight dorsal comminution, length of radial styloid ≤ 4, dorsal angulation &gt; 5°.</td>
</tr>
<tr>
<td>IV</td>
<td>Comminution of distal radius (including the dorsal part), often with intraarticular involvement. Length of radial styloid usually negative, dorsal angulation &gt; 5°.</td>
</tr>
</tbody>
</table>

Table 2. The Older classification modified by Solgaard.

The Frykman classification 1967

The basic distinction in this system is between extra and intra-articular DRF and whether or not there is also a fracture of the distal ulna (table 3). The classification does not take into consideration the degree and direction of displacement and comminution. In his thesis, Frykman concluded that the type of fracture was correlated with the end result, which was worse for intra-articular than extra-articular DRF, especially if the DRUJ was involved. He also concluded that a simultaneous fracture in the distal ulna involved some deterioration in the functional outcome of DRF. Mackenney et al. found that in fractures with no involvement of the distal radioulnar joint (a Frykman score of 1 to 4), malunion occurred more frequently in fractures involving the ulnar styloid (a Frykman score of 2 and 4). Other studies trying to verify the value of this classification however have failed. In most studies of the classification, the interobserver reliability has been fair.
The Frykman classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Extra-articular fractures without fracture of the distal ulna</td>
</tr>
<tr>
<td>II.</td>
<td>Extra-articular fractures accompanied by fracture of the distal ulna</td>
</tr>
<tr>
<td>III.</td>
<td>Intra-articular fractures involving the radio-carpal joint but without fracture of the distal ulna</td>
</tr>
<tr>
<td>IV.</td>
<td>Intra-articular fractures involving the radio-carpal joint and accompanied by fracture of the distal ulna</td>
</tr>
<tr>
<td>V.</td>
<td>Intra-articular fractures involving the distal radio-ulnar joint but without fracture of the distal ulna</td>
</tr>
<tr>
<td>VI.</td>
<td>Intra-articular fractures involving the distal radio-ulnar joint and accompanied by fracture of the distal ulna</td>
</tr>
<tr>
<td>VII.</td>
<td>Intra-articular fractures involving both the radio-carpal and the distal radio-ulnar joint but without fracture of the distal ulna</td>
</tr>
<tr>
<td>VIII.</td>
<td>Intra-articular fractures involving both the radio-carpal and the distal radio-ulnar joint and accompanied by fracture of the distal ulna</td>
</tr>
</tbody>
</table>

Table 3. The Frykman classification.

The Melone classification 1984

Melone published a classification of intra-articular DRF patterns. The classification does not take extra-articular DRF into consideration and is therefore not all-inclusive. The classification system brought attention to the lunate facet and its importance in functional outcome. Melone divided the radiocarpal articular injuries into 4 parts: the radial styloid, radial diaphysis, and the dorsomedial and palmar medial fragments of the lunate facet of the distal radius. The initial classification had 4 classes based on the number of articular fragments.

Type I is a stable fracture, nondisplaced or with variable displacement of the medial complex as a unit, stable after closed reduction. Type II is an unstable "die-punch" fracture, if reducible it is type IIA, if irreducible it is type IIB. Type III is an unstable fracture with displacement of the medial complex as a unit as well as displacement of an additional spike fragment from the comminuted radial shaft. Type IV is an unstable fracture with the medial complex severely comminuted, separated and sometimes rotated. A fifth class was added in 1993 to incorporate an extremely comminuted fracture (explosion type). This classification has been used in defining indications and methods of surgical fixation. The reliability has been fair when evaluated. Trumble et al. found a significant decrease in clinical outcome.
with more severe fracture patterns as defined by the Malone classification. As far as we know radiological and clinical outcome has not been validated in other clinical studies.

The Comprehensive classification-AO

The AO (Comprehensive/Muller) system\textsuperscript{106,107} is one of the most commonly used classification systems. It was introduced in 1986 and revised in 1990. The three basic types are called A, B and C. Type A represent extra-articular fractures, type B represents partial articular fractures and type C represents complete articular fractures. The three basic types are divided into another three groups and then further subdivided into three subgroups. In each step the fracture is organized in order of increasing severity. Altogether 27 subgroups can be identified. The AO classification system is extremely detailed but its reproducibility has proven to be a problem when the groups and subgroups were evaluated. \textsuperscript{97,98,100,101,108,109} Reducing the AO system to the three main types brought agreement to the substantial level in one study.\textsuperscript{97} Mackenney at al.\textsuperscript{10} found that AO type 3 fractures (A3, B3, C3) predicted instability in initially minimally displaced fractures but not in initially displaced fractures.

The Universal Classification (Rayhack, Cooney)

Rayhack and Cooney believed that a common weakness in many classification systems was that they did not make a distinction between non-displaced and displaced intra-articular fractures for which treatment varies widely. Therefore they proposed a universal classification system\textsuperscript{110} based on fracture displacement, articular involvement, reducibility and stability.

The Universal classification of distal radius fractures as proposed by Cooney et al. is fairly simple and divides the DRF into 4 main types. Type II and IV is then further divided into three subgroups (table 4).
<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>Non-articular, undisplaced</td>
</tr>
<tr>
<td>Type II</td>
<td>Non-articular, displaced</td>
</tr>
<tr>
<td></td>
<td>A: reducible, stable</td>
</tr>
<tr>
<td></td>
<td>B: reducible, unstable</td>
</tr>
<tr>
<td></td>
<td>C: irreducible</td>
</tr>
<tr>
<td>Type III</td>
<td>Intra-articular, undisplaced</td>
</tr>
<tr>
<td>Type IV</td>
<td>Intra-articular, displaced</td>
</tr>
<tr>
<td></td>
<td>A: reducible, stable</td>
</tr>
<tr>
<td></td>
<td>B: reducible, unstable</td>
</tr>
<tr>
<td></td>
<td>C: irreducible</td>
</tr>
</tbody>
</table>

Table 4. The Universal Classification.

The Universal classification was evaluated by Jin et al.\textsuperscript{101} who found moderate and substantial interobserver and intraobserver reliability of the Cooney classification without subtype, but only slight reliability when the subgroups were considered.

The Mayo Clinic classification

The Mayo classification includes DRF with intra-articular fracture patterns and is not all-inclusive. The fractures are divided into 4 types; I-intra-articular undisplaced, II-displaced scaphoid fossa fragment, III-displaced lunate fossa (die punch) fragment and IV-displaced scaphoid and lunate fossa fragments.

Andersen et al.\textsuperscript{97} evaluated the reliability of the classification system. They found interobserver reliability of the system to be moderate. Gliatis et al evaluated the clinical outcome of the Mayo classification in adults under the 50 years by using a validated, patient-based outcome questionnaire (The Patient Evaluation Measure Questionnaire for Hand Surgery).\textsuperscript{111} The questionnaire responses demonstrated that the Mayo classification of DRF did not predict outcome.\textsuperscript{99}
The Fernandez classification

The classification proposed by Fernandez and Jupiter is based on the mechanism of injury.\textsuperscript{112,113} It is assumed that this approach would provide a better overall assessment of the associated soft tissue damage. The classification system also includes the children fracture equivalent. The fractures are divided into 5 classes: Type I-“bending” extra-articular fractures; Type II-shear fractures of the joint surface, Type III-compression fractures of the joint surface, Type IV-avulsion fractures and radiocarpal fracture-dislocations and Type V-combined fractures associated with high-velocity injury. Fernandez assumed that the fracture classification would be predictive of outcome because the complexity of the bone lesion and the associated soft tissue injuries would increase from type I through to type V fractures.

Furthermore, Fernandez and Jupiter suggested that DRUJ lesions are placed in three possible categories\textsuperscript{112}; stable (Type I), unstable (Type II) and potentially unstable (Type III, DRUJ intra-articular). Each category of DRUJ lesion is then further divided into 2 main appearances called A and B.

The reliability of the Fernandez classification system has been evaluated by Kural et al.\textsuperscript{102} and Küçük et al.\textsuperscript{103}. The interobserver and intraobserver agreement was found to be fair to moderate (table 5).

Issues using fracture classifications

The existing classification systems are indeed well thought-out, however, the values of these are limited since they have not showed satisfactory interobserver and intraobserver reliability\textsuperscript{97,109,100,101,102,103} (Table 5). Furthermore, the utility of these systems to predict radiographic or clinical outcome is not proven yet\textsuperscript{84,98,99,114,115}. These shortcomings may be one reason why we still do not have a good instrument for assessing whether or not a distal radius fracture should undergo surgery. Nor do we know which surgical techniques are preferable for different fractures or at different ages. Altogether, optimal DRF management is still controversial\textsuperscript{13}. New classification systems, predictive of outcome and easy to use, are required to maintain a common language when defining distal radius fractures\textsuperscript{102,103}.
Examples of studies testing different classification systems of DRF.

<table>
<thead>
<tr>
<th>Study</th>
<th>Classification systems tested</th>
<th>No. of patients</th>
<th>No. of observers</th>
<th>Interobserver Reliability</th>
<th>Intraobserver Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderssen et al. 1996</td>
<td>Frykman Melone Mayo AO</td>
<td>55</td>
<td>4</td>
<td>Fair</td>
<td>Fair-Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fair-Moderate</td>
</tr>
<tr>
<td>Flinkkilä et al. 1998</td>
<td>AO</td>
<td>30</td>
<td>5</td>
<td>Poor-Fair</td>
<td>Not tested</td>
</tr>
<tr>
<td>Illarramendi et al. 1998</td>
<td>Frykman AO</td>
<td>200</td>
<td>3</td>
<td>Moderate</td>
<td>Substantial</td>
</tr>
<tr>
<td>Filho et al. 2004</td>
<td>Frykman AO Universal</td>
<td>40</td>
<td></td>
<td>Fair</td>
<td>Moderate</td>
</tr>
<tr>
<td>Jin et al. 2007</td>
<td>Frykman AO Universal</td>
<td>43</td>
<td>3</td>
<td>Fair-Moderate</td>
<td>Fair-Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fair-Moderate</td>
</tr>
<tr>
<td>Kural et al 2010</td>
<td>Fernandez AO Melone Universal</td>
<td>32</td>
<td>9</td>
<td>Substantial</td>
<td>Fair</td>
</tr>
<tr>
<td>Küçük et al 2013</td>
<td>Universal AO Fernandez Frykman</td>
<td>50</td>
<td>20</td>
<td>Fair</td>
<td>Fair</td>
</tr>
</tbody>
</table>

Table 5. Reliability among different classification systems.
The development of a new classification

The Buttazzoni Classification

Older’s classification, as modified by Solgaard in 1985, has shown high interobserver agreement and intraobserver reproducibility\(^\text{94}\) when used to evaluate the need of reduction and to choose the initial treatment. Maybe as a result of this, it also has shown significance for radiological\(^\text{53,59}\) and clinical outcome\(^\text{93}\). For this reason, in Östersund, between approximately 1990 and 2002, Older’s classification was used.

External fixation and intrafocal (Kapandji)\(^\text{15}\) pinning were the dominating surgical methods in Östersund at this time. It was soon observed that with these methods exact volar apposition was of the utmost importance for stability. It was first observed that “Smith” fractures or fractures that at operation had been over-reduced and were only supported by pins were very unstable and tended to displace first in a volar direction and then axially with bad clinical results, especially on forearm rotation. The impression was that stability depending on axial support through the “radial calcar” (volar cortex) depends on exact apposition of the volar cortex as well as of its integrity. Thus in order to identify axially unstable fractures a local addendum to Older’s classification was introduced and fractures with comminution of the volar cortex were called “Older 5”. Furthermore it was noted that the AO type B fractures/Fernandez type II shearing fractures and Fernandez type IV carpal fracture dislocations could not be classified according to Older’s classification system. These fractures were therefore called “Older 0”.

In this way Older’s classification was further developed in order to cover all patterns of distal radial fractures and to emphasise the volar cortex. In Older’s classification, several different parameters such as the length of the radial styloid, the dorsal angulation, and the comminution of the dorsal cortex are measured. However, there is an overlap between the measurements and groups, and this could cause confusion and compromise inter- and intraobserver reliability.

The modified classification system, called the Buttazzoni classification after its creator, covers all distal radius fractures, takes into account dorsal comminution, intraarticularity and also, as the first classification, adds the presence of volar comminution as a separate parameter. The rationale for adding volar comminution is the biomechanical forces affecting the distal radius. The distal joint surface of the radius is centred over the distal
projection of the volar cortex, not over the centre of the shaft. On a lateral view, a line drawn over and parallel to the volar cortex of the radial shaft will cross through the middle of the joint and pin the radial styloid. This line is normally called the “volar line of Lewis”\textsuperscript{41}. A cadaveric study revealed that the volar cortex is thicker than the dorsal cortex\textsuperscript{116}, which implicates that most of the load over the radiocarpal joint passes through the volar cortex if the joint is anatomically placed. Consequently, if a radius fracture is anatomically reduced, the load applied over the joint while exercising finger motion or carrying weights will be transmitted through the volar cortex.

Our theory is that a discontinuity of this weight bearing calcar, for example when comminuted, could severely affect the stability of a reduced DRF. We believe that the volar cortex and comminution of it is of utmost importance for fracture stability and choice of treatment, as it behaves as the calcar of the distal radius\textsuperscript{116}. The main parameters evaluated are the degree of comminution of the dorsal and volar cortices of the distal radius as well as the involvement of the radio-carpal articular surface.

The classification is hierarchal and a fracture will always be given the highest possible number according to the fracture characteristics. The difference between Buttazzoni 1 and 2 is in the comminution of the dorsal cortex. If the fracture is intraarticular, it will be classified as Buttazzoni 3 regardless of dorsal metaphyseal comminution. Likewise, if the fracture has comminution of the volar cortex, it will be classified as Buttazzoni 4 regardless of both dorsal comminution and if it is intraarticular. If it is a complete metaphyseal fracture (BI-BIV) it takes one to three questions to decide the fracture class as illustrated in figure 6.
Presentation of the new classification:

Figure 1. Buttazzoni 1: extraarticular DRF with no cortical (metaphyseal) comminution;

Figure 2. Buttazzoni 2: extra-articular DRF with comminution of the dorsal cortex;
Figure 3. Buttazzoni 3: intraarticular (radio-carpal joint) DRF with or without metaphyseal comminution (completely articular fractures as in AO classification type C);

Figure 4. Buttazzoni 4: DRF with comminution of the volar cortex regardless of other coexisting fracture lines;
Figure 5. Buttazzoni 0: Partially articular fractures (AO type B, such as volar/dorsal Barton fractures, Chauffeur fractures and carpal fracture dislocations).

Figure 6. A simplified way to decide fracture class according to Buttazzoni.

Volar Comminuted fracture?
- Yes. It is a B IV

Intra-articular fracture?
- Yes. It is a B III

Dorsal Comminuted fracture?
- Yes. It is a B II
- No. It is a B I
A classification system should be simple, reliable, clinically relevant, and all-inclusive and with as few subtypes as possible. Audigé\textsuperscript{90} and Slono\textsuperscript{91} stated that any classification system should be evaluated among observers at different stages of experience to assess its reliability and accuracy. Thereafter, its use can be validated for assessing treatment options and outcomes.

The primary purpose of this thesis was not to create a new classification system but to evaluate a modification of Older's classification used for some years in Östersund Hospital based on experience. Furthermore, we wanted to evaluate the parameters included in the modified classification system separately, regardless of fracture class. As recommended by Audigé\textsuperscript{90} and Slono\textsuperscript{91} we intended to perform this evaluation step by step.
Aims of the thesis

The general aims of the studies were to evaluate the new classification as well as the included parameters and its usefulness in early assessment of DRF.

The specific aims of these investigations were:

I. To evaluate the interobserver and intraobserver reliability of a new classification system of DRF.

II. To investigate whether volar or dorsal cortical comminution and intra-articular involvement as well as the new classification system can predict displacement in DRF.

III. To test the predictive value of cortical comminution and intra-articular involvement on clinical outcome of DRF and complete the evaluation of the Buttazzoni classification regardless of the treatment option used.

IV. To investigate the clinical outcome in conservatively treated DRF with late displacement compared with conservatively treated DRF with minimal displacement after union.
Hypotheses of the studies

I. The hypothesis of this study was that the interobserver and intraobserver reliability of the classification could be better than other commonly used well-known classifications for DRF.

II. The hypothesis of this study was that fractures with comminution and intra-articular involvement are less stable than fractures without comminution. Volar comminution is the most relevant factor in predicting displacement. The Buttazzoni classification is predictive of radiological outcome.

III. The hypothesis in this study was that clinical outcome would be affected by type of comminution and intraarticular involvement in DRF and that clinical outcome differs among the different classes of the Buttazzoni classification.

IV. The hypothesis in this study was that ROM, grip strength, complication rates and self reported function, quality of life and pain VAS would differ between DRF with late displacement and DRF with minimal displacement.
Materials and methods

Patients

In study I, during January to December 2002, the PA and lateral plain radiographs of 232 consecutive DRF in adults (growth plates fused) seeking treatment at Östersund Hospital, Sweden were evaluated. No patients were excluded. We analysed the patients in two ways: Firstly, as one group to study the reliability in the whole cohort. Secondly, due to the etiological differences among different age groups found by others⁹,¹¹, the patients were divided into two groups. The first group included men older than 59 years and women older than 49 years. Distal radial fractures in this age group were operationally considered osteoporotic⁹. The second group included men and women below these ages. The most common reason for DRF in young patients is high-energy trauma⁹. In older patients the fracture is usually caused by a simple fall. The young “non-osteoporotic” group consisted of 77 patients and the elderly “osteoporotic” group consisted of 155 patients.

In study II, between 1st of October 2009 and 30th of September 2011, patients with DRF at two teaching county hospitals (Sundsvall and Östersund) in Northern Sweden were invited to participate in a prospective study. Patients between 15 and 74 years, with closed physes of the distal radius and ulna were included. Exclusion criteria were dementia, previous fracture to the same wrist, open fracture, other concomitant or existing damage or injury to the wrist, Galeazzi fracture, rheumatoid arthritis, alcohol or drug abuse and neurologic impairment. Four hundred and seventeen patients with 428 fractures were included and consented to participate. As in study I, we have divided the patients into two groups, one “non-osteoporotic” and one “osteoporotic”. We considered women above 49 years and men above 59 years as “osteoporotic”. Those below these age limits were considered “non-osteoporotic”.

The patients in Study III came from the same cohort as study II but “bilateral fractures” was added as an exclusion criterion. Of the initial 417 patients, 11 had bilateral fractures. These were excluded since this would affect the comparison between the injured and uninjured hand at follow-up. Thus 406 patients were included in this study. According to recommendations from reviewers of the article, the age groups were adjusted to include the same age limits for men and women. The reason for
this division is the favourable outcome in patients > 60 years reported by Young et al\textsuperscript{22} regardless of gender.

In study II it was found that late displacement of DRF, still in acceptable radiologic position after 10-14 days, occurred in approximately 1/3 of cases. Despite this, we have not been able to find any study focusing on evaluating the clinical outcome in patients with late displacement. In total 222 DRF were still in good position after 10-14 days. Thirteen of these were bilateral and were therefore excluded since comparison with an uninjured wrist was not possible. Thus, 209 unilateral DRF from study 2 were included in \textbf{study IV} (figure 7).

*Figure 7. Flowchart of inclusion procedure in study IV.*
Methods

To assess the inter- and intraobserver reliability for the classification in study I, three orthopaedic surgeons performed evaluation of DRF radiographs: observer 1 had developed the classification system. Observer 2 was a hand-surgery interested orthopaedic surgeon with limited previous experience of this classification system and, observer 3 was a general orthopaedic surgeon with limited experience of this classification system. The content of the new classification was made available for the observers during the assessment, but no other information was given. The fractures were classified according to the new system. The main parameters evaluated were the presence of comminution of the dorsal and volar cortices of the distal radius as well as the involvement of the radio-carpal articular surface. All the observers were blinded to each other’s results. The observers reclassified the fractures 1 year after the first assessment, unaware of their previous classification.

The patients in studies II, III, and IV were assessed with plain radiographs in PA and lateral views. The radiographs were classified by the registrar on call, who had been trained on the Buttazzoni classification and who also had all the needed information of the classification available. To simplify the evaluation there was a study protocol (appendix 1) with checkboxes for each patient. Acceptable anatomic values were set from the clinical practice in the two hospitals and were in accordance with the recommendations of the AAOS.\(^7\) Displacement involving volar inclination of < 20°, dorsal inclination of < 10° and radial tilt of > 10° was considered acceptable. Positive ulnar variance of < 2mm and an intra-articular step of < 2mm were also acceptable. Fractures within these boundaries were described as minimally displaced while those beyond were described as displaced. Undisplaced or minimally displaced fractures were immobilized in a short arm cast from distal to the elbow to proximal to the MCP-joints. Displaced fractures were reduced under local anaesthesia using hematoma block or intravenous regional anaesthesia at the emergency department, immobilized in a short arm cast and then radiologically re-examined. In cases of re-displacement at post-reduction X-ray, the fractures were registered as primary instability and further treated according to the treatment protocol. If the fracture was both initially minimally displaced and reduction was successful, radiographic examination was performed after 10-14 days.

If still acceptable at 10-14 days, the fractures were treated in Plaster of Paris (PoP) for a total of 4-6 weeks. If the fracture at follow-up had displaced, it
was registered as secondary instability and further treatment was discussed with the patient. After 3 or more months, radiographs were again obtained to confirm union and final position of the fracture. Fractures with an acceptable position at 10-14 days which later malunited were registered as late instability. Separate study protocols were used at each follow-up at 10-14 days and at 3 months to keep evaluation blinded from initial assessment of fracture class. To make a separate analysis of dorsal comminution and intra-articular involvement possible, the presence of dorsal comminution in B3 and B4 fractures and intra-articular involvement in B4 fractures was documented. MW and GB did this evaluation together as a consensus on initial radiographs.

If reduction to an acceptable position was not achieved initially or was lost at the 10-14 days control this was considered to be the end-point for this particular fracture in study II. Thus all fractures that entered and finished study II can either be considered to have been stable i.e. went to union in an acceptable position without operation, or unstable i.e. were fractures that at one point or another showed that they were so unstable that an acceptable position could not be established or kept with conservative means. The treatment algorithm is shown in figure 8.
Figure 8. Flowchart with numbers of patients in study II. The 13 patients who were lost before the 3 months follow-up are not presented (see results). Note that the endpoint for each fracture in the study occurs directly after redisplacement or at union after 3 months. MD=minimally displaced; D=displaced; PoP=Plaster of Paris; R=reduction.
In study III, the patients received the quickDASH and EQ-5D questionnaires at their first visit at the emergency department. They were asked to value their function before the injury, as a baseline data, and return the questionnaires at 10-14 days follow-up. Although the patients received written information about completion, it became obvious that some of them recorded their symptoms as at the first 10-14 days after the fracture. These patients were contacted by a research nurse to correct the questionnaires. However, we suspect that this may also have been the case in some patients with better quickDASH results. Therefore we did not consider the baseline data reliable.

Clinical evaluation was made at 3 months and at 1 year after the fracture. The QuickDASH73-77, EQ-5D67 questionnaire and EQ-5D67 health VAS were used to assess the functional outcome and quality of life respectively. An independent occupational therapist or physiotherapist blinded to fracture class measured objective function including grip strength, active range of motion (ROM) and pain VAS. Carpal tunnel syndrome (CTS)118,119, extensor pollicis longus (EPL) ruptures120,121 and complex regional pain syndrome (CRPS)122 according to clinical criteria119,120,122 were either rejected or confirmed. If the patient showed other signs or symptoms such as distal radio-ulnar joint (DRUJ) instability, paresthesia or tenosynovitis, this was recorded in free text.

Grip strength was measured using a JAMAR dynamometer.64 The contralateral wrist was used as a control. Grip strength was expressed as percentage of the value of the uninjured wrist.

The active ROM of the radiocarpal joint was measured in both hands using a standard goniometer. Flexion-extension arc, pronation-supination arc and radial-ulnar deviation arc were registered. The total ROM was calculated as the sum of these three. The loss of ROM in the fractured wrist was expressed in angular degrees compared with the contralateral uninjured wrist. Complications were documented as existing or absent for each diagnosis during the first year.

In Study IV, the clinical outcome in study III was correlated to the final radiological outcome at 3 months for fractures with minimal displacement at 10-14 days in study II. The fractures were dichotomized according to the same radiologic parameters as above into those with union in acceptable position (minimally displaced) and those with late displacement (late displaced).
Statistics

In study I the assessment of intraobserver reliability was accomplished by the use of Cohen's kappa coefficient, and assessment of interobserver reliability between the three observers at a single time was accomplished by the use of Fleiss kappa. The assessment of the measured kappa values were evaluated as proposed by Landis and Koch. The kappa value ranges from −1.0 (complete disagreement) through 0.0 (chance agreement) to 1.0 (complete agreement) (Table).

<table>
<thead>
<tr>
<th>Kappa-value (κ)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0</td>
<td>No agreement</td>
</tr>
<tr>
<td>0.0–0.20</td>
<td>Slight agreement</td>
</tr>
<tr>
<td>0.21–0.40</td>
<td>Fair agreement</td>
</tr>
<tr>
<td>0.41–0.60</td>
<td>Moderate agreement</td>
</tr>
<tr>
<td>0.61–0.80</td>
<td>Substantial agreement</td>
</tr>
<tr>
<td>0.81–1.00</td>
<td>Almost perfect agreement</td>
</tr>
</tbody>
</table>

Table 6. Assessment of kappa value as suggested by Landis and Koch.

In study II we first performed a power analysis to estimate the number of patients needed in the study. We assumed that Buttazzoni 1 fractures would account for 30% and Buttazzoni 4 fractures for 5% of the fractures. Furthermore we assumed that displacement would occur in at least 15% of Buttazzoni 1 fractures and 50% of Buttazzoni 4 fractures. With a power of 0.80 and a significance level (alpha) of 0.05, approximately 300 patients were needed to detect a clinically significant difference.
The patients were analysed as a whole group and according to the initial presentation of the fracture. We analysed the risk of displacement according to the Buttazzoni classification. Fisher’s exact test was used to compare each pair of types. In order to correct for multiple comparisons, the p-values from Fischer’s exact test were corrected with the Benjamini–Hochberg correction. The IBM SPSS Statistics for Windows, Version 20.0. (IBM Corp., Armonk, New York) was used for most analyses except for Fisher’s exact test with the correction, where R, version 2.15 was used with package fmsb (functions for medical statistics book). We used a logistic regression analysis adjusted for age and gender to evaluate the risk of displacement for dorsal and volar comminution, intra-articular involvement and initial presentation of the fracture regardless of fracture class. This was presented as an odds ratio (OR) with 95% confidence intervals (95% CIs). A p-value < 0.05 was considered statistically significant. The false-discovery-rate for the Benjamini–Hochberg correction was set as 0.05.

In Study III a power analysis was performed based on comparing the quickDASH score. With a power of 0.80 and a significance level (alpha) of 0.05, a minimum of 32 patients was needed in each group to detect a clinically significant 10-points difference (standard deviation 16) in quickDASH among the groups. We assumed that a 10-point difference in quickDASH was the smallest effect that would be clinically relevant. The effect of dorsal and volar comminution, intra-articular involvement, initial position of the fracture, age, gender and treatment on ROM and grip strength were analysed using the t-test. The different fracture classes were compared for grip strength, ROM and age distribution using ANOVA with a Tukey HSD post-hoc test. A General Linear Model (GLM) was created for multiple regression analysis to evaluate the effect of age, gender, fracture class, dorsal comminution, volar comminution, intraarticular involvement and treatment on objective outcome. A stepwise approach was used in which only those parameters with independent predictive significance using the t-test or ANOVA were included in the model.

The QuickDASH, EQ-5D and EQ-VAS data are ordinal. Therefore the Mann-Whitney U test was used to evaluate the effect of dorsal and volar comminution, intra-articular involvement, initial position of the fracture, age group, gender and treatment on these outcome parameters. The effect of fracture class on QuickDASH, EQ-5D and pain VAS were analysed using the Kruskal-Wallis non-parametric test with post-hoc test. Even though some studies use this data on an interval scale, the data also showed a skewed distribution making the non-parametric test more appropriate. The data
were presented as median with interquartile range. Mean and standard deviation for quickDASH are included to enable comparison with previously published studies.

Fishers exact test was used to detect differences in presence of CTS, EPL-rupture, CRPS and others among the fracture classes.

A p-value < 0.05 was considered significant.

In study IV, the fractures were dichotomized into minimally displaced and late displaced fractures. The outcome between these two groups was analysed with a t-test to detect differences in grip strength, ROM and age distribution. For QuickDASH, EQ-5D and pain VAS the Mann-Whitney U test was used. Fisher’s exact test was used to detect differences in presence of CTS, EPL-rupture, CRPS and any other complaint. As regression analysis we used a General Linear Model (GLM) to evaluate the effect of age, gender and late displacement on objective outcome separately. The GLM is mathematically identical to a multiple regression analysis but stresses its suitability for both multiple qualitative and multiple quantitative variables. A p-value < 0.05 was considered significant.
Results

Study I

Interobserver Reliability

The Fleiss kappa value for the new classification among the observers regardless of the age of the patient was 0.47 (moderate). When separated by age, the Fleiss kappa values were 0.42 (moderate) for the elderly group and 0.54 (moderate) for the young group.

Intraobserver Reliability

The mean kappa values for intraobserver reproducibility for observer 1 were 0.52 (moderate) for the whole group, 0.45 (moderate) for the elderly group, and 0.62 (substantial) for the young group. For observer 2, the mean kappa values were 0.61 (substantial) for the whole group, 0.57 (moderate) for the elderly group, and 0.68 (substantial) for the young group. For observer 3, the mean kappa values were 0.29 (fair) for the whole group, 0.28 (fair) for the elderly group, and 0.30 (fair) for the young group.

The mean kappa values for intraobserver reliability among observers are shown in Table 7.

<table>
<thead>
<tr>
<th>Intraobserver reproducibility</th>
<th>The entire cohort</th>
<th>The young group</th>
<th>The elderly group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observer 1</strong></td>
<td>0.52 (moderate)</td>
<td>0.62 (substantial)</td>
<td>0.45 (moderate)</td>
</tr>
<tr>
<td><strong>Observer 2</strong></td>
<td>0.61 (substantial)</td>
<td>0.68 (substantial)</td>
<td>0.57 (moderate)</td>
</tr>
<tr>
<td><strong>Observer 3</strong></td>
<td>0.29 (fair)</td>
<td>0.30 (fair)</td>
<td>0.28 (fair)</td>
</tr>
</tbody>
</table>

Table 7.
Study II

In study II, 417 patients with 428 fractures were included and consented to participate.

Nine patients did not agree to continue participating after the control x-rays at 10-14 days. Furthermore one patient was excluded because of rapidly progressing dementia, two because of deteriorating health and one died during the first three months.

Thus 415 fractures in 404 patients were left for analysis (11 patients with bilateral fractures) and were followed up until fracture union or fracture dislocation that were considered as endpoints.

Three hundred and five patients (with 311 fractures) were female and 99 (with 104 fractures) were male. The age distribution can be seen in figure 9.

Fig 9. Age distribution among women and men included in study II.
Outcome according to fracture class

There were 81 fractures of the B1 class, 145 fractures of the B2 class, 117 fractures of the B3 class, 55 fractures of the B4 class and 17 fractures of the B0 class. The age distribution among fracture classes did not differ significantly (p=0.053) but there was a tendency for younger patients to have more B3 and B4 fractures (Figure 10).

Of the B3 fractures 96/117 (82%) were dorsally comminuted while 22/55 (40%) B4 fractures were intra-articular and 41/55 (75%) were dorsally comminuted. Only 10/55 (18%) B4 fractures had isolated volar cortical comminution.

The frequency of displacement in the different types of fracture is shown in Table 8. There was a statistically significant difference in displacement between each pair of Buttazzoni types (p < 0.001), except for B0 vs. B1 and B2 vs. B3. The B0 and B1 types were less, and the B4 type more prone to displace than the other types (Figure 11).
<table>
<thead>
<tr>
<th>Buttazzoni class</th>
<th>Number of fractures</th>
<th>Overall instability</th>
<th>Primary instability</th>
<th>Secondary instability</th>
<th>Late instability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bo</td>
<td>17</td>
<td>1(6%)</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>B1</td>
<td>81</td>
<td>13(16%)</td>
<td>0</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>B2</td>
<td>145</td>
<td>106(73%)</td>
<td>31</td>
<td>53</td>
<td>22</td>
</tr>
<tr>
<td>B3</td>
<td>117</td>
<td>84(72%)</td>
<td>39</td>
<td>26</td>
<td>19</td>
</tr>
<tr>
<td>B4</td>
<td>55</td>
<td>53(96%)</td>
<td>22</td>
<td>21</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 8. The frequency of displacement in different Buttazzoni classes regardless of initial position (displaced or minimally displaced)

Figure 11. Survival curve of all included distal radius fractures according to Buttazzoni class. Percentage of fractures with acceptable position. The “reduction” point is an imaginary position during the reduction procedure. Outcome according to the initial presentation of the fracture.
We divided our patients into two groups depending on the initial presentation of the fracture; minimally displaced or displaced fracture.

In initially minimally displaced fractures, 29% displaced later on. The frequency of displacement in different classes is shown in table 9. There was a statistically significant difference in displacement frequency between Buttazzoni class B0 and B2-B4 (p<0.001 B2, p<0.01 B3-B4) and between B1 and B2-B4 (p<0.001 B2, p<0.05 B3-B4). All other comparisons were non-significant. The B1 and B0 classes were more stable compared to the other classes (figure 12).

<table>
<thead>
<tr>
<th>Buttazzoni class</th>
<th>Number of fractures</th>
<th>Overall instability</th>
<th>Secondary instability</th>
<th>Late instability</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td>16</td>
<td>0(0%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B1</td>
<td>74</td>
<td>10(14%)</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>B2</td>
<td>49</td>
<td>25(51%)</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>B3</td>
<td>36</td>
<td>14(39%)</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>B4</td>
<td>6</td>
<td>4(67%)</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 9: The frequency of displacement in different Buttazzoni classes in initially minimally displaced distal radius fractures.
In initially displaced fractures, 87% displaced later on. The frequency of displacement in different classes is shown in table 10. There was a statistically significant difference in displacement frequency (B0 not included) between Buttazzoni class B1 and B2-B4 (p<0.05 B2-B3, p<0.001 B4) and between B4 and B1-B3 (p<0.001 B1-B2, p<0.05 B3), but not for B2 vs. B3. The B1 class was more stable while the B4 class was less stable compared to other classes (Figure 13).
<table>
<thead>
<tr>
<th>Buttazzoni class</th>
<th>Number of fractures</th>
<th>Overall instability</th>
<th>Primary instability</th>
<th>Secondary instability</th>
<th>Late instability</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td>1</td>
<td>1(100%)</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>B1</td>
<td>7</td>
<td>3(43%)</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>B2</td>
<td>96</td>
<td>81(84%)</td>
<td>31</td>
<td>39</td>
<td>11</td>
</tr>
<tr>
<td>B3</td>
<td>81</td>
<td>70(86%)</td>
<td>39</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>B4</td>
<td>49</td>
<td>49(100%)</td>
<td>22</td>
<td>19</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 10: The frequency of displacement in different Buttazzoni classes in initially displaced distal radius fractures.

Fig 13. Survival curve of initially displaced distal radius fractures according to Buttazzoni class. Percentage of fractures with acceptable position.
Looking separately at late instability, displacement occurred in 63 of 221 (29%) fractures that were still in good alignment after 10-14 days. The frequency of late displacement in different classes is shown in table 11. There was a statistically significant difference in late displacement frequency between all Buttazzoni classes (p<0.001), except for B0 vs. B1 and B2 vs. B3. The B0 and B1 classes were more stable while the B4 class was less stable compared to other classes also in late instability.

<table>
<thead>
<tr>
<th>Buttazzoni Class</th>
<th>Number of fractures</th>
<th>Late instability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bo</td>
<td>16</td>
<td>0(0%)</td>
</tr>
<tr>
<td>B1</td>
<td>80</td>
<td>12(15%)</td>
</tr>
<tr>
<td>B2</td>
<td>61</td>
<td>22(36%)</td>
</tr>
<tr>
<td>B3</td>
<td>52</td>
<td>19(37%)</td>
</tr>
<tr>
<td>B4</td>
<td>12</td>
<td>10(83%)</td>
</tr>
</tbody>
</table>

Table 11: The frequency of late instability in different Buttazzoni classes in fractures with acceptable position at 10-14 days follow-up.

We analysed the importance of the initial presentation within each Buttazzoni class. In all classes except for B1 the fractures were significantly less stable if initially displaced, for B1 (86% vs. 57%, p=0.08), for B2 (49% vs. 16%, p<0.001), for B3 (61% vs. 14%, p<0.001) and for B4 (33% vs. 0%, p=0.010).

Outcome according to fracture patterns regardless of fracture class

We decided to analyse the fracture patterns and patient characteristics without the hierarchic classification system. Therefore a multiple logistic regression analysis adjusted for age and gender was performed. The logistic regression analysis (table 12) showed that dorsal and volar comminution as well as initial presentation of the fracture were risk factors for displacement. Intra-articular involvement was not a risk factor for instability. There was a tendency for the elderly group to be less stable but the difference was not
statistically significant ($p=0.053$). However, looking separately at women and men, age was a risk factor for women (odds ratio 3.68) but not for men (odds ratio 0.97)(unpublished data).

<table>
<thead>
<tr>
<th>Variabel</th>
<th>Crude OR</th>
<th>95% CI</th>
<th>Adjusted OR*</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsal comminution</td>
<td>11.98***</td>
<td>(7.28-19.70)</td>
<td>5.86***</td>
<td>(3.11-11.06)</td>
</tr>
<tr>
<td>Intra-articularity</td>
<td>1.60*</td>
<td>(1.05-2.43)</td>
<td>1.28</td>
<td>(0.71-2.28)</td>
</tr>
<tr>
<td>Volar comminution</td>
<td>20.36***</td>
<td>(4.89-84.86)</td>
<td>18.64***</td>
<td>(3.78-92.00)</td>
</tr>
<tr>
<td>Initial presentation</td>
<td>16.42***</td>
<td>(9.97-27.06)</td>
<td>6.83***</td>
<td>(3.84-12.15)</td>
</tr>
<tr>
<td>Age</td>
<td>2.00**</td>
<td>(1.31-3.06)</td>
<td>1.91</td>
<td>(0.99-3.69)</td>
</tr>
<tr>
<td>Gender</td>
<td>0.53**</td>
<td>(0.34-0.84)</td>
<td>0.64</td>
<td>(0.32-1.30)</td>
</tr>
</tbody>
</table>

*Adjusted for all variables in the table. *$=p<0.05$, **$=p<0.01$, ***$=p<0.001$

Table 12. Results of logistic regression analysis of comminution and initial fracture presentation as risk factors for displacement in DRF. Odds ratios (OR) and confidence intervals (CI) are presented.

The 17 fractures (17 patients) of the Bo type represent other patterns of fracture than dorsal or volar comminution. They were therefore excluded in the published article which focused on the effect of comminution in DRF. The tables and figures in the thesis therefore differ from study II regarding this fracture class.
Study III

In study III we analysed the clinical 1-year follow-up.

Outcome according to fracture class

Of the initial 417 patients, 11 had bilateral fractures. These were excluded since comparison with an uninjured hand was not possible. Of the remaining 406 patients, 72 patients were lost to follow-up. This left the cohort with 334 (82%) patients who completed the 1-year follow-up. Two of these patients who were re-operated with corrective osteotomy, for malunion with restricted ROM and pain, had their pre-operative data registered at 6 and 10 months respectively.

There were 267 women and 67 men. The mean ages were 58 years for women and 51 for men. The mean age was 57 years for the whole cohort.

There were 12 B0 fractures, 64 B1 fractures, 118 B2 fractures, 98 B3 fractures and 42 B4 fractures. Age distribution did not differ significantly between fracture classes (p=0.341). B0 fractures were underpowered according to our power analysis.

There were no significant differences in grip strength among the fracture classes for the whole cohort. However, when looking at patients < 60 years of age, there were significant differences in grip strength with a post hoc p-value of 0.016 between B1 and B4 fractures (Table 13). The GLM showed that the difference in strength was an effect of operative treatment (p<0.05), not fracture class (p=0.285) or gender (p=0.885). According to the GLM, patients < 60 years of age recovered their strength better when conservative treatment was possible, while patients > 60 years of age lost the same amount of strength after DRF regardless of operative or conservative treatment.
There was a significant difference between non-comminuted fracture classes (Bo and B1) and comminuted fracture classes (B2, B3 and B4) in loss of total ROM. Significant between-classes post hoc tests for each arc of motion are shown in table 14. The difference in ROM was manifest for fracture class (p<0.001) also after adjustment for operative treatment (p=0.418), age (p=0.183) and gender (p=0.093).

We found no statistically significant differences in QuickDASH, EQ-5D questionnaire, EQ-5D health status VAS and pain VAS scores among the fracture classes (Table 15).
Surgical technique differed among the fracture classes (Table 16). No B0 and only one B1 fracture were treated surgically. Intrafocal pinning was the most commonly used surgical method in B2 fractures while volar plating was used in most cases for B3 and B4 fractures.

<table>
<thead>
<tr>
<th>Class</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QuickDASH</strong></td>
<td>p=0.479</td>
<td>8 (2-23)</td>
<td>11 (5-28)</td>
<td>14 (5-31)</td>
<td>10 (2-30)</td>
</tr>
<tr>
<td><strong>EQ-5D questionnaire</strong></td>
<td>p=0.362</td>
<td>0.827 (0.816-1)</td>
<td>0.827 (0.816-1)</td>
<td>0.827 (0.800-1)</td>
<td>0.827 (0.816-1)</td>
</tr>
<tr>
<td><strong>EQ-5D HealthVAS</strong></td>
<td>p=0.196</td>
<td>90 (75-95)</td>
<td>80 (72-94)</td>
<td>80 (70-90)</td>
<td>85 (75-95)</td>
</tr>
<tr>
<td><strong>Pain VAS</strong></td>
<td>p=0.810</td>
<td>0.5 (0-4)</td>
<td>2 (0-4)</td>
<td>2 (0-4)</td>
<td>2 (0-5)</td>
</tr>
</tbody>
</table>

Table 15. The clinical outcome at one year for the questionnaires. Median and quartiles are presented.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Class</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B0</td>
<td>B1</td>
</tr>
<tr>
<td>Kapandji</td>
<td>0 (0 %)</td>
<td>0 (0 %)</td>
</tr>
<tr>
<td>Volar plate</td>
<td>0 (0 %)</td>
<td>1 (2 %)</td>
</tr>
<tr>
<td>Dorsal plating</td>
<td>0 (0 %)</td>
<td>0 (0 %)</td>
</tr>
<tr>
<td>External fixation</td>
<td>0 (0 %)</td>
<td>0 (0 %)</td>
</tr>
<tr>
<td>Combined method</td>
<td>0 (0 %)</td>
<td>0 (0 %)</td>
</tr>
<tr>
<td>Conservative Cast</td>
<td>12 (100 %)</td>
<td>63 (98 %)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>12</td>
<td>64</td>
</tr>
</tbody>
</table>

Table 16. The Choice of treatment among the fracture classes.
Regarding complications during the first year, there were no significant differences among the fracture classes (table 17). Of the complications, 8 of the radial neuralgias were iatrogenic, 4 after intrafocal pinning, 1 after dorsal plating, 2 after external fixation and one after combined external fixation and pinning. Three cases of CRPS were postoperative, one after intrafocal pinning, one after volar plate and one after external fixation. Malunion was registered as a complication in the 2 patients requiring osteotomy. Otherwise the effect of a malunion was reflected by the clinical outcome i.e. a malunion with a good clinical outcome did not have any negative impact on the results for that fracture class. We had no postoperative infections and no non-unions.

<table>
<thead>
<tr>
<th>Complications</th>
<th>BO</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpal Tunnel Syndrome (p=0.18)</td>
<td>4 (33%)</td>
<td>12 (19%)</td>
<td>24 (21%)</td>
<td>11 (11%)</td>
<td>9 (21%)</td>
</tr>
<tr>
<td>EPL rupture (p=0.40)</td>
<td>0</td>
<td>2 (3%)</td>
<td>3 (4%)</td>
<td>0</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>CRPS (p=0.56)</td>
<td>0</td>
<td>0</td>
<td>3 (3%)</td>
<td>4 (4%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Radial nerve paresthesia (p=0.06)</td>
<td>1 (8%)</td>
<td>0</td>
<td>7 (6%)</td>
<td>1 (1%)</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Ulnar nerve paresthesia (p=0.64)</td>
<td>0</td>
<td>0</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Cold intolerance (p=0.54)</td>
<td>0</td>
<td>0</td>
<td>1 (1%)</td>
<td>2 (2%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Trigger finger (p=0.07)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4 (4%)</td>
<td>0</td>
</tr>
<tr>
<td>DRUJ instability (p=0.07)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4 (4%)</td>
<td>0</td>
</tr>
<tr>
<td>Malunion with osteotomy (p=0.90)</td>
<td>0</td>
<td>0</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
<td>0</td>
</tr>
<tr>
<td>Mb de Quervain (p=0.90)</td>
<td>0</td>
<td>0</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 17. Complications registered among the fracture classes during the first year after DRF.

Outcome according to fracture patterns

As in study II we decided to analyse the fracture patterns and patient characteristics at presentation without the hierarchic classification system. Of the 334 fractures, 231 (69%) had dorsal comminution, 42 (13%) had volar comminution and 130 (39%) had intra-articular involvement. The parameters studied are shown in table 18a+b.
In this study we analysed the importance of different fracture patterns at presentation of the fracture. The final position of the fracture after union is therefore not analysed.

The initial position of the fracture was the parameter with the highest impact on the clinical outcome. Displacement at presentation was associated with worse quickDASH (table 19) and EQ-5D. It was also associated with reduced ROM and reduced grip strength compared to fractures with acceptable position at presentation.
Dorsal comminution was associated with a worse quickDASH (table 18a), reduced flexion and reduced pro-supination arc. Volar comminution at presentation was associated with reduced extension at one year. Intra-articular involvement resulted in a reduced flexion-extension arc. It was also associated with a worse EQ-5D.

Women had a worse quickDASH after 1 year. Older age was also a predictor for a worse quickDASH at 1 year; however, we did not have a reliable basic pre-fracture value for quickDASH among the patients.

Surgery versus conservative treatment did not affect the clinical outcome after regression using GLM. Nor were there any significant differences in surgical technique used.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement at presentation</td>
<td>Median 15 (5-32)</td>
<td>Median 9 (2-20)</td>
</tr>
<tr>
<td></td>
<td>Mean 19.8 (17.2-22.3)</td>
<td>Mean 12.9 (10.5-15.3)</td>
</tr>
<tr>
<td>Dorsal comminution</td>
<td>Median 12 (5-30)</td>
<td>Median 8 (2-20)</td>
</tr>
<tr>
<td></td>
<td>Mean 18.4 (16.1-20.6)</td>
<td>Mean 13.5 (10.5-16.5)</td>
</tr>
</tbody>
</table>

Table 19. QuickDASH in displaced/non-displaced and dorsal comminuted/dorsal non-comminuted fractures.
Study IV

Of the 209 fractures 175 (84%) had both radiological 3-month follow-up and clinical follow-up at 1 year. There were 135 women and 40 men. One hundred and twenty six (72%) fractures had united in a good position (minimally displaced) and 49 (28%) had late displacement with malunion. There were no non-unions. The mean age was 53 years in those with minimal displacement and 58 years in those with late displacement (p<0.05). The non-dominant wrist was fractured in 91 patients and the dominant wrist was fractured in 80 patients. Four patients considered themselves as ambidextrous. There was no difference in dominant wrist frequency between late displaced and minimally displaced fractures (p=0.98).

There were significant differences in the loss of ROM and grip strength between the minimally displaced and late displaced groups when compared with the non-injured side. The worse outcome was in the “late displacement” group (table 20).

The GLM showed that the late displacement was predictive for loss of total ROM and grip strength while patient’s age was predictive for grip strength (Table 21).

The subjective outcome evaluated with the quickDASH score, EQ-5D questionnaire, EQ-5D health VAS and pain VAS is presented in table 22. The differences among minimally displaced and late displaced DRF were not statistically significant.
<table>
<thead>
<tr>
<th>Outcome</th>
<th>Uninjured wrist ROM in degrees</th>
<th>Injured wrist Loss of ROM in degrees</th>
<th>Minimally Displaced</th>
<th>Late displaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grip strength (p&lt;0.05)</td>
<td>Reference (100%)</td>
<td>93% (89%-96%)</td>
<td>85% (79%-90%)</td>
<td></td>
</tr>
<tr>
<td>Flexion-Extension Arc (p&lt;0.05)</td>
<td>139° (137°-141°)</td>
<td>8.2° (6.2°-10.1°)</td>
<td>13.2° (9.3°-17.2°)</td>
<td></td>
</tr>
<tr>
<td>Ulnar-Radial deviation Arc (p=0.22)</td>
<td>55° (53°-57°)</td>
<td>2.4° (1.2°-3.5°)</td>
<td>3.9° (1.4°-6.3°)</td>
<td></td>
</tr>
<tr>
<td>Pronation-Supination Arc (p&lt;0.001)</td>
<td>162° (161°-164°)</td>
<td>3.4° (1.9°-4.8°)</td>
<td>10.5° (6.7°-14.2°)</td>
<td></td>
</tr>
<tr>
<td>Total ROM (p&lt;0.001)</td>
<td>357° (352°-361°)</td>
<td>13.9° (10.6°-17.2°)</td>
<td>27.5° (18.9°-36.2°)</td>
<td></td>
</tr>
</tbody>
</table>

Table 20. The clinical outcome at one year for minimally displaced and late displaced fractures respectively. Grip strength in percentage of the contralateral uninjured wrist. Loss of ROM in the injured wrist and average ROM in the uninjured wrist are presented in degrees. Mean and 95% Confidence intervals for mean are presented.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Loss of ROM</th>
<th>Grip strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late displacement</td>
<td>p&lt;0.01</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Age</td>
<td>p=0.18</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Gender</td>
<td>p=0.16</td>
<td>p=0.97</td>
</tr>
</tbody>
</table>

Table 21. Result of the GLM.
Table 22. Subjective outcome 1 year after DRF. Median and quartiles are presented. Mann-Whitney U tests.

<table>
<thead>
<tr>
<th></th>
<th>Minimally displaced N=126</th>
<th>Late displaced N=49</th>
</tr>
</thead>
<tbody>
<tr>
<td>QuickDASH p=0.146</td>
<td>9 (0.5-20)</td>
<td>12.5 (5-20)</td>
</tr>
<tr>
<td>EQ-5D Questionnaire p=0.434</td>
<td>0.827 (0.816-1)</td>
<td>0.827 (0.810-1)</td>
</tr>
<tr>
<td>EQ-5D Health VAS p=0.415</td>
<td>87 (80-95)</td>
<td>80 (70-94)</td>
</tr>
<tr>
<td>Pain VAS p=0.199</td>
<td>0 (0-3)</td>
<td>2 (0-4.25)</td>
</tr>
</tbody>
</table>
General discussion

DRF is the most common fracture encountered in clinical practice. Every year, more than 20000 people in Sweden suffer from this injury. The fracture is presented with wrist-pain, tenderness, swelling and potential deformity. The treatment aims to relieve pain and maintain function of the wrist.

An issue has been to make a correct initial assessment of the fracture. Even though most patients recover their abilities well, there is a correlation between anatomical reduction and function following DRF. If union results in a clinically significant deformity the patients may suffer from substantial morbidity, persistent pain and disability. Many fractures are unstable despite an acceptable position after a successful closed fracture reduction. Furthermore, the relationship between anatomic reduction and function has been questioned in the elderly and the use of operative intervention is debated in this group. There is no consensus on how or if DRF should be operated. Most treatments are associated with known risks, especially invasive treatments. Therefore, assessment of available treatments, patient’s functional demands and expected benefits for the individual patient must be considered and discussed in every case.

Despite the high frequency of DRF, the Cochrane Database has concluded that evidence is lacking regarding many aspects of management of distal radius fractures. The American Academy of Orthopaedic Surgeons (AAOS) published 29 recommendations on DRF. No recommendation was considered strong and controversies span the entire spectrum of treatment. Numerous classification systems have been developed for evaluation of DRF.

The classification systems aim to gain insight into the typical fracture patterns, mechanism, management plan, and prognosis for a given fracture. Furthermore, a common language among clinicians is created to communicate and compare results published in different studies. However, the value of the most commonly used classification systems are limited since they have not showed satisfactory reliability. Furthermore, the well-established classification systems of DRF have failed to predict radiographic or clinical outcome in repeated studies. These shortcomings may be one reason why optimal DRF management is still controversial. This has led to requests for a new classification system for DRF, predictive of outcome and easy to use. Improvement in the initial assessment of DRF could benefit a large group of patients, as well as society, in reducing persistent symptoms and disability.
Discussion on radiological evaluation and results

In study I we presented the modification of Older’s classification system. This new classification was named after its inventor and was called the Buttazzoni classification.

In evaluating a new classification system, one must first demonstrate its reliability, only then can the clinical significance be investigated. The classification system should be simple, reliable, clinically relevant, and all-inclusive and with as few subtypes as possible. Audige et al.90 and Slongo et al.91 stated that any classification system must also be evaluated among observers at different stages of experience to assess its reliability and accuracy. As recommended by Audige and Slongo90,91, we started evaluating the utility of this system by testing its interobserver reliability and intraobserver reproducibility.

The evaluation included radiographs of 232 patients with DRF seeking treatment at Östersund Hospital. The evaluation of the classification system was made by two orthopaedic surgeons with special interest in hand surgery as well as one general orthopaedic surgeon. The sample size was larger than most previous comparable studies but at the same time we had fewer observers. This made the study more sensitive to the individual result for each observer.

To evaluate both interobserver and intraobserver reliability, the observers classified the images twice with a 1-year interval. The evaluation using Cohen’s and Fleiss kappa was the same as most previous studies on reliability making comparisons with these possible. The 1-year interval between the first and second evaluation of radiographs was longer than most previous studies and minimized possible bias due to remembering some of the images. The quality of the evaluated radiographs was similar to those used in everyday practice, i.e., we demanded no high-quality films or special views to make the evaluation.

The classification system is fairly simple and depends on the configuration of the fracture. There are no measurements of displacement, angulation, or radial shortening in contrast to many other classifications. The only parameters to observe are: dorsal metaphyseal comminution, intraarticularity, and volar metaphyseal comminution. This could minimize disagreement between observers encountered in certain fracture patterns.
Despite that the ideal classification should have a reliability that is the same regardless of the age of the patients, we chose to study the reliability of the Buttazzoni classification in different age groups in addition to the whole cohort. Lindau et al.\textsuperscript{9} found that distal radial fractures in men younger than 60 and women younger than 50 represent a special group and were intra-articular in more than two thirds of the cases, displaced in 50%, and were mostly caused by severe trauma. Furthermore, they were often combined with intra-articular pathology as inter-carpal ligament ruptures, TFCC injuries, and cartilage damage. Because of these factors, we thought that this group of patients would probably have a different outcome and should be analysed separately in the studies.

The interobserver and intraobserver reliability of the classification system used in study I was comparable with some of the better results reported for previously studied classification systems. Still, the classification only averaged at the moderate level of reliability and did not reach the same level of reliability as the Older classification reported by Andersen et al.\textsuperscript{97} We found that both interobserver and intraobserver reliability was better in the young group. This might be due to the better bone quality in this group allowing easier and more reliable evaluation of radiographs.

Most authors agree that no classification system is adequate to determine treatment and predict outcomes unless interobserver and intraobserver reliability is substantial. This level of agreement was only reached for two of the three observers and only in younger patients. Therefore, the reliability of the classification system in itself is a limitation for further studies on radiological and clinical outcome. Despite this, we thought that some aspects of the classification could still be interesting and decided to continue the evaluation of the classification radiologically and clinically in a new study.

**Assessment of stability in DRF**

A difficulty has been to make an initial assessment of the stability of DRF. Fractures that cannot be reduced or that re-displace directly after reduction can be easily detected. However, numerous fractures displace later on, despite an initially acceptable fracture reduction. In study II, we conducted a prospective multicenter clinical trial to evaluate if cortical comminution and intra-articular involvement using the Buttazzoni classification could predict the radiological stability of DRF. The treatment algorithm used was based on previous experience by Abramo et al\textsuperscript{72} who demonstrated good outcome in both non-operatively and operatively managed fractures using the DASH questionnaire. We advocated initial non-operative treatment for
high-energy trauma if the fracture was reducible and stability was
maintained with cast immobilization.

Supposed risk factors for instability include age\textsuperscript{10,50,51,52,53,54,55}, initial degree of displacement\textsuperscript{21,50,52,54}, comminution of the fracture\textsuperscript{10,54,57,58,59,60}, concomitant fracture of the ulna\textsuperscript{58} and intra-articular involvement\textsuperscript{46}. Scoring systems using mathematical formulas for the evaluation of fracture stability have also been developed\textsuperscript{10,61}. These have to some extent been able to predict instability, but they can be difficult to use in clinical practice and repeated studies have shown a tendency for them to underestimate the degree of fracture instability\textsuperscript{62}.

\textbf{Age}

Age is a patient dependent parameter. Age could affect stability of DRF, partly because of the higher frequency of high-energy trauma in younger patients but also because of the fact that the strength of bone varies with age. Moreover, factors such as gender, ethnicity, social status, previous fractures, smoking and alcohol influence the strength of bone.\textsuperscript{129} The regression analysis showed a tendency for the osteoporotic group to displace more often but the difference was not significant when looking at the whole cohort. Further analysis revealed that age was a risk factor for women but not for men. This is probably caused by the occurrence of osteoporosis in many women above 50 years of age. In other studies age has been the most important factor predicting instability.\textsuperscript{10,55} In this study, patients older than 75 years were excluded, as it is considered that they can tolerate even massive displacement.\textsuperscript{22,51} This could be an explanation why age was not a risk factor for men where osteoporosis develops later. Younger men may also have high risk behaviour, replacing the age factor due to osteoporosis as a risk factor.

\textbf{Initial degree of displacement}

The initial displacement of DRF, both dorsal angulation and axial shortening, is considered to be of importance in DRF stability.\textsuperscript{21,50} Our findings agree with previous reports and initial displacement was the second highest risk factor for redisplacement after adjusting for age and gender. We looked at minimally displaced fractures and displaced fractures respectively as well as the whole material. In all classes, except for B1, the fractures were significantly less stable if initially displaced. The initial degree of displacement should be considered in the early management of a DRF when evaluating fracture stability.
Comminution

Comminution can either be intraarticular, involving the articular cartilage, or extraarticular, involving the metaphysis. Metaphyseal cortical comminution can be volar or dorsal. Many studies have shown that comminution of the dorsal cortex is of prognostic significance for stability of a reduced DRF10,54,59. Intraarticularity in the radiocarpal joint has also been suggested to cause instability.46,58,104,130

We found that fractures that were not comminuted (B1) were significantly more stable than those that were comminuted (B2, B3, B4) both in initially minimally displaced and displaced fractures. These findings agree with previous reports.10,58,92 Mackenney et al10, for instance, found that malunion was three times more common in fractures with any type of comminution. Interestingly, 12 of our 13 displacements in non-comminuted fractures occurred as “late instability”.

Dorsal comminution

We found that dorsal comminution (type B2) was a risk factor for displacement, which concurs with other studies.10,59,66,92 We found that of initially minimally displaced B2 fractures, 51% displaced later on, compared to 84% displacement for those that were initially displaced. This displacement risk was significantly higher compared to the B1 class. Despite the fact that Makhni et al60 reported similar displacement risk in their dorsally comminuted DRF (57% and 82% respectively), their findings compared to non comminuted fractures were not significant for each group, probably owing to their relatively small sample size. Therefore; this study, to the best of our knowledge, is the first report that shows a significant role of isolated dorsal comminution in the instability of DRF in both initially minimally displaced and displaced fractures.

Intra-articular involvement

The B3 class represents DRF with complete intra-articular involvement in the radiocarpal joint with or without dorsal comminution. Intra-articular involvement has been suggested to cause instability.58,104,130,132, Knirk and Jupiter46 also described these fractures in young adults as inherently unstable. However, it was not clear if these fractures had associated cortical comminution. In our opinion none of the above-mentioned studies clearly identifies intra-articularity as an individual risk factor. In intra-articular DRFs, a step-off of > 2 mm has been shown to cause posttraumatic arthritis.46,131,132.
In our study, the addition of intra-articular involvement to the cortical comminution did not seem to increase the risk of displacement. This was true both after the logistic regression analysis and the fact that we found no statistical difference in stability between the B2 and B3 classes. Our results concur with a recently published meta-analysis by Walenkamp et al, who found that intra-articular involvement was not a risk factor for instability.\textsuperscript{56}

On the other hand, there were eight fractures (six B3 and two B4) where step-off was the sole reason for the position being unacceptable after initial reduction. Furthermore, two fractures (one B3 and one B0) did develop step-off at 10 to 14 days. For this reason we propose that intra-articular involvement should be included in the initial assessment of a DRF and that a step-off of > 2 mm should not be accepted. Furthermore, intra-articular involvement is often found in high-energy DRF in young adults where other intra-articular pathologies, such as ligamentous injuries, TFCC injuries and cartilage injuries to the carpal bones can be encountered.\textsuperscript{132,133} Even though there were no significant differences in stability between B2 and B3 fractures, the separation of B2 from B3 classes might be clinically adequate because fractures where step-off is the sole reason for the position being unacceptable after initial reduction must be recognised.

The B0 class includes partially intra-articular fractures (AO B) like Barton or reverse Barton fractures, chauffeur fractures or fracture-dislocation such as Fernandez type 4. The treatment of these fractures needs special consideration. In the present study, we had no Barton or reversed Barton fractures, which are usually considered highly unstable. This could be the explanation why this class showed good stability.

**Volar comminution**

Mackenney et al\textsuperscript{10} and Older et al\textsuperscript{92} have discussed the role of volar comminution in the stability of DRFs. The B4 class represents DRF with comminution of the volar cortex regardless of other coexisting fracture properties. The rationale for evaluating comminution of the volar cortex is that there is evidence suggesting that this factor in itself adds to instability of the fracture.\textsuperscript{116} The distal joint surface of the radius is centred over the distal projection of the volar cortex, not over the centre of the shaft. On a lateral view, a line drawn over and parallel to the volar cortex of the radial shaft will cross through the middle of the joint and pin the radial styloid. This line is normally called the “volar line of Lewis”. The fact that the volar cortex is thicker than the dorsal cortex\textsuperscript{116} implicates that most of the load over the radiocarpal joint passes through the volar cortex if the joint is anatomically
placed. Consequently, if a radius fracture is anatomically reduced, the axial load applied over the joint while exercising finger motion will be transmitted through the volar cortex. The volar cortex might be considered as the calcar of the wrist joint, and this difference in the thickness could reflect its importance for axial stability in DRF. Comminution of this segment may be followed by both axial and volar angular instability. As classifications of DRF until now have not addressed this problem, very little has been published on this matter. Our theory is that comminution of the volar cortex, overlooked by previous classifications, is of utmost importance in stability of DRF. However, the role of the volar cortex for the stability of DRF has not been previously shown.

In the present study, the initially minimally displaced volar comminuted fractures were few but yet significantly less stable than other non-comminuted fractures. Initially displaced volar comminuted fractures were significantly less stable than all other classes and displaced in 100% before union (8 of 49 later than 10-14 days). The regression analysis showed that volar comminution was the strongest predictor of displacement. We think that our study is the first study evaluating the role of volar comminution as a separate parameter.

Recently LaMartina et al published an article on stability in conservatively treated DRF. Their hypothesis was that “volar hooking” would be another factor that would independently predict the maintenance of a closed reduction in a cast. They used the lateral radiograph to assess whether or not the initial reduction resulted in restoration of the volar cortex. They defined volar cortical alignment, or volar hook, as having collinear alignment of the cortical edges of the fracture at the volar surface. They found that restoring volar cortical continuity by hooking the volar cortex in the initial reduction proved to be the strongest predictor of final volar tilt, the change in volar tilt, and carpal malalignment at union. Even though LaMartina et al did not evaluate volar comminution, their suggestion that the volar cortex is the supporting calcar of the wrist is in accordance with our results.

Volarly comminuted fractures tended to be more common in the younger “non-osteoporotic” cohort probably due to the higher frequency of high-energy trauma in younger patients.

Our conclusion is that volarly comminuted fractures should always be operated if fracture stability is to be achieved.
Late instability

A separate analysis showed that late instability occurred in 29% of fractures that were still in good alignment after 10-14 days. Furthermore, there was a statistically significant difference in frequency of late displacement between all Buttazzoni types of fracture (p < 0.01), except for B2 versus B3 types (p = 1.00). Type B1 fractures were less and B4 fractures were more likely to displace than other types also after 10 to 14 days. The volar comminuted fractures had late displacement in 83% of the cases despite an acceptable position at 10-14 days. The AAOS guidelines 2011 made a consensus: "In the absence of reliable evidence, it is the opinion of the work group that distal radius fractures that are treated non operatively be followed by ongoing radiographic evaluation for 3 weeks and at cessation of immobilization". The high incidence of late displacement in this study supports this statement.
Discussion on clinical evaluation and results

In study III, we aimed to evaluate the effect of dorsal and volar comminution, intra-articular involvement and initial displacement on clinical outcome. We also aimed to complete the evaluation of the classification by studying if different fracture classes would show different clinical outcome parameters. The previous division with different age limits used for men and women were in the eyes of the reviewers of the article considered controversial. Instead we allocated the patients into two groups: below and above 60 years of age. The reason for this division is the favorable outcome in patients > 60 years reported by Young et al.\textsuperscript{22}.

Factors predicting clinical outcome

Known factors of importance for clinical outcome after DRF are the degree of anatomical reduction,\textsuperscript{57,77,79} associated ligament injuries,\textsuperscript{82,83} fracture comminution,\textsuperscript{78} age,\textsuperscript{72,78,84} patient education level,\textsuperscript{85,86} socioeconomic status,\textsuperscript{84} and injury compensation.\textsuperscript{85,86} The relationship between the degree of anatomical reduction and clinical outcome has been questioned in the elderly.\textsuperscript{22,51,80,81}

In study III we evaluated individual fracture patterns, present at the initial presentation of the fracture, and their predictive value on clinical outcome.

Age

Older age group and female gender were associated with a worse outcome in quickDASH at one year. This finding concurs with the study by Abramo et al.\textsuperscript{72} who found that older patients had a worse DASH score after DRF. Our results also concur with Chung et al.\textsuperscript{84} who found that older age was significantly associated with a poorer long-term outcome 1 year after surgery of DRF when the Michigan Hand Outcomes Questionnaire (MHQ) was used for evaluation.
Initial degree of displacement

Initial displacement of the fracture was the factor with the greatest impact on clinical outcome. Initial displacement was associated with loss of total ROM, loss of grip strength and a worse outcome in quickDASH and EQ-5D one year after the fracture. Our findings are in contrast with a study by Grewal et al.85 who found no correlation between initial degree of displacement and clinical outcome when evaluated using the PRWE score. In their study only education level, injury compensation and comorbidity were associated with outcome, while no injury characteristic, including the degree of initial fracture displacement, was found to significantly influence the 1-year PRWE score. Their study however only included extra-articular DRF.

Comminution

Dorsal comminution

Dorsal comminution was associated with loss of flexion and forearm rotation. The reduced flexion ability of dorsally comminuted fractures is probably the result of the tendency for these fractures to displace with dorsal angulation while our impression is that volarly comminuted fractures often displace with axial compression or volar angulation. Dorsal comminution was also associated with a worse outcome in quickDASH at one year. Our findings regarding ROM concur with the results found by Cowie et al.78 who found that dorsal comminution was associated with loss of supination. In their study dorsal comminution also predicted loss of grip strength. The DASH questionnaire was not used in Cowie’s study.

Intra-articular involvement

Besides causing post-traumatic arthritis45,131,132, intra-articular involvement and the degree of intra-articular displacement has been reported to affect clinical outcome99,105,114,134. The impact of intraarticular union without a step is uncertain46,99. In study III we analysed intra-articular involvement at presentation. We found that intra-articular involvement correlated to a reduced flexion-extension arc. Furthermore intra-articular involvement was associated with a worse EQ-5D. Our findings are partly in agreement with those reported by Karnezis et al.114 who found that the presence of a post-operative articular step affects the range of wrist extension, and those of Gliatis et al.99 who found that union with a step in the articular surface was associated with loss of wrist mobility. However, since we have analysed
initial intra-articular involvement and not final step or gap after union, study III only evaluates the importance of presence or absence of intra-articular involvement.

**Volar comminution**

Volar comminution was associated with loss of extension. Our impression is that volarly comminuted fractures often displace with axial compression or volar angulation. In fractures with volar or dorsal comminution there may be a shift in the arc of motion in a dorsal or volar direction without affecting the total arc of motion. Cowie et al.78 also found that lower extension was associated with volar comminution. In their study volar comminution was also associated with loss of flexion-extension arc and poorer functional score using a validated system135.

**Fracture class**

B0 and B1 fractures showed minimal loss of motion compared with B2, B3 and B4 fractures. The reason for this could be more severe soft tissue injuries in comminuted fractures. The latter were also more likely to require surgery to maintain stability, however, after adjusting for this, the fracture type was still a crucial factor for the loss of ROM in the injured wrist.

We found that patients <60 years of age had a statistically significant difference in grip strength between B1 and B4 fractures, where B1 fractures were associated with stronger grip strength than B4 fractures. The difference, however, was explained by the need for surgery among B4 fractures to maintain stability. Patients below 60 years of age recovered their strength better when conservative treatment was possible, while patients above 60 years of age lost the same amount of strength after DRF regardless of operative or conservative treatment.

We found no significant difference in quickDASH among different fracture classes. Regarding complications, there were no significant differences among the fracture classes. The rates among less common complications may be underpowered to detect differences.
The correlation between objective and subjective outcome

Karnezis et al. found that in DRF, patients grip strength, but not wrist extension and flexion, was predictive of better self-reported outcome using the PRWE score. Wilcke et al. reported a similar finding regarding reduced grip strength but also that loss of extension and ulnar deviation correlated with a poorer DASH score. Chung et al. concluded that the optimal cut-off points that distinguish satisfaction from dissatisfaction occurred when patients had recovered 65% of their grip strength and 95% of their ROM. The differences in strength and ROM between the fracture classes in this study may therefore be too small to affect the subjective outcome.

We chose to use quickDASH because it is commonly used and well validated in Sweden. However, quickDASH includes the overall functional status of the upper limb as a unit and therefore may not be responsive enough to compare functional outcome of DRF patients with small differences. The PRWE score was the most responsive instrument for evaluating the outcome in patients with distal radius fractures in a review article of 2008. On reflection the wrist specific PRWE score would have been an interesting complement to the quickDASH.

EQ-5D enables different dimensions of health to be combined to form an overall single index. We hypothesized that fracture patterns or type of DRF could affect other aspects of health than those covered by the upper limb questionnaires. We found that patients with initial displacement and intra-articular involvement had a worse EQ-5D. The difference in EQ-5D however was small and the clinical value of this finding may be limited. Other fracture patterns and fracture classes showed comparable results in EQ-5D. These findings concur with those of Dolan et al. who evaluated health-related quality of life of patients with DRF. They found that the EQ-5D loss associated with DRF is about 2%. They concluded that EQ-5D is unlikely to be sensitive enough and be less appropriate to use when planning individual treatment. Our results also concur with De Putter et al. who found that proximal upper extremity injuries, such as upper arm fractures, showed more loss in EQ-5D than distal injuries, such as wrist and hand fractures.
Clinical outcome in relation to radiological outcome

The idea of Study IV arose after studies II and III. In study II we found that late displacement of DRF, still in acceptable radiologic position after 10-14 days, occurred in approximately 1/3 of cases. This was in accordance with a larger study on DRF by Mackenney et al. Despite this, there are no studies focusing on the clinical outcome in patients with late displaced DRF. The available studies on clinical outcome are either postoperative, a combination of operatively and conservatively treated DRF, or a mix of conservatively treated early and late displaced DRF. Since the management of DRF in low demanding and elderly patients is controversial, there may be a selection bias in studies of conservatively treated DRF, where the low demanding group is overrepresented. The outcome of displaced conservatively treated DRF studies may be difficult to evaluate since there could be a selection based on functional demands, dominant wrist etc. To overcome this bias it would be necessary to investigate patients where the displacement has occurred after the decision of final treatment has been made. It would also be necessary not to operate any fracture before displacement has occurred, i.e. no fracture is operated on if still in acceptable position in the cast.

This study included only conservatively treated DRF still in good position after 10-14 days. No fracture with acceptable position according to the radiologic criteria was operated on. Late displacement occurred in 28% of the patients.

Fractures with late displacement had a significant reduction in strength compared to those with union in acceptable position. High age was also an independent risk factor for loss of grip strength after the fracture. This is partly in contrast to the studies published by Young and Anzarut who concluded that final radiologic outcome does not affect clinical outcome. These studies, however, focused on subjective outcome.

The ability to restore ROM in extension-flexion arc, supination-pronation arc, radial-ulnar deviation arc and total ROM was worse in late displaced DRF compared to minimally displaced fractures. The loss of supination-pronation arc was the most affected part and may be the result of DRUJ-incongruence in late displaced DRF. The results concur with the findings by Ishikawa et al. who showed that changes in palmar tilt and ulnar variance might lead to restricted forearm rotation after distal radial fracture.
The subjective outcome according to the self-evaluating questionnaires quickDASH and EQ-5D did not show any significant differences between late displaced DRF and minimally displaced DRF. Nor were there any differences in quickDASH among the fracture classes. The median for quickDASH was slightly higher in late displaced fractures than in minimally displaced fractures but, besides being non significant, the clinical implication of this may be questioned since a 10-point difference in quickDASH was the smallest effect that would be relevant to patients.

The functional outcomes studied with EQ-5D were comparable among late displaced and minimally displaced DRF. As mentioned earlier, Dolan found that EQ-5D is unlikely to be sensitive enough and less valuable when evaluating DRF treatment.

Regarding complications, there were no significant differences among late displaced and minimally displaced DRF. The rates among less common complications may be underpowered to detect differences.

The AAOS conclude that supporting evidence is lacking in the question for how long distal radius fractures should be followed radiologically. In our previous prospective multicenter study we concluded that late displacement is common in non-operative treatment of distal radius fractures. In this extended study of the material the late displaced fractures had a significant reduction in range of motion and grip strength. However, we could not find any significant differences in subjective outcome. Therefore, the AAOS recommendation that distal radius fractures should be followed for more than 2 weeks may be further discussed. The value of reduced grip strength and ROM may play a role at least in high functioning patients. A shorter follow-up time may be an alternative in low demanding patients.
Strengths and weaknesses of the thesis

The reliability of the classification system varied considerably among the observers in study I. Since there were only 3 observers, the impact for each observer was large. The study would probably have benefitted from an increased number of observers. Most authors agree that no classification system is adequate to determine treatment and predict outcomes unless interobserver and intraobserver reliability is substantial. In study I, this level of agreement was only reached for two of the three observers and only in younger patients. Therefore, the reliability of the classification system in itself is a limitation for further studies on radiological and clinical outcome. In hindsight, a separate “classless” evaluation of the interobserver and intraobserver reliability in detecting dorsal comminution, intraarticular involvement and volar comminution would have been of great value.

In studies II, III and IV the evaluation on the radiographs was made on AP and lateral views. Some comminution may not appear on AP and lateral radiographs. No other views, such as oblique views, were used. CT scan may also reveal comminution, however, CT scan was used only as preoperative evaluation after the evaluation of fracture class. This could be a limitation but could also be considered a strength as the evaluated radiographs were similar to those used in everyday practice.

The obtained results in studies II and III can be evaluated according to the treatment algorithm used, which is commonly advocated in Sweden and has shown good results for both non-operatively and operatively treated fractures. Also, in study III functional outcome may have been influenced by the choice of treatment. However only small differences among surgical techniques have been described despite numerous studies.

Involvement of the DRUJ and fractures of the ulnar styloid have been suggested to predict instability and clinical outcome. Evaluation of TFCC injuries is not possible clinically in the presence of a fresh DRF, thus it would imply either including an MRI or arthroscopy in the initial evaluation of the fracture. A limitation of studies II-IV is that involvement of the DRUJ and the triangular fibrocartilage complex (TFCC) at follow up is not registered in all patients. In study II the DRUJ has been registered only as displaced or minimally displaced according to the ulnar variance. In studies III and IV the individual evaluation of the DRUJ was not documented unless the patient showed signs or symptoms of distal radio-ulnar joint instability or ulnar sided pain. The 2 patients who were osteotomized due to limited ROM and pain, both had involvement of the DRUJ. Despite numerous studies,
however, the AAOS are unable to recommend for or against concurrent surgical treatment of distal radioulnar joint instability and ulnar styloid fractures in patients with operatively treated distal radius fractures. In a recently published study with a mean follow-up of 4 years, the presence of clinical DRUJ instability did not affect functional outcome after DRF. In a prospective five year follow-up, it was found that instability of the DRUJ did not worsen the outcome using the quickDASH questionnaire. In this perspective study, including an MRI or arthroscopy in the initial evaluation of the fracture does not seem necessary.

Even though DRUJ involvement was not registered in the study we consider evaluation of the DRUJ important, both on initial post reduction x-rays and at clinical follow up.

A limitation of study IV is that we have only analysed the fractures as displaced or not i.e. we have not analysed different directions of displacement. This is for future research.

These limitations of studies II-IV are counterbalanced by the strength of the studies, which are a prospective multicenter approach that evaluated cortical comminution and intra-articular involvement with adequate sample size and well validated objective methods and outcome scores.
Conclusions

As for the outcome following DRF:

- The Buttazzoni classification had a moderate reliability. This is not ideal for a classification system and may be considered a limitation when using the classification in a clinical setting or for research purposes.
- Dorsal comminution was an independent risk factor for instability. It also resulted in functional loss with less flexion and pronation-supination arc and worsened quickDASH.
- Volar comminution was the strongest risk factor for instability and resulted in displacement in 96% of the cases. It also resulted in loss of extension.
- Intra-articular involvement did not lead to instability. However it resulted in a reduced flexion-extension arc and a worse EQ-5D score.
- Initial displacement was an important instability factor and was also the single most important factor for clinical outcome. Initial displacement resulted in worse quickDASH and EQ-5D scores. Moreover it resulted in reduced grip strength and ROM.
- Late displacement is common and resulted in reduced grip strength and ROM. Subjective outcomes did not differ significantly from minimally displaced fractures.
- The new classification system was predictive of instability. Non-comminuted fractures (B0 and B1) are more stable than all other fracture classes and volar comminuted fractures (B4) are less stable than all other fracture classes. This is also true for the risk of late displacement. Of clinical relevance, there are differences in ROM 1 year after DRF between non-comminuted fracture classes (B0 and B1) and comminuted fracture classes (B2, B3 and B4).
Implications for future research

During the work on this thesis some of our questions have been answered. Concurrently new questions arose.

As assessment of reliability was the first step in this thesis it was done on a yet as unused classification. Possibly results would have been different if this assessment had been made at a later stage. It would be of interest if other clinicians made this assessment now that the classification is in use. The Buttazzoni classification has not been evaluated together with other classification systems and a direct comparison would be of value.

The reference point on the ulnar border of the radius used to measure UV, radial height and radial inclination is not clearly defined in many studies. Further investigation on the relationship of the position of the volar ulnar border and volar inclination is warranted.

We found initial displacement to be a risk factor for both instability and clinical outcome. We have not analysed whether it was dorsal angulation, radial inclination, UV or intraarticular step-off that had the greatest impact on outcome.

Our material contains data on final radiological position, clinical outcome, trauma mechanism and surgical technique used. We think the material will provide us with more useful information in the future.

Previous studies have shown continuous improvement in DRF also after 1-year follow-up; moreover intra-articular involvement has been shown to cause post-traumatic arthritis, which may affect long-term outcome. Further follow-up of the patients would provide data for long term prognosis following DRF.
Acknowledgements

This thesis would have been impossible for me to complete without the support and help from colleagues, friends and family. I would like to thank you all from the bottom of my heart.

Göran Sjödén
My supervisor who introduced me to research and encouraged me to take part in this project. You have been a fantastic teacher both in operative orthopaedics and science. I find it amazing that you maintained your positive attitude, patience and support, and still believed in me, when I started the journey at a snail’s pace.

Arkan Sayed-Noor
My co-supervisor and dear friend. For speeding up my tempo when you found the abstract to article one on my old mobile phone! Without your enthusiasm and passion for research this thesis would not have been finished. I will always be grateful for your guidance, support and friendship.

Gunnar Buttazzoni
Senior orthopaedic surgeon, inventor of the new classification system and colleague at Östersund hospital. One of the most creative minds I have ever met. Discussing DRF with you always creates ideas for new studies. I am honoured that you have let me take part of your thoughts and wide experience in the field.

Erling Englund
PhD and Statistician at the Department of Research and Development, Västernorrland County. For your incredible patience and support from the beginning to the end of the work.

Lillemor Wågström
Occupational therapist and one of my most important co-workers. For all your hard work in following the patients.

Anne-Charlotte Söderlind, Helene Sörell, Elieann Broman
Our research nurses at the Orthopaedic Department of Sundsvall Hospital. For all your effort in the studies included in this thesis.
Staff at Östersund Hospital

For each person in Sundsvall Hospital involved in the project, there is an equivalent in Östersund. Even though I haven’t met you all, the work would only have been half as valuable without your participation.

Lennart Bengtsson, Sigge Norberg, Johan Nilsson

Former and present heads of the department of orthopaedic surgery, Sundsvall hospital. For your support and for giving me space to work on this thesis.

Fredrik Andersson

My colleague, roommate at work and dear friend. Even during the busiest days, there is always time for a good laugh. Thank you for being there!

Björn Knutsson

In advance for helping me with the party to this thesis!

The research group at our clinic. Anna Grauers, Bakir Kadum, Sarwar Mahmood, Sebastian Mukka

Thank you for your support and help.

Research and development center (FOU), Landstinget Västernorrland

For financial support of this thesis.

Raymond Pollock

For grammar correction.

Joachim Petterson

For being my close friend for 40 years.

Ann-Louise Jansson and Kjell Jansson

My parents. Thank you for building the solid ground I’m still standing on!

Anna, Carl and Ella

My dear children. Simply for being the best there is.

Lotta

For everything.
References


4. **Smith RW.** A treatise on fractures in the vicinity of joints and on certain forms of accidental and congenital dislocations. *Hodges Smith* 1847.


33. **Wilcke MKT, Abbaszadegan H, Adolphson PY.** Wrist function recovers more rapidly after volar locked plating than after external
fixation but the outcomes are similar after 1 year. *Acta Orthop* 2011;82(1):76–81.


66. **Ware JE, Kosinski M, Bayliss MS, McHorney CA, Rogers WH, Raczek A.** Comparison of methods for the scoring and statistical analysis of SF-36 health profile and summary measures:


73. **Gummesson C, Ward MM, Atroshi I.** The shortened disabilities of the arm, shoulder and hand questionnaire (QuickDASH): validity and reliability based on responses within the full-length DASH. BMC Musculoskelet Disord 2006;7:44.


82. Lindau T, Runnquist K, Aspenberg P. Patients with laxity of the distal radioulnar joint after distal radial fractures have impaired function, but no loss of strength. *Acta Orthop Scand* 2002;73(2):151–156.


Appendix

Appendix 1: Checklist

Person nummer: 

Buttazzoni klass
Ringa in alternativ, se lathunden för detaljer

0  I  II  III  IV

Initialt frakturläge: (Kryss i rutan innebär kriteriet uppfyllt
för acceptabelt frakturläge)

- Volar inclination +20 till – 10 grader på sidoprojektion (1)
- Radiell inclination >= 10 grader på frontalprojektion (2)
- Ulnavarian ≤ +2 mm mätt mot volara hörnet i lunatumfossan på radius (3)
- Eventuell intraartikulär nivåinkongruens ≤ 2 mm

Vid volarbockning visar röda pilen volara kanten, vid dorsalbockning visar den blå pilen volara kanten

Efter reposition (om ej acceptabelt läge initialt):

- Volar inclination +20 till – 10 grader på sidoprojektion
- Radiell inclination >= 10 grader på frontalprojektion
- Ulnavarian ≤ +2 mm mätt mot volara hörnet i lunatumfossan på radius
- Eventuell intraartikulär nivåinkongruens ≤ 2 mm
Formulär EQ-5D

Rörlighet
1. Jag går utan svårigheter
2. Jag kan gå men med viss svårighet
3. Jag är sängliggande

Hygien
1. Jag behöver ingen hjälp med min dagliga hygien, mat eller påklädning
2. Jag har vissa problem att tvätta eller klä mig själv
3. Jag kan inte tvätta eller klä mig själv

Huvudsakliga aktiviteter (t ex arbete, studier, hushålssysslor, familje- och fritidsaktiviteter)
1. Jag klarar av mina huvudsakliga aktiviteter
2. Jag har vissa problem med att klara av mina huvudsakliga aktiviteter
3. Jag klarar inte av mina huvudsakliga aktiviteter

Smärtor/besvär
1. Jag har varken smärtor eller besvär
2. Jag har måttliga smärtor eller besvär
3. Jag har svåra smärtor eller besvär

Oro/nedstämdhet
1. Jag är inte orolig eller nedstämd
2. Jag är orolig eller nedstämd i viss utsträckning
3. Jag är i högsta grad orolig eller nedstämd
Generellt hälsotillstånd

Ditt bästa tänkbara hälsotillstånd markerats med 100 och Ditt sämsta tänkbara hälsotillstånd med 0.

Vi vill att Du på denna skala markerar hur bra eller dåligt Ditt hälsotillstånd är, som Du själv bedömer det. Gör detta genom att dra en linje från nedanstående ruta till den punkt på skalan som markerar hur bra eller dåligt Ditt nuvarande hälsotillstånd är.

0-------------------------------50-------------------------------100
Hälsoenkät (arm/axel/hand)

Denna enkät berör Dina symptomer och Din förmåga att utföra vissa aktiviteter. Svara på varje fråga, baserat på hur Du har haft den senaste veckan, genom att kryssa för ett svarsalternativ för varje fråga.

Om det är någon aktivitet Du inte har utfört den senaste veckan får Du kryssa för det svar som Du bedömer stämmer bäst om Du hade utfört aktiviteten. Det har ingen betydelse vilken arm eller hand Du använder för att utföra aktiviteten. Svara baserat på Din förmåga oavsett hur Du utför uppgiften.

<table>
<thead>
<tr>
<th>Ingen svårighet</th>
<th>Viss svårighet</th>
<th>Måttlig svårighet</th>
<th>Stor svårighet</th>
<th>Omöjligt att göra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Öppna en ny burk eller hårt sittande lock</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Utföra tunga hushållssysslor (t ex tvätta golv, pusta finster, hänga tvätt)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Bära matkasser eller portfölj</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Tvätta Din rygg</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Använda en kniv för att skära upp maten</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Fritidsaktiviteter som tar upp viss kraft eller stöt genom arm, axel eller hand (t ex spela golf, använda hammare, spela tennis, skytte, bowling)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

7. Under den senaste veckan, i vilken utsträckning har Dina arm-, axel- eller handproblem stört Ditt vanliga vaflume med anhöriga, vänner, grannar eller andra?
☐ Inte alls  ☐ Lite  ☐ Måttligt  ☐ Mycket  ☐ Väldigt mycket

8. Under den senaste veckan, i vilken utsträckning har Dina arm-, axel- eller handproblem stört Ditt vanliga arbete eller andra dagliga aktiviteter?
☐ Inte alls  ☐ Lite  ☐ Måttligt  ☐ Mycket  ☐ Väldigt mycket

Ange svårighetsgraden på Dina symptomer den senaste veckan:

<table>
<thead>
<tr>
<th>Ingen</th>
<th>Lätt</th>
<th>Måttlig</th>
<th>Svår</th>
<th>Mycket svår</th>
</tr>
</thead>
<tbody>
<tr>
<td>Värk/smärta i arm, axel eller hand</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Stickningar (sockerdrickskänsla) i arm, axel eller hand</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

11. Hur Du haft svårt att sova, under den senaste veckan, på grund av värk/smärta i arm, axel eller hand?
☐ Inte alls  ☐ Viss svårighet  ☐ Måttlig svårighet  ☐ Stor svårighet  ☐ Mycket stor svårighet

QuickDASH Gummesson/Atroshi 2006

(© 2013 R Adams Cowley Snakebite Initiative)