WRIST TRAUMA

DIAGNOSIS, TREATMENT AND PROGNOSIS

Monique M.J. Walenkamp

WRIST TRAUMA

DIAGNOSIS, TREATMENT AND PROGNOSIS

STELLINGEN

1. Physicians are afraid not to order radiography in patients with wrist trauma, even if they have a low clinical suspicion of a distal radius fracture • *dit proefschrift*

2. We urgently require a definition of what constitutes an unstable distal radius fracture • *dit proefschrift*

3. There is a considerable unwarranted variation in the treatment of patient with a distal radius fractures in the Netherlands • *dit proefschrift*

4. Open reduction and internal fixation with a volar locking plate is preferred over bridging external fixation for surgical treatment of distal radius fractures • *dit proefschrift*

5. Clinical decision models should be externally validated before implementation in clinical practise • *dit proefschrift*

6. Sample-size calculations should be based on the minimal clinically important difference of a patient-reported outcome measure • *dit proefschrift*

7. If you want something said, ask a man. If you want something done, ask a woman • *Margareth Thatcher*

8. Je kan beter spijt hebben van de dingen die je wel gedaan hebt dan van de dingen die je niet gedaan hebt • *Simona Walenkamp*

9. The world is a book, and those who do not travel read only one page • *Sint-Augustinus*

10. Zelfs een vlieg heeft een pols • *naar Desiderius Erasmus*

WRIST TRAUMA

DIAGNOSIS, TREATMENT AND PROGNOSIS

Monique Margaretha Jozefa Walenkamp

Wrist trauma diagnosis, treatment and prognosis
Thesis, University of Amsterdam, The Netherlands

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WRIST TRAUMA

DIAGNOSIS, TREATMENT AND PROGNOSIS

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Faculteit der Geneeskunde

Nullius in Verba

Voor mijn moeder

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GENERAL INTRODUCTION & OUTLINE OF THE THESIS

GENERAL INTRODUCTION & OUTLINE OF THE THESIS

Wrist trauma is one of the most common Emergency Department attendances.[1] Annually, 1 million patients are treated in one of the Dutch Emergency Departments[2], of which 29% constitute patients with hand and wrist injuries. This amounts to 287,000 patients each year. This thesis aims to improve diagnosis, treatment and prognosis of patients with wrist injury.

PART 1: DIAGNOSIS

Around 40% of the patients who attend the Emergency Department with wrist trauma have sustained a fracture.[3] However, most patients are routinely referred for radiography.[3-5] In a number of hospitals, patients receive radiographs even before clinical examination, challenging the traditional sequence of taking a history, performing a physical exam and (only) then ordering necessary diagnostic tests.

There are several possible explanations for this routine, including Emergency Department crowding and efficient management of time.[6] Physicians working the Emergency Department may also be uncritical when it comes to referring patients for X-ray examinations to reassure the patient, or because of the possible medicolegal consequences of a missed fracture.[6,7] The latter reason classifies as defensive medicine and is associated with high costs.[8]

Selecting patients for wrist radiography could result in more efficient use of X-ray examinations in the Emergency Department.[5] However, this requires physicians to be able to interpret clinical findings and accurately rule out a fracture of the wrist on the basis of their clinical findings alone.[9] In **Chapter 1** we examine physicians' ability to rule out a distal radius fracture based on clinical findings.

Several studies have demonstrated differences among hospitals in referral ratio for X-rays of patients following wrist trauma.[3,4] This variability between physicians in their perception of what constitutes clinical suspicion of fractures implies a lack of clear guidelines regarding the X-ray referral policy.[3,4,10] A validated clinical decision rule could reinforce physicians' clinical judgment and support them in their decision not to request radiography. Several clinical decision rules for musculoskeletal trauma already exist including for ankle[11], elbow[12] and knee trauma.[13] The most famous clinical decision rule is probably the Ottawa Ankle Rules.[11] However, despite the high incidence of wrist trauma, there are no guidelines or criteria available that indicate which patients with wrist trauma require an X-ray. In **Chapter 2** we derive and externally validate a clinical decision rule for the use of radiography in acute wrist trauma.

Radiographic imaging following acute wrist trauma is often performed routinely in children as well.[3] This unnecessarily exposes children to possible stressful examinations and radiation. Although radiation exposure of plain radiography of the wrist is low, it is important to prevent unnecessary radiation exposure.[14]

With the potential benefits of selective radiography in children in mind, Webster et al. attempted to develop a clinical decision rule for paediatric patients with acute wrist trauma.[15] However, their decision rule was never externally validated. External validation is the process of assessing the generalizability of a clinical prediction model or rule.[16] This is attained by testing the rule a different patient population and comparing the observed outcomes to the predicted outcomes. Evaluating the performance of a prediction model or a clinical decision rule in a new patient population is essential before its implementation. In **Chapter 3**, we derive and externally validate a clinical decision rule for the use of radiography in acute wrist trauma for paediatric patients.

PART 2: TREATMENT

The most common fracture of the wrist is the distal radius fracture, followed by a scaphoid fracture.[17,18] The annual incidence of distal radius fracture in the Netherlands is around 200 to 400 per 100,000 persons.[19-21] The incidence increases after the age of fifty, especially in women due to osteoporosis.[22] With the current ageing of the population, it is likely that the incidence of distal radius fracture will further rise in the near future.

Despite the high incidence of distal radius fractures, no evidence regarding the best treatment method exists. And as such, management of distal fractures continues to stimulate debate. Non-dislocated fractures generally tend to be stable and can be treated conservatively. However, two-thirds of the distal radius fractures are displaced and require reduction.[23] The optimal treatment of these types of fractures hinges on alleged fracture instability.

Treatment of unstable distal radius fractures is the subject of numerous studies. Nevertheless, a prerequisite for implementing the findings of these studies is the generalizability of the results. Generalizability refers to the degree to which the findings in the study population can be applied to another, future population of patients.[24,25] Studies that focus on the treatment of unstable distal radius fractures should therefore clearly describe what they regarded as an unstable fracture. However, instability is in the eye of the beholder and therefore a situation that is difficult to capture in a definition. In **Chapter 4** we describe the most common definitions of an unstable distal radius fracture in literature to examine if there is one preferred evidence-based definition for future authors.

The absence or variability in definitions of an unstable distal radius fracture in literature hampers apparent comparison of studies. As such, there is still no optimum treatment for distal radius fractures.[26] While the evidence remains inconclusive, the choice of treatment is frequently based on surgeon's preference. These preferences vary according to surgeon's age and background and likely result in variations in practice across hospitals.[27-29] Variation based on these non patient-related factors is unwarranted and suggests potential to improve cost-effectiveness. The first step in addressing potentially unwarranted variation is insight into the extent in which variation across practices exists. In **Chapter 5** we examine the variation in surgical treatment rates across all Dutch hospitals.

When two types of treatment generally achieve acceptable results and literature does not substantiate the choice for one over the other, cost-effectiveness comes into play. Annually, hand and wrist injuries account for 740 million U.S. dollars and are the most expensive type of injury, outranking lower limb and knee fractures.[1] Around 56% of the costs are related to loss of productivity.[1] Internal fixation allows early mobilisation of the injured wrist possibly resulting in less absence from work. However, the direct costs of operative management are two to three times higher than conservative treatment.[30,31] Conversely, secondary fracture dislocation following closed reduction occurs in up to 59% of the patients[32,33], after which surgical fixation is the treatment of choice.[33] In **Chapter 6** we compare functional outcome of volar locking plate versus external fixation in patients with unstable distal radius fractures. In **Chapter 7** we describe the design of a multicentre randomised controlled trial to compare the functional outcome following surgical reduction and fixation with a volar locking plate with the functional outcome following closed reduction and plaster immobilisation in patients with displaced extra-articular distal radius fractures. Simultaneously, we describe the parallel economic evaluation study of these two treatment modalities.

If secondary fracture dislocation is left untreated, patients can develop a symptomatic malunion of the distal radius.[34-36] A corrective osteotomy for patients with a malunited radius fracture can improve wrist function and reduce stiffness and pain.[37] However, malunions of the radius commonly involve complex three dimensional deformations in different planes, and therefore represent a therapeutic challenge to surgeons.[38-42] Conscientious preoperative planning of the procedure and accurate surgical repositioning is required to achieve accurate anatomical reconstruction.[43-45] Computer-assisted preoperative and intra-operative planning may optimise the results of corrective osteotomies of the radius. In **Chapter 8** we analyse the radiological results of computer-assisted 3-D planned corrective osteotomy in a series of patients with a malunited radius fracture.

PART 3: PROGNOSIS

Ideally, patients with a significant risk of secondary fracture displacement are identified at the time of presentation and selected for pre-emptive surgical treatment. This would enable timely definitive management, avoid unnecessary painful manipulation and possibly reduce the incidence of malunions.[32] Unfortunately, patients with potentially unstable distal radius fractures are difficult to identify. In **Chapter 9** we describe the results of a meta-analysis of predictors of secondary displacement in distal radius fractures.

Another method to identify a patient with an unstable distal radius fracture is by using a clinical prediction model. The largest study to develop a clinical decision rule was Mackenney et al., who performed a study in over 4,000 patients.[32] However, although the model is available as an online calculator and can thus be used in clinical practice, it has never been externally validated. In **Chapter 10** we describe the results of the external validation of this model in a different patient population with displaced distal radius fractures.

Although the goal of treatment of distal radius fractures is to achieve and maintain anatomic alignment, radiologic parameters are not always predictive for functional outcome.[46,47] Especially in elderly patients, for whom subjective functional results generally tend to be less susceptible to distal radius fracture alignment.[47-49] This is one of the reasons why patient-reported outcomes have started to gain importance in orthopaedic research.[50-52]

One of the most frequently used outcome measures in distal radius fracture studies is the Patient-rated Wrist Evaluation score, a 15-item questionnaire designed to measure patient wrist pain and disability. To recognize a treatment effect expressed as a change in PRWE score, it is important to be aware of the minimum clinically important difference (MCID) of the PRWE score. The MCID represents the smallest change in score that would be perceived by the patient as beneficial.[51,53,54] Consequently, a numeric change in score that is less than the MCID, even if statistically significant, does not represent a true clinically relevant change. Because the MCID defines a difference that is considered important to patients, it also serves as the basis for estimating the necessary sample size in designing future studies.[55] in **Chapter 11** we determine the Minimum Clinically Important Difference of the PRWE for patients with distal radius fractures.

REFERENCES

1. de Putter CE, Selles RW, Polinder S, Panneman MJ, Hovius SE, van Beeck EF. Economic impact of hand and wrist injuries: health-care costs and productivity costs in a population-based study. J Bone Joint Surg Am 2012 May 2;94(9):e56.

2. Larsen CF, Mulder S, Johansen AM, Stam C. The epidemiology of hand injuries in The Netherlands and Denmark. Eur J Epidemiol 2004;19(4):323-327.

3. van den Brand CL, van Leerdam RH, van Ufford JH, Rhemrev SJ. Is there a need for a clinical decision rule in blunt wrist trauma? Injury 2013 Nov;44(11):1615-1619.

4. ROYAL COLLEGE OF RADIOLOGISTS WORKING PARTY. Radiography of injured arms and legs in eight accident and emergency units in England and Wales. Royal College of Radiologists Working Party. Br Med J (Clin Res Ed) 1985 Nov 9;291(6505):1325-1328.

5. Gleadhill DN, Thomson JY, Simms P. Can more efficient use be made of x ray examinations in the accident and emergency department? Br Med J (Clin Res Ed) 1987 Apr 11;294(6577):943-947.

6. Long AE. Radiographic decision-making by the emergency physician. Emerg Med Clin North Am 1985 Aug;3(3):437-446.

7. de Lacey G, Barker A, Wignall B, Reidy J, Harper J. Reasons for requesting radiographs in an accident department. Br Med J 1979 Jun 16;1(6178):1595-1597.

8. Sethi MK, Obremskey WT, Natividad H, Mir HR, Jahangir AA. Incidence and costs of defensive medicine among orthopedic surgeons in the United States: a national survey study. Am J Orthop (Belle Mead NJ) 2012 Feb;41(2):69-73.

9. Stiell IG, Wells GA. Methodologic standards for the development of clinical decision rules in emergency medicine. Ann Emerg Med 1999 Apr;33(4):437-447.

10. Walenkamp MM, Schep NW. Re: Is there a need for a clinical decision rule in blunt wrist trauma? Injury 2014 Nov;45(11):1798-1799.

11. Stiell IG, Greenberg GH, McKnight RD, Nair RC, McDowell I, Worthington JR. A study to develop clinical decision rules for the use of radiography in acute ankle injuries. Ann Emerg Med 1992 Apr;21(4):384-390.

12. Appelboam A, Reuben AD, Benger JR, Beech F, Dutson J, Haig S, et al. Elbow extension test to rule out elbow fracture: multicentre, prospective validation and observational study of diagnostic accuracy in adults and children. BMJ 2008 Dec 9;337:a2428.

13. Stiell IG, Wells GA, McDowell I, Greenberg GH, McKnight RD, Cwinn AA, et al. Use of radiography in acute knee injuries: need for clinical decision rules. Acad Emerg Med 1995 Nov;2(11):966-973.

14. Frush DP, Frush KS. The ALARA concept in pediatric imaging: building bridges between radiology and emergency medicine: consensus conference on imaging safety and quality for children in the emergency setting, Feb. 23-24, 2008, Orlando, FL - Executive Summary. Pediatr Radiol 2008 Nov;38 Suppl 4:S629-32.

15. Webster AP, Goodacre S, Walker D, Burke D. How do clinical features help identify paediatric patients with fractures following blunt wrist trauma? Emerg Med J 2006 May;23(5):354-357.

16. Steyerberg EW, Vergouwe Y. Towards better clinical prediction models: seven steps for development and an ABCD for validation. Eur Heart J 2014 Aug 1;35(29):1925-1931.

17. van Staa TP, Dennison EM, Leufkens HG, Cooper C. Epidemiology of fractures in England and Wales. Bone 2001 Dec;29(6):517-522.

18. Karl JW, Olson PR, Rosenwasser MP. The Epidemiology of Upper Extremity Fractures in the United States, 2009. J Orthop Trauma 2015 Mar 16.

19. Oskam J, Kingma J, Klasen HJ. Fracture of the distal forearm: epidemiological developments in the period 1971-1995. Injury 1998 Jun;29(5):353-355.

20. Bentohami A, Bosma J, Akkersdijk GJM, van Dijkman B, Goslings JC, Schep NWL. Incidence and characteristics of distal radial fractures in an urban population in The Netherlands. Eur J Trauma Emerg Surg 2014;40:357--361.

21. de Putter CE, Selles RW, Polinder S, Hartholt KA, Looman CW, Panneman MJ, et al. Epidemiology and health-care utilisation of wrist fractures in older adults in The Netherlands, 1997-2009. Injury 2013 Apr;44(4):421-426.

22. Schuit SC, van der Klift M, Weel AE, de Laet CE, Burger H, Seeman E, et al. Fracture incidence and association with bone mineral density in elderly men and women: the Rotterdam Study. Bone 2004 Jan;34(1):195-202.

23. Brogren E, Petranek M, Atroshi I. Incidence and characteristics of distal radius fractures in a southern Swedish region. BMC Musculoskelet Disord 2007 May 31;8:48.

24. Grobbee DE, Hoes AW. Introduction. Clinical Epidemiology: Principles, Methods, and Applications for Clinical Research: Jones & Bartlett Learning; 2009. p. 21.

25. Grobbee DE, Hoes AW. Randomized Trials. Clinical Epidemiology: Principles, Methods, and Applications for Clinical Research: Jones & Bartlett Learning; 2009. p. 275.

26. Lichtman DM, Bindra RR, Boyer MI, Putnam MD, Ring D, Slutsky DJ, et al. American Academy of Orthopaedic Surgeons clinical practice guideline on: the treatment of distal radius fractures. J Bone Joint Surg Am 2011 Apr 20;93(8):775-778.

27. Chung KC, Shauver MJ, Birkmeyer JD. Trends in the United States in the treatment of distal radial fractures in the elderly. J Bone Joint Surg Am 2009 Aug;91(8):1868-1873.

28. Ansari U, Adie S, Harris IA, Naylor JM. Practice variation in common fracture presentations: a survey of orthopaedic surgeons. Injury 2011 Apr;42(4):403-407.

29. Waljee JF, Zhong L, Shauver MJ, Chung KC. The influence of surgeon age on distal radius fracture treatment in the United States: a population-based study. J Hand Surg Am 2014 May;39(5):844-851.

30. Shauver MJ, Yin H, Banerjee M, Chung KC. Current and future national costs to medicare for the treatment of distal radius fracture in the elderly. J Hand Surg Am 2011 Aug;36(8):1282-1287.

31. Dutch Society for Surgery. Distal Radius Fractures, diagnosis and treatment. 2010; Available at: http://www.heelkunde.nl/uploads/h8/VM/h8VMOlRX83oW2NS-R_5rTWw/Richtlijn_Distale_radius_fracturen_definitieve_versie_0511.pdf. Accessed 06/11, 2015.

32. Mackenney PJ, McQueen MM, Elton R. Prediction of instability in distal radial fractures. J Bone Joint Surg Am 2006 Sep;88(9):1944-1951.

33. Jenkins NH. The unstable Colles' fracture. J Hand Surg Br 1989 May;14(2):149-154.

34. Cooney WP,3rd, Dobyns JH, Linscheid RL. Com-

plications of Colles' fractures. J Bone Joint Surg Am 1980;62(4):613-619.

35. McKay SD, MacDermid JC, Roth JH, Richards RS. Assessment of complications of distal radius fractures and development of a complication checklist. J Hand Surg 2001 sep;26(5):916-922.

36. Crisco JJ, Moore DC, Marai GE, Laidlaw DH, Akelman E, Weiss AP, et al. Effects of distal radius malunion on distal radioulnar joint mechanics--an in vivo study. J Orthop Res 2007 Apr;25(4):547-555.

37.Buijze GA, Prommersberger KJ, Gonzalez Del Pino J, Fernandez DL, Jupiter JB. Corrective osteotomy for combined intra- and extra-articular distal radius malunion. J Hand Surg Am 2012 Oct;37(10):2041-2049.

38. Bilic R, Zdravkovic V, Boljevic Z. Osteotomy for deformity of the radius. Computer-assisted three-dimensional modelling. J Bone Joint Surg Br 1994 Jan;76(1):150-154.

39. Miyake J, Murase T, Yamanaka Y, Moritomo H, Sugamoto K, Yoshikawa H. Comparison of three dimensional and radiographic measurements in the analysis of distal radius malunion. J Hand Surg Eur Vol 2013 Feb;38(2):133-143.

40. Pennock AT, Phillips CS, Matzon JL, Daley E. The effects of forearm rotation on three wrist measurements: radial inclination, radial height and palmar tilt. Hand Surg 2005 Jul;10(1):17-22.

41. Cirpar M, Gudemez E, Cetik O, Turker M, Eksioglu F. Rotational deformity affects radiographic measurements in distal radius malunion. European Journal of Orthopaedic Surgery & Traumatology 2010 Jun;21(1):13-20.

42. Capo JT, Accousti K, Jacob G, Tan V. The effect of rotational malalignment on X-rays of the wrist. J Hand Surg Eur Vol 2009 Apr;34(2):166-172.

43. Fernandez DL. Correction of post-traumatic wrist deformity in adults by osteotomy, bone-grafting, and internal fixation. J Bone Joint Surg Am 1982 Oct;64(8):1164-1178.

44. Prommersberger KJ, Van Schoonhoven J, Lanz UB. Outcome after corrective osteotomy for malunited fractures of the distal end of the radius. J Hand Surg Br 2002 Feb;27(1):55-60.

45. Vroemen JC, Dobbe JG, Strackee SD, Streekstra GJ. Positioning evaluation of corrective osteotomy for the malunited radius: 3-D CT versus 2-D radiographs. Orthopedics 2013 Feb;36(2):e193-9.

46. Bentohami A, Bijlsma TS, Goslings JC, de Reuver P, Kaufmann L, Schep NW. Radiological criteria for acceptable reduction of extra-articular distal radial fractures are not predictive for patient-reported functional outcome. J Hand Surg Eur Vol 2013 Jun;38(5):524-529.

47. Beumer A, McQueen MM. Fractures of the distal radius in low-demand elderly patients: closed reduction of no value in 53 of 60 wrists. Acta Orthop Scand 2003 Feb;74(1):98-100.

48. Grewal R, MacDermid JC. The risk of adverse outcomes in extra-articular distal radius fractures is increased with malalignment in patients of all ages but mitigated in older patients. J Hand Surg Am 2007 Sep;32(7):962-970.

49. Grewal R, MacDermid JC. The risk of adverse outcomes in extra-articular distal radius fractures is increased with malalignment in patients of all ages but mitigated in older patients. J Hand Surg Am 2007 Sep;32(7):962-970.

50. Sorensen AA, Howard D, Tan WH, Ketchersid J, Calfee RP. Minimal clinically important differences of 3 patient-rated outcomes instruments. J Hand Surg Am 2013 Apr;38(4):641-649.

51. Smith MV, Calfee RP, Baumgarten KM, Brophy RH, Wright RW. Upper extremity-specific measures of disability and outcomes in orthopaedic surgery. J Bone Joint Surg Am 2012 Feb 1;94(3):277-285.

52. Swiontkowski MF, Buckwalter JA, Keller RB, Haralson R. The outcomes movement in orthopaedic surgery: where we are and where we should go. J Bone Joint Surg Am 1999 May;81(5):732-740.

53. Calfee RP, Adams Aa. Clinical research and patient-rated outcome measures in hand surgery. J Hand Surg 2012 apr;37(4):851-855.

54. Jaeschke R, Singer J, Guyatt GH. Measurement of health status. Ascertaining the minimal clinically important difference. Control Clin Trials 1989 Dec;10(4):407-415.

55. Schmitt JS, Di Fabio Richard P. Reliable change and minimum important difference (MID) proportions facilitated group responsiveness comparisons using individual threshold criteria. J Clin Epidemiol 2004 oct;57(10):1008-1018.

PART 1

DIAGNOSIS

CHAPTER 1

A MULTICENTRE CROSS SECTIONAL STUDY TO EXAMINE PHYSICIANS' ABILITY TO RULE OUT A DISTAL RADIUS FRACTURE BASED ON CLINICAL FINDINGS

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ABSTRACT

Purpose
To study current use of radiography in patients with wrist trauma and examine physicians' ability to ruleout a distal radius fracture based on their physical findings.

Methods
We performed a multicentre cross-sectional observational study in five Emergency Departments (ED) between November 2010 and June 2014 and included all consecutive adult patients with wrist trauma. Physicians were asked to perform a standardized examination of the wrist and to subsequently indicate the probability of a distal radius fracture.

Results
The majority of the 924 included patients were referred for radiography (99.6%). Of the 920 patients that were imaged, 402 (44%) had sustained a distal radius fracture, 82 (9%) an isolated carpal fracture and 12 (1%) an isolated ulna fracture. Overall, physicians were able to accurately discriminate between patients with and without a distal radius fracture (area under the receiver operating characteristics curve: 0.87, 95% CI: 0.85 - 0.89). Physicians were absolutely certain of their clinical diagnosis in 180 patients (19%), for whom they indicated either a 0% or a 100% probability. In these patients, physicians showed a 99% sensitivity (95% CI: 98% - 100%) and 67% specificity (95% CI: 53% - 80%) for predicting a distal radius fracture.

Conclusions
Although physicians in the ED are able to accurately discriminate between patients with and without a distal radius fracture based on their physical findings, they were only completely certain of their diagnosis in 19% of the patients. A validated clinical decision rule could reinforce physician's clinical judgment and support them in their decision not to routinely request radiography.

INTRODUCTION

Radiography for patients with wrist trauma is routine in most hospitals.[1-3] However, only 40% of these patients have sustained a fracture of the wrist.[2] This conservative approach entails unnecessary exposure to radiation, waiting time for the patient and additional health care expenditure.

Selecting patients for radiography could result in more efficient use of X-ray examinations in the Emergency Department.[1] However, others advocate that the high prevalence of fractures in patients with wrist trauma mandates radiography in all patients.[2] Regardless, since there are no recognized guidelines or criteria available to rely on, physicians will have an overly cautious attitude and continue to request X-rays on a routine basis.

A validated clinical decision rule could reinforce physicians' clinical accuracy and reduce the use of radiography in the Emergency Department. However, this requires physicians to be able to interpret clinical findings and accurately rule out a fracture of the wrist on the basis of their clinical findings alone.[4]

The aim of this study was to study the efficiency of current use of radiography in patients with wrist trauma and examine physicians' ability to accurately rule out a distal radius fracture based on their physical examination.

METHODS

Study design and setting

We performed a multicentre cross-sectional observational study in the Emergency Departments of five Dutch hospitals from November 2010 to April 2014. The participating hospitals included one academic hospital, three teaching hospitals and one non-teaching hospital. The Medical Ethical Review Committees of all participating hospitals approved the study, without the need for informed consent.

Selection of Participants

Enrolment took place 24 h per day, 7 days a week. We included all consecutive adult patients (18 years and older) who presented to the Emergency Department in one of the participating hospitals with pain or tenderness secondary to wrist trauma. The wrist was defined as the proximal segment of the hand, including the carpal bones and the associated soft tissue, and the distal segment of the ulnar and radial bone. Wrist trauma was defined as any high or low energetic accident involving the wrist, such as a fall on outstretched hand (FOOSH). We excluded patients who had sustained multiple injuries (Injury Severity Score ≥16), whose injury had occurred 72 h prior and patients whose X-rays were requested prior to their visit to the Emergency Department (for example by their general practitioner). Additionally, physicians were instructed not to include patients if radiographs had already been ordered, for instance by their General Practitioner, and they were aware of the outcome (fracture present or not). This was ensured, by cross-checking the medical records of all patients 6 months after inclusion and verifying that radiographs had been requested by a provider from the same hospital (and not the General Practitioner). Additionally, the discharge letters were reviewed for any sign that patients had been referred to the Emergency Department with X-rays obtained elsewhere.

For all patients without radiographs taken on the initial visit, we assessed the radiology report during a 6 month period after the ED visit to check for missed fractures. Additionally, we contacted the patients by telephone and inquired if they had visited any other hospital since their ED visit or suffered from prolonged (>2 weeks) wrist pain.

Methods and measurements

Data was collected prospectively using standardized Case Record Forms (CRF). The assessors were asked to perform a standardized examination of each patient with pain or tenderness secondary to wrist trauma. Items included mechanism of injury, physical examination of the wrist and functional tests (Table 1). Additionally, they were asked to indicate the probability of the presence of a distal radius fracture on a 10-cm Visual Analogue Scale (VAS) from 0 to 100. Referral for radiography and type of treatment was at the discretion of the treating physician.

Table 1. Elements of standardized physical examination

Sex
Age
Hand dominance
Mechanism of injury: FOOSH Traumatic hyperflexion Traffic accident Direct blow or compression[a] Punch Other or unknown
Swelling of the wrist
Visible deformation
Distal radius tender to palpation
Distal ulna tender to palpation
Active mobility painful at: Dorsiflexion Palmar flexion Supination Ulnar deviation Radial deviationt
Functional tests painful
Radioulnar ballottement test[b]
Axial compression of forearm

FOOSH, fall on outstretched hand

a. A direct blow to the wrist or compression between two surfaces

b. Test is positive if pain occurs when the ulna is translated from volar to dorsal while the radius manually fixated

Assessors

In the Netherlands, most Emergency Departments are run by emergency physicians. Providers include emergency physicians; emergency medicine registrars; surgical registrars; orthopaedic registrars; junior doctors not in training and 2nd year general practice registrars. Registrars are either supervised by emergency physicians or by their attending (surgeon or orthopaedic surgeon).

The assessors included interns under supervision of a registrar; junior doctors not in training; emergency medicine physicians; emergency medicine registrars; surgical registrars; orthopaedic registrars and 2nd year general practice registrars. All physicians (interns, emergency medicine physicians; emergency medicine registrars; surgical registrars; orthopaedic registrars and general practice registrars) received regular instructions and training on how to assess the clinical variables in a standardized manner. Additionally, we provided informative pocket cards and posters. Medical students and nurses operated under supervision and

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were instructed by one of the physicians.

Outcomes

The reference standard was the presence of a distal radius fracture on the conventional X-ray at presentation, as described in the radiologist report. A fracture was defined as the presence or disruption of one or more of the cortices of the bone. A fissure and an avulsion were recorded as a fracture. The reporting radiologist was blinded to the contents of the Case Record Forms. Patients without any bony fractures of the wrist were diagnosed with a wrist sprain or contusion. Radiographic series comprised at least one posterior-anterior (PA) and one lateral view with approximately 90 degrees of elbow flexion; and any further conventional imaging available (for example scaphoid series). Findings on additional Computed Tomography scans or Magnetic Resonance Image scans were not taken into account. Patients who were not imaged did not return or went elsewhere because persisting complaints were classified as not having sustained a distal radius fracture.

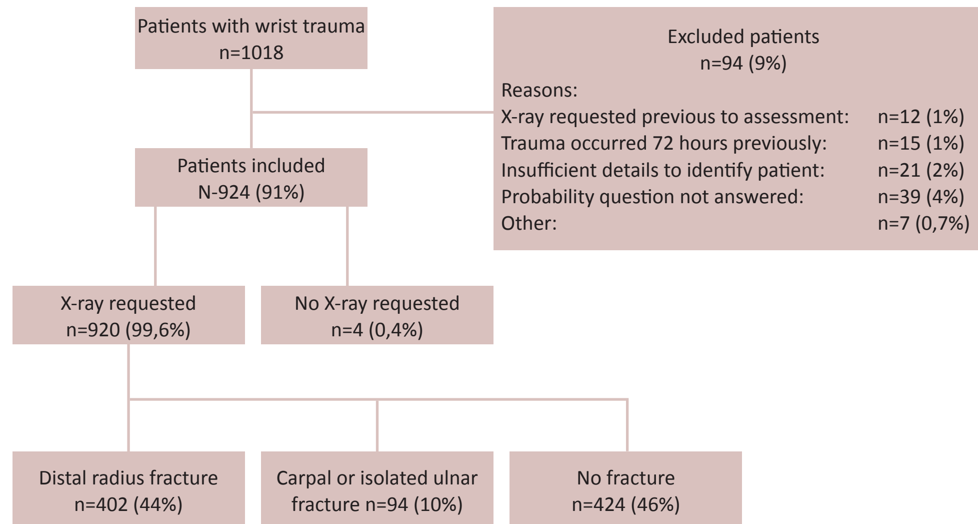
Analysis

Data entry and analysis were performed with the Statistical Package for Social Sciences (SPSS) version 21.0 for Windows. We calculated test characteristics (sensitivity, specificity, predictive values and likelihood ratios) with 95% confidence intervals for patients in the no risk group (0 % probability) and the definite fracture group (100% probability). To estimate the ability of the assessors to discriminate between patients with and without a distal radius fracture, we calculated the area under the receiver operating characteristics curve (AUC) of the predicted probability. The AUC ranges from 0.5 to 1, with higher scores indicating better prediction.

RESULTS

During the study period, 1018 patients visited the ED for wrist trauma and were enrolled in our study. Ninety-two patients (9%) were excluded from the analysis for various reasons (Fig. 1).

Fig. 1 Flowchart of patients through study



A total of 924 patients were analyzed (Table 2). The majority of patients were referred for radiography (99.6%). Of the 920 patients that were imaged, 402 (44%) had sustained a distal radius fracture, 82 (9%) an isolated carpal fracture, 12 (1%) an isolated ulna fracture, and 11 (1%) a fracture of the distal radius and a concomitant carpal fracture. There were 48 scaphoid fractures, 32 triquetrum fractures and 2 other carpal fractures.

Table 2. Demographic characteristics of study population (N = 924)

Age, median (IQR)	49 (31-63)
Female, no. (%)	558 (60)
Mechanism of injury, no. (%)	
FOOSH	607 (66)
Traffic accident	77 (8)
Direct blow	63 (7)
Traumatic hyperflexion	26 (3)
Punch	18 (2)
Other or unknown	133 (14)
Patients with distal radius fracture, no. (%)	402 (44)
Patients with isolated distal ulna fracture, no. (%)	12 (1)
Patients with carpal fracture, no. (%)	82 (9)
Patients with multiple wrist fractures, no. (%)[a]	11 (1)
Treatment	
Expectant	68 (7)
Compression bandag	183 (20)
Plaster immobilisation	447 (48)
Reduction and plaster immobilisation	184 (20)
Primary operative	35 (4)
Not recorded in patients records	7 (1)

IQR, interquartile range; FOOSH, fall on outstretched hand

a. Patients with a distal radius fracture and a concomitant fracture of one or more of the carpal bones

There were eight different types of assessors (Table 3). Surgical registrars and emergency physicians completed most Case Record Forms (Table 3). Four patients were not imaged. The physicians indicated a probability of a distal radius fracture of 0% for two patients and 20% for the other two patients. None of these four patients returned because of persisting complaints, nor did they indicate to have gone elsewhere for a diagnostic workup.

Table 3. Characteristics of assessors and their diagnostic accuracy

Background assessor (N = 924)	Number of assessors	Number of patients assessed (%)	AUC (95 % CI)[a]
Surgical registrar	60	284 (31)	0.85 (0.8 0- 0.89)
Emergency physician	16	214 (23)	0.90 (0.86 - 0.94)
Junior doctor	16	171 (19)	0.92 (0.87 - 0.96)
2nd year GP registrar	43	122 (13)	0.82 (0.74 - 0.90)
Intern under supervision	42	66 (7)	0.78 (0.67 - 0.90)
Emergency registrar	10	59 (6)	0.92 (0.85 - 0.99)
Orthopaedic registrar	4	5 (0.5)	Not calculated
Not recorded in patients files	-	3 (0.5)	Not calculated

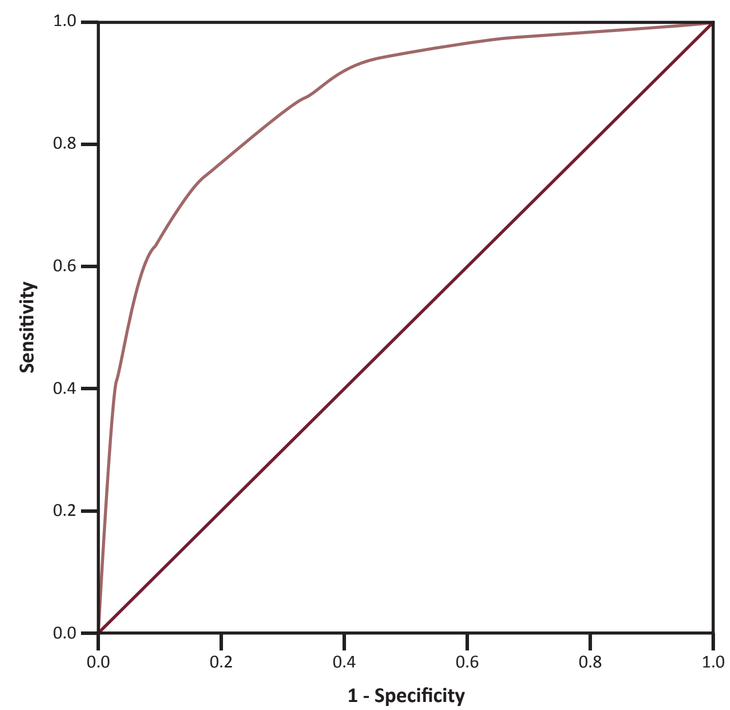
AUC, area under the receiver operating characteristics curve; CI, confidence interval; GP, general practitioner

[a] Area under the receiver operating characteristics curve for physicians' predicted probability of a distal radius fracture

The mean predicted probability of a distal radius fracture was 58% (SD: 33) and the median was 65% (IQR: 25 - 90). Overall, the physicians' predicted probability showed a good discrimination between patients with and without a distal radius fracture: the area under the receiver operating characteristics curve (AUC) was 0.87 (95% CI: 0.85 - 0.89, Fig. 2). The AUC was similar for all types of physicians.

Most patients (N = 292, 32%) were considered to have a medium to high risk of a distal radius fracture. Of those, 123 (42%) had sustained a distal radius fracture (Fig. 3). Physicians were absolutely certain of their clinical diagnosis in 180 patients (19%), for whom they indicated either a 0% or a 100% risk of a distal radius fracture. In 31 patients, the assessors indicated no risk (0%) of a distal radius fracture. They correctly ruled out a distal radius fracture in 30 patients, and missed one minor nondisplaced fracture. In 149 patients, physicians predicted a definite distal radius fracture (100%). They were correct in 134 (90%) patients and incorrect in fifteen (10%) patients. Three of those fifteen patients had sustained a scaphoid fracture and not a distal radius fracture. This resulted in a sensitivity of 99% and a specificity of 67% for predicting a distal radius fracture (Table 4).

Fig. 2 Receiver operating characteristics curve for physicians' predicted probability of a distal radius fracture. The area under the curve is 0.87 (95% CI: 0.85 - 0.90). The green line represents an area under the curve of 0.5, which is equal to a coin toss.



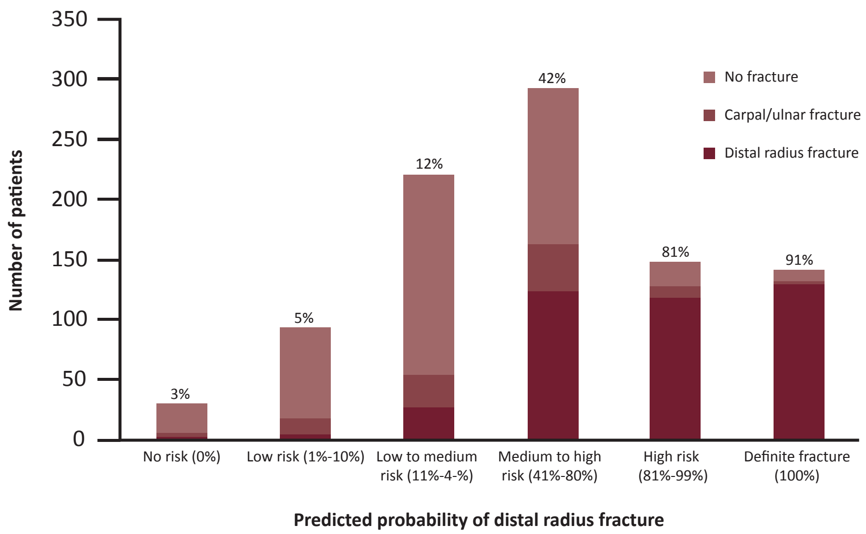


Fig. 3 Distribution of patients (N = 922) with and without fracture by physicians' predicted probability of a distal radius fracture. The percentages are the proportions of patients with a distal radius fracture in each probability group.

Table 4 Diagnostic accuracy of physicians when certain of a presence of distal radius fracture (95% CI)

	Patients with distal radius fracture	Patients without distal radius fracture	Total
No risk (0%)	1	30	31
Definite fracture (100%)	134	15	149
Total	135	45	180
Sensitivity (%)	99.3 (97.8 - 100.0)		
Specificity (%)	67.7 (52.9 - 80.4)		
Positive likelihood ratio	3.0 (2.0 - 4.5)		
Negative likelihood ratio	0.01 (0.0 - 0.08)		

CI, confidence interval

DISCUSSION

This study confirms our expectation that physicians in the Emergency Department are able to accurately rule out the presence of a distal radius fracture based on physical findings alone. For a randomly selected pair of patients, one with and one without a distal radius fracture, the probability that a physician working in the ED will correctly identify the patient with a distal radius fracture is 87%.

The mean predicted probability of 58% versus the observed distal radius fracture rate of

44% shows that physicians tend to overestimate the probability of a distal radius fracture. This study also shows that most patients were classified in the "grey area" with a probability of 41% - 80% of a distal radius fracture. Physicians were only completely sure about their diagnosis in 19% of the patients. Nevertheless, once they were certain, they were able to predict a distal radius fracture with high sensitivity. The low negative likelihood ratio of 0.01 confirms that physicians' judgement is a powerful tool to rule out a distal radius fracture in adults.[5]

Although our study did not mandate radiography for all patients, physicians requested X-rays for 99.6%. This high referral ratio implies a lack of support of physicians in their decision-making and a potential for more efficient use of radiography for wrist trauma. A similar situation existed for ankle injury in the early nineties. Stiell et al. [6] found that physicians requested X-rays for most patients with ankle injury, even though they were able to accurately discriminate between patients with and without a fracture. Their findings suggested a great potential for more efficient use of radiography and lead to the development of the renowned Ottawa Ankle Rules.[7]

This study has several limitations. We did not ask physicians to indicate the probability of a carpal or ulnar fracture. Wrist X-rays are not only requested to rule out a distal radius fracture, but also carpal bone and ulnar fractures. Physicians were not asked to corroborate their decision to request an X-ray of the wrist. It is therefore possible that patients were imaged because of a suspected scaphoid fracture, while a low probability of a distal radius fracture was indicated. Furthermore, physicians might have felt obligated to request an X-ray of the wrist because of the introduction of this study. Although they were otherwise instructed, this could have resulted in an overestimation of the true ratio of patients referred for radiography.

The findings of this study might not be generalizable to other Emergency Departments. In Dutch hospitals, patients are generally examined by emergency physicians, junior doctors not in training or registrars (surgical, emergency, GP and orthopaedic). These include physicians with various levels of training and experience who might put less trust in their clinical judgement. Nevertheless, our results showed a similar diagnostics accuracy among physicians from different backgrounds (Table 3). We acknowledge that clinical judgement is not the only factor that affects the decision to refer a patient for radiography. Patient's expectations, crowded EDs and possible medicolegal consequences of a missed fracture also play a substantial role.[8] However, these factors do not completely account for different referral ratios found among hospitals.[2,3] The significant variability in clinical practice among similar institutions suggests a lack of clinical guidelines.[9]

CONCLUSION

Although physicians in the ED are able to accurately discriminate between patients with and without a distal radius fracture based on their physical findings, they were only completely certain of their diagnosis in 19% of the patients. These findings confirm the potential for more efficient use of radiography for wrist trauma in the Emergency Department. A validated clinical decision rule could reinforce physicians' clinical judgment and support them in their decision not to request radiography. We are currently developing such a clinical decision rule.[10]

REFERENCES

1. van den Brand CL, van Leerdam RH, van Ufford JH, Rhemrev SJ. Is there a need for a clinical decision rule in blunt wrist trauma? Injury 2013 Nov;44(11):1615-1619.

2. ROYAL COLLEGE OF RADIOLOGISTS WORKING PARTY. Radiography of injured arms and legs in eight accident and emergency units in England and Wales. Royal College of Radiologists Working Party. Br Med J (Clin Res Ed) 1985 Nov 9;291(6505):1325-1328.

3. Gleadhill DN, Thomson JY, Simms P. Can more efficient use be made of x ray examinations in the accident and emergency department? Br Med J (Clin Res Ed) 1987 Apr 11;294(6577):943-947.

4. Stiell IG, Wells GA. Methodologic standards for the development of clinical decision rules in emergency medicine. Ann Emerg Med 1999 Apr;33(4):437-447.

5. Worster A, Innes G, Abu-Laban RB. Diagnostic testing: an emergency medicine perspective. CJEM 2002 Sep;4(5):348-354.

6. Stiell IG, McDowell I, Nair RC, Aeta H, Greenberg G, McKnight RD, et al. Use of radiography in acute ankle injuries: physicians' attitudes and practice. CMAJ 1992 Dec 1;147(11):1671-1678.

7. Stiell IG, Greenberg GH, McKnight RD, Nair RC, McDowell I, Worthington JR. A study to develop clinical decision rules for the use of radiography in acute ankle injuries. Ann Emerg Med 1992 Apr;21(4):384-390.

8. Long AE. Radiographic decision-making by the emergency physician. Emerg Med Clin North Am 1985 Aug;3(3):437-446.

9. Walenkamp MM, Schep NW. Re: Is there a need for a clinical decision rule in blunt wrist trauma? Injury 2014 Nov;45(11):1798-1799.

10. Bentohami A, Walenkamp MM, Slaar A, Beerekamp MS, de Groot JA, Verhoog EM, et al. Amsterdam wrist rules: a clinical decision aid. BMC Musculoskelet Disord 2011 Oct 17;12:238.

CHAPTER 2

THE AMSTERDAM WRIST RULES: THE MULTICENTRE PROSPECTIVE DERIVATION AND EXTERNAL VALIDATION OF A CLINICAL DECISION RULE FOR THE USE OF RADIOGRAPHY IN ACUTE WRIST INJURY

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BMC Musculoskelet Disord. 2015

ABSTRACT

Background

Although only 39% of patients with wrist trauma have sustained a fracture, the majority of patients is routinely referred for radiography. The purpose of this study was to derive and externally validate a clinical decision rule that selects patients with acute wrist trauma in the Emergency Department (ED) for radiography.

Methods

This multicenter prospective study consisted of three components: (1) derivation of a clinical prediction model for detecting wrist fractures in patients following wrist trauma; (2) external validation of this model; and (3) design of a clinical decision rule. The study was conducted in the EDs of five Dutch hospitals: one academic hospital (derivation cohort) and four regional hospitals (external validation cohort). We included all adult patients with acute wrist trauma. The main outcome was fracture of the wrist (distal radius, distal ulna or carpal bones) diagnosed on conventional X-rays.

Results

A total of 882 patients were analysed; 487 in the derivation cohort and 395 in the validation cohort. We derived a clinical prediction model with eight variables: age; sex, swelling of the wrist; swelling of the anatomical snuffbox, visible deformation; distal radius tender to palpation; pain on radial deviation and painful axial compression of the thumb. The Area Under the Curve at external validation of this model was 0.81 (95% CI: 0.77 - 0.85). The sensitivity and specificity of the Amsterdam Wrist Rules (AWR) in the external validation cohort were 98% (95% CI: 95% - 99%) and 21% (95% CI: 15% - 28). The negative predictive value was 90% (95% CI: 81% - 99%).

Conclusions

The Amsterdam Wrist Rules is a clinical prediction rule with a high sensitivity and negative predictive value for fractures of the wrist. Although external validation showed low specificity and 100% sensitivity could not be achieved, the Amsterdam Wrist Rules can provide physicians in the Emergency Department with a useful screening tool to select patients with acute wrist trauma for radiography. The upcoming implementation study will further reveal the impact of the Amsterdam Wrist Rules on the anticipated reduction of X-rays requested, missed fractures, Emergency Department waiting times and health care costs.

BACKGROUND

Wrist trauma is one of the most common Emergency Department (ED) attendances and accounts for approximately 20% of all injuries.[1-3] Only 39% of patients with wrist trauma have a fracture; however, most patients are routinely referred for radiography.[4-6]
Unlike ankle[7], elbow[8] and knee[9] injury, there are no guidelines or criteria available that indicate which patients with wrist trauma require an X-ray. A clinical decision rule that selects patients for radiography could avoid unnecessary wrist X-rays and therefore decrease radiation exposure; ED waiting times and reduce health care expenditure.[6,10-12]
Two previous studies investigated the diagnostic value of physicals findings in patients with acute wrist trauma.[13,14] However, these studies were limited by small study populations and did not present a clinical decision rule.

The purpose of this study was to derive and externally validate a clinical decision rule that selects patients with acute wrist trauma in the Emergency Department for radiography.

METHODS

Study design and setting

The study protocol has previously been published.[15] We performed a multicenter prospective study that consisted of three components. (1) derivation of a clinical prediction model for detecting wrist fractures in patients following wrist trauma; (2) external validation of the model in a new patient population enrolled in a different setting; and (3) design of a clinical decision rule. The study was conducted in the Emergency Departments of five Dutch hospitals from November 11, 2010 to June 25 2014. The participating hospitals included one academic hospital and four regional teaching hospitals. The derivation cohort comprised all patients enrolled in the academic hospital. The validation cohort included all patients enrolled in the four other participating hospitals.

Selection of participants

We included all consecutive adult patients who presented to the Emergency Department with pain or tenderness secondary to wrist trauma. The wrist was defined as the proximal segment of the hand, including the carpal bones and the associated soft parts; and the distal segment of the ulnar and radial bone. Wrist trauma was defined as any high or low energetic trauma involving the wrist, such as a fall on outstretched hand (FOOSH). We excluded patients whose injury occurred more than 72 hours previously or multi trauma patients (Injury Severity Score ≥16). Patients who already had an X-ray made previous to their visit to the Emergency Department (for example requested by their general practitioner or by another hospital) were excluded as well. Additionally, physicians were instructed not to include patients if radiographs had already been ordered and they were aware of the outcome (fracture present or not).

Data collection and variables

Eligible patients were included upon presentation in the Emergency Department. Data were collected prospectively by the treating physicians on standardized Case Record Forms (CRF).

Box 1. Potential predictors considered in the full model

Sex (if male)
Age (continuous)
Swelling of wrist
Swelling of the anatomical snuffbox
Visible deformation
Distal radius tender to palpation
Distal ulna tender to palpation
Anatomical snuffbox tender to palpation
Scaphoid tubercle tender to palpation
Active mobility painful dorsiflexion palmar flexion supination pronation ulnar deviation radial deviation
Functional tests painful radioulnar ballottement test[a] axial compression of forearm axial compression thumb pinch grip test

[a] Test is positive if pain occurs when the ulna is translated from volar to dorsal while the radius manually fixated. Except for age, all predictors were ordinal and coded yes (if present) or no (of not present).

Patients were evaluated for 19 clinical variables including patient characteristics, physical examination and functional testing (Box 1). We based the selection of variables on clinical experience and previous studies.[13,14] The questions on the Case Record Form (CRF) were presented in a dichotomous nature (yes/no). Eligibility and data collection forms were verified by two authors by cross-checking the medical records of all patients six months after inclusion.

The assessors were all physicians and included consultant emergency medicine physicians; emergency medicine residents; surgical residents; orthopaedic residents and general practice residents. All physicians received regular instructions and training on how to assess the clinical variables in a standardized manner. Additionally, we provided informative pocket cards and posters. In order not to disrupt common practice, referral for radiography and

type of treatment were at the discretion of the treating physician. Although the study did not mandate radiographs on all wrist-injured patients, only 5 out of 1019 patients (0.5%) did not receive an X-ray of the wrist.

Outcomes

The reference standard was the presence of a fracture of the distal radius, ulna or one of the carpal bones, as assessed by the attending radiologist on the X-ray at presentation. A fracture was defined as a disruption of one or more of the cortices. A fissure and an avulsion were recorded as a fracture. The radiologist was blinded to the contents of the Case Record Forms. Radiographic series comprised at least one posterior-anterior (PA) and one lateral view with 90 degrees of elbow flexion; and any further conventional imaging available (for example scaphoid series). We did not take findings on additional Computed Tomography scans or Magnetic Resonance Image scans into account.

Sample size

A common rule of thumb to determine the sample size of the development of a prediction model is at least ten events (fractures) per variable.[16] Patients were evaluated for 19 variables. Therefore the inclusion of minimum of 190 patients who sustained a fracture was required in the derivation cohort. According to a similar rule of thumb, external validation requires at least 100 patients with an event (fracture) and 100 patients without an event (no fracture).[16] We continued enrolling patients after the required sample size was achieved to maintain the study infrastructure required for the subsequent implementation study. 2

Analysis

For efficient statistical analysis[17-19], we used imputation techniques to impute the missing values (aregImpute function from the Hmisc library, R, version 3.0.1.) For each variable containing missings, the aregImpute package draws values from a random sample from the non-missing values with replacement. Using this data, aregImpute fits a flexible model that predicts the missing target variable while finding its optimum transformation. Each missing variable is then imputed with the observed value whose predicted transformed value is closest to the predicted transformed value of the missing variable. We considered an imputation model that included all dichotomous variables; prehensile grip strength and the outcome. The set of first imputations was used for the analyses.

Model development and internal validation

We derived two clinical prediction models: one for all wrist fractures (distal ulna, distal radius and carpal bone) and one for distal radius fractures only. Using data on patients enrolled in the academic hospital, multivariate logistic regression models with all 19 potential predictors were fit. These full modes were reduced using a stepwise backward elimination process based on a liberal p-value of 0.2.[20] To estimate the internal validation of performance we used bootstrapping (500 replications). Bootstrapping provided the shrinkage factor that was used for the regression coefficients.[21]

External model validation and final model development

To assess general applicability, we validated the shrunk models in the cohort that included all patients enrolled in the four other participating hospitals. For each patient in the validation cohort, the probability of a wrist fracture or of a distal radius fracture was calculated using the prediction models. The validity of the models was assessed by comparing the predicted probabilities of a fracture with the observed fractures. To estimate the ability of the models to discriminate between patients with and without a fracture, we calculated the Areas under the Receiver Operating Characteristics Curve (AUC). The AUC ranges from 0.5 to 1, with a higher score indicating more accurate predictions. The models were also evaluated for their agreement between predicted fractures and observed fractures. This is otherwise known as the model calibration and was assessed by plotting the predicted probability of a fracture and the observed frequency of fractures. The ideal slope of such a plot is 1, indicating perfect agreement between observed and predicted risks.[20] As a final step, the models were fit on data from both cohorts combined to obtain robust estimates of the regression coefficients. These final modes were internally validated by bootstrapping as for the initial models.

Clinical decision rule

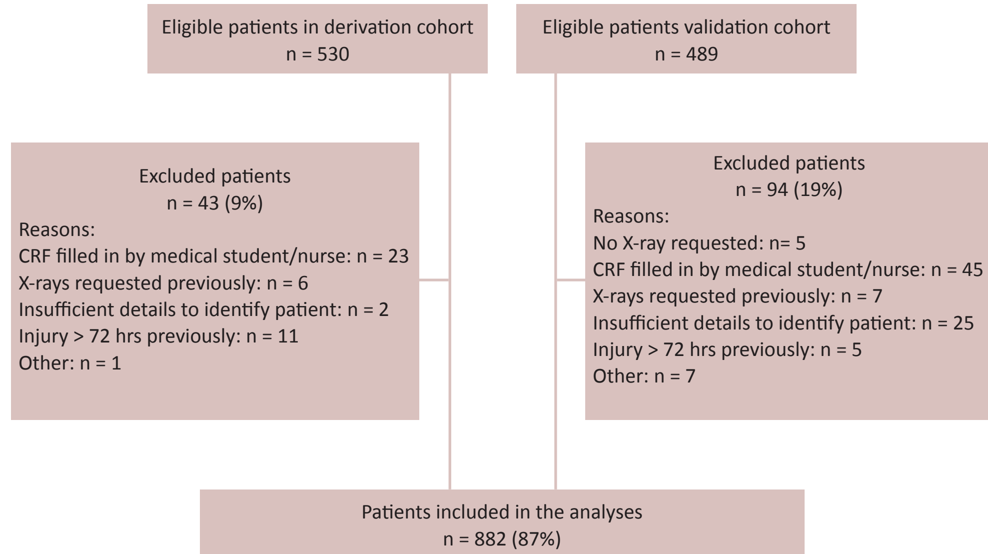
A clinical prediction model provides an estimated risk of a certain outcome. A clinical decision rule goes one step further and links a recommendation to the predicted risk. In this study, the recommendation would be to request an X-ray yes or no. A clinical decision rule therefore requires a cut-off value for the predicted probability of a fracture to classify patients as low or high risk (or recommend an X-ray yes or no). We decided beforehand to select a cut-off value at which the sensitivity of the Amsterdam Wrist Rules would not drop below 98%, while maintaining the highest specificity.

RESULTS

Characteristics of study subjects

We enrolled 1019 patients from five participating hospitals. A total of 137 patients (13%) were excluded patients from the analysis for various reasons (Fig. 1). In total, 882 patients were analyzed (Table 1). In 470 patients (53%), a fracture of the distal radius, distal ulna or one of the carpal bones was identified on conventional radiographic series. A distal radius fracture was the most common fracture (44%).

Figure 1. Flowchart of patients through study



In the derivation cohort, 487 patients were analyzed with a median age of 48 years (interquartile range, 29 - 61) and women were slightly overrepresented (57%). A fall on outstretched hand was the most common mechanism of injury (66%). In 251 patients (52%) in the derivation cohort, a fracture of the distal radius, ulna or one of the carpal bones was identified.

In the validation cohort, 395 patients with similar demographic characteristics were analyzed (Table 1). In 219 of these patients (55%), a fracture of the distal radius, distal ulna or one of the carpal bones was identified.

Table 1. Clinical and demographic Characteristics of derivation cohort and validation cohort

Characteristics	Derivation cohort[a] (n = 487)	Validation cohort[b] (n = 395)	Total[c]
Age, median (IQR)	48 (29-61)	52 (33-68)	50 (31-63)
Female, No. (%)	276 (57)	256 (64.8)	532 (60.3)
Mechanism of injury, No. (%)			
FOOSH	320 (65.7)	265 (67.1)	585 (66.3)
Direct blow or compression	42 (8.6)	22 (5.5)	64 (7.3)
Traffic accident	37 (7.6)	33 (8.4)	70 (8.0)
Forced hyperflexion	19 (3.9)	6 (1.5)	25 (2.8)
Punch	13 (2.7)	4 (1.0)	17 (1.9)
Other/unknown	56 (11.5)	65 (16.5)	121 (13.7)
Patients with a wrist fracture[d], No. (%)	251 (51.5)	219 (55.4)	470 (53.3)
Distal radius fracture, No. (%)[e]	200 (41.1)	184 (46.6)	384 (43.5)
Triquetrum fracture, No. (%)[e]	26 (5.3)	11 (2.8)	37 (4.2)
Scaphoid fracture, No. (%)[e]	25 (5.1)	23 (5.8)	48 (5.4)
Isolated distal ulna fracture, No. (%)[e]	7 (1.4)	3 (0.8)	10 (1.1)
Other carpal bone fracture, No. (%)[e]	2 (0.4)	1 (0.3)	3 (0.3)
Patients with multiple wrist fractures, No. (%)	7 (1.4)	4 (1)	11 (1.2)
Treatment[f]			
Expectant	38 (7.8)	28 (7.0)	66 (7.5)
Compression bandage	94 (19.3)	73 (18.5)	167 (18.9)
Plaster immobilisation	243 (49.9)	190 (48.1)	433 (49.1)
Reduction and plaster immobilisation	94 (19.3)	82 (20.8)	176 (19.9)
Primary operative	18 (3.7)	17 (4.3)	35 (4.0)
Unknown[g]	0	5 (1.3)	5 (0.6)

Abbreviations: IQR, interquartile range; FOOSH, fall on outstretched hand.

a. Data from the academic hospital, the derivation cohort

b. Data from the other four hospitals, the validation cohort

c. The final derivation cohort

d. Fracture of the distal radius, distal ulna or one of the carpal bones.

e. Percentage of total number of patients. Because some patients had multiple fractures, the total number of different fractures is not equal to number of patients with a wrist fracture.

f. Treatment for patients with and without fractures

g. Not recorded in patients files

Missing values and imputation

In both the derivation and the development cohort, around 80% of the cases had fully complete Case Record Forms. With the exception of prehensile grip strength, missing values comprised less than 5% for each variable (see appendix).

Model development

A clinical prediction model for all fractures was derived that included eight variables: age; sex (if male), swelling of the wrist; swelling of the anatomical snuffbox, visible deformation; distal radius tender to palpation; pain on radial deviation and painful axial compression of the thumb. The Area Under the Curve (AUC) of this model was 0.84 (95% CI: 0.81 - 0.88) and 0.82 (95% CI: 0.79 - 0.85) after correcting for model optimism by bootstrapping. The coefficient of each dichotomous variable reflects the amount of change in the probability of a fracture (Table 2). The presence of a dichotomous variable with a positive coefficient adds to the probability of a fracture. The presence of a dichotomous variable with a negative coefficient decreases the probability. The coefficient of the continuous variable age reflects the amount of change in probability for every ten-year increase in age. Except for painful axial compression of the thumb (coefficient -0.37), the presence of all variables adds to the probability of a fracture. Painful axial compression of the thumb decreases the probability of a fracture.

Table 2. Predictors in model for all fractures[a]

Predictor	Coefficient (95% CI)	Odds ratio (95% CI)
Age (per 10 years)	0.35 (0.22 - 0.49)	1.04 (1.02 - 1.05)
Sex (if male)	0.38 (-0.10 - 0.86)	1.46 (0.90 - 2.35)
Swelling wrist	1.48 (1.00 - 1.96)	4.40 (2.72 - 7.11)
Swelling anatomical snuffbox	0.47 (-0.08 - 1.02)	1.60 (0.92 - 2.78)
Visible deformation	1.32 (0.54 - 2.09)	3.73 (1.72 - 8.11)
Distal radius tender to palpation	0.88 (0.23 - 1.53)	2.41 (1.25 - 4.63)
Pain with radial deviation	0.67 (0.08 - 1.26)	1.95 (1.08 - 3.51)
Pain with axial compression of the thumb	-0.37 (-0.88 - 0.14)	0.69 (0.41 - 1.15)

The coefficient of each dichotomous variable reflects the amount of change in the log odds of a fracture. The coefficient of the continuous variable age reflects the amount of change in the log odds of a fracture for every ten-year increase in age.

Abbreviations: CI, Confidence Interval

a. Derived from data from the academic hospital

A clinical prediction model for only distal radius fractures was derived that also included eight variables: age; swelling of the wrist; visible deformation; distal radius tender to palpation; pain on ulnar deviation; palmar flexion, supination and the painful radioulnar ballottement test (Table 3). The presence of all variables except pain on ulnar deviation increases the probability of a distal radius fracture. Pain on ulnar deviation (coefficient -0.67 (95% CI: -1.35 - -0.02) decreases the probability of a distal radius fracture. The Area Under the Curve (AUC) of this model was 0.91 (95% CI: 0.88 - 0.93) and 0.90 (95% CI: 0.87 - 0.92) after optimism correction by bootstrapping.

Table 3. Predictors in model for distal radius fractures[a]

Predictor	Coefficient (95% CI)	Odds ratio (95% CI)
Age (per 10 years)	0.40 (0.25 - 0.54)	1.04 (1.02 - 1.06)
Swelling wrist	2.07 (1.44 - 2.70)	7.92 (4.24 - 14.8)
Visible deformation	1.38 (0.59 - 2.17)	3.97 (1.81 - 8.74)
Distal radius tender to palpation	2.75 (1.22 - 4.28)	15.7 (3.40 - 72.4)
Pain on palmar flexion	0.64 (-0.15 - 1.43)	1.90 (0.86 - 4.18)
Pain on supination	0.81 (0.15 - 1.47)	2.25 (1.16 - 4.37)
Pain on ulnar deviation	-0.67 (-1.35 - -0.02)	0.51 (0.26 - 1.02)
Pain on radioulnar ballottement test	0.56 (-0.02 - 1.15)	1.76 (0.98 - 3.16)

The coefficient of each dichotomous variable reflects the amount of change in the log odds of a fracture. The coefficient of the continuous variable age reflects the amount of change in the log odds of a fracture for every ten-year increase in age.
Abbreviations: CI, Confidence Interval
a. Derived from data from the academic hospital

External model validation and test characteristics
The external performance of the models was assessed in the 395 patients in the validation cohort. The Area Under the Curve at external validation of the model for all fractures was 0.81 (95% CI: 0.77 - 0.85) and the calibration slope was 0.94 (95% CI: 0.74 - 1.13). The Area Under the Curve at external validation of the model for only distal radius fractures was 0.86 (95% CI: 0.82 - 0.89) and the calibration slope was 1.07 (95% CI: 0.84 - 1.29).

The Amsterdam Wrist Rules (AWR) for all wrist fractures showed a sensitivity and specificity of 98% (95% CI: 95% - 99%) and 21% (95% CI: 15% - 28%) (Table 4). Its negative predictive value was 90% (95% CI: 81% - 99%). The sensitivity and specificity for only distal radius fractures were 98% (95% CI: 97% - 100%) and 25% (95% CI: 19% - 31%) (Table 4). The AWR was able to rule out 19% (41 / 219) of the patients without a wrist fracture and 25% (53 / 211) of the patients without a distal radius fracture. If the AWR had been used for all fractures, an X-ray would have been requested for 89.6% (354 / 395) of patients instead of 100%. This is an absolute reduction of 10.4%. The final formula to calculate the probabilities are depicted in Box 2. The AUC of the final model after bootstrapping was 0.88 (95% CI: 0.86 - 0.90)

Table 4. The performance of the Amsterdam Wrist Rules at external validation (N=395)

All Fractures		
Amsterdam Wrist Rules indicate X-ray	215	139
Amsterdam Wrist Rules indicate no X-ray	4	37
Total	219	176
Sensitivity (%)	98.2 (95.1 - 99.4)	15.7 (3.40 - 72.4)
Specificity (%)	21.0 (15.4 - 27.9)	1.90 (0.86 - 4.18)
Distal Radius Fractures		
Amsterdam Wrist Rules indicate X-ray	179	158
Amsterdam Wrist Rules indicate no X-ray	3	53
Total	184	211
Sensitivity (% [95% CI])	98.4 (96.5 - 100.0)	
Specificity (% [95% CI])	25.1 (19.3 - 31.0)	

Abbreviations: CI, Confidence Interval
a. Tested on data from the validation cohort
The cut-off point for X-ray yes or no was a predicted probability of 21% for all fractures and 4% for only distal radius fractures.

Box 2. Calculation of the linear predictor and probability[a]

Linear predictor[b] ALL WRIST FRACTURES
0.0309 * age + 0.5862 * (if male) + 1.1486 * (if swelling wrist present) + 0.5757 * (if swelling anatomical snuff box is present) + 1.7123 * (if visible deformation present) + 0.7029 * (if distal radius tender to palpation) + 0.4963 * (if pain on radial deviation) - 0.1793 * (if on axial compression thumb) - 3.616

Linear predictor[b] DISTAL RADIUS FRACTURES
0.0341 * age + 1.7298 * (if swelling of wrist present) + 1.6462 * (if visible deformation present) + 1.8117 * (if distal radius tender to palpation) + 0.4228 * (if pain on palmar flexion) + 0.6567 * (if pain on supination) - 0.2941 * (if pain on ulnar deviation) + 0.5949 * (if pain during radioulnar ballottement test) - 6.0202

All individual parameters add to the probability of a fracture.
a. Coefficients were derived from a fit of the model on both cohort combined (N = 882) and corrected for optimism by bootstrapping (N=500 replications

DISCUSSION

We have developed a clinical prediction rule with a high sensitivity (98%) and negative predictive value (90%) for fractures of the wrist. Previous studies have illustrated that the X-ray referral policy for patients with wrist trauma is often obscure and unfounded, and to date no guidelines or criteria were available.[5,13,14,22] The Amsterdam Wrist Rules can provide physicians with an externally validated screening tool trauma in the Emergency Department to select patients with acute wrist trauma for radiography.

The foremost strength of the Amsterdam Wrist Rules is that it is one of the few clinical decision rules that have been externally validated. Most clinical decision rules only undergo internal validation, often by bootstrapping.[23] However, evaluating the performance of a prediction model or a clinical decision rule in a new patient population is essential before its implementation. The Amsterdam Wrist Rules underwent this most stringent form of external validation: the rules were tested in a patient population from different type of hospitals with different physicians.[24] The performance of the Amsterdam Wrist Rules expressed in the AUC reflects excellent discriminative ability in a new patient population.

However, the Amsterdam Wrist Rules showed disappointing specificity at external validation. We could have developed the clinical decision rule with higher specificity and number of X-rays avoided. However, this would have resulted in a decreased sensitivity and consequently more fractures missed. Preferably, clinical decision rules in the Emergency Department have a very high sensitivity and negative predictive value. We believe that physicians will be reluctant to use any clinical decision rule with a sensitivity below 98%.[25] In a similar way Stiell et al. devised the Ottawa Ankle Rules with a sensitivity of 100% because they felt that physicians would not accept to miss fractures. However, they also expressed the hope that society will come to accept the small price of an occasionally missed fracture that would probably have led to very little morbidity for the patients.[7]

If the Amsterdam Wrist Rules had been applied in the external validation cohort, the 10% absolute reduction in X-rays would have been accompanied by 4 (1.6%) missed fractures: two scaphoid fractures, one intra-articular distal radius fracture and one extra-articular distal radius fracture. None of these fractures were dislocated or required surgery. Consequently, we advise caution in the use of the Amsterdam Wrist Rules before its true effects on both patient care and use of resources have been evaluated in the upcoming implementation study. After implementation of the Ottawa Ankle Rules, a relative reduction of 26% of ankle radiographies was recorded in the intervention hospital without any missed fractures or patient discontent.[11,26]

Another difference between the study population of the Ottawa Ankle Rules and our study is the pre-test probability. Ankle fractures occurred in around 14% of the patients with ankle injury whereas 53% of our patients had sustained a wrist fracture. This issue was also raised by colleagues van der Brand et al., who concluded that the high percentage of patients that had sustained a fracture warrants radiography in all patients with wrist trauma.[5] We have to agree that the low specificity of the Amsterdam Wrist Rules is somewhat disappointing. However, we feel that referring every patient for radiography would be rash and not appropriate in light of the ever-rising health care costs.[22] Moreover, although specificity of the Amsterdam Wrist Rules was low at external validation, it is better than the current practice to refer nearly all patients for radiography.[5,22] Furthermore, while a 10% reduction in X-rays may seem small, on a national level it corresponds to thousands of X-rays annually.
We decided to derive a second decision rule dedicated to the most common wrist fracture: a distal radius fracture. The performance of this model was better and therefore we recommend its use in patients who are only suspected of a distal radius fracture. We are currently also working on deriving a clinical decision rule dedicated to detecting scaphoid fractures.

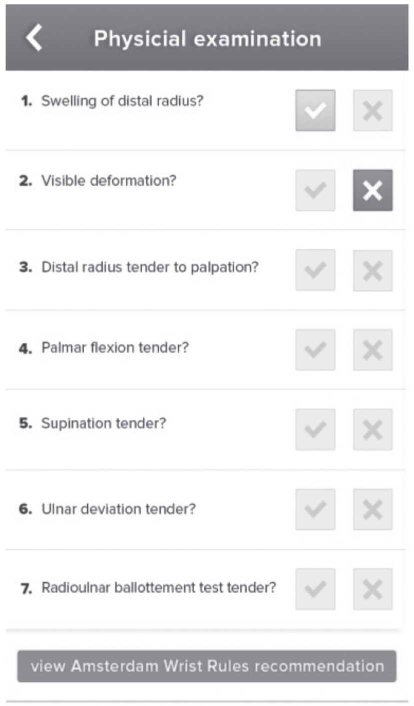
To determine the actual effect of the Amsterdam Wrist Rules in clinical practise we have recently started the implementation study and currently enrolled over a 100 patients. In this study, we will evaluate the reduction in radiographs requested, costs, ED waiting times, missed fractures, patient satisfaction and clinical sensibility to physicians. To simplify application of the Amsterdam Wrist Rules, the formula to predict the probability of a fracture (Box 2) will be made available in a smartphone application (Fig. 2). Upon entering the clinical variables, the application will calculate the probability of fracture and give a recommendation (X-ray yes/no). A secondary implementation study is scheduled to take place in general practitioner's offices. Implementation in this more general setting, where X-ray apparatuses are not readily available, might result in a higher diagnostic yield and even more cost savings.

This study has several limitations. According to methodological standards for the development of clinical decision rules in the Emergency Department, the reliability of predictor variables should be tested by determining the intraobserver and interobserver agreement.[25] However, we considered it unethical to subject patients with a painful wrist to two comprehensive physical examinations. Therefore we were unable to assess the consistency of the candidate predictors.

CONCLUSION

The Amsterdam Wrist Rules is a clinical prediction rule with a high sensitivity and negative predictive value for fractures of the wrist. The Amsterdam Wrist Rules can provide physicians in the Emergency Department with a useful screening tool to select patients with acute wrist trauma for radiography.

Figure 2. A screen shot of the smart phone application that will be used during the implementation study. After entering the clinical findings, the application will calculate the probability of a distal radius fracture using the formula depicted in Box 1. If the probability of a distal radius fracture is <4%, the Amsterdam Wrist Rules application will recommend no radiography. The application was built by ApplicationBuilders.



Ideally, the reference standard for this study was the presence of a distal radius fracture on Multi Slice Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) scans.[16] However, considering the number of participants this was both unethical and not feasible. Therefore, the outcome used for the analysis was the radiographic diagnosis made by the attending independent skeletal radiologist based on the available radiographs at presentation. Consequently, this approach has resulted in a clinical decision rule that does not detect injuries that are not diagnosed on conventional radiography.

REFERENCES

1. Larsen CF, Mulder S, Johansen AM, Stam C. The epidemiology of hand injuries in The Netherlands and Denmark. Eur J Epidemiol 2004;19(4):323-327.

2. de Putter CE, Selles RW, Polinder S, Hartholt KA, Looman CW, Panneman MJ, et al. Epidemiology and health-care utilisation of wrist fractures in older adults in The Netherlands, 1997-2009. Injury 2012 Nov 27.

3. Angermann P, Lohmann M. Hand and wrist injuries. A study of 50.272 injuries. Ugeskr Laeger 1995 Feb 6;157(6):734-737.

4. ROYAL COLLEGE OF RADIOLOGISTS WORKING PARTY. Radiography of injured arms and legs in eight accident and emergency units in England and Wales. Royal College of Radiologists Working Party. Br Med J (Clin Res Ed) 1985 Nov 9;291(6505):1325-1328.

5. van den Brand CL, van Leerdam RH, van Ufford JH, Rhemrev SJ. Is there a need for a clinical decision rule in blunt wrist trauma? Injury 2013 Nov;44(11):1615-1619.

6. Gleadhill DN, Thomson JY, Simms P. Can more efficient use be made of x ray examinations in the accident and emergency department? Br Med J (Clin Res Ed) 1987 Apr 11;294(6577):943-947.

7. Stiell IG, Greenberg GH, McKnight RD, Nair RC, McDowell I, Worthington JR. A study to develop clinical decision rules for the use of radiography in acute ankle injuries. Ann Emerg Med 1992 Apr;21(4):384-390.

8. Appelboam A, Reuben AD, Benger JR, Beech F, Dutson J, Haig S, et al. Elbow extension test to rule out elbow fracture: multicentre, prospective validation and observational study of diagnostic accuracy in adults and children. BMJ 2008 Dec 9;337:a2428.

9. Stiell IG, Wells GA, McDowell I, Greenberg GH, McKnight RD, Cwinn AA, et al. Use of radiography in acute knee injuries: need for clinical decision rules. Acad Emerg Med 1995 Nov;2(11):966-973.

10. Stiell IG, Clement CM, Grimshaw J, Brison RJ, Rowe BH, Schull MJ, et al. Implementation of the Canadian C-Spine Rule: prospective 12 centre cluster randomised trial. BMJ 2009 Oct 29;339:b4146.

11. Stiell I, Wells G, Laupacis A, Brison R, Verbeek R, Vandemheen K, et al. Multicentre trial to introduce the Ottawa ankle rules for use of radiography in acute ankle injuries. Multicentre Ankle Rule Study Group. BMJ 1995 Sep 2;311(7005):594-597.

12. Charny MC, Ennis WP, Roberts CJ, Evans KT. Can the use of radiography of arms and legs in accident and emergency units be made more efficient? Br Med J (Clin Res Ed) 1987 Jan 31;294(6567):291-293.

13. Cevik AA, Gunal I, Manisali M, Yanturali S, Atilla R, Pekdemir M, et al. Evaluation of physical findings in acute wrist trauma in the emergency department. Ulus Travma Acil Cerrahi Derg 2003 Oct;9(4):257-261.

14. Calvo-Lorenzo I, Martínez-de la Llana O, Blanco-Santiago D, Zabala-Echenagusia J, Laita-Legarreta A, Azores-Galeano X. Would it be possible to develop a set of Ottawa wrist rules to facilitate clinical decision making? Revista Española de Cirugía Ortopédica y Traumatología (English Edition) 2008 0;52(5):315-321.

15. Bentohami A, Walenkamp MM, Slaar A, Beerekamp MS, de Groot JA, Verhoog EM, et al. Amsterdam wrist rules: a clinical decision aid. BMC Musculoskelet Disord 2011 Oct 17;12:238.

16. Steyerberg E. Study design for prediction models. Clinical prediction models, a practical approach to development, validation, and updating New York: Springer; 2009. p. 50-51.

17. Cummings P. Missing data and multiple imputation. JAMA Pediatr 2013 Jul;167(7):656-661.

18. Janssen KJ, Donders AR, Harrell FE,Jr, Vergouwe Y, Chen Q, Grobbee DE, et al. Missing covariate data in medical research: to impute is better than to ignore. J Clin Epidemiol 2010 Jul;63(7):721-727.

19. Sterne JA, White IR, Carlin JB, Spratt M, Royston P, Kenward MG, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. BMJ 2009 Jun 29;338:b2393.

20. Steyerberg E. Evaluation of performance. Clinical Prediction Models, a Practical Approach to Development, Validation, and Updating. New York: Springer; 2009. p. 270--279.

21. Steyerberg E. Overfitting and optimism in prediction models. Clinical prediction models, a practical approach to development, validation, and updating New York: Springer; 2009. p. 94-95,96.

22. Walenkamp MM, Schep NW. Re: Is there a need for a clinical decision rule in blunt wrist trauma? Injury 2014 Nov;45(11):1798-1799.

23. Bleeker SE, Moll HA, Steyerberg EW, Donders AR, Derksen-Lubsen G, Grobbee DE, et al. External validation is necessary in prediction research: a clinical example. J Clin Epidemiol 2003 Sep;56(9):826-832.

24. Moons KG, Kengne AP, Grobbee DE, Royston P, Vergouwe Y, Altman DG, et al. Risk prediction models: II. External validation, model updating, and impact assessment. Heart 2012 May;98(9):691-698.

25. Stiell IG, Wells GA. Methodologic standards for the development of clinical decision rules in emergency medicine. Ann Emerg Med 1999 Apr;33(4):437-447.

26. Stiell IG, Greenberg GH, McKnight RD, Nair RC, McDowell I, Reardon M, et al. Decision rules for the use of radiography in acute ankle injuries. Refinement and prospective validation. JAMA 1993 Mar 3;269(9):1127-1132.

CHAPTER 3

A CLINICAL DECISION RULE FOR THE USE OF PLAIN RADIOGRAPHY IN CHILDREN AFTER ACUTE WRIST INJURY: DEVELOPMENT AND EXTERNAL VALIDATION OF THE AMSTERDAM PEDIATRIC WRIST RULES

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ABSTRACT

Background
In most hospitals, children with acute wrist trauma are routinely referred for radiography.

Objective
To develop and validate a clinical decision rule to decide whether radiography in children with wrist trauma is required.

Materials and methods
We prospectively developed and validated a clinical decision rule in two study populations. All children who presented in the emergency department of four hospitals with pain following wrist trauma were included and evaluated for 18 clinical variables. The outcome was a wrist fracture diagnosed by plain radiography.

Results
Included in the study were 787 children. The prediction model consisted of six variables: age, swelling of the distal radius, visible deformation, distal radius tender to palpation, anatomical snuffbox tender to palpation, and painful or abnormal supination. The model showed an area under the receiver operator characteristics curve of 0.79 (95% CI: 0.76 - 0.83). The sensitivity and specificity were 95.9% and 37.3%, respectively. The use of this model would have resulted in a 22% absolute reduction of radiographic examinations. In a validation study, 7/170 fractures (4.1%, 95% CI: 1.7% - 8.3%) would have been missed using the decision model.

Conclusion
The decision model may be a valuable tool to decide whether radiography in children after wrist trauma is required.

INTRODUCTION

In children, wrist trauma is one of the most common reasons for visiting the emergency department.[1-3] A fracture of the wrist accounts for approximately 25% to 36% of all pediatric fractures.[4-8] The most common diagnosed type of injury following wrist trauma is a fracture of the distal forearm. Occurrence of carpal fractures is low, varying from 1% to 3% in children with a wrist fracture.[7-9]

During the last 4 decades, an increase of distal forearm fractures in children was reported.[2, 3, 6] Due to the increase in incidences, health care costs for pediatric forearm fractures in the United States currently exceed $2 billion per year.[10] An important cause for this rise in health care costs is the increase in the number of radiographs requested.[3, 11]

Unlike ankle and cervical spine injury[12-14], no guidelines are available that indicate when children with wrist trauma require radiography. Therefore, radiographic imaging in children following acute wrist trauma is often performed routinely in most hospitals.[15, 16] However, in one study only 51% of radiograph studies performed in children after wrist trauma demonstrated a fracture.[17]

Because of this routine referral for radiography, unnecessary costs are incurred, waiting time is extended and radiation exposure is increased.[18-21]

The goal of this study was twofold: 1) to derive a clinical decision tool, and 2) to externally validate a clinical decision tool that physicians can use to decide whether referral for radiography in children with acute wrist trauma is required and consequently whether this would lead to a reduction in the number of radiographs requested.

MATERIALS AND METHODS

Design and setting
This study was part of a combined study in which the adult population was analysed separately from the pediatric population. The study protocol of the adult patient group has previously been published.[22] In the pediatric population, we applied practically the same protocol. The results are addressed in this article. We performed a multicenter prospective study from April 6, 2011, to April 15, 2014, in four national hospitals - one university hospital and three non-university teaching hospitals. The children included in the university hospital formed the development cohort. The children included in the three other hospitals formed the validation cohort. We did not expect a difference in referral patterns among hospitals since the university hospital also functions as a local referral center for general practitioners.

The study consisted of three components: 1) to prospectively define a clinical decision tool, 2) to externally validate this clinical decision tool and (3) to define a clinical decision tool.

The Medical Ethical Review Committees of all participating hospitals approved the study (Dutch Trial Registry number NTR2651) and waived informed consent.

Participants

All children younger than 18 years old who presented in the emergency department in one of the four participating hospitals with pain following wrist trauma were included. Children younger than 3 years old were excluded, as it is difficult to obtain an objective physical examination. We also excluded patients whose injury occurred more than 72 h previously or patients who had sustained multiple injuries (Injury Severity Score ≥16). Patients whose radiographs were requested previous to their visit to the emergency department (e.g., by their general practitioner) were excluded as well.22 Patients with pre-existing musculoskeletal disease, coagulopathy or developmental delay and patients with previous history of surgery or recent (<3 months) injury of the affected wrist were also excluded. Physicians were instructed not to include patients if they were aware of the outcome of the radiograph performed before physical examination. Since it was not mandatory to obtain radiography in all children following wrist trauma only 12 out of 897 patients (1.3%) did not undergo radiographic imaging. These children were also not included in the study.

Definitions

Wrist trauma was defined as any high or low energetic accident involving the wrist. Corresponding to the protocol of the adult study population, wrist injury was defined as injury to the proximal segment of the hand, including the carpal bones and the associated soft parts, and the distal one third of the ulnar and radial bone.[22] Since the incidence of carpal fractures in children is low and since scaphoid fractures are frequently occult on plain radiography, carpal fractures were not taken into account.[7, 9, 23] A fracture was defined as a disruption of one or more of the cortices of the bone. Buckle fractures or bowing fractures were also recorded as a true fracture, as were fissures and avulsions. A combined fracture of the ulna and radius, known as an antebrachii fracture, was recorded as one fracture.

Data collection and variables

We used standardized case record forms to prospectively collect our data in all four participating hospitals. The case record form consisted of 18 clinical variables, including patient characteristics, physical examination and functional testing (Appendix 1). All variables were selected after evaluation of previous studies and consensus agreement of clinical experts.[24-26] All variables on the case record form, in exception of grip strength, were dichotomous (yes/no). The attending physician included eligible children after physical examination. The case record forms were filled in after physical examination. The assessors were all physicians and included consultant emergency medicine physicians, general practice registrars, and specialist registrars of the departments of (trauma) surgery, emergency medicine or orthopedics. All physicians received regular instructions and training before recruiting children to the study. Additionally, informative pocket cards and posters were provided. In order not to disrupt common practice, referral for radiography was left to the discretion of the attending physician.

Test methods

The outcome was the presence or absence of a radiologically detected fracture of the distal forearm (radius, ulna or both) diagnosed by the attending radiologist. A third-year resident in radiology (A.S.) and a clinical physician (M.M.J.W.) revised all radiographic imaging and radiologic reports. Any discrepancies in diagnosis were resolved in consensus reading. Where necessary, a pediatric radiologist (R.R.vR.) with more than 10 years of experience was consulted.

Regular clinical information was available for the radiologist, but the content of the case record form was not provided. Conforming to standard clinical practice, plain radiographic imaging consisted of at least one posterior-anterior and one lateral view and any further conventional imaging available (e.g., scaphoid series).

Sample size

A common rule of thumb to determine the sample size of the development of a prediction model is 10 events per variable.[27] Since our case record form (CRF) consisted of 18 variables, the inclusion of a minimum of 180 children who sustained a fracture was required. External validation required at least 100 events (fractures) and 100 non-events.[27]

Statistical analysis

For efficient statistical analysis, we used imputation techniques to input the missing values (aregImpute function from the Hmisc library, R, version 3.0.1.)[28-30] For each missing variable, this algorithm initializes the values from a random sample from the non-missing values. Using this data, it then fits a flexible model that predicts the missing target variable while finding its optimum transformation. Each missing value is imputed with the observed value whose predicted transformed value is closest to the predicted transformed value of the missing variable. We considered an imputation model that included all potential predictor variables and the outcome. The first set of imputations was used for the analyses.

Model development and internal validation

We derived a clinical prediction model from data on patients enrolled in the university hospital.

We fitted a logistic regression model with 18 predictors, which was reduced using a stepwise backward elimination process based on a P-value of 0.15.[31] We used bootstrapping to estimate the internal validity (500 replications). Bootstrapping mimics the process of sampling from the underlying population and is a method to quantify the optimism of a prediction model: the difference between performance in the bootstrap sample and performance in the original sample.[32] A shrinkage factor, also obtained by bootstrap validation, was used for multiplication of the regression coefficients.

External model validation and final model development
To assess general applicability, we validated the model in the cohort that included all children enrolled in the three other participating hospitals. For each patient in the three other hospitals (the validation cohort), the probability of a distal forearm fracture was calculated using the prediction model. To estimate the ability of the model to discriminate between patients with and without a fracture, we calculated the area under the receiver operating characteristics curve (AUC). An AUC of 0.5 means that the test is not predictive. An AUC of 1.0 means that the predictive value is very high. The agreement between observed outcomes and predictions (the calibration of the model) was determined by plotting the predicted probability of a fracture and the observed frequency of a fracture. A slope of 1 is ideal for the observed outcomes versus predicted risk.[31]

In order to provide a recommendation (whether to perform radiography or not), we established a cutoff value for a predicted probability. Previous literature used a threshold varying from 20% to 25% for the use of radiography in children and adolescents for detecting upper extremity injury.33 Therefore, we used a threshold probability of 23% (the mean of 20-25%), beyond which the Amsterdam Pediatric Wrist Rules recommend radiographic imaging for all children with wrist trauma and below which none would undergo radiographic imaging.

As a final step, the model was fitted on data from both cohorts combined to obtain the final estimates of the regression coefficients.

RESULTS

Participants
A consecutive series of 897 children with wrist injury was recruited in the four participating hospitals. We excluded 110 patients (12.2%) for various reasons (Fig. 1). In 364 children (46.3%), a fracture of the distal forearm was diagnosed (Table 1). In the development cohort (the university hospital), we included 408 patients. The mean age was 12 years (standard deviation: 3.0); more than half of them were male (66.7%). A fracture of the distal forearm was diagnosed in 194 patients (47.5%). In the validation cohort (three teaching hospitals), 379 patients were included. There were no significant differences between the cohorts (Table 1). The mean age in the validation cohort was 11 years (standard deviation: 2.9) and 53% were male. In 170 patients (44.9%), a fracture of the distal forearm was diagnosed. The observers had several months up to 21 years of experience in the emergency department (median: 3.5, interquartile range: 2 - 11).

Fig. 1 Flowchart demonstrates patient selection and outcomes

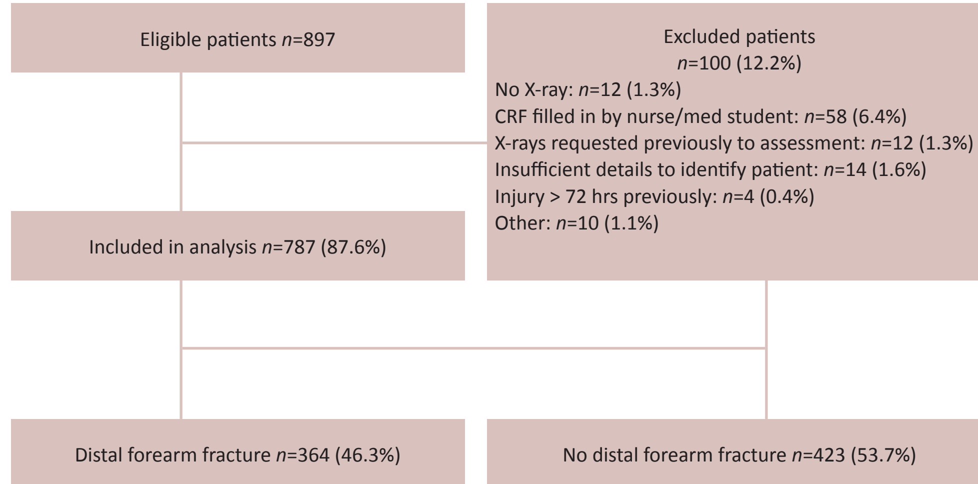


Table 1. Clinical and Demographic Characteristics of Development Cohort, Validation Cohort and Total Cohort

Characteristics	Development Cohort[a] (n = 408)	Validation Cohort[b] (n = 379)	Total[c] (n = 787)
Age, median (SD)	12 (3)	11 (2.9)	11 (2.9)
Male, No. (%)	272 (66.7)	201(53.0)	473 (60.1)
Patients with a fracture of the distal forearm, No. (%)	194 (47.5)	170 (44.9)	364 (46.3)
Fractures	N=207	N=180	N=387
Distal radius	165 (79.8)	155 (86.1)	320 (82.7)
Distal ulna	2 (0.97)	0 (0.0)	2 (0.52)
Antebrachii	27 (13.0)	15 (8.3)	42 (10.9)
Other[d]	13 (6.3)	10 (5.6)	23 (5.9)

Abbreviations: SD, standard deviation
a. Data from the academic hospital, the initial development cohort
b. Data from the other three hospitals, the validation cohort
c. Patients included in the analysis (data from all four hospitals), the final development cohort
d. Fractures of the carpal bones and metacarpal bones.

Missing values and imputation
In both the development and validation cohorts, 83% of the cases were complete. Missing values comprised less than 5% for all variables with the exception of prehensile grip strength, which was not completed in 12.5% of the patients (Appendix 2).

3

Model development

The clinical prediction model derived included six variables: age, swelling of the distal radius, visible deformation, distal radius tender to palpation, anatomical snuffbox tender to palpation and painful supination (Table 2). The AUC of the model was 0.81 (95% CI: 0.76 - 0.85); after correction for optimism by bootstrapping the AUC was 0.77 (95% CI: 0.73 - 0.82). We evaluated lack of fit of the model by relaxing assumptions of linearity and additivity of predictor effects. We hereto examined nonlinear transformations of the variable age, including the square term and the log transformations. We also examined interaction terms between swelling of the distal radius and painful palpation, swelling of the distal radius and visible deformation and painful palpation (Appendix 3). We found no evidence of non-linearity of the effects of age and none of the interactions terms was statistically significant.

Table 2. Contribution of variables as predictors of the presence of a distal forearm fracture in the clinical decision rule

Predictor	Coefficient (95% CI)
Age	-0.14 (-0.22 - -0.061)
Swelling of distal radius present	1.18 (0.706 - 1.65)
Visible deformation	1.58 (0.412 - 2.745)
Bone tenderness distal radius	1.14 (0.278 - 2.004)
Bone tenderness of anatomical snuff box	-1.75 (-2.37 - -1.136)
Supination painful	0.52 (0.006 - 1.028)

Abbreviations: CI, Confidence Interval

External model validation and test characteristics

The external performance of the model was assessed in the 379 patients in the validation cohort. The AUC of the external validation was 0.79 (95% CI: 0.76 - 0.82) and the calibration slope 1.07 (95% CI: 0.82 - 1.33). After applying a threshold of 23%, the sensitivity and specificity of the Amsterdam Pediatric Wrist Rules for detecting fractures of the distal forearm in the validation cohort were respectively 95.9% (95% CI: 91.7% - 98.0%) and 37.3% (95% CI: 31.0% - 44.1%) (Table 3). The Amsterdam Pediatric Wrist Rules led to an absolute reduction of 22% of requested radiographs.

Table 3. Test characteristics and performance of the Amsterdam Paediatric Wrist Rules in the external validation cohorta (95% CI)

	Patients with fracture	Patients without fracture	Total
Amsterdam Paediatric Wrist Rules indicate radiograph	163	131	294
Amsterdam Paediatric Wrist Rules indicate no radiograph	7	78	85
Total	170	209	379
Sensitivity (%)	95.9 (91.7 - 98.0)		
Specificity (%)	37.3 (31.0 - 44.1)		

Abbreviations: CI, Confidence Interval

[a]Tested on data from the other three hospitals (the validation cohort), cut-off point for radiograph yes or no was a predicted probability of 23%.

After applying the Amsterdam Pediatric Wrist Rules, 7/170 fractures (4.1%, 95% CI: 1.7% - 8.3%) were missed in the external validation cohort (Appendix 4). They consisted of six buckle fractures of the distal radius and one non-displaced distal radius fracture with a buckle component. All these missed fractures were found in boys ages 10-15 years old.

3

DISCUSSION

Our derived prediction model, the Amsterdam Pediatric Wrist Rules, is a valuable tool for physicians in the emergency department in deciding if referral for radiography is required in children after acute wrist trauma. We showed that a combination of six clinical variables was able to discriminate between children with and without a fracture with an AUC of 0.79. By applying the Amsterdam Pediatric Wrist Rules, the number of requested radiographs would have been reduced by 22%. The incidence of children with a fracture in the Netherlands in 2009 was 4.465 per 100,000 children from 5-19 year old.[6] Since approximately 50 % of the children with wrist injury are diagnosed with a fracture, this resulted in 8,930 children with wrist injury per 100,000 children in 2009.[17, 34]

By applying the Amsterdam Pediatric Wrist Rules, radiographic imaging could have been prevented in almost 2,000 children per 100,000 (22% reduction). At a price of 48 Euro/$50 per radiograph, the possible reduction of health care cost will be 96.000 euro per 100,000 children annually.[16, 17] This amount is probably an underestimation because the provided incidence included children ages 5-19 years old and the population that could benefit from the Amsterdam Pediatric Wrist Rules is 3-18 years old. As was the case following the implementation study of the Ottawa Ankle Rules, a reduction in waiting time may be expected after applying the Amsterdam Pediatric Wrist Rules.[35] Additionally, we assume that applying the Amsterdam Pediatric Wrist Rules will generate a reduction in radiation exposure. Although radiation exposure of plain radiography of the wrist is low (effective dose: 0.16 µSv), it is important to prevent unnecessary radiation exposure according to the ALARA principle (As Low As Reasonably Achievable), especially in children.[11, 36] Obtaining a US for detecting wrist fractures in children might also reduce radiation exposure; however, only a few studies have been performed, all with small study groups.[36, 37] Moreover, it is unclear if the use of sonography leads to a reduction in health care costs.

After applying the Amsterdam Pediatric Wrist Rules in seven patients (4.3%), a fracture would have been missed. The missed fractures consisted of six buckle fractures of the distal radius and one non-displaced distal radius fracture with a buckle component without displacement. According to literature and an expert panel consisting of two pediatric surgeons, one trauma surgeon and one orthopedic surgeon, none of these fractures needed closed reduction or operative treatment, but would have been treated with a splint.[38-40] This type of treatment is identical to treatment for children without a fracture who are diagnosed with a contusion or sprain of the wrist. We also expect that in children in a lot of pain, physicians are more likely to give a cast for pain regulation. Therefore, we consider that the treatment and prognosis would not have been influenced by a missed or delayed diagnosis.[41] Moreover, in children with stable buckle fractures, it is known that subacute treatment does no lead to adverse clinical outcomes.[42] However, a follow-up evaluation by telephone, or the advice to contact the hospital if symptoms remain after 1 week, can be considered for patients who did not initially require a radiograph, according to the Amsterdam Pediatric Wrist Rules.

Because physicians were not obligated to refer patients for radiography, in 12 patients no radiograph of the wrist was obtained. These patients were not included in the study, but none of these 12 children returned to the hospital for persisting complaints in the following 4 weeks.

A limitation of the Amsterdam Pediatric Wrist Rules is its specificity of 37.3%. We could have generated a higher specificity by using another threshold, but this would have led to a decrease in the sensitivity and thus an increase of missed fractures. In accordance with Maguire et al.[43], we judged it would not be applicable since it misses >5% of fractures in children. Since we aimed to reduce the number of requested wrist radiographs, a threshold compromise between missed fractures and reduction of radiographs was chosen.[33, 44] According to the literature, we determined that about three avoided radiographs outweigh one missed fracture and therefore we used a threshold value of 23.0% (1/25) for the predicted probability.[33] The sensitivity prediction rule was 96%. Adding anamnestic variables to the model could possibly strengthen our prediction rule and result in a higher sensitivity. However, since children are not always capable or trustworthy of telling what type of trauma occurred, we did not take clinical history variables into account.

Another limitation is that some patients with wrist pain were missed due to crowding in the

emergency department. This might have introduced a selection bias. However, we expect that the reasons for missing patients were mostly related to emergency department crowding and not to patient characteristic. Therefore, we consider this bias minimal.

We might have introduced another type of selection bias since this study took place in only university hospitals and non-university teaching hospitals, and not in a non-teaching hospital. We assume that in non-teaching hospitals the referral for radiography is routinely done by triage nurses, while in (university) teaching hospitals the referral for radiography is usually done by physicians. Upcoming studies should reveal if the Amsterdam Pediatric Wrist Rules could also be applied by triage nurses. Nevertheless, we expect that the clinical signs and the incidence of wrist fractures in children in non-teaching hospitals do not significantly differ from (university) teaching hospitals and therefore we do not expect that this has significantly influenced our results.

The final limitation of our study is that in 12.5% of the CRFs the valuable prehensile grip strength was not completed. In several cases, the physician wrote that this was because the patient was in too much pain to perform this test. However, the difference between patients with and without prehensile grip strength as a missing variable was small and therefore it is not likely that our results were influenced by the imputation of this variable.

Three preceding studies have considered the diagnostic value of physical findings in children with acute wrist trauma. In 1986, Rivara et al.[26] retrospectively studied 116 children and found gross deformity and point tenderness to be the best predictors for a fracture of the upper extremity, with a sensitivity of 81% and a specificity of 82%. The sample size and, more importantly, the sensitivity of this study were much lower than in our study results. In 2000, Pershad et al.[24] performed a prospective study in 48 children and found that a 20% or more reduction of grip strength and distal radius point tenderness were predictive values for the presence of a wrist fracture. These clinical predictors had a sensitivity of 79% and a specificity of 63%. However, this study was also limited by a small sample size.

A study performed in 2006 in 227 children showed that radial tenderness, focal swelling and abnormal supination/ pronation were associated with wrist fractures in children.25 These predictive variables showed a sensitivity of 99.1% and specificity of 24%. The predictive variables and sensitivity of these variables were almost similar, but our specificity was higher and thus the potential reduction of the amount of requested radiographs in our study is higher (22% vs. 13%).

None of the decision rules is externally validated, which is recommended.[45] The Amsterdam Pediatric Wrist Rules did undergo external validation in a study population with different type of hospitals and physicians.
An upcoming implementation study will evaluate the impact of the Amsterdam Pediatric

Wrist Rules on the number of radiographs, emergency department waiting times and health care costs. The formula to predict the probability of a fracture (Table 4) will be made available in a smartphone application (Fig. 2). This application will give physicians a recommendation if radiography is recommended according to the probability of a distal forearm fracture.

Table 4. Linear predictors and probability

Linear predictor[a]
-0.185* age (per year) + 1.144 * (if swelling of distal radius present) + 1.56 *(if visible deformation present) + 1.183* (if bone tenderness of distal radius present) + -1.424* (if bone tenderness of anatomical snuff box present) + 0.356 *(if supination painful) + 0.466
Probability of a fracture based on final model
1/ (1+EXP(-Linear Predictor))

[a]Coefficients were derived from a fit of the model on both cohorts combined (n=787)
All individual parameters add to the probability of a fracture.

CONCLUSION

The derived clinical decision model (Amsterdam Pediatric Wrist Rules) may be used as a tool for physicians in the emergency department in deciding if referral for radiography in children after acute wrist trauma is necessary. Applying the model, 7/170 fractures (4.1%, 95% CI: 1.7% - 8.3%) were missed in an external validation study.

Fig. 1 Flowchart demonstrates patient selection and outcomes

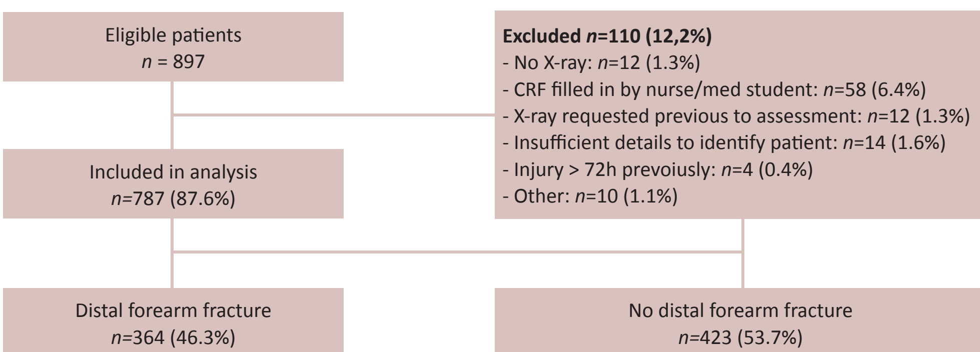
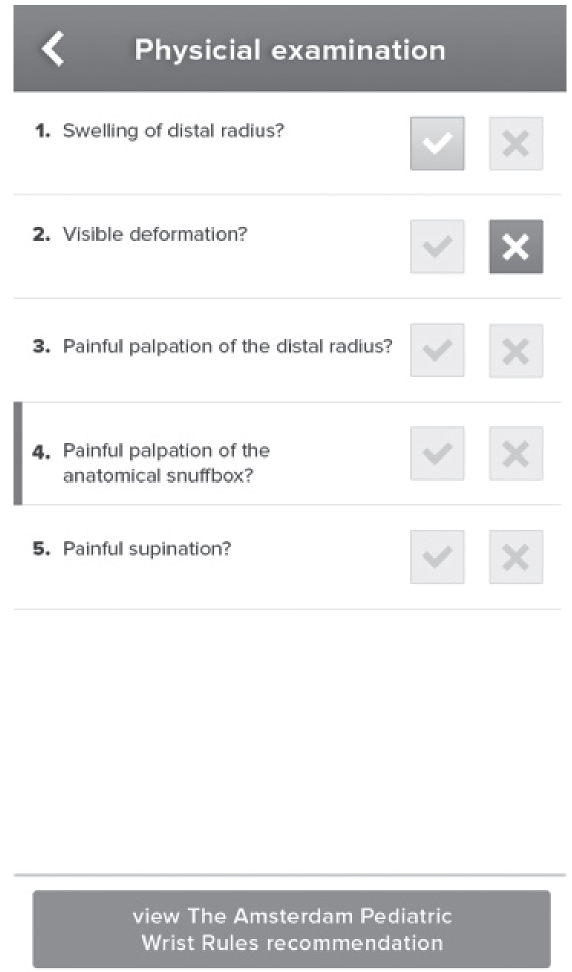


Fig. 2 Screenshot of the smartphone application of the decision model used for the implementation study (built by ©Applicationbuilders, Amstelveen, The Netherlands)



REFERENCES

1. Ruffing T, Arend G, Forster J, Winkler H, Muhm M. Emergency radiographs in injured children and adolescents. Unfallchirurg 2015 Jul;118(7):607-614.

2. Immerman I, Livermore MS, Szabo RM. Use of emergency department services for hand, wrist, and forearm fractures in the United States in 2008. J Surg Orthop Adv 2014 Summer;23(2):98-104.

3. Khosla S, Melton LJ,3rd, Dekutoski MB, Achenbach SJ, Oberg AL, Riggs BL. Incidence of childhood distal forearm fractures over 30 years: a population-based study. JAMA 2003 Sep 17;290(11):1479-1485.

4. Cooper C, Dennison EM, Leufkens HG, Bishop N, van Staa TP. Epidemiology of childhood fractures in Britain: a study using the general practice research database. J Bone Miner Res 2004 Dec;19(12):1976-1981.

5. Hedstrom EM, Svensson O, Bergstrom U, Michno P. Epidemiology of fractures in children and adolescents. Acta Orthop 2010 Feb;81(1):148-153.

6. de Putter CE, van Beeck EF, Looman CW, Toet H, Hovius SE, Selles RW. Trends in wrist fractures in children and adolescents, 1997-2009. J Hand Surg Am 2011 Nov;36(11):1810-1815.e2.

7. Rennie L, Court-Brown CM, Mok JY, Beattie TF. The epidemiology of fractures in children. Injury 2007 Aug;38(8):913-922.

8. Lyons RA, Sellstrom E, Delahunty AM, Loeb M, Varilo S. Incidence and cause of fractures in European districts. Arch Dis Child 2000 Jun;82(6):452-455.

9. Journeau P. Carpal injuries in children. Chir Main 2013 Sep;32 Suppl 1:S16-28.

10. Ryan LM, Teach SJ, Searcy K, Singer SA, Wood R, Wright JL, et al. Epidemiology of pediatric forearm fractures in Washington, DC. J Trauma 2010 Oct;69(4 Suppl):S200-5.

11. Frush DP, Frush KS. The ALARA concept in pediatric imaging: building bridges between radiology and emergency medicine: consensus conference on imaging safety and quality for children in the emergency setting, Feb. 23-24, 2008, Orlando, FL - Executive Summary. Pediatr Radiol 2008 Nov;38 Suppl 4:S629-32.

12. Stiell IG, Wells GA, Vandemheen KL, Clement CM, Lesiuk H, De Maio VJ, et al. The Canadian C-spine rule for radiography in alert and stable trauma patients. JAMA 2001 Oct 17;286(15):1841-1848.

13. Hoffman JR, Mower WR, Wolfson AB, Todd KH, Zucker MI. Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. National Emergency X-Radiography Utilization Study Group. N Engl J Med 2000 Jul 13;343(2):94-99.

14. Plint AC, Bulloch B, Osmond MH, Stiell I, Dunlap H, Reed M, et al. Validation of the Ottawa Ankle Rules in children with ankle injuries. Acad Emerg Med 1999 Oct;6(10):1005-1009.

15. ROYAL COLLEGE OF RADIOLOGISTS WORKING PARTY. Radiography of injured arms and legs in eight accident and emergency units in England and Wales. Royal College of Radiologists Working Party. Br Med J (Clin Res Ed) 1985 Nov 9;291(6505):1325-1328.

16. van den Brand CL, van Leerdam RH, van Ufford JH, Rhemrev SJ. Is there a need for a clinical decision rule in blunt wrist trauma? Injury 2013 Nov;44(11):1615-1619.

17. Slaar A, Bentohami A, Kessels J, Bijlsma TS, van Dijkman BA, Maas M, et al. The role of plain radiography in paediatric wrist trauma. Insights Imaging 2012 Oct;3(5):513-517.

18. Gleadhill DN, Thomson JY, Simms P. Can more efficient use be made of x ray examinations in the accident and emergency department? Br Med J (Clin Res Ed) 1987 Apr 11;294(6577):943-947.

19. Stiell IG, Clement CM, Grimshaw J, Brison RJ, Rowe BH, Schull MJ, et al. Implementation of the Canadian C-Spine Rule: prospective 12 centre cluster randomised trial. BMJ 2009 Oct 29;339:b4146.

20. Stiell I, Wells G, Laupacis A, Brison R, Verbeek R, Vandemheen K, et al. Multicentre trial to introduce the Ottawa ankle rules for use of radiography in acute ankle injuries. Multicentre Ankle Rule Study Group. BMJ 1995 Sep 2;311(7005):594-597.

21. Charny MC, Ennis WP, Roberts CJ, Evans KT. Can the use of radiography of arms and legs in accident and emergency units be made more efficient? Br Med J (Clin Res Ed) 1987 Jan 31;294(6567):291-293.

22. Bentohami A, Walenkamp MM, Slaar A, Beerekamp MS, de Groot JA, Verhoog EM, et al. Amsterdam wrist rules: a clinical decision aid. BMC Musculoskelet Disord 2011 Oct 17;12:238.

23. Tiel-van Buul MM, van Beek EJ, Broekhuizen AH, Nooitgedacht EA, Davids PH, Bakker AJ. Diagnosing scaphoid fractures: radiographs cannot be used as a gold standard! Injury 1992;23(2):77-79.

24. Pershad J, Monroe K, King W, Bartle S, Hardin E, Zinkan L. Can clinical parameters predict fractures in acute pediatric wrist injuries? Acad Emerg Med 2000 Oct;7(10):1152-1155.

25. Webster AP, Goodacre S, Walker D, Burke D. How do clinical features help identify paediatric patients with fractures following blunt wrist trauma? Emerg Med J 2006 May;23(5):354-357.

26. Rivara FP, Parish RA, Mueller BA. Extremity injuries in children: predictive value of clinical findings. Pediatrics 1986 Nov;78(5):803-807.

27. Steyerberg E. Study design for prediction models. Clinical prediction models, a practical approach to development, validation, and updating New York: Springer; 2009. p. 50-51.

28. Cummings P. Missing data and multiple imputation. JAMA Pediatr 2013 Jul;167(7):656-661.

29. Janssen KJ, Donders AR, Harrell FE,Jr, Vergouwe Y, Chen Q, Grobbee DE, et al. Missing covariate data in medical research: to impute is better than to ignore. J Clin Epidemiol 2010 Jul;63(7):721-727.

30. Sterne JA, White IR, Carlin JB, Spratt M, Royston P, Kenward MG, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. BMJ 2009 Jun 29;338:b2393.

31. Steyerberg E. Evaluation of performance. Clinical Prediction Models, a Practical Approach to Development, Validation, and Updating. New York: Springer; 2009. p. 270--279.

32. Steyerberg E. Overfitting and optimism in prediction models, a practical approach to development, valdiation and updating. New York: Springer; 2009.

33. McConnochie KM, Roghmann KJ, Pasternack J, Monroe DJ, Monaco LP. Prediction rules for selective radiographic assessment of extremity injuries in children and adolescents. Pediatrics 1990 Jul;86(1):45-57.

34. CBS Statistics Netherlands (CBS):www.cbs.nl; last accessed on Sept 22; 2014. http://www.cbs.nl/. Accessed 22 Sep 2014

35. Stiell IG, McKnight RD, Greenberg GH, McDowell I, Nair RC, Wells GA, et al. Implementation of the Ottawa ankle rules. JAMA 1994 Mar 16;271(11):827-832.

36. Eckert K, Ackermann O, Schweiger B, Radeloff E, Liedgens P. Sonographic diagnosis of metaphyseal forearm fractures in children: a safe and applicable alternative to standard x-rays. Pediatr Emerg Care 2012 Sep;28(9):851-854.

37. Herren C, Sobottke R, Ringe MJ, Visel D, Graf M, Muller D, et al. Ultrasound-guided diagnosis of fractures of the distal forearm in children. Orthop Traumatol Surg Res 2015 Jun;101(4):501-505.

38. Noonan KJ, Price CT. Forearm and distal radius fractures in children. J Am Acad Orthop Surg 1998 May-Jun;6(3):146-156.

39. Plint AC, Perry JJ, Tsang JL. Pediatric wrist buckle fractures. Should we just splint and go? CJEM 2004 Nov;6(6):397-401.

40. Symons S, Rowsell M, Bhowal B, Dias JJ. Hospital versus home management of children with buckle fractures of the distal radius. A prospective, randomised trial. J Bone Joint Surg Br 2001 May;83(4):556-560.

41. Dello Russo B, Miscione HF. Delayed diagnosis and management of injuries involving the distal radioulnar joint and distal ulna in the pediatric population: recognition and conduct. J Child Orthop 2009 Dec;3(6):465-472.

42. Bennett DL, Mencio GA, Hernanz-Schulman M, Nealy BJ, Damon B, Kan JH. Buckle fractures in children: Is urgent treatment necessary? J Fam Pract 2009 Oct;58(10):E1-6.

43. Maguire JL, Kulik DM, Laupacis A, Kuppermann N, Uleryk EM, Parkin PC. Clinical prediction rules for children: a systematic review. Pediatrics 2011 Sep;128(3):e666-77.

44. Tigges S, Pitts S. Introduction to clinical prediction rules for radiologists. AJR Am J Roentgenol 1999 Dec;173(6):1443-1446.

45. Green SM, Schriger DL, Yealy DM. Methodologic standards for interpreting clinical decision rules in emergency medicine: 2014 update. Ann Emerg Med 2014 Sep;64(3):286-291.

PART 2

TREATMENT

CHAPTER 4

THE UNSTABLE DISTAL RADIUS FRACTURE: HOW DO WE DEFINE IT?

A SYSTEMATIC REVIEW

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J Wrist Surg. 2015

ABSTRACT

Background
Unstable distal radius fractures are a popular research subject. However, to appreciate the findings of studies that enrolled patients with unstable distal radius fractures, it should be clear how the authors defined an unstable distal radius fracture.

Questions
In what percentage of studies involving patients with unstable distal radius fractures did the authors define unstable distal radius fracture? What are the most common descriptions of an unstable distal radius fracture? And is there one preferred evidence-based definition for future authors?

Methods
A systematic search of literature was performed to identify any type of study with the term unstable distal radius fracture. We assessed whether a definition was provided and determined the level of evidence for the most common definitions.

Results
The search yielded 2489 citations of which 479 were included. In 149 studies, it was explicitly stated that patients with unstable distal radius fractures were enrolled. In 54% (81/149) of these studies, the authors defined an unstable distal radius fracture. Overall, we found 143 different definitions. The seven most common definitions were: displacement following adequate reduction; Lafontaine's definition; irreducibility; an AO type C2 fracture; a volarly displaced fracture; Poigenfürst's criteria and Cooney's criteria. Only Lafontaine's definition originated from a clinical study (level IIIb).

Conclusion
In only half of the studies involving patients with an unstable distal radius fracture, did the authors define what they considered an unstable distal radius fracture. None of the definitions stood out as the preferred choice. A general consensus definition could help to standardize future research.

INTRODUCTION
Unstable distal radius fractures are the subject of numerous studies. However, a prerequisite for implementing the findings of these studies is the generalizability of the results. Generalizability is the degree to which the findings in the study population can be applied to another, future population of patients.[1,2] Studies that focus on the treatment of unstable distal radius fractures should therefore clearly describe what their authors regard as an unstable fracture.

However, instability is in the eye of the beholder and therefore a situation that is difficult to capture in a definition. It is often quoted that a fracture of the distal radius is considered to be unstable if it is unable to resist displacement once it has been anatomically reduced. There are various radiological and clinical criteria that would predispose distal radius fractures to instability, but it remains a subjective assessment. Nevertheless, clinical studies require established inclusion criteria and consequently a clear definition of an unstable distal radius fracture.

The absence of this definition or variability in definitions hampers apparent comparison of studies. Standardization or agreement on a definition for an unstable distal radius fracture would facilitate combining study outcomes in meta-analyses and contribute to a higher level of evidence. Therefore, we sought to examine (1) in what percentage of studies involving patients with unstable distal radius fractures the authors defined what they considered an unstable distal radius fracture; (2) what the most commonly mentioned descriptions of an unstable distal radius fracture in any type of study were; and (3) whether there was one preferred definition to recommend to future authors.

METHODS
The present study was reported according to the PRISMA guidelines (Preferred Reporting Items for Systematic reviews and Meta-Analyses).[3] A review protocol was drafted and registered on PROSPERO with number CRD42014011840.

Data Sources
Two reviewers (MMJW) and (LMV) independently conducted a search of the Medline, EMBASE and Cochrane Central Register of Controlled trials databases on November 24, 2013 for any type of study in which the term unstable distal radius fracture occurred (see appendix for the detailed search strings). In order not to miss recently published literature, the use of Medical Subject Heading (MESH) terms was avoided. The complete search strategy is depicted in the supplementary files. The bibliographies of all articles included were reviewed for additional articles of interest.

Eligibility Criteria and Study Selection
Two reviewers independently reviewed all titles and abstracts for relevance. If title and ab-

stract did not provide sufficient information, full text was examined. All articles with the term unstable or instability in combination with distal radius/radial fracture were included. Publication language was restricted to English, German or Dutch. Studies were excluded if (1) they regarded paediatric patients; (2) they used the term unstable or instability in relation with carpal instability or the Distal Radioulnar Joint (DRUJ); (3) it was not clear to what the term unstable or instability referred; and (4) they regarded conference abstracts. Disagreement was resolved by discussion between the two reviewers.

Data Extraction

Two reviewers extracted data independently from eligible studies using a data collection form. Items included general information (authors, year, journal), study type and number of subjects. Additionally, they determined whether unstable distal radius fracture was used as an inclusion criterion. Subsequently, the reviewers evaluated whether a clear definition of fracture instability was described in the methods section or elsewhere in the paper. Definitions were documented word for word.

We regarded the following description as a definition: 1) radiologic criteria or patients characteristics; 2) fracture types; 3) fracture classifications. We did not consider statements that denoted a possibility of fracture instability a definition (for example: intra-articular fractures are sometimes unstable).

Data Synthesis and Quality Assessment

The primary outcome was the percentage of clinical studies involving patients with unstable distal radius fractures in which the authors defined what they considered an unstable distal radius fracture. We regarded randomised controlled trials; cohort; case-control and case series as clinical studies. Secondary outcomes included the most frequently mentioned description of an unstable distal radius fracture in any type of study (including systematic reviews, current concepts and cadaver studies) and the available evidence for these descriptions or definitions.

If applicable, we procured the full text manuscripts of the study from which each definition or description of an unstable distal radius fracture originated. Subsequently, we evaluated the overall quality of the study and determined if the primary research question was to define the term unstable distal radius fracture. If this was the case, we determined the level of evidence using the Oxford Centre for Evidence-based Medicine Levels of Evidence (March 2009).[4]

RESULTS

The initial search yielded 2489 citations of which 479 studies were included in this review (Figure 1, Table 1).

Figure 1. PRISMA flowchart

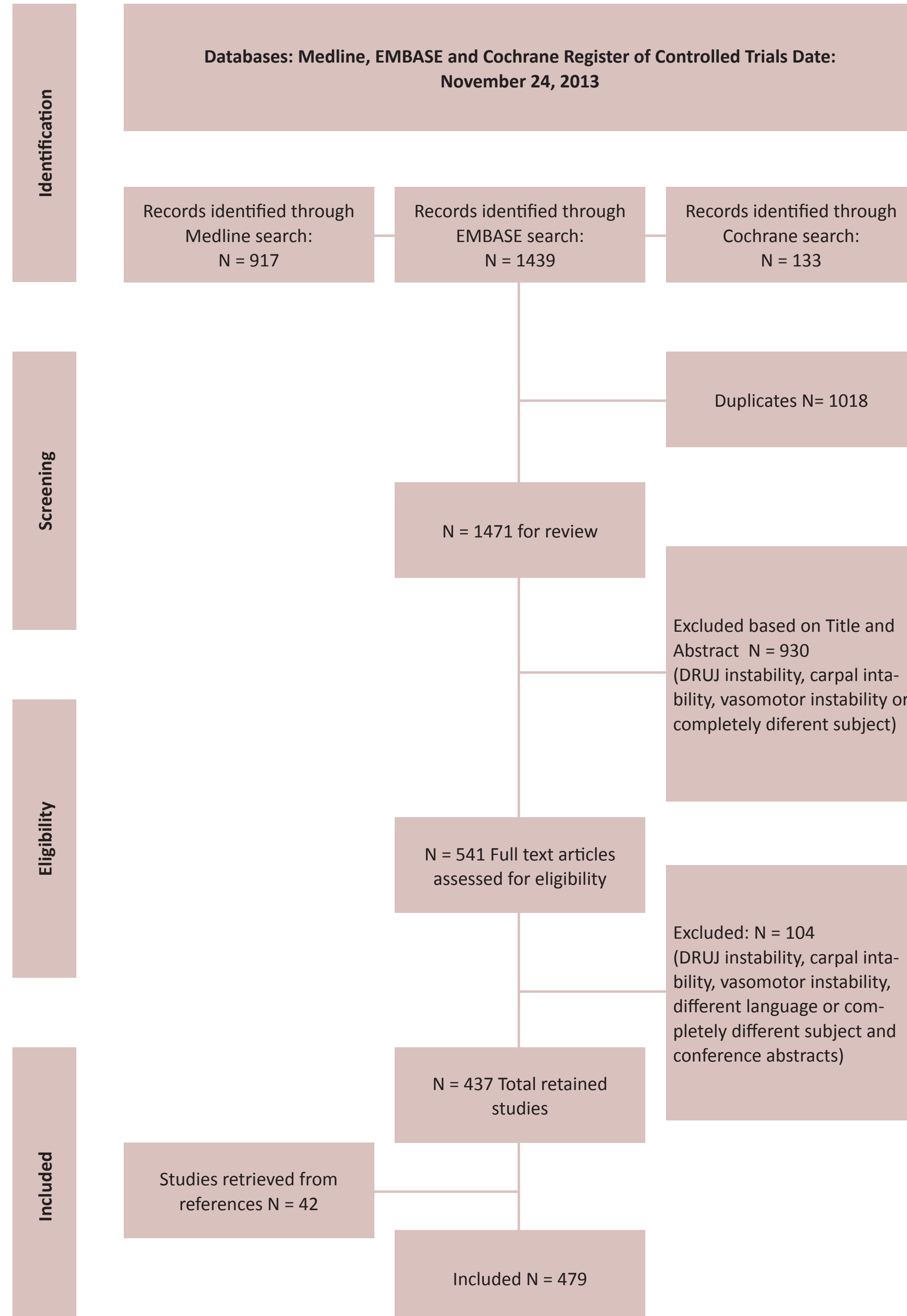

Table 1. Type of studies included (N=479)

	N (%)
Meta-analysis	5 (1.0)
Systematic Review	10 (2.1)
Randomised controlled trial	45 (9.4)
Cohort study	224 (46.8)
Case-control	2 (0.4)
Case series	33 (6.9)
Case report	6 (1.3)
Surgical technique	23 (4.8)
Cadaver study	36 (7.5)
Biomechanical study	9 (1.9)
Current concepts/ nonsystematic review	73 (15.2)
Letter to the editor	6 (1.3)
Editorial	3 (0.6)
Other[a]	4 (0.8)

a. guideline (N=1), decision analytic model (N=1), translation (N=1) and interobserver study (N=1)

In what percentage of clinical studies involving patients with unstable distal radius fractures did the authors define the term?
There were 254 clinical studies and in 149 studies (59%) the authors explicitly stated that they enrolled patients with an unstable distal radius fracture. In 54% (81/149) of these studies, the authors defined what they considered an unstable distal radius fracture.

What were the most commonly mentioned descriptions of an unstable distal radius fracture in any type of study?
Overall, 213 of the 479 studies (45%) provided one or more descriptions of an unstable distal radius fracture. In total, we found 143 different descriptions. There were seven descriptions that were used most frequently to define an unstable distal radius fracture. The most commonly mentioned description was a situation in which displacement or loss of position following anatomical closed reduction had occurred (20%, 42/213, Table 2).[5-46] The second most common description that was mentioned was the definition proposed by Lafontaine et al. (9%, 20/213).[47] According to this definition, a distal radius fracture is unstable if three or more of the following factors are present: dorsal angulation exceeding 20°; dorsal comminution; intra-articular radiocarpal fracture; associated ulnar fracture and age over 60 years.[48]

Table 2. The most common descriptions or definitions of an unstable distal radius fracture

Ranking	Definition	N (%)a	Total
1	Loss of position following adequate reduction	42 (19.7)	294
2	Lafontaine	20 (9.4)	85
3	Volarly displaced fracture (Smith's or reversed Barton)	12 (5.6)	379
4	Irreducible fracture	11 (5.2)	
5	AO type C2	10 (4.7)	
6	Poigenfürst	9 (4.2)	
7	Cooney	9 (4.2)	

a. percentage of total studies with definition (N=213)

The third most common description was a volarly displaced fracture (Smith or volar Barton fracture) that was defined as an inherently unstable fracture in 6% of the studies.[27,49-59] This was followed by an irreducible fracture in 5% (11/213) of the studies.[10,33,40,42,43,60-65]

The most frequently used classification system to describe an unstable distal radius fracture was the AO classification (8%, 18/213).[23,66-82] An AO type C2 was the fifth most commonly mentioned description used to define an unstable distal radius fracture (5%, 10/213).[66,67,70-74,79,81,82]

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In 4% (9/213) of the studies, the description according to Poigenfürst (radioulnar separation; the presence of dorsal comminution and an associated ulnar fracture) was used.[49,83-90] An equal number of studies (4%, 9/213) mentioned the definition of an unstable distal radius fracture according to Cooney (severe comminution; intra-articular components and severe displacement defined as >20° dorsal angulation and > 10 mm of radial shortening).[27,42,44,91-96] All other type of descriptions were mentioned in only three studies (1%) or less.

Is there one preferred definition to recommend to future authors?
Where possible, we verified the origin of the most common definitions and procured the full text manuscripts of the original studies. Four definitions did not originate from any study but were stated as expert opinions (loss of position, volar displacement, irreducibility and AO type C2 fractures). Poigenfuerst's definition was proposed in 1980 in a narrative article as an expert opinion[90] According to Poigenfürst, the presence of an associated ulnar styloid fracture resulting in a rupture of the ulnar ligaments from the carpal bones, would permit further shift of the distal fracture fragment and therefore constitute fracture instability.[90,97]

Cooney's definition was first used in 1979 when Cooney et al. performed a cohort study in which 130 patients were treated with an external fixator.[44] They included patients with an unstable distal radius fracture and defined unstable as: "the inability to maintain satisfactory fracture alignment at the time of reduction or in the presence of severe comminution; intra-articular components and severe displacement defined as >20° dorsal angulation and > 10 mm of radial shortening". No reference or explanation as to the choice of these criteria was provided and therefore this definition is an expert opinion (Table 3).

Table 3. Level of evidence for the most commonly used definitions

	Year	Definition	Level of evidence[a]
Secondary Displacement	NA	Displaced fracture following adequate reduction	Expert opinion (V)
Lafontaine [47,48]	1989	At least three of the following criteria: - dorsal angulation > 20° - dorsal comminution - intra-articular radiocarpal fracture - associated ulnar fracture - age > 60 years	III
Volarly displaced	NA	- Smith fracture - Reversed Barton fracture	Expert opinion (V)
Irreducible	NA	- Irreducible fracture	Expert opinion (V)
AO type C2	1990	- complete articular fractures - simple articular fracture - multifragmentary metaphyseal component	Expert opinion (V)
Poigenfürst	1980	- radioulnar separation - the presence of dorsal comminution - associated ulna fracture resulting in ulnar desinsertion	Expert opinion (V)
Cooney [44]	1979	radial shortening of 10 mm - dorsal angulation > 20° - and/or marked comminution combined with intra-articular fragments	Expert opinion (V)

a. The levels of evidence for definition of unstable distal radius fracture based in original study on the Oxford Centre for Evidence-based Medicine Levels of Evidence (March 2009) [4]
Abbreviations: NA, not applicable

Only the Lafontaine's definition originated from a clinical study describing a retrospective cohort of 167 cases.[47] Lafontaine et al. performed a univariate analysis for each risk factor and found a significant influence of each factor on the radiological outcome. They concluded that only patients with three or less instability factors had a satisfactory radiological outcome. Accordingly, Lafontaine considered a distal radius fracture unstable if three or more of the following factors were present: dorsal angulation exceeding 20°; dorsal comminution; intra-articular radiocarpal fracture; associated ulnar fracture and age over 60 years.[48] Based on the Oxford Centre for Evidence-based Medicine Levels of Evidence, this study is a level 3b (non-consecutive retrospective cohort study without consistently applied reference standards).

DISCUSSION

In clinical studies, specification of the inclusion criteria for enrolment is paramount. These criteria are used to define the study population and therefore reflect if the findings in this population are generalizable to other future patients. Some criteria however, such as an unstable distal radius fracture, can be hard to capture in a definition.

The term unstable distal radius fracture describes a situation in which the distal radius fracture has an intrinsic potential for secondary displacement.[98] It is an assessment of the probability that a fracture will lose its position and therefore it is highly subjective. However, regardless of its subjectivity, a standardized or universally accepted definition for an unstable distal radius fracture could have several benefits. It would increase awareness of the importance of specification of inclusion criteria among authors, help authors to write their study protocols and facilitate combining study outcomes in meta-analyses. Conversely, there might not exist a universal definition that all experts in the field agree upon. Moreover, defining what constitutes an unstable distal radius fracture could impact clinical practice and surgical decision-making. Nevertheless, for the sake of standardization in research we sought to examine (1) in what percentage of clinical studies involving patients with unstable distal radius fractures the authors defined what they considered an unstable distal radius fracture; (2) what the most commonly mentioned descriptions of an unstable distal radius fracture were in any type of study; and (3) whether any of these descriptions was the preferred definition that can recommend to future authors.

We found that in only 54% of the clinical studies that explicitly stated that they enrolled patients with an unstable distal radius fracture, did the authors define what they considered an unstable distal radius fracture.

Our search in any type of article resulted in 143 different descriptions of an unstable distal radius fracture. There were seven descriptions that were used most frequently to define an unstable distal radius fracture: (1) displacement of the fracture following anatomical reduction; (2) Lafontaine's; (3) an irreducible fracture; (4) an AO type C2 fracture; (5) a fracture with volar dislocation; (6) Poigenfürst's definition and; (7) Cooney's definition.

The most obvious description was secondary displacement after adequate closed reduction. The occurrence of secondary displacement is what constitutes an unstable fracture and is a clear definition.

The second most common description of an unstable distal radius fracture was according to the definition from Lafontaine. It was used in 9% of the studies,[11,32,34,43,47,99-112] of which six studies added radial shortening exceeding 5 mm to the definition.[104,107-110] The definition originates from a French publication on a retrospective study of 167 cases.[47] In this study the authors conclude that only patients with three or less instability predictors had a satisfactory radiological outcome. Since then, two studies have attempted to validate Lafontaine's criteria.[98,100] Of all five criteria, only age > 60 years was found to be predictive of fracture instability.[100]

All other definitions were expert opinions. A volarly displaced fracture for example is generally considered inherently unstable and primary operative treatment is regularly recommended.[113,114] However, we found no studies that assessed fracture instability in volarly displaced fractures. The same is true for irreducibility that cannot be equalled to instability.[115]

Instability, or the inability of a fracture to resist displacement after closed reduction[100], is often defined according to criteria regarding initial displacement such as dorsal angulation, shortening and the presence of dorsal comminution. The definition is in fact an assessment of the probability that a fracture will redisplace. Predictors of redisplacement have been studied extensively and several scoring systems to calculate the probability of instability based on initial presentation and injury films exist.[48,98,116,117] The largest study to investigate predictors of instability was performed by Mackenney et al. who examined 1595 patients. They identified several significant risk factors for fracture instability with displaced fractures and found that age, the presence of any type of comminution and a positive ulnar variance compared to the uninjured radius were significant predictors of early (<2 weeks) instability.[113] Other studies found that age >60 years; initial shortening and dorsal angulation exceeding 20° are significant predictors of redisplacement.[32,82,117-120] Surprisingly, more than half the definitions were not based on any of these predictors.

This systematic review is limited by the quality of the articles included and the subjectivity of the reviewers. The exclusion of the literature not in English, Dutch or German also introduces a source of bias. Determining the level of evidence for a definition was a subjective endeavour. Most definitions did not originate from any study and were therefore not suited to establish any level of evidence for. We have attempted to reduce subjectivity as much as possible by discussing any doubts or disagreements between reviewers. Nevertheless, we have demonstrated that there is little evidence for definitions that are most frequently used.

CONCLUSION AND RECOMMENDATION

In only half of the studies that explicitly stated to have enrolled patients with an unstable distal radius fracture, did the authors define what they considered an unstable distal radius fracture. There is an enormous variety of different descriptions of an unstable distal radius fracture circulating in the literature. Unfortunately, none of the descriptions we found stands out as the preferred definition to be used in future studies. For the sake of generalizability, we would like to urge future authors to clearly describe what they regard as an unstable distal radius fracture. We propose that the definition of an unstable distal radius fracture includes the predictors that are known to increase the probability of displacement such as comminution, initial shortening and age > 60 years. Further attempts to arrive upon a universally accepted consensus definition could possibly help to standardize distal radius fracture research.

REFERENCES

1. Grobbee DE, Hoes AW. Introduction. Clinical Epidemiology: Principles, Methods, and Applications for Clinical Research: Jones & Bartlett Learning; 2009. p. 21.

2. Grobbee DE, Hoes AW. Randomized Trials. Clinical Epidemiology: Principles, Methods, and Applications for Clinical Research: Jones & Bartlett Learning; 2009. p. 275.

3. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int J Surg 2010;8(5):336-341.

4. Oxford Centre for Evidence-based Medicine Levels of Evidence. . March 2009; Available at: http://www.cebm.net/oxford-centre-evidence-based-medicine-levels-evidence-march-2009/. Accessed July 5, 2014.

5. Arora R, Gabl M, Gschwentner M, Deml C, Krappinger D, Lutz M. A comparative study of clinical and radiologic outcomes of unstable colles type distal radius fractures in patients older than 70 years: nonoperative treatment versus volar locking plating. J Orthop Trauma 2009 apr;23(1531-2291 (Electronic)):237-242.

6. Arora R, Lutz M, Hennerbichler A, Krappinger D, Espen D, Gabl M. Complications following internal fixation of unstable distal radius fracture with a palmar locking-plate. J Orthop Trauma 2007 may;21(0890-5339 (Print)):316-322.

7. Grala P, Zielinski W. Hybrid external fixation for neglected fractures of the distal radius: results after one year. J Orthop Traumatol 2008 Dec;9(4):195-200.

8. Grala P, Kierzynka G, Machynska-Bucko Z. Hybrid external fixation of unstable distal radius fractures: Initial experience. Journal of Orthopaedics and Traumatology 2005;6:138-144.

9. Harley BJ, Scharfenberger A, Beaupre LA, Jomha N, Weber DW. Augmented external fixation versus percutaneous pinning and casting for unstable fractures of the distal radius - A prospective randomized trial. J Hand Surg 2004 sep;29(5):815-824.

10. Hayes AJ, Duffy PJ, McQueen MM. Bridging and non-bridging external fixation in the treatment of unstable fractures of the distal radius: a retrospective study of 588 patients. Acta Orthop 2008 aug;79(1745-3682 (Electronic)):540-547.

11. Herrera M, Chapman CB, Roh M, Strauch RJ, Rosenwasser MP. Treatment of unstable distal radius fractures with cancellous allograft and external fixation. J Hand Surg Am 1999 nov;24(0363-5023 (Print)):1269-1278.

12. Hossain M. Re: a randomised comparison of locking and non-locking palmar plating for unstable Colles' fractures in the elderly, Koshimune et al., Journal of Hand Surgery, 2005, 30B: 499-503. J Hand Surg [Br] 2006 Apr 2006;31(2):244; author rey 244.

13. Jeong GK, Kaplan FT, Liporace F, Paksima N, Koval KJ. An evaluation of two scoring systems to predict instability in fractures of the distal radius. J Trauma 2004 nov;57(0022-5282 (Print)):1043-1047.

14. Kamano M, Honda Y, Kazuki K, Yasuda M. Palmar Plating with Calcium Phosphate Bone Cement for Unstable Colles' Fractures. Clin Orthop 2003 November 2003(416):285-290.

15. Kimura M, Kuroshima N, Torihama T, Fukasawa K, Matsushita T. A convenient dynamic wire traction-fixation method for hand and forearm fractures. J Orthop Trauma 2006 Oct;20(9):631-636.

16. Lawson GM, Hajducka C, McQueen MM. Sports fractures of the distal radius--epidemiology and outcome. Injury 1995 jan;26(0020-1383 (Print)):33-36.

17. Margaliot Z, Haase SC, Kotsis SV, Kim HM, Chung KC. A meta-analysis of outcomes of external fixation versus plate osteosynthesis for unstable distal radius fractures. J Hand Surg Am 2005 nov;30(0363-5023 (Print)):1185-1199.

18. McQueen MM, Simpson D, CM C. Use of the Hoffman 2 compact external fixator in the treatment of redisplaced unstable distal radial fractures. J Orthop Trauma 1999 sep;13(0890-5339 (Print)):501-505.

19. McQueen MM. Redisplaced unstable fractures of the distal radius. Journal of Bone and Joint Surgery - Series B 1998 July 1998;80(4):665-669.

20. McQueen MM. Non-spanning external fixation of the distal radius. Hand Clin 2005 August 2005;21(Distal Radius Fractures.):375-380.

21. McQueen MM, Michie M, CM C. Hand and wrist function after external fixation of unstable distal radial fractures. Clin Orthop Relat Res 1992 dec(0009-921X (Print)):200-204.

22. Nakata RY, Chand Y, Matiko JD, Frykman GK, Wood VE. External fixators for wrist fractures: a biomechanical and clinical study. J Hand Surg Am 1985 nov;10(0363-5023 (Print)):845-851.

23. Nalbantoglu U, Gereli A, Kocaoglu B, Turkmen M. Percutaneous cannulated screw fixation in the treatment of distal radius fractures. Arch Orthop Trauma Surg 2012 Sep;132(9):1335-1341.

24. Orbay JL, Touhami A, Orbay C. Fixed angle fixation of distal radius fractures through a minimally invasive approach. Tech Hand Up Extrem Surg 2005 Sep;9(3):142-148.

25. Rizzo M, Katt BA, Carothers JT. Comparison of locked volar plating versus pinning and external fixation in the treatment of unstable intraarticular distal radius fractures. Hand (N Y) 2008 jun;3(1558-9447 (Print)):111-117.

26. Ruschel PH, Albertoni WM. Treatment of unstable extra-articular distal radius fractures by modified intrafocal Kapandji method. Tech.Hand Up Extrem.Surg 2005 mar;9(1089-3393 (Print)):7-16.

27. Sakano H, Koshino T, Takeuchi R, Sakai N, Saito T. Treatment of the unstable distal radius fracture with external fixation and a hydroxyapatite spacer. J Hand Surg Am 2001 Sep;26(5):923-930.

28. Abramo A, Kopylov P, Geijer M, Tagil M. Open reduction and internal fixation compared to closed reduction and external fixation in distal radial fractures: a randomized study of 50 patients. Acta Orthop 2009 aug;80(1745-3674 (Print)):478-485.

29. Slutsky DJ. Predicting the outcome of distal radius fractures. Hand Clin 2005 Aug;21(3):289-294.

30. Brady O, Rice J, Nicholson P, Kelly E, O'Rourke SK. The unstable distal radial fracture one year post Kapandji intrafocal pinning. Injury 1999 may;30(0020-1383 (Print)):251-255.

31. Suman RK. Unstable fractures of the distal end of the radius (Transfixion pins and a cast). Injury 1983;15(3):206-211.

32. Tahririan MA, Javdan M, Nouraei MH, Dehghani M. Evaluation of instability factors in distal radius fractures. Journal of Research in Medical Sciences 2013;18:892-896.

33. Uchikura C, Hirano J, Kudo F, Satomi K, Ohno T. Comparative study of nonbridging and bridging external fix-

4

ators for unstable distal radius fractures. J Orthop Sci 2004;9(6):560-565.

34. Wei DH, Raizman NM, Bottino CJ, Jobin CM, Strauch RJ, Rosenwasser MP. Unstable distal radial fractures treated with external fixation, a radial column plate, or a volar plate. A prospective randomized trial. J Bone Joint Surg Am 2009 jul;91(1535-1386 (Electronic)):1568-1577.

35. Werber KD, Raeder F, Brauer RB, Weiss S. External fixation of distal radial fractures: four compared with five pins: a randomized prospective study. J Bone Joint Surg Am 2003 apr;85-A(0021-9355 (Print)):660-666.

36. Chen YX, Zheng X, Shi HF, Wangyang YF, Yuan H, Xie XX, et al. Will the untreated ulnar styloid fracture influence the outcome of unstable distal radial fracture treated with external fixation when the distal radioulnar joint is stable. BMC Musculoskelet Disord 2013 Jun 12;14:186-2474-14-186.

37. Chung KC, Petruska EA. Treatment of unstable distal radial fractures with the volar locking plating system. Surgical technique. J Bone Joint Surg Am 2007 sep;89 Suppl 2(0021-9355 (Print)):256-266.

38. Clayton RA, Gaston MS, Ralston SH, CM C, McQueen MM. Association between decreased bone mineral density and severity of distal radial fractures. J Bone Joint Surg Am 2009 mar;91(1535-1386 (Electronic)):613-619.

39. Deakin DE, Deshmukh SC. Dorsally angulated fractures of the distal radius. Trauma 2010;12(1):21-29.

40. Diaz-Garcia RJ, Oda T, Shauver MJ, Chung KC. A systematic review of outcomes and complications of treating unstable distal radius fractures in the elderly. J Hand Surg Am 2011 may;36(1531-6564 (Electronic)):824-835.

41. Dumont C, Fuchs M, Folwaczny EK, Heuermann C, Sturmer KM. [Results of palmar T-plate osteosynthesis in unstable fractures of the distal radius]. Chirurg 2003 sep;74(0009-4722 (Print)):827-833.

42. Ebraheim NA, Ali SS, Gove NK. Fixation of unstable distal radius fractures with intrafocal pins and trans-styloid augmentation: a retrospective review and radiographic analysis. Am J Orthop (Belle Mead NJ) 2006 aug;35(1078-4519 (Print)):362-368.

43. Gluck JS, Chhabra AB. Loss of alignment after closed reduction of distal radius fractures. J Hand Surg Am 2013 Apr;38(4):782-783.

44. Cooney WP,3rd, Linscheid RL, Dobyns JH. External pin fixation for unstable Colles' fractures. J Bone Joint Surg Am 1979 Sep;61(6A):840-845.

45. McQueen MM. Redisplaced unstable fractures of the distal radius. A randomised, prospective study of bridging versus non-bridging external fixation. J Bone Joint Surg Br 1998 Jul;80(4):665-669.

46. McBirnie J, Court-Brown CM, McQueen MM. Early open reduction and bone grafting for unstable fractures of the distal radius. J Bone Joint Surg Br 1995 Jul;77(4):571-575.

47. Lafontaine M, Delince P, Hardy D, Simons M. Instability of fractures of the lower end of the radius: apropos of a series of 167 cases. Acta Orthop Belg 1989 1989;55(2):203-216.

48. Lafontaine M, Hardy D, Delince P. Stability assessment of distal radius fractures. Injury 1989;20(4):208-210.

49. Letsch R, Schmit-Neuerburg KP, Schax M. [Choice of surgical procedure of the distal radius. Bore wire versus plate]. Aktuelle Traumatol 1987 jun;17(0044-6173 (Print)):113-119.

50. Medoff RJ. Fragment-Specific Fixation of Distal Radius Fractures. Atlas of Hand Clinics 2006;11:163-174.

51. Ponziani L, Galli G, Rollo G, Pascarella R. The external fixator for the treatment of wrist fractures. Chir Organi Mov 1997 Jan-Mar;82(1):33-40.

52. Beck E, Gabl M. Conservative treatment of distal radial fractures - Indication, techique, results. Acta Chir Austriaca 1997;29(4):194-196.

53. Oestern HJ. Distal radius fracture. Orthopade 1988 feb;17(1):52-63.

54. Bassett RL. Displaced intraarticular fractures of the distal radius. Clinical Orthopaedics and Related Research.No 1987;214:148-152.

55. Swan JaK, Capo JT, Tan V. Distal radius plating options. Current Opinion in Orthopaedics 2003;14:238-244.

56. Tang Z, Yang H, Chen K, Wang G, Zhu X, Qian Z. Therapeutic effects of volar anatomical plates versus locking plates for volar Barton's fractures. Orthopedics 2012 August 2012;35(8):e1198-e1203.

57. Andress H-. Distal fracture of the radius. MMW-Fortschritte der Medizin 2005 10 Nov 2005;147(45):67-68.

58. Rodriguez-Merchan EC. Management of comminuted fractures of the distal radius in the adult. Conservative or surgical? Clin Orthop Relat Res 1998 Aug;(353)(353):53-62.

59. THOMAS FB. Reduction of Smith's fracture. J Bone Joint Surg Br 1957 Aug;39-B(3):463-470.

60. Abramo A, Kopylov P, Tagil M. Evaluation of a treatment protocol in distal radius fractures: a prospective study in 581 patients using DASH as outcome. Acta Orthop 2008 Jun;79(3):376-385.

61. Foster BJ, Bindra RR. Intrafocal pin plate fixation of distal ulna fractures associated with distal radius fractures. J Hand Surg Am 2012 feb;37(1531-6564 (Electronic)):356-359.

62. Gereli A, Nalbantoglu U, Kocaoglu B, Turkmen M. Comparative study of the closed reduction percutaneous cannulated screw fixation and open reduction palmar locking plate fixation in the treatment of AO type A2 distal radius fractures. Arch Orthop Trauma Surg 2013 oct(1434-3916 (Electronic)).

63. Murray PM, Trigg SD. Treatment of distal radius fractures with external fixation: technical considerations for rehabilitation. Tech.Hand Up Extrem.Surg 2002 dec;6(1089-3393 (Print)):213-218.

64. Orbay JL. The treatment of unstable distal radius fractures with volar fixation. Hand Surg 2000 dec;5(0218-8104 (Print)):103-112.

65. Qu Y, Xu J, Jiang T, Zhao H, Gao Y, Hou W. Unstable distal radius fractures: restoration of the radial length with use of special palmar fixed-angle plate. Handchir Mikrochir Plast Chir 2013 Feb;45(1):1-5.

66. Siebert HR, Grossmann T. Guidelines: treatment of distal radius fracture. Langenbecks Archiv fur Chirurgie. Supplement.Kongressband.Deutsche Gesellschaft fur Chirurgie.Kongress 1997;114:138-141.

67. Hove LM, Krukhaug Y, Revheim K, Helland P, Finsen V. Dynamic compared with static external fixation of unstable fractures of the distal part of the radius: a prospective, randomized multicenter study. J Bone Joint Surg Am 2010 jul;92(1535-1386 (Electron-

ic)):1687-1696.

68. Jupiter JB. Complex Articular Fractures of the Distal Radius: Classification and Management. J Am Acad Orthop Surg 1997 may;5(1067-151X (Print)):119-129.

69. Kandemir U, Matityahu A, Desai R, Puttlitz C. Does a volar locking plate provide equivalent stability as a dorsal nonlocking plate in a dorsally comminuted distal radius fracture?: a biomechanical study. J Orthop Trauma 2008 Oct;22(9):605-610.

70. Karnezis IA, Fragkiadakis EG. Association between objective clinical variables and patient-rated disability of the wrist. J Bone Joint Surg Br 2002 sep;84(0301-620X (Print)):967-970.

71. Karnezis IA, Panagiotopoulos E, Tyllianakis M, Megas P, Lambiris E. Correlation between radiological parameters and patient-rated wrist dysfunction following fractures of the distal radius. Injury 2005 dec;36(0020-1383 (Print)):1435-1439.

72. Low CK, Liau KH, Chew WY. Results of distal radial fractures treated by intra-focal pin fixation. Ann Acad Med Singap 2001 nov;30(0304-4602 (Print)):573-576.

73. Thielke K-, Spors-Schrodter L, Wagner T, Soleymani H, Hillrichs B, Echtermeyer V. Angle-stable radius plate: Progress in treatment of problematical distal radius fracture? Aktuelle Traumatol 2002;32:245-250.

74. Uzdil T, Neumann W, Bauschke A, Winker KH. Goniometrically stable palmar osteosynthesis with plates in distal radius fractures. Aktuelle Traumatol 2001;31:141-148.

75. Vasenius J. Operative treatment of distal radius fractures. Scandinavian Journal of Surgery 2008 2008;97(4):290-296.

76. Zamzuri Z, Yusof M, Hyzan MY. External fixation versus internal fixation for closed unstable intra-articular fracture of the distal radius. Early results from a prospective study. Med J Malaysia 2004;59(1):15-19.

77. Zhang QL, Zhu XD, Li GD, Tang H, Li M, Wu DJ. Treatment of type C3 distal radius fracture resulted from high-energy injuries by volar plate in combination with external fixator. Chin Med J 2009 jul;122(0366-6999 (Print)):1517-1520.

78. Ziegler IP, Remiger A. [Treatment of unstable distal radius fractures with a small AO-fixateur externe not bridging the joint]. Unfallchirurg 1996 nov;99(0177-5537 (Print)):836-840.

79. Zimmermann R, Gabl M, Lutz M, Angermann P, Gschwentner M, Pechlaner S. Injectable calcium phosphate bone cement Norian SRS for the treatment of intra-articular compression fractures of the distal radius in osteoporotic women. Arch Orthop Trauma Surg 2003 Feb;123(1):22-27.

80. Knox J, Ambrose H, McCallister W, Trumble T. Percutaneous pins versus volar plates for unstable distal radius fractures: a biomechanic study using a cadaver model. J Hand Surg Am 2007 Jul-Aug;32(6):813-817.

81. Kulej M, Dragan S, Dragan SL, Krawczyk A, Plochowski J, Orzechowski W, et al. Efficacy of closed reduction and maintenance of surgical outcome in plaster cast immobilization in different types of distal radius fractures. rptopedia Traumatologia Rehabilitacja 2007;9(6):577-590.

82. Einsiedel T, Freund W, Sander S, Trnavac S, Gebhard F, Kramer M. Can the displacement of a conservatively treated distal radius fracture be predicted at the beginning of treatment? Int Orthop 2009 Jun;33(3):795-800.

83. Brunner U, Habermeyer P, Schweiberer L. Fractures of the distal end of the radius. Orthopade 1989 Jun;18(3):214-224.

84. Boszotta H, Helperstorfer W, Sauer G. Indications for surgery in distal radius fractures. Unfallchirurg 1991 Aug;94(8):417-423.

85. Goehre F, Otto W, Schwan S, Mendel T, Vergroesen PP, Lindemann-Sperfeld L. Comparison of palmar fixed-angle plate fixation with K-wire fixation of distal radius fractures (AO A2, A3, C1) in elderly patients. The Journal of hand surgery, European volume 2014 mar;39(3):249-257.

86. Letsch R, Schmit-Neuerburg KP, Towfigh H. Indications and results of plate osteosynthesis of the distal radius. Langenbecks Arch Chir 1984;364:363-368.

87. Meffert R, Bangen D, Ochman S, Raschke MJ, Langer M. External fixation out of fashion? Complications after ORIF using palmar locked plates for unstable distal radius fractures. Chirurgische Praxis 2006;66:75-91.

88. Schmit-Neuerburg KP, Letsch R, Sturmer KM, Koeser K. [Special forms of distal radius fractures]. Langenbecks Arch Chir Suppl II Verh Dtsch Ges Chir 1990(0173-0541 (Print)):667-674.

89. Siebert HR. Treatment of fractures of the distal radius and the associated injuries of the carpal compartments by different types of non-operative and operative methods. Aktuelle Traumatol 1997;27(1):7-15.

90. Poigenfürst J. Brüche am distalen Unterarmende. Einteilung der Bruchformen und Indikation. Hefte Unfallheilkd 1980;148:53-59.

91. Afzal S, Mir MR, Halwai MA, Ahmad S. Treatment of fractures of the distal radius with external fixator. JK Practitioner 2003;10:112-114.

92. Greatting MD, Bishop AT. Intrafocal (Kapandji) pinning of unstable fractures of the distal radius. Orthop Clin North Am 1993 apr;24(0030-5898 (Print)):301-307.

93. Tobe M, Mizutani K, Tsubuku Y. Treatment of distal radius fracture with the use of calcium phosphate bone cement as a filler. Tech Hand Up Extrem Surg 2004 Jun;8(2):95-101.

94. Cooney WP. External fixation of distal radial fractures. Clin Orthop Relat Res 1983 Nov;(180)(180):44-49.

95. Hutchinson DT, Strenz GO, Cautilli RA. Pins and plaster vs external fixation in the treatment of unstable distal radial fractures. A randomized prospective study. J Hand Surg Br 1995 Jun;20(3):365-372.

96. Cooney W. Management of Colles' fractures. The Journal of Hand Surgery: Journal of the British Society for Surgery of the Hand 1989 may;14(2):137-139.

97. Poigenfuerst J, Tuchmann A. The significance of injuries to the ulnar ligaments of the wrist in Colles' fractures. Handchirurgie 1978 1978;10(3):121-125.

98. Alemdaroglu KB, Iltar S, Aydogan NH, Say F, Kilinc CY, Tiftikci U. Three-point index in predicting redisplacement of extra-articular distal radial fractures in adults. Injury 2010 Feb;41(2):197-203.

99. Gofton W, Liew A. Distal Radius Fractures: Nonoperative and Percutaneous Pinning Treatment Options. Hand Clin 2010;26(1):43-53.

100. Nesbitt KS, Failla JM, Les C. Assessment of instability factors in adult distal radius fractures. J Hand Surg 2004 nov;29(6):1128-1138.

101. Sonderegger J, Schindele S, Rau M, Gruenert JG. Palmar multidirectional fixed-angle plate fixation in distal radius fractures: do intraarticular fractures have

a worse outcome than extraarticular fractures? Arch Orthop Trauma Surg 2010 oct;130(1434-3916 (Electronic)):1263-1268.

102. Szyluk K, Jasinski A, Koczy B, Widuchowski W, Widuchowski J. Results of operative treatment of unstable distal radius fractures using percutaneous K wire fixation. Ortop Traumatol Rehabil 2007 Sep-Oct;9(5):511-519.

103. Carter PR, Frederick HA, Laseter GF. Open reduction and internal fixation of unstable distal radius fractures with a low-profile plate: a multicenter study of 73 fractures. J Hand Surg Am 1998 mar;23(0363-5023 (Print)):300-307.

104. Frederick H. Dorsal plating of distal radius fractures. Techniques in Orthopaedics 2000;15:318-327.

105. Xarchas KC, Verettas DA, Kazakos KJ. Classifying fractures of the distal radius: Impossible or unnecessary? Review of the literature and proposal of a grouping system. Medical Science Monitor 2009;15(3):RA67-RA74.

106. Mostafa MF. Treatment of distal radial fractures with antegrade intra-medullary Kirschner wires. Strategies in trauma and limb reconstruction (Online) 2013 aug;8(2):89-95.

107. Belloti JC, Moraes VY, Albers MB, Faloppa F, Santos JBGD. Does an ulnar styloid fracture interfere with the results of a distal radius fracture?. Journal of Orthopaedic Science 2010;15(2):216-222.

108. Belloti JC, Tamaoki MJ, Atallah AN, Albertoni WM, dos Santos JB, Faloppa F. Treatment of reducible unstable fractures of the distal radius in adults: a randomised controlled trial of De Palma percutaneous pinning versus bridging external fixation. BMC Musculoskelet Disord 2010;11(1471-2474 (Electronic)):137.

109. Egol Ka, Walsh M, Romo-Cardoso S, Dorsky S, Paksima N. Distal radial fractures in the elderly: operative compared with nonoperative treatment. The Journal of bone and joint surgery.American volume 2010 aug;92(9):1851-1857.

110. Egol K, Walsh M, Tejwani N, McLaurin T, Wynn C, Paksima N. Bridging external fixation and supplementary Kirschner-wire fixation versus volar locked plating for unstable fractures of the distal radius: a randomised, prospective trial. J Bone Joint Surg Br 2008 Sep;90(9):1214-1221.

111. Tyllianakis M, Mylonas S, Saridis A, Kallivokas A, Kouzelis A, Megas P. Treatment of unstable distal radius fractures with Ilizarov circular, nonbridging external fixator. Injury 2010 Mar;41(3):306-311.

112. Pechlaner S, Gabl M, Lutz M, Krappinger D, Leixnering M, Krulis B, et al. Distal radius fractures--aetiology, treatment and outcome. Handchir Mikrochir Plast Chir 2007 Feb;39(1):19-28.

113. Mackenney PJ, McQueen MM, Elton R. Prediction of instability in distal radial fractures. J Bone Joint Surg Am 2006 Sep;88(9):1944-1951.

114. Handoll HH, Huntley JS, Madhok R. Different methods of external fixation for treating distal radial fractures in adults. Cochrane Database Syst Rev 2008(1469-493X (Electronic)):D006522.

115. Wichlas F, Haas NP, Lindner T, Tsitsilonis S. Closed reduction of distal radius fractures: does instability mean irreducibility? Arch Orthop Trauma Surg 2013 aug;133(8):1073-1078.

116. Mackenney PJ. Re: An evaluation of two scoring systems to predict instability in fractures of the distal radius. J Trauma 2005 dec;59(6):1535; author repy 1535.

117. Abbaszadegan H, Jonsson U, Sivers Kv. Prediction of instability of Colles’ fractures. Acta Orthop Scand 1989 Dec;60(6):646-650.

118. Hove LM, Solheim E, Skjeie R, Sorensen FK. Prediction of secondary displacement in Colles’ fracture. Journal of hand surgery (Edinburgh, Scotland) 1994 dec;19(6):731-736.

119. Leone J, Bhandari M, Adili A, McKenzie S, Moro JK, Dunlop RB. Predictors of early and late instability following conservative treatment of extra-articular distal radius fractures. Arch Orthop Trauma Surg 2004 Jan;124(1):38-41.

120. Altissimi M, Mancini GB, Azzara A, Ciaffoloni E. Early and late displacement of fractures of the distal radius. The prediction of instability. Int Orthop 1994 Apr;18(2):61-65.

CHAPTER 5

VARIATION IN THE SURGICAL TREATMENT RATES OF DISTAL RADIUS FRACTURES: WHAT YOU GET IS SURGEON AND HOSPITAL DEPENDENT

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ABSTRACT

Purpose
Variations in medical practice have already been documented for a number of elective procedures. Generally, this variation is warranted if it is attributable to patient-related factors and unwarranted if it is attributable to factors such as physician's local beliefs and preferences. Because the evidence for the optimum treatment for patients with distal radius fractures remains inconclusive, we hypothesized that there would be a considerable variation in treatment. The aim of this study was to examine the variation in surgical treatment rates of patients with distal radius fractures across Dutch hospitals.

Methods
We obtained all reimbursement data for the treatment of distal radius fractures for 2012 and 2013 categorized by hospital. The surgical rate across hospitals was corrected for possible explanatory variables using linear regression analyses.

Results
We analyzed a total of 95,754 reimbursements. The operative rate ranged from 0% to 23%, with a mean of 9.6%. Hospital type, the percentage of females, the percentage of patients over 65, the mean age, average socioeconomic status and the total number of patients treated explained only 2.6% of the observed differences in the operative rate among hospitals in 2012 and 11.6% in 2013.

Conclusions
There is considerable and possibly unwarranted variation in the treatment of patients with distal radius fractures across the Netherlands that cannot be explained by hospital type and characteristics of the patient population. Our results suggest that non-scientific influences, such as surgeon's local beliefs and preferences, prevail and drive therapeutic decisions in patients with distal radius fractures.
Clinical relevance: the results of our study illustrate the arbitrariness of the treatment of distal radius fractures and should make surgeons critically evaluate their current practices.

INTRODUCTION

While the evidence remains inconclusive, the optimum treatment for most patients with distal radius fractures is still a matter of debate.[1] Patient age, fracture pattern, displacement and alleged fracture instability are considered crucial to guide treatment.[2,3] However, in the absence of recommendations substantiated by evidence in current guidelines, the choice of treatment is likely based on factors such as the availability of resources, surgeon density, socioeconomic circumstances and surgeon's preference. The latter of these, surgeon's preferences in turn vary according to surgeon's age and background.[4-7] All these factors likely result in regional variations in the treatment of patients with distal radius fractures.

Considerable variations in medical practice have already been documented for a number of elective procedures such as tonsillectomy, hip replacement and prostatectomy.[8] Variation in healthcare practices can arise from three general factors: chance alone, patient-related factors and provider-related factors Generally, some variation is warranted if it is attributable to patient-related factors that affect the need for surgery. Such factors include variations in regional incidence of diseases that demands surgical treatment, regional differences in patients' willingness to undergo surgical intervention and the presence of specialized referral centers.[8,9] Differences in patient-related factors are also known as the case-mix of a treatment center.

However, surgical variation can also be caused by provider-related (or care-related) factors. Primarily, physician's local culture of beliefs and preferences about appropriateness of surgery; the extent to which physicians include patients in treatment decisions; and broader factors such as regional diffusion of developments in surgical care.[8,9] Variation based on these factors is unwarranted and suggests potential to improve cost-effectiveness by reducing provision of unnecessary surgery.

Nevertheless, variation cannot be regarded as strictly unwarranted if there is no clear optimum treatment. While we await the results of several randomized clinical trials to delineate the optimum treatment for distal radius fractures [10,11], the first step in addressing potentially unwarranted variation is insight into the extent in which variation across practices exists.

Only one previous study described such variation across regions or practices concerning distal radius fractures. In this study, the authors assessed the regional variation in treatment of distal radius fractures in the United States.[12] They studied a sample of Medicare claims and found a significant variation that was mainly driven by age and region. However, variation in the surgical treatment rate of distal radius fractures has never been investigated in a European setting. We hypothesized that, although the Dutch health care system is different from the health care system in United States and basic health insurance is mandatory, there would still be a considerable variation in practice. Hence, the aim of this study was to examine the variation in surgical treatment rates across all Dutch hospitals.

METHODS

We obtained data from the national insurance database on healthcare for the calendar years 2012 and 2013 that covers 100% of the Dutch population. This database is managed by a third party (Vektis, Zeist, The Netherlands) and contains reimbursement data of all medical treatments paid for by Dutch insurance companies. Almost 99% of Dutch inhabitants have private health care insurance (http://statline.cbs.nl/Statweb/?LA=en), which pays for treatment of a distal radius fracture. Reimbursement of hospital care is exclusively claimed using the Diagnosis Treatment Combinations Codes (Diagnose Behandeling Code [DBC]).

These codes are recorded by physicians for reimbursement purposes, similar to the internationally Disease Related Group (DRG) system. Each DBC code contains information about the diagnosis, the type of treatment and the physician. DBC codes for distal radius fractures differentiate between conservative treatment and surgical treatment. The billing for a conservatively (non-operatively) treated distal radius fracture is €506 and €6073 for a surgically treated distal radius fracture.

Our database comprised the following data arranged by each Dutch hospital: the number of patients treated conservatively, the number of patients treated surgically, the percentage of female patients, the percentage of patients over 65, the mean age and the mean socioeconomic status (SES). In the Netherlands, most patients with fractures are treated by trauma surgeons with a general surgery background. Only a small percentage is treated by orthopaedic surgeons.

Data was provided as aggregate data arranged by hospital. There are four types of hospital in the Netherlands: (1) university hospitals; (2) tertiary teaching hospitals that provide both basic and highly specialized care and train doctors in collaboration with university hospitals; (3) general hospitals that provide non-specialized care; and (4) independent single-specialty treatment centers for specialist care.
Socioeconomic status was based on patients' residential postal codes, which were correlated to data from 2010 from the Netherlands Institute for Social Research. For a small percentage of DBCs (<0.1%), no patient characteristics were available. These DBSs were equally distributed across all hospitals.

For the purpose of our analyses, we assumed that the number of procedures (both conservative and surgical treatment) equaled the number of patients. This assumption does not account for patients with bilateral fractures, however from experience we expect this number to be negligible and estimate that it is not more than 50 patients each year. [13]

Continuous variables were reported as mean with standard deviation (SD). We calculated Pearson's correlation coefficients to determine the correlation between the number of patients treated operatively in 2012 and 2013. We used linear regression analyses to model the relationship between the surgical treatment rate and possible explanatory variables (hospital type, percentage of females, percentage of patients over 65, mean age, mean socioeconomic status and total number of patients). A value of $p < 0.05$ was considered significant in the linear regression analyses.

RESULTS

We obtained aggregated data on a total of 95,754 reimbursements for distal radius fractures: 49,615 in 2012 and 46,139 in 2013. A total of 79% of the patients was treated by a general/trauma surgeon and 21% by an orthopaedic surgeon. Overall, surgeons had an operative rate of 10% and ortopaedic surgeons a rate of 9%.

The operative rate per hospital ranged from 0% to 23%. Figure 1 and Figure 2 illustrate the spread in operative rates per hospital in 2012 and 2013. The mean operative rate was similar for 2012 and 2013, 9.6% with a standard deviation of respectively 3.9% and 3.8% (Table 1).

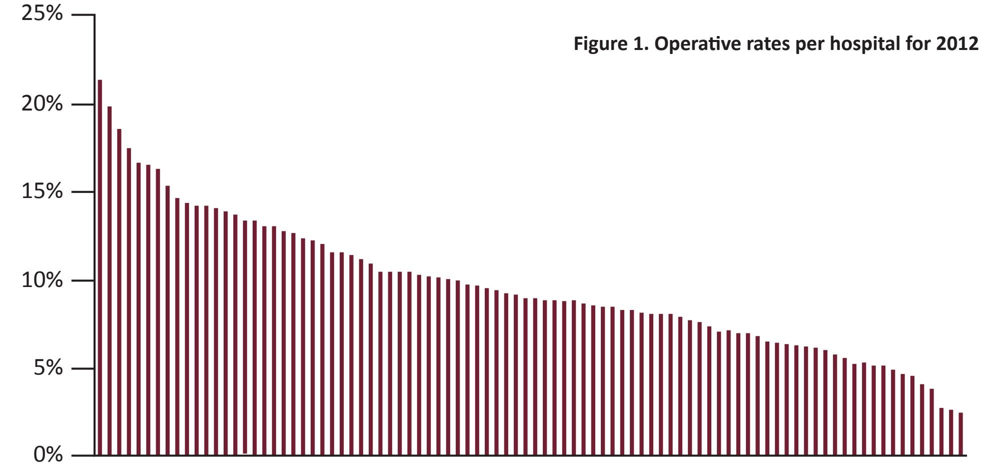


Figure 1. Operative rates per hospital for 2012

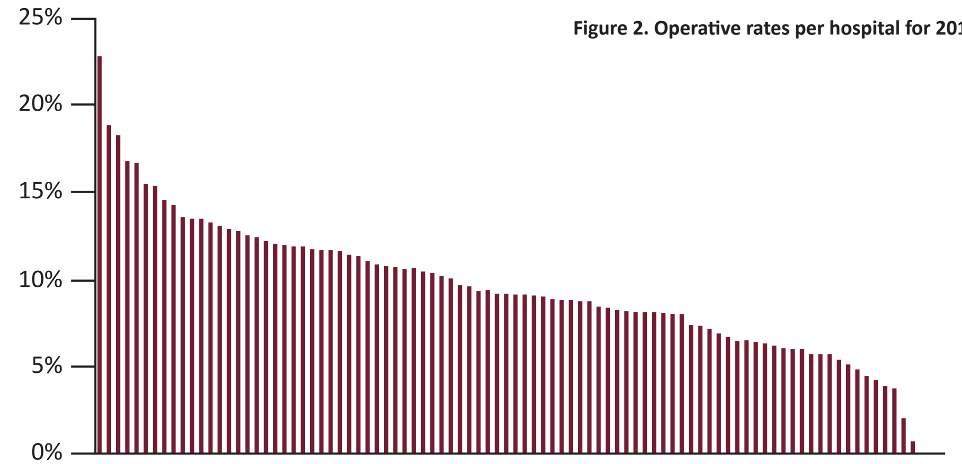


Figure 2. Operative rates per hospital for 2013

Table 1. Demographic overview (N = 95,754)

Year	2012	2013	Correlation[a]
Percentage of operative treatments (range)	9.6 (2.4 - 21.3)	9.6 (0 - 22.7)	0.65 (p<0.001)
Percentage of females (range)	61.6 (48.7 - 72.3)	61.1 (50.0 - 73.9)	0.46 (p<0.001)
Percentage of patients >65 (range)	23.8 (4.0 - 37.5)	26.4 (17.2 - 38.7)	0.55 (p<0.001)
Mean age (range)	38.3 (30.2 - 52.3)	38.5 (30.9 - 55.1)	0.70 (p<0.001)
Mean SES (range)	0.05 (-1.3 - 1.4)	0.03 (-1.5 - 1.4)	0.94 (p<0.001)

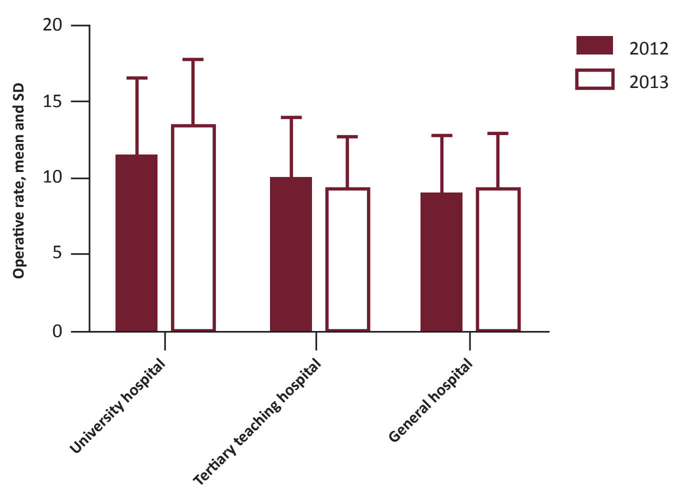
Abbreviations: SES, Socioeconomic Status

[a]Pearson's correlation coefficient and p-value between brackets

The number of operations in 2012 and 2013 were positively correlated (Pearson's correlation coefficient: 0.81, p < 0.001), indicating a consistent pattern over the years. The same was true for number of patients treated conservatively over these two years (Pearson's correlation coefficient: 0.88, p < 0.001).

The 90 hospitals in the Netherlands included in this study comprised eight university hospitals, 53 general hospitals, 28 tertiary teaching hospitals and one independent treatment center. The operative rate was highest in the university hospitals (Figure 3).

Figure 3. Mean of the operative rates per hospital type



Regression analysis showed that hospital type, the percentage of females, the percentage of patients over 65, the mean age, the mean socioeconomic status and the total number of patients explained 2.6% of the differences in the operative rate among hospitals in 2012, and 11.6% in 2013 (adjusted R squared = 0.026 and 0.116). Except for the mean age in 2013, none of these variables was independently related to the operative rate (Table 2).

Table 2. Results of multiple linear regression analysis

Year	2012		2013	
	B	p-value	B	p-value
University hospital	0.008	0.686	0.016	0.345
Tertiary teaching hospital	0.009	0.382	-0.003	0.776
Percentage of females	-0.014	0.896	-0.181	0.183
Percentage of patients >65	-0.087	0.528	-0.270	0.140
Mean age	0.004	0.089	0.005	0.022
Mean SES	0.007	0.391	-0.004	0.582
Total number of patients	0.000	0.935	0.000	0.616

Statistically significant p-values are printed in bold.

Abbreviations: SES, Socioeconomic Status

DISCUSSION

There is a considerable variation in the treatment of patients with distal radius fractures across the country with operative rates varying from 0% to as much as 23%. The high correlation between operative rates in 2012 and 2013 indicates a consistent pattern of variation over the years. These differences could not be explained by the hospital type, the percentage of females, the percentage of patients over 65 years of age, the mean age, the mean socioeconomic status or the total number of patients in each hospital. In fact, there was not a single variable that was significantly associated with the operative rate. Only the mean age of the patients had a small significant influence on the operative rate in 2013 (B = 0.005, p-value = 0.022). Adjusted for the other factors, an increase in average age of the population of one year, results in an average increase in operative rate of 0.5%. However this relationship was not significant for 2012.

These results might suggest that the choice for operative treatment of patients with distal radius fractures is not completely attributable to patient-related factors, but also to care-related factors such as the surgeon's beliefs and preferences. Previous studies have already indicated that younger surgeons are more likely to perform open reduction and internal fixation (ORIF) of distal radius fractures in patients over 65 years of age compared to older surgeons.[5-7] The surgeon's background also plays a role: orthopedic surgeons are significantly more likely to use ORIF than hand surgeons. [4] Given the lack of evidence supporting the appropriate treatment option for most patients with distal radius fractures, these findings are not surprising. After all, in absence of an optimum treatment, a surgeon's preference (ideally in a shared decision making process with the patient) is decisive.

Another possible explanation for differences in operative rates is the high variability in fracture patterns.[14] Every patient is unique and every fracture is different, thus requiring a patient-tailored treatment. The higher operative rate found in university hospitals might be explained by a larger percentage of multitrauma patients who sustained high energy trauma resulting in comminuted fractures. Nevertheless, besides this, if the patient populations were similar one would not expect major differences in distribution of fracture types among hospitals. When we accounted for differences in patient population this only explained a very small percentage of the variation among hospitals.

This study has several limitations. The use of reimbursement data is limited by the depth of the data. Ideally we would have considered other case mix factors that might influence the type of treatment such as injury mechanism, fracture pattern, hand dominance, functional status of the patient and occupation. Unfortunately this data is not centrally registered, nor is it possible to receive individual patient data due to confidentially issues. Therefore aggregated data per hospital was provided. We attempted to correct for individual differences by accounting for the percentage of females and the percentage of patients over 65 years of age in each hospital. Nevertheless, we do not expect that correcting for individual factors at hospital level would greatly reduce the practice style variation we observed.

Another limitation of the data is that the reimbursement codes do not differentiate between external fixation and ORIF. In our experience, external fixation is performed infrequently and surgeons prefer ORIF.[15,16] Nevertheless, we were unable to examine any difference in the rates of external fixation among hospitals.

Although our results only regard the situation in the Netherlands, variation in surgery rates within countries appear to be similar across national boundaries.[8] A previous study by Fanuele et al. already showed a significant regional variation in the treatment of distal radius fractures in the United States.[12] They concluded that the type of treatment depended mostly on the patient's age and address. We also found a substantial variation among hospital services areas, however, the patient's age showed to be of minor importance.

Variation in treatment is not just restricted to distal radius fractures. Considerable variations in medical practice have previously been identified for a number of elective procedures such as tonsillectomy, hip replacement and prostatectomy.[8,17] Some of this regional variation might be due to the presence of specialized referral centers. However, distal radius fractures

are not commonly referred to specialized centers but treated locally in the nearest hospital. This is also evident from our data that shows that all hospitals, including highly specialized university hospitals, treat patients with distal radius fractures. This renders patients with distal radius fractures a valid population for a variation in treatment study.
Considering the €5500 difference in billings between conservative treatment and surgical treatment, and assuming that conservative treatment prevails in the majority of the cases, there is a substantial potential to reduce costs. If we regard an operative rate of 10% appropriate (around the mean that we observed in 2013), the annual savings from one hospital with a rate of 15% and a volume of 600 patients can be as high as €165,000 (0.05 * 600 * €5500). On a national scale, this figure could run into millions of Euros cost savings each year. Conversely, the low operative rates found in some hospitals could also be an indication of suboptimal treatment of patients with distal radius fractures. A hospital that has an operative rate of only 5% might achieve worse functional results than a hospital with a higher rate.

Our database provided a comprehensive overview of al reimbursements of distal radius fractures in the Netherlands. It also showed that there is considerable variation in the treatment of distal radius fractures among hospitals. Although these findings might not be surprising, they are alarming. The variation across the country reflects a lack of evidence and suggests that non-scientific influences, such as surgeon's age, background and local culture, prevail and drive therapeutic decisions.

We do not know what is the appropriate rate of operative treatment of distal radial fractures, and without detailed knowledge on each individual patient it is impossible to comment on the appropriateness. Even more so because we did not investigate patients' experiences with the provided care, Patient Reported Outcomes or other functional outcomes. Nevertheless, the variation that we observed suggests the potential for an increase in quality and appropriateness of care for patients with distal radius fractures. It also supports the notion that we require well-designed randomized studies to delineate the optimum treatment for patients with distal radius fractures.

REFERENCES

1. Lichtman DM, Bindra RR, Boyer MI, Putnam MD, Ring D, Slutsky DJ, et al. American Academy of Orthopaedic Surgeons clinical practice guideline on: the treatment of distal radius fractures. J Bone Joint Surg Am 2011 Apr 20;93(8):775-778.

2. Ng CY, McQueen MM. What are the radiological predictors of functional outcome following fractures of the distal radius? J Bone Joint Surg Br 2011 Feb;93(2):145-150.

3. Kodama N, Imai S, Matsusue Y. A simple method for choosing treatment of distal radius fractures. J Hand Surg Am 2013 Oct;38(10):1896-1905.

4. Chung KC, Shauver MJ, Birkmeyer JD. Trends in the United States in the treatment of distal radial fractures in the elderly. J Bone Joint Surg Am 2009 Aug;91(8):1868-1873.

5. Ansari U, Adie S, Harris IA, Naylor JM. Practice variation in common fracture presentations: a survey of orthopaedic surgeons. Injury 2011 Apr;42(4):403-407.

6. Waljee JF, Zhong L, Shauver MJ, Chung KC. The influence of surgeon age on distal radius fracture treatment in the United States: a population-based study. J Hand Surg Am 2014 May;39(5):844-851.

7. Neuhaus V, Bot AG, Guitton TG, Ring DC. Influence of surgeon, patient, and radiographic factors on distal radius fracture treatment. J Hand Surg Eur Vol 2014 Oct 22.

8. Birkmeyer JD, Reames BN, McCulloch P, Carr AJ, Campbell WB, Wennberg JE. Understanding of regional variation in the use of surgery. Lancet 2013 Sep 28;382(9898):1121-1129.

9. McCulloch P, Nagendran M, Campbell WB, Price A, Jani A, Birkmeyer JD, et al. Strategies to reduce variation in the use of surgery. Lancet 2013 Sep 28;382(9898):1130-1139.

10. Walenkamp MM, Goslings JC, Beumer A, Haverlag R, Leenhouts PA, Verleisdonk EJ, et al. Surgery versus conservative treatment in patients with type A distal radius fractures, a randomized controlled trial. BMC Musculoskelet Disord 2014 Mar 19;15:90-2474-15-90.

11. Beerekamp MS, Ubbink DT, Maas M, Luitse JS, Kloen P, Blokhuis TJ, et al. Fracture surgery of the extremities with the intra-operative use of 3D-RX: a randomized multicenter trial (EF3X-trial). BMC Musculoskelet Disord 2011 Jul 6;12:151-2474-12-151.

12. Fanuele J, Koval KJ, Lurie J, Zhou W, Tosteson A, Ring D. Distal radial fracture treatment: what you get may depend on your age and address. J Bone Joint Surg Am 2009 Jun;91(6):1313-1319.

13. Ehsan A, Stevanovic M. Skeletally mature patients with bilateral distal radius fractures have more associated injuries. Clin Orthop Relat Res 2010 Jan;468(1):238-242.

14. Mandziak DG, Watts AC, Bain GI. Ligament contribution to patterns of articular fractures of the distal radius. J Hand Surg Am 2011 Oct;36(10):1621-1625.

15. Walenkamp MM, Bentohami A, Beerekamp MS, Peters RW, van der Heiden R, Goslings JC, et al. Functional outcome in patients with unstable distal radius fractures, volar locking plate versus external fixation: a meta-analysis. Strategies Trauma Limb Reconstr 2013 Aug;8(2):67-75.

16. Xie X, Xie X, Qin H, Shen L, Zhang C. Comparison of internal and external fixation of distal radius fractures. Acta Orthop 2013 Jun;84(3):286-291.

17. Westert GP, Groenewegen PP, Boshuizen HC, Spreeuwenberg PM, Steultjens MP. Medical practice variations in hospital care; time trends of a spatial phenomenon. Health Place 2004 Sep;10(3):215-220.

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CHAPTER 6

FUNCTIONAL OUTCOME IN PATIENTS WITH UNSTABLE DISTAL RADIUS FRACTURES, VOLAR LOCKING PLATE VERSUS EXTERNAL FIXATION: A META-ANALYSIS

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Strategies Trauma Limb Reconstr. 2013

ABSTRACT

The aim of this study was to compare bridging external fixation with volar locked plating in patients witht unstable distal radial fractures regarding functional outcome. A systematic search was performed in the Cochrane Central Register of Controlled Trials, Medline and EMBASE. All randomized controlled trials that compared bridging external fixation directly with volar locked plating in patients with distal radial fractures were considered. Three reviewers extracted data independently from eligible studies using a data collection form. Studies in which the primary endpoint was measured on the disabilities of the arm shoulder and hand (DASH) score at 3, 6 and 12 months were included in the analysis. To this end, mean scores and standard deviations were extracted. The software package Revman 5 provided by the Cochrane Collaboration was used for data analysis. Three studies involving 174 patients were analyzed. Ninety patients were treated with an (augmented) bridging external fixator and 84 with a volar locking plate. Data were analyzed with the random effects model. The robustness of the results was explored using a sensitivity analysis. Patients treated with a volar locking plate showed significantly lower DASH scores at all times. A difference of 16 ($p = 0.006$), six ($p = 0.008$) and eight points ($p = 0.06$) was found at 3, 6 and 12 months follow-up, respectively. Patients treated with a volar locking plate showed significantly better functional outcome throughout the entire follow-up. However, this difference was only clinically relevant during the early postoperative period (3 months)

INTRODUCTION

Fractures of the distal radius are common and account for an estimated 17% of all fractures diagnosed.[1,2] Two-thirds of these fractures are displaced and require reduction.[3] Several treatment modalities have been advocated, and decision-making is mainly based on fracture type.[4,5]

One possible surgical treatment method is bridging external fixation. This technique relies on ligamentotaxis to obtain and maintain fracture alignment.[6] However, since the introduction of locking plates, open reduction and internal fixation (ORIF) has become increasingly popular in surgical reduction.[7] This technique provides immediate stable fixation that allows early mobilization[5,8] and may result in a more rapid recovery and improved regain of function.[9] Conversely, bridging external fixation augmented (with or without additional Kirschner wires) is a less demanding, less invasive and faster procedure. Excellent results have been described for both techniques.[10-15] However, no conclusive evidence has been published favoring ORIF with a volar locking plate over bridging external fixation or vice versa.[16]

Margaliot et al.[11] conducted a meta-analysis of studies published between 1980 and 2004 on external and internal fixation of distal radial fractures. They concluded there was not sufficient evidence to support the use of ORIF over external fixation. However, outcome data from a large variety of different techniques of internal fixation were pooled. Studies on both locking and nonlocking implants were included resulting in considerable heterogeneity across studies.[11] More recently, Wei et al.[17] performed a similar meta-analysis comparing functional outcome at 1 year in patients with unstable distal radius fractures. The authors pooled data from 12 randomized and nonrandomized trials on seven different techniques of internal fixation. A secondary subgroup analysis of four studies for volar locking plates revealed a significant difference on the disabilities of the arm shoulder and hand (DASH) score in favor of this technique. Unfortunately, exact DASH scores could not be reported, and therefore, clinical relevance of these differences is difficult to evaluate.[18] Moreover, this analysis included one retrospective study[19] and one trial that compared volar locking plates with closed reduction and percutaneous pinning.[20] The authors emphasized that their results were tempered by a substantial heterogeneity present across studies.[17] However, their significant findings justify further examination regarding the benefits of volar locking plates.

Recent studies on ORIF with volar locking plate have described most benefit in the early postoperative period.[21,22] In addition to improved functional results at 1 year, a more rapid recovery is of clinical interest as well. Therefore, the primary aim of this meta-analysis was to compare bridging external fixation with volar locked plating in patients with unstable distal radius fractures, regarding functional outcome as measured on the DASH score, at 3, 6 and 12 months follow-up. The secondary aim was to compare grip strength, flexion and extension and radiological parameters at 1 year follow-up.

MATERIALS AND METHODS

The present study was reported according to the PRISMA guidelines (Preferred Reporting Items for Systematic reviews and Meta-Analyses).[23]

Eligibility criteria

All randomized clinical trials that compared (augmented) bridging external fixation with volar locking plates in adult patients with unstable distal radial fractures were considered. Publication language was restricted to English and Dutch. Studies that did not clearly define the patient population (unstable distal radius fracture) and thus did not the fine the indication for surgery were not included. Trials that compared different fixation techniques or other implants were not included either. Studies that reported functional outcome on the disability of arm, shoulder and hand score at 3, 6 and 12 months follow-up were included.

Types of outcome measures

The primary outcome measure of this meta-analysis was a functional outcome defined by the DASH score at 3, 6 and 12 months follow-up. The DASH score is a validated 30-item, self-report questionnaire designed to measure physical function and symptoms in patients with musculoskeletal disorders of the upper limb. Lower scores indicate a better functional outcome. The total scale score ranges from 0 (no disability) to 100 (most severe disability).[24] The secondary outcome measures of this review were as follows: grip strength measured as a percentage of the uninjured side, flexion and extension in degrees, and radiological parameters including radial inclination, volar tilt, ulnar variance and radial length at a minimal of 1 year follow-up.

Data sources

We conducted a search for three electronic databases: Cochrane Central Register of Controlled Trials, Medline and EMBASE in March 2013. In order not to miss recently published literature, the use of MESH terms was avoided. The complete search strategy is depicted in Table 1. Additionally, a cross-reference check for the articles of interest was performed.

Table 1. Search Strategy

Medline

((((distal[Title/Abstract]) AND fracture*[Title/Abstract]) AND ((radius[Title/Abstract]) OR radial[Title/Abstract])) OR (((((colles’ fracture*[Title/Abstract]) OR colles fracture*[Title/Abstract]) OR smith fracture*[Title/Abstract]) OR barton fracture*[Title/Abstract]) OR wrist fracture*[Title/Abstract])) AND (((volar[Title/Abstract]) OR palmar[Title/Abstract]) OR palmer[Title/Abstract]) AND ((((external fix*[Title/Abstract]) OR fixation ext*[Title/Abstract]) OR fixateur ext*[Title/Abstract]) OR fixator ext*[Title/Abstract])

EMBASE

((((distal.ti,ab) AND fracture*.ti,ab) AND ((radius.ti,ab) OR radial.ti,ab)) OR (((((colles’ fracture*.ti,ab) OR colles fracture*.ti,ab) OR smith fracture*.ti,ab) OR barton fracture*.ti,ab) OR wrist fracture*.ti,ab)) AND (((volar.ti,ab) OR palmar.ti,ab) OR palmer.ti,ab) AND ((((external fix*.ti,ab) OR fixation ext*.ti,ab) OR fixateur ext*.ti,ab) OR fixator ext*.ti,ab)

Cochrane Central Register of Controlled Trials

(distal:ti,ab,kw and fracture*:ti,ab,kw) AND (radius:ti,ab,kw or radial:ti,ab,kw or ‘‘Colles’ fracture*’’:ti,ab,kw or ‘‘Colles fracture*’’:ti,ab,kw or ‘‘Barton’s fracture’’:ti,ab,kw or smith fracture*:ti,ab,kw or ‘‘Smith’s fracture*’’:ti,ab,kw or wrist fracture*:ti,ab,kw) AND (‘‘volar’’:ti,ab,kw

Study selection

All titles that resulted from the search strategy described above were screened independently by three reviewers. Publications reporting on completely different subjects were identified and excluded. If titles did not provide sufficient information, abstracts were examined. Cohort studies, case studies, comments and current (management) views were excluded. Eligibility with regard to the in- and exclusion criteria of the remaining articles was subsequently assessed based on full text. Disagreement was resolved by means of discussion, which included a second trauma surgeon with a master in clinical epidemiology (NS).

Data extraction

Three reviewers extracted data independently from eligible studies using a data collection form. Items include study type, number of subjects, patient characteristics, fracture types, treatment method, length of follow-up and outcome measures. Means and standard deviations were extracted for continuous outcomes or calculated from confidence intervals. Studies in which these values were not reported were excluded.[15] If multiple treatment types were studied, only data regarding patients treated with bridging external fixation or ORIF were extracted. Risk of bias was assessed using the GRADE guidelines.[25]

Data synthesis
The software package Revman 5 provided by the Cochrane Collaboration was used for data analysis.[26] The mean differences in DASH scores between treatment groups at 3, 6 and 12 months were calculated with 95 percent confidence intervals. The random effects model was used to pool data.[27] Heterogeneity was explored using the chi square test, with significance set at p<0.1. For quantification, I2 was used with values less than 30% indicating low heterogeneity.[28,29]

Sensitivity analysis
The stability of the results regarding the DASH scores at 3, 6 and 12 months was tested using a sensitivity analysis under different assumptions. Sensitivity analyses were performed based on methodological quality of the included studies and the meta-analytic model. In addition, the robustness of results was explored by consecutively excluding one study.

RESULTS

Literature search
The search yielded 197 results, three of which met our inclusion criteria (Fig. 1).[30-32] In total, 174 patients were included, of which 90 were treated with an (augmented) bridging external fixator and 84 patients with a volar locking plate.

Description of included studies
The study characteristics are summarized in Table 2. Egol et al.[31] randomized 88 patients with an unstable distal radial fracture to undergo either bridging external fixation (EBI, Parsippany, New Jersey or Stryker, Mahwah, New Jersey) and a K-wire construct or ORIF with a volar locking plate (Hand Innovations, Miami, Florida or Stryker). Inclusion criteria were as follows: loss of reduction following closed reduction and cast immobilization, open fractures or anticipated fracture instability. Criteria for an adequate reduction measured on conventional X-rays included residual dorsal angulation of <10° and loss of radial height of <2 mm. Randomization was performed with a random number generator. The result was handed in a sealed envelope to the treating physician. Seventy-seven patients were included in the analysis, 38 received external fixation with supplementary K-wires and 39 a volar locking plate. DASH scores were reported at a follow-up of 3, 6 and 12 months.

Figure 1. Flow diagram of in- and excluded studies

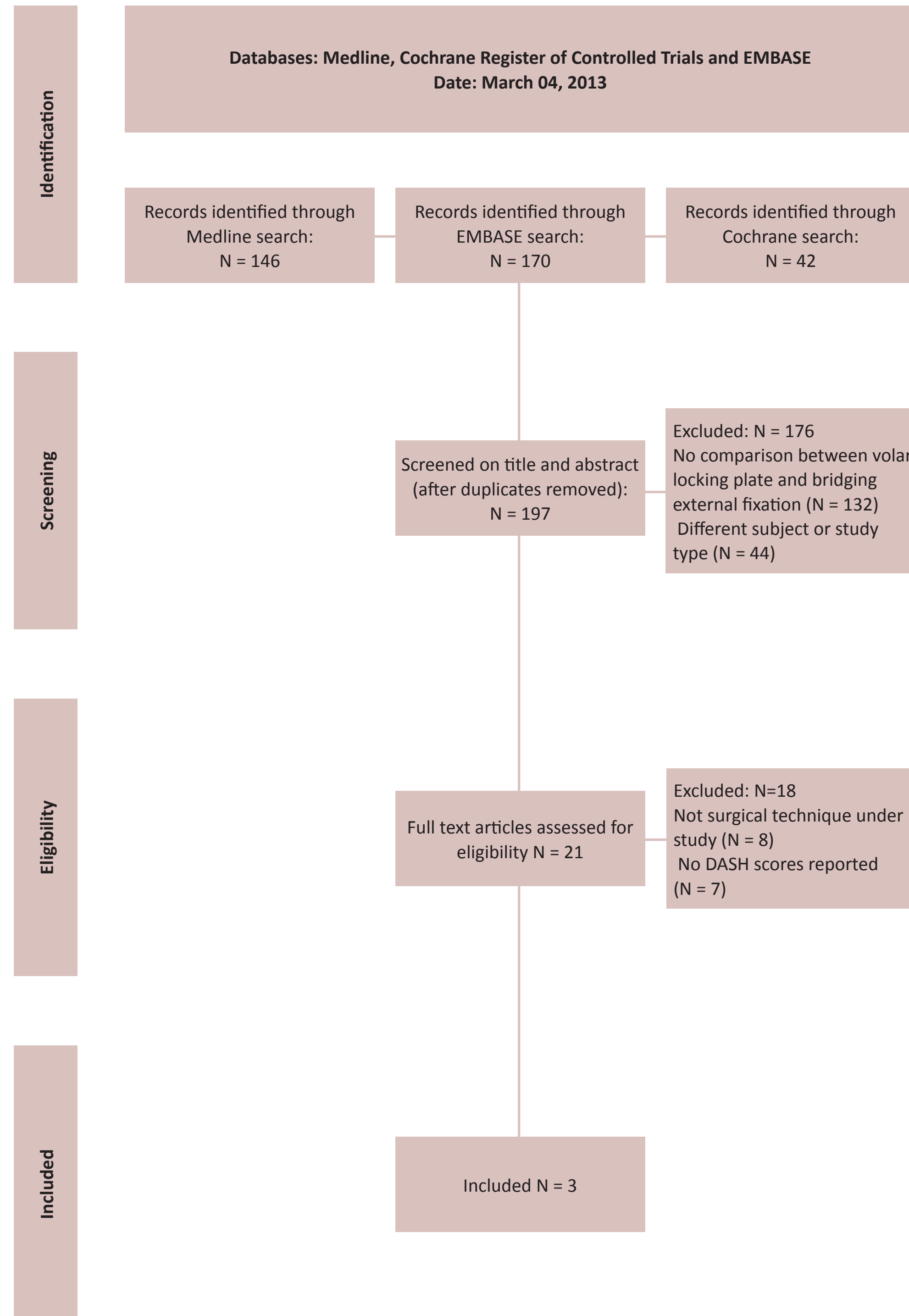


Table 2. Details of included studies

Author	Study Design	AO classification of included fractures	Sample Size		Mean age (years)	Country	Year published	DASH reported at
			Fix ex	Vo. Lo. Plate				
Egol et al.	RCT	A, B, C	38	39	51	USA	2008	3, 6, 12 months
Wei et al.	RCT	A3, C1, C2, C3	22	12	57	USA	2009	3, 6, 12 months
Wilcke et al.	RCT	A, C1	30	33	56	Sweden	2011	3, 6, 12 months

Abbreviations: RCT, randomized controlled trial

Wei et al.[30] randomized 46 patients with an unstable distal radius fracture to be treated with augmented external fixation (n = 22), a volar locking plate (n = 12) or a radial locking column plate (n = 12). Fractures were considered unstable if fracture fragments were redisplaced following closed reduction and cast immobilization, or if three of the following criteria were met: dorsal angulation of >20°, dorsal comminution, an intra-articular fracture, an associated ulnar styloid fracture or age >60 years. Patients were randomized into three study arms in two phases. First, patients were assigned to be treated with augmented external or internal fixation. During a second randomization, the patients who had been assigned to receive internal fixation were further randomized to be treated with either a volar locking (EBI OptiLock, Parsippany, New Jersey) or a radial locking column plate. Randomization was done by computer-generated allocation using sealed, opaque envelopes. Only data on patients treated with an external fixator or with a volar locking plate were included in this meta-analysis. Treatment with external fixation (Hoffmann II Compact, Stryker) was augmented with K-wires in all patients, additional small buttress plates (n = 2) or filling of the metaphyseal void with cancellous bone allograft (n = 4) as deemed appropriate by the surgeon. Two patients who had originally been assigned to be treated with a volar locking plate received additional fixation with a dorsal plate, and four patients received supplemental bone grafting following fixation with a volar locking plate. These patients were included in the analysis in the group they were originally assigned to. DASH scores were reported at a follow-up of 3, 6 and 12 months.

Wilcke et al.[32] randomized 63 patients under the age of 70 into volar locking plating (n = 33) or bridging external fixation (n = 30). Only dorsally displaced AO type A and C1 fractures with an axial shortening of ≥4 mm or a dorsal angulation of ≥20° were included. Randomization was performed by a sealed envelope procedure. Randomization was conducted in blocks of

20 with age stratification set on 50 years. Patients were treated with a volar locking plate (Ko¨nigsee; Swemac, Sweden) or an external fixator (Hoffmann II Compact, Stryker). In one patient, additional augmentation with a K-wire was performed. DASH scores were reported at a follow-up of 3, 6 and 12 months.

Methodological quality

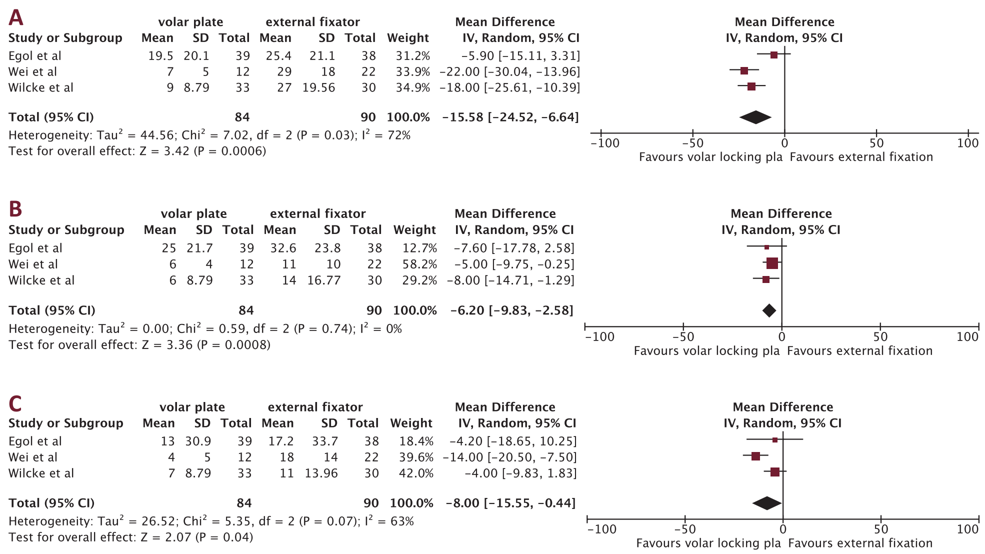
The methodological quality of the included randomized controlled trials was moderate according to the guidelines of the GRADE working group.[25] All studies described the process of allocation concealment. Wei et al. randomized their patients into three study arms in two phases resulting in three treatment groups with unequal numbers of subjects. Patients were not blinded since the treatment involved a surgical procedure. Completion of follow-up at 1 year was 78% in Wei's study and 100% in the two other included studies.

In the study by Wei et al., all patients were analysed based on the intention to treat principle. Egol et al. did not clearly describe crossover to other treatment arms and the type of analysis applied. In the study by Wilcke, one patient in the external fixator group was reoperated and received a supplementary volar plate. This patient was analyzed in the external fixator treatment arm. Power calculations were done for all three trials.

Functional and radiological outcome

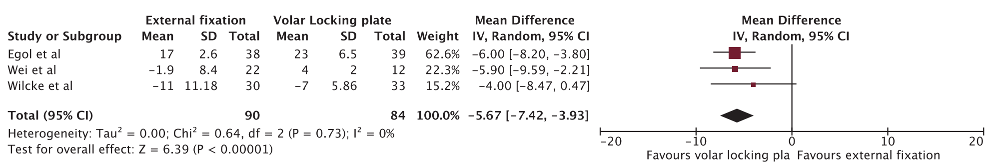
At 3 months follow-up, there was a significant difference of 16 points in DASH score favoring the locking plate (95% CI: -24.52, -6.64). At 6 and 12 months, we found a significant difference of 6 (95% CI: -9.83, -2.58) and eight points (95% CI: -15.55, -0.44), respectively (Fig. 2a-c). A significant difference in volar tilt was observed in favor of treatment with a volar locking plate (Fig. 3). No significant differences were demonstrated in the other secondary outcomes (Table 3).

Figure 2. DASH scores at 3, 6 and 12 months. A. Table and forest plot illustrating functional outcome based on DASH scores comparing external fixation with a volar locking plate at 3 months with a random effects model. B. Table and forest plot illustrating functional outcome based on DASH scores comparing external fixation with a volar locking plate at 6 months with a random effects model. C. Table and forest plot illustrating functional outcome based on DASH scores comparing external fixation with a volar locking plate at 12 months with a random effects model.



Abbreviations: SD, standard deviation CI; confidence interval; df, degrees of freedom; IV, inverse variance

Figure 3. Volar tilt. Table and forest plot illustrating radiographic outcome based on volar tilt comparing external fixation with a volar locking plate at 12 months with a random effects model. The found difference of six degrees indicates a more accurate anatomical reconstruction of the volar tilt after treatment with a volar locking plate.



Abbreviations: SD, standard deviation CI; confidence interval; df, degrees of freedom; IV, inverse variance

Table 3. For the secondary outcomes such as grip strength, flexion, extension, radial inclination, ulnar variance and radial length, no significant differences were demonstrated

Outcome	Number of studies	Mean difference
Grip strength as percentage of uninjured side	3	-1.73 (-12.27, 15.73)
Flexion (degrees)	2	0.44 (-4.66, 5.53)
Extension (degrees)	2	4.46 (-5.21, 14.14)
Radial inclination (degrees)	2	-2.06 (-4.6, 0.49)
Ulnar variance (mm)	3	-0.086 (-1.82, 0.10)
Radial length (mm)	3	-0.96 (-1.96, 0.04)

Sensitivity analysis

Based on methodological quality, the study by Egol et al. was first excluded since they used a per protocol analysis. Subsequently, the trial by Wei et al. was excluded because of their considerable lost to follow-up. These analyses did not alter the findings or conclusions; all differences remained significant. This was similar when the metaanalytic model was changed. Considerable heterogeneity was found in the analysis of DASH score at 3 and 12 months. Data were homogenous for the DASH score at6 months (I^2 = 0%). When the study by Egol et al. was excluded, data were homogenous (I^2 = 0%) for the analysis of DASH score at 3 months as well. The same was witnessed for the DASH score at 12 months when the trial by Wei et al. was excluded.

Complications

A complication rate of 26% in the external fixator group and 20% in the volar locking plate group was found (Table 4). These differences were not significant (Fig. 4).

Table 4: Complications

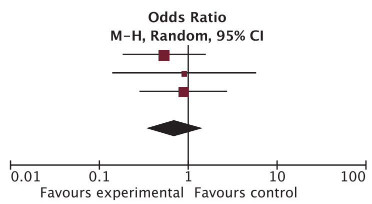
Complication	ORIF with volar locking plate (N)	Bridging external fixator (N)
Pin tract infection		9
Deep infection	1	
Ruptured extensor/flexor pollicis longus tendon	3	1
CRPS		3
Nonunion	1	1
Painful retained hardware	4	
CTS	2	
Tenolysis for postoperative stiffness		1
Malunion		4
Tendinitis	1	1
Total	**17/84 (20%)**	**23/90 (26%)**

Abbreviations: CRPS, Complex Regional Pain Syndrome; CTS, Carpal Tunnel Syndrome

Figure 4. Complications. Table and forest plot illustrating the complication rate comparing treatment with external fixation with a volar locking plate with a random effects model.

	volar plate		external fixator			Odds Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Egol et al	7	39	11	38	44.8%	0.54 [0.18, 1.58]
Wei et al	2	12	4	22	14.9%	0.90 [0.14, 5.81]
Wilcke et al	8	33	8	30	40.3%	0.88 [0.28, 2.74]
Total (95% CI)		**84**		**90**	**100.0%**	**0.71 [0.34, 1.46]**
Total events	17		23			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.46$, df = 2 (P = 0.80); $I^2 = 0\%$
Test for overall effect: Z = 0.94 (P = 0.35)



Abbreviations: CI, confidence interval; df, degrees of freedom; M-H, Mantel-Haenszel

DISCUSSION

This meta-analysis revealed a better functional outcome in patients with unstable distal radius fractures treated with a volar locking plate compared with (augmented) external fixation at 3, 6 and 12 months follow-up. Patients treated with a volar locking plate showed faster rehabilitation reflected in a 16-point difference in DASH score at 3 months. This difference subsided at 6 and 12 months to six and eight points, respectively.

However, in order to fully appreciate these finding, the clinical relevance of the differences in DASH scores should be taken into consideration. The minimal clinically important difference is the smallest difference in an outcome score that a patient perceives as beneficial. In patients with wrist pathology, the minimal clinically important difference in DASH score ranges between 10 points and 15 points.[18,33] Therefore, functional outcome at 3 months can be considered to be both significantly better and clinically relevant for patients treated with a volar locking plate.

Although considerable heterogeneity was found in the analysis of DASH scores at 3 and 12 months, the differences remained significant under the sensitivity analyses. No clinical or methodological issues could be identified explaining this heterogeneity.

Another significant difference between treatment methods was a slightly improved anatomical restoration of the volar tilt in the ORIF group. The mean difference between external fixation and volar locking plate was six degrees, which indicates a more accurate anatomical reconstruction. Nevertheless, we should keep in mind that radiographic parameters are surrogate endpoints and their clinical relevance remains disputed.[34,35]

There are several strengths to this meta-analysis which include the comprehensive search of the literature and the inclusion of similar trials. Studies in which implants other than volar locking plates, e.g., the fragment-specific wrist fixation system, nonlocking plates or a combination of volar and dorsal plating were used, were not included.[14,20,36-39] Similarly, studies using a different form of external fixation and studies with an unclear definition of unstable fractures were excluded as well.[20] Therefore, the results of this meta-analysis will most likely reveal the true magnitude and direction of the differences between the treatments under study.

However, the results of this study should be interpreted with caution because of the following limitations. The power of this meta-analysis was limited since the sample size of the included studies was relatively small. Moreover, the three trials included various AO fracture types and used different definitions of fracture instability and therefore indication for surgery. Finally, unfortunately, only three trials could be included in this analysis. Nevertheless, the quality of a meta-analysis is often considered to be more susceptible to heterogeneity present across studies than the number of included trials.[40,41] After all, pooled results can be obtained from as few as two studies.

A traditional argument in favor of ORIF with a volar locking plate is early mobilization, which theoretically results in less muscle weakness and therefore improved regain of wrist function. Additionally, the locking principle provides a more rigid construction in the subchondral area of the distal radius, especially in patients with osteoporosis. This theory is in accordance with the results of the current meta-analysis that revealed a significant and clinically relevant improved patient-reported functional outcome for volar locking plate at 3 months. This difference remained significant under a sensitivity analysis and can therefore be considered to be robust. A more rapid recovery might benefit high demanding patients or athletes, and therefore, treatment with volar locking plate for these types of patients with an unstable distal radius fracture is recommended.

REFERENCES

1. Singer BR, McLauchlan GJ, Robinson CM, Christie J. Epidemiology of fractures in 15,000 adults: the influence of age and gender. J Bone Joint Surg Br 1998 Mar;80(2):243-248.

2. Owen RA, Melton LJ,3rd, Johnson KA, Ilstrup DM, Riggs BL. Incidence of Colles' fracture in a North American community. Am J Public Health 1982 Jun;72(6):605-7.

3. Brogren E, Petranek M, Atroshi I. Incidence and characteristics of distal radius fractures in a southern Swedish region. BMC Musculoskelet Disord 2007 May 31;8:48.

4. DSo S. Guidelines Distal Radius Fractures, diagnosis and treatment. 2010.

5. Drobetz H, Kutscha-Lissberg E. Osteosynthesis of distal radial fractures with a volar locking screw plate system. Int Orthop 2003;27(1):1-6.

6. Slutsky DJ. Nonbridging external fixation of intra-articular distal radius fractures. Hand Clin 2005 Aug;21(3):381-394.

7. Orbay J. Volar plate fixation of distal radius fractures. Hand Clin 2005 Aug;21(3):347-354.

8. Hakimi M, Jungbluth P, Windolf J, Wild M. Functional results and complications following locking palmar plating on the distal radius: a retrospective study. J Hand Surg Eur Vol 2010 May;35(4):283-8.

9. Dias JJ, Wray CC, Jones JM, Gregg PJ. The value of early mobilisation in the treatment of Colles' fractures. J Bone Joint Surg Br 1987 May;69(3):463-467.

10. Handoll HH, Huntley JS, Madhok R. Different methods of external fixation for treating distal radial fractures in adults. Cochrane Database Syst Rev 2008(1469-493X (Electronic)):D006522.

11. Margaliot Z, Haase SC, Kotsis SV, Kim HM, Chung KC. A meta-analysis of outcomes of external fixation versus plate osteosynthesis for unstable distal radius fractures. J Hand Surg Am 2005 nov;30(0363-5023 (Print)):1185-1199.

12. Jupiter JB, Marent-Huber M. Operative management of distal radial fractures with 2.4-millimeter locking plates: a multicenter prospective case series. Surgical technique. J Bone Joint Surg Am 2010 Mar;92 Suppl 1 Pt 1:96-106.

13. Henry MH. Distal radius fractures: current concepts. J Hand Surg Am 2008 Sep;33(7):1215-1227.

14. Leung F, Tu YK, Chew WY, Chow SP. Comparison of external and percutaneous pin fixation with plate fixation for intra-articular distal radial fractures. A randomized study. J Bone Joint Surg Am 2008 Jan;90(1):16-22.

15. Wright TW, Horodyski M, Smith DW. Functional outcome of unstable distal radius fractures: ORIF with a volar fixed-angle tine plate versus external fixation. J Hand Surg Am 2005 mar;30(0363-5023 (Print)):289-299.

16. Kvernmo HD, Krukhaug Y. Treatment of distal radius fractures. Tidsskrift for den Norske laegeforening : tidsskrift for praktisk medicin, ny raekke 2013 feb;133(4):405-411.

17. Wei DH, Poolman RW, Bhandari M, Wolfe VM, Rosenwasser MP. External fixation versus internal fixation for unstable distal radius fractures: a systematic review and meta-analysis of comparative clinical trials. J Orthop Trauma 2012 jul;26(1531-2291 (Electronic)):386-394.

18. Beaton DE, Katz JN, Fossel AH, Wright JG, Tarasuk V, Bombardier C. Measuring the whole or the parts? Validity, reliability, and responsiveness of the Disabilities of the Arm, Shoulder and Hand outcome measure in different regions of the upper extremity. J Hand Ther 2001 Apr-Jun;14(2):128-46.

19. Schmelzer-Schmied N, Wieloch P, Martini AK, Daecke W. Comparison of external fixation, locking and non-locking palmar plating for unstable distal radius fractures in the elderly. Int Orthop 2009 jun;33(1432-5195 (Electronic)):773-778.

20. Rozental TD, Blazar PE, Franko OI, Chacko AT, Earp BE, Day CS. Functional outcomes for unstable distal radial fractures treated with open reduction and internal fixation or closed reduction and percutaneous fixation. A prospective randomized trial. J Bone Joint Surg Am 2009 aug;91(1535-1386 (Electronic)):1837-1846.

21. Arora R, Gabl M, Gschwentner M, Deml C, Krappinger D, Lutz M. A comparative study of clinical and radiologic outcomes of unstable colles type distal radius fractures in patients older than 70 years: nonoperative treatment versus volar locking plating. J Orthop Trauma 2009 Apr;23(4):237-242.

22. Arora R, Lutz M, Deml C, Krappinger D, Haug L, Gabl M. A prospective randomized trial comparing nonoperative treatment with volar locking plate fixation for displaced and unstable distal radial fractures in patients sixty-five years of age and older. Orthopedics 2012;35(1):50-51.

23. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int J Surg 2010;8(5):336-341.

24. Atroshi I, Gummesson C, Andersson B, Dahlgren E, Johansson A. The disabilities of the arm, shoulder and hand (DASH) outcome questionnaire: reliability and validity of the Swedish version evaluated in 176 patients. Acta Orthop Scand 2000 Dec;71(6):613-618.

25. Atkins D, Best D, Briss PA, Eccles M, Falck-Ytter Y, Flottorp S, et al. Grading quality of evidence and strength of recommendations. BMJ 2004 Jun 19;328(7454):1490.

26. The Nordic Cochrane Centre, The Cochrane Collaboration. Review Manager. RevMan 2008;5.0.

27. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials 1986 Sep;7(3):177-188.

28. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002 Jun 15;21(11):1539-1558.

29. Higgins JPT, Green S editors. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. : The Cochrane Collaboration; 2011.

30. Wei DH, Raizman NM, Bottino CJ, Jobin CM, Strauch RJ, Rosenwasser MP. Unstable distal radial fractures treated with external fixation, a radial column plate, or a volar plate. A prospective randomized trial. J Bone Joint Surg Am 2009 Jul;91(7):1568-77.

31. Egol K, Walsh M, Tejwani N, McLaurin T, Wynn C, Paksima N. Bridging external fixation and supplementary Kirschner-wire fixation versus volar locked plating for unstable fractures of the distal radius: a randomised, prospective trial. J Bone Joint Surg Br 2008 Sep;90(9):1214-1221.

32. Wilcke MK, 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 feb;82(1745-3682 (Electronic)):76-81.

33. Roy JS, MacDermid JC, Woodhouse LJ. Measuring shoulder function: a systematic review of four questionnaires. Arthritis Rheum 2009 May 15;61(5):623-632.

34. Bentohami A, Bijlsma TS, Goslings JC, de Reuver P, Kaufmann L, Schep NW. Radiological criteria for acceptable reduction of extra-articular distal radial fractures are not predictive for patient-reported functional outcome. J Hand Surg Eur Vol 2013 Jun;38(5):524-529.

35. Grewal R, MacDermid JC. The risk of adverse outcomes in extra-articular distal radius fractures is increased with malalignment in patients of all ages but mitigated in older patients. J Hand Surg Am 2007 Sep;32(7):962-970.

36. Abramo A, Kopylov P, Geijer M, Tagil M. Open reduction and internal fixation compared to closed reduction and external fixation in distal radial fractures: a randomized study of 50 patients. Acta Orthop 2009 Aug;80(4):478-485.

37. Westphal T, Piatek S, Schubert S, Winckler S. Outcome after surgery of distal radius fractures: no differences between external fixation and ORIF. Arch Orthop Trauma Surg 2005 Oct;125(8):507-514.

38. Kapoor H, Agarwal A, Dhaon BK. Displaced intra-articular fractures of distal radius: a comparative evaluation of results following closed reduction, external fixation and open reduction with internal fixation. Injury 2000 Mar;31(2):75-79.

39. Kreder HJ, Hanel DP, Agel J, McKee M, Schemitsch EH, Trumble TE, et al. Indirect reduction and percutaneous fixation versus open reduction and internal fixation for displaced intra-articular fractures of the distal radius: a randomised, controlled trial. The Journal of bone and joint surgery.British volume 2005 jun;87(6):829-836.

40. Grobbee DE, Hoes AW. Meta-Analysis. Clinical Epidemiolgy, Principles, Methods, and Appications for Clinical Research Sudbury, Massachusetts: Jones and Bartlett Publishers; 2009. p. 288-324.

41. Higgins J, Thompson S, Deeks J, Altman D. Statistical heterogeneity in systematic reviews of clinical trials: a critical appraisal of guidelines and practice. J Health Serv Res Policy 2002 Jan;7(1):51-61.

CHAPTER 7

SURGERY VERSUS CONSERVATIVE TREATMENT IN PATIENTS WITH TYPE A DISTAL RADIUS FRACTURES, A RANDOMIZED CONTROLLED TRIAL

In memory of Robert Wilde

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ABSTRACT

Background

Fractures of the distal radius are common and account for an estimated 17% of all fractures diagnosed. Two-thirds of these fractures are displaced and require reduction. Although distal radius fractures, especially extra-articular fractures, are considered to be relatively harmless, inadequate treatment may result in impaired function of the wrist. Initial treatment according to Dutch guidelines consists of closed reduction and plaster immobilisation. If fracture redisplacement occurs, surgical treatment is recommended. Recently, the use of volar locking plates has become more popular. The aim of this study is to compare the functional outcome following surgical reduction and fixation with a volar locking plate with the functional outcome following closed reduction and plaster immobilisation in patients with displaced extra-articular distal radius fractures.

Design

This single blinded randomised controlled trial will randomise between open reduction and internal fixation with a volar locking plate (intervention group) and closed reduction followed by plaster immobilisation (control group). The study population will consist of all consecutive adult patients who are diagnosed with a displaced extra-articular distal radius fracture, which has been adequately reduced at the Emergency Department. The primary outcome (functional outcome) will be assessed by means of the Disability Arm Shoulder Hand Score (DASH). Secondary outcomes comprise the Patient-Rated Wrist Evaluation score (PRWE), quality of life, pain, range of motion, radiological parameters, complications and cross-overs. Since the treatment allocated involves a surgical procedure, randomisation status will not be blinded. However, the researcher assessing the outcome at one year will be unaware of the treatment allocation. In total, 90 patients will be included and this trial will require an estimated time of two years to complete and will be conducted in the Academic Medical Centre Amsterdam and its partners of the regional trauma care network.

Discussion

Ideally, patients would be randomised before any kind of treatment has been commenced. However, we deem it not patient-friendly to approach possible participants before adequate reduction has been obtained.

BACKGROUND

Fractures of the distal radius account for an estimated 17% of all fractures diagnosed.[1,2] Two-thirds of these fractures are displaced and require reduction.[3] Although extra-articular distal radius fractures are considered to be relatively harmless, inadequate treatment may result in severely impaired function of the wrist.[4,5] The consequences of post-traumatic loss of function are comprehensive, both on individual and societal level, and have long been underestimated.[6]

Several treatment modalities to obtain and maintain reduction exist and decision-making is mainly based on fracture type, region and surgeon's preference.[7] Although good results have been described for both conservative and surgical management, the ideal treatment method remains unknown.

According to current Dutch guidelines, standard treatment for patients with displaced extra-articular distal radius fractures consists of closed reduction and cast immobilisation for four to six weeks.[8] Nevertheless, redisplacement occurs in up to 60% of cases and functional recovery is frequently poor.[9-11] If fracture redisplacement occurs, surgical reduction and fixation is the treatment of choice.[8]

A well-established and widely applied surgical approach is open reduction and internal fixation (ORIF). This procedure involves surgical (open) fracture reduction and internal fixation by means of locking plates. Over the past years, the use of volar locking plates has become increasingly popular.[12] This type of osteosynthesis requires a relatively simple volar approach to the wrist, followed by fracture fixation using fixed angle implants.[13] The technique allows more accurate reduction and immediate stable fixation. Subsequent removal of the plate is rarely necessary.[7,14] The fracture stability allows for early mobilisation and may therefore result in an improved recovery of function.[7,14] By 1987 already, Dias et al. concluded that patients who were encouraged to mobilise their injured wrist from the start in a modified cast which only restricted extension, recovered function more quickly than those whose who were immobilised in a conventional plaster cast.[10]

A recent randomised controlled trial by Arora et al. compared open reduction and internal fixation with a volar locking plate with closed reduction and plaster immobilisation. They included patients of 65 years and older who had suffered all types of displaced distal radius fractures with inadequate reduction or redisplacement.[15] The operative treatment group showed better wrist function in the early post-operative period. However, at six and twelve months there were no significant differences in wrist function between treatment groups. At all times, grip strength was significantly better in the operative group. These results are consistent with a previous retrospective cohort study among elderly patients conducted by Arora et al. as well.[16] Future studies compare the quality of life between patients treated with a volar locking plate or closed reduction and plaster immobilisation.[17]

Despite the high incidence of displaced distal radius fractures and the substantial possible implications of suboptimal management, no high level evidence regarding the best treatment method yet exists. To our knowledge, no studies have been performed comparing conservative treatment with ORIF in patients of all ages with displaced extra-articular distal radius fractures. Therefore, we are proposing to conduct a randomised controlled trial to compare the functional outcome, assessed with the Disability Arm Shoulder Hand Score (DASH), after ORIF with a volar locking plate with closed reduction followed by plaster immobilisation, in patients with displaced extra-articular distal radius fractures. We hypothesise that surgical reduction will result in a more rapid recovery and better functional results at one year follow up than conservative treatment consisting of closed reduction and plaster immobilisation.

The aim of this study is to compare two treatment methods for patients with displaced extra-articular distal radius fractures regarding functional outcome at one year follow up. These treatment methods include open reduction and internal fixation (ORIF) with a volar locking plate and closed reduction followed by plaster immobilisation.

METHODS/DESIGN

This single blinded randomised controlled trial will randomise between open reduction and internal fixation (ORIF) with a volar locking plate (intervention group) and closed reduction followed by plaster immobilisation (control group).

Participants
The eligible study population will consist of all consecutive adult patients who are diagnosed with a displaced extra-articular distal radius fracture, which has been adequately reduced at the Emergency Department of the Academic Medical Centre Amsterdam or one of the other participating hospitals.

Inclusion criteria

- Patients ≥ 18 years and ≤ 75 years
- Extra-articular (AO type A) displaced distal radius fracture, as classified on lateral, posterior-anterior and lateral carporadial radiographs by a radiologist or trauma surgeon.
- Acceptable closed reduction obtained according to current Dutch guidelines. 8
- <15° dorsal or <20° volar angulation of the distal fracture fragment
- <5 mm loss of radial height
- ≥15° radial inclination

Exclusion criteria

- Open distal radius fractures
- Multiple trauma patients (Injury Severity Score (ISS) ≥16)
- Other fractures of the affected extremity
- Patients who indicate to have had impaired wrist function prior to injury, for example due to rheumatoid arthritis, neurological disorders of the upper limb or previous malunions in the affected limb.
- Patients suffering from disorders of bone metabolism known to adversely effect fracture healing, such as osteomalacia.
- Patients suffering from connective tissue or (joint) hyperflexibility disorders known to adversely effect fracture healing and/or soft tissue and wound healing.
- Patients unable to understand the treatment information and informed consent forms as judged by the attending physician.

Interventions
All patients will initially be treated with closed reduction and cast immobilisation. This will take place under local anaesthesia by means of a haematoma block with 20 cc Lidocaine 1%. Closed reduction will be performed according to the Robert-Jones method.[18] This involves increasing the deformity first, then applying continuous traction and immobilising wrist and hand in the reduced position. Additional radiographs will be performed to verify the quality of the reduction (see inclusion criteria). After this has been confirmed, the wrist will be immobilised according to Dutch guidelines: a dorsal splint for one week. Once informed consent is obtained, patients will be randomized at one week between open reduction and internal fixation with a volar locking plate, or continuation of cast immobilization.

The intervention group will be treated with open reduction and internal fixation with a volar locking plate. The surgery will be performed by a general, trauma or orthopaedic surgeon. In order not to disturb clinical practise, and to provide an accurate comparison of two treatment modalities as they are applied in clinical practise, no specific interval to surgery is prescribed. According to the current standard treatment protocol, antibiotic prophylaxis will be administered pre-operatively. The distal radius will be approached according to Henry, which involves an incision between the tendon of the flexor carpi radialis and the radial artery. The advantage of this approach is the possibility of an easy extension to the proximal or distal part of the forearm and the fact that the plate will be optimally covered by soft tissue.[19] Moreover, the median nerve is not at risk using this technique. After the fracture site is exposed, the fracture will be reduced and provisionally fixed with K-Wires and/or reduction forceps. An appropriate volar locking plate which best suits the anatomy of the wrist and the fracture type will be selected. Screw placement and fracture reduction will be confirmed intra operatively by radiographic images. Wound closure will be performed at the discretion of the surgeon using standard techniques and no post-operative fixation or immobilisation will be applied. During the first follow up visit at five to ten days, wound inspection will be performed. Patients will be instructed to use the affected extremity in daily activities as pain allows.

The control group will continue treatment with cast immobilisation according to Dutch guidelines: a circular cast for another four weeks.[8] At one week and three weeks following initial immobilisation, radiographs will be performed in both groups to ensure that loss of reduction has not occurred. Loss of reduction is defined as: >15° dorsal or >20° volar angulation of the distal fracture fragment, >5 mm loss of radial height, or ≤15° radial inclination.[8] If this is the case, operative treatment will be offered. According to Dutch treatment standards, vitamin C 500 milligrams will be prescribed to all patients at initial presentation and for a duration of two months in order to prevent Complex Regional Pain Syndrome.[8]

Randomisation

All patients diagnosed with an extra-articular AO type A1, A2 or A3 distal radius fractures will be requested to participate in this study. Patients will be eligible after adequate reduction of the fracture has been acquired. Upon obtaining informed consent, patients will be randomised into either the intervention group (ORIF with a volar locking plate) or the control group (closed reduction and plaster immobilisation). This will be performed online by randomisation software provided by the Clinical Research Unit of the Academic Medical Centre Amsterdam. In order to avoid any imbalances between treatment groups, patients will be randomised into three strata according to age: 18-30, 31-60 and >60 years using a block randomisation.

Blinding

Randomisation status will not be blinded since the treatment allocated involves a surgical procedure.

Primary outcome

The primary endpoint of this study is wrist function, pain and disability as measured with the DASH score at one year follow up.[20] The Disabilities of the Arm, Shoulder and Hand (DASH) score is a 30-item, self-report questionnaire designed to measure physical function and symptoms in patients with any or several musculoskeletal disorders of the upper limb. The DASH outcome measure is scored in two components: the Disability/Symptom and the optional high performance Sport/Music module. The DASH Disability/Symptom score is a summation of the responses to 11 questions on a scale of 1 to 5, with 0 (no disability) to 100 (severe disability). The questions test the degree of difficulty in performing a variety of physical activities because of arm, shoulder, or hand problems (6 items). It also investigates the severity of pain, tingling (2 items), as well as the effect of the upper limb problem on social activities, work, and sleep (3 items).

Secondary outcomes

- Wrist pain and disability expressed as change on Patient-Rated Wrist Evaluation Score (PRWE). The PRWE is a validated tool for assessing functional outcome in patients with distal radius fractures.[21,22] This score was first described in 1998 by McDermid et al. and developed by expert surveys.[22] The PRWE is a 15-item questionnaire designed to measure wrist pain and disability in activities of daily living. The PRWE allows patients to rate their levels of wrist pain and disability from 0 to 10, and consists of three subscales: Pain, Function and Cosmetics.

- Quality of Life assessed using the Short Form-36 (SF-36®) questionnaire. The SF-36 is a validated multipurpose, short form health survey which contains 36 questions representing eight different health domains.[23] These domains are combined into a mental and physical component scale. From each domain, scores ranging from 0 to 100 points are derived, with lower scores indicating poorer quality of life.

- Pain as indicated on a Visual Analogue Scale (VAS), in which 0 implies no pain and 10 the worst possible pain. Patients will be asked to give an estimation of the type and quantity of pain medication taken during all follow up visits.

- Patient satisfaction at one year by simply asking patients if they are satisfied with the result (yes/no).

- Range of motion of the wrist measured on both sides with a handheld goniometer.

- Prehensile grip strength as measured with a Baseline dynamometer.

- Radiological parameters: radial inclination, volar/dorsal tilt, communition, ulnar variance and radial length measured digitally in the Picture Archiving and Communication System (PACS) on standard posterior anterior (PA), lateral carporadial and lateral X-rays of the wrist. Radiographs will be obtained according to standardised procedures. PA radiographs with the shoulder in 90 degrees abduction, elbow in 90 degrees flexion and the wrist in neutral position; lateral X-rays with the shoulder in neutral position and elbow in 90 degrees flexion; and the lateral carporadial radiographs will be obtained by positioning the lower arm on a 20-25 degrees angled wedge.

- Rate of cross-overs

- Complications such as: loss of reduction, fracture malunion or non-union, wound and/or plate infection, tendon irritation and/or rupture, neuropathy and the occurrence of complex regional pain syndrome according to the criteria by Veldman et al.[24]

Side-effects reporting

All adverse events will be described in patient file during consult at any of the follow-up visits or any other moment if indicated or requested by the patient.[24] Serious adverse events will be reported through the web portal ToetsingOnline to the Medical Ethical Review Committee of the Academic Medical Centre of the University of Amsterdam, which approved the protocol, within 15 days after the sponsor has first knowledge of the serious adverse reactions.

Data collection and follow-up

Baseline characteristics will be obtained after randomisation but before treatment takes place. During follow up patients will be asked to return to the hospital for follow up at; one, three and six weeks and three, six and twelve months, according to standard Dutch protocols. 8 During these visits patients will be asked about any complaints and/or complications and physical and radiological examination will be performed. For details, see Table 1. Procedures additional to standard care are bold.

Table 1. Follow-up visits

Follow-up at:	Tests:
1 week	VAS, X-ray
3 weeks	VAS, **X-ray**
6 weeks	VAS, ROM, Grip strength, QoL, X-ray, PRWE, DASH
3 months	VAS, ROM, Grip strength, QoL, X-ray, PRWE, DASH
6 months	VAS, ROM, Grip strength, QoL, X-ray, PRWE, DASH
12 months	VAS, ROM, Grip strength, QoL, X-ray, PRWE, DASH

Examinations additional to standard care are bold

Abbreviations: VAS, Visual Analogue Scale; ROM, Range of Motion; QoL, Quality of Life; PRWE, Patient-Rated Wrist Evaluation Score; DASH, Disabilities of the Arm Shoulder and Hand Score

Sample size

This sample size calculation is based on the primary endpoint, the DASH score. The DASH score of an individual without any complaints of the wrist is 0. The mean DASH score after closed reduction and cast treatment after one year of follow up is 19 with a standard deviation (SD) of 18.[25] This figure was measured in a patient population in which 72% suffered from a displaced extra-articular distal radius fracture. We assume that treatment with volar plating will decrease the DASH score which is achieved by conservative cast treatment by 15 points, from 19 to 4. Therefore at α = 0.05% and a power of 90%, with an estimated lost to follow-up of 10%, we would require 66 patients in total and 33 per treatment arm, to participate in the trial. This figure was calculated using the standard formula for means of superiority trials: $n = [A + B]^2 * 2 * SD^2/DIFF^2$, where N = the number of patients required per arm, A the level of significance, B the power, SD the standard deviation of the primary outcome and DIFF the difference between the means. For safety measures and to correct for natural deaths, 45 patients in each arm will be included. From a separate study being conducted at the Academic Medical Centre Amsterdam and two other teaching hospitals, it was established that of the 703 distal radius fractures encountered in one year, 328 were an AO type A2 and A3. Therefore we estimate that we require a maximum of two years to include and follow up the patients in this trial.

Statistical analysis

Patients will be analysed according to the intention-to-treat protocol. General descriptive statistics on patient characteristic at baseline will be performed including factors such as gender and age. The primary outcome, DASH at one year, will be corrected for age and assessed using an analysis of co-variance (ANCOVA). Trends in DASH scores among the different time points will be assessed using a repeated measures ANOVA. The secondary outcomes; PRWE, quality of life (QoL SF-36), pain as indicated on a Visual Analogue Scale (VAS) and Range of Motion (ROM) will be analysed in a similar manner. The radiological outcome, number of conversions and complication rate will be determined using either a Fisher Exact of a Chi square test, depending on the order of magnitude of the results. Subgroup analyses with regard to DASH score will be performed for gender and age for each randomisation stratum.

Ethical considerations

This study was approved by the Medical Ethical Review Committee of the Academic Medical Centre.

Regulation statement

This study will be conducted according to the principles of the Declaration of Helsinki version 59, October 2008 and in accordance with the Medical Research Involving Human Subjects Act (WMO) and other guidelines, regulations and Acts.

Recruitment and informed consent

Patients diagnosed with a displaced extra-articular distal radius fracture will be approached by the investigators and informed about this trial. Patients will receive an elaborate information sheet and contact details of both the investigator and an independent physician. Possible participants will have a period of reflection of five working days. If a patient decides to participate, written and oral informed consent will be obtained.

Benefits and risks assessment, group relatedness

The treatment that patients will receive is a component of the standard treatment of care, which currently depends on the surgeon's preference and the complexity of the fracture. Patients will be asked to return to the hospital for follow up at one, three and six weeks, three months, six months and at twelve months. All visits are part of standard care following a fracture treated in this hospital. During these visits patients will be asked about any complaints and/or complications and physical examination will be performed. The assessment of the range of motion of the wrist will take approximately five minutes. Additional to standard care, patients will be asked to fill out three questionnaires at six weeks, three months, six months and one year. Patients will be asked to fill out a DASH form, rate their pain on a Visual Analogue Scale and give an estimation of the type and quantity of pain medication taken during all visits. This will take approximately ten minutes of their time. The PRWE score and the SF-36 will approximately take another ten minutes each. Subjects could experience mild discomfort during physical examination and testing, but this will be no different from that experienced during physical examination during routine follow-up. X-rays will be taken during every visit of which only the final radiographs at one year are additional to standard care. The burden experienced regarding time spent is difficult to estimate but will most likely not exceed 30 minutes. In the total duration of this study, patients will spend an approximate 150 minutes more. The risks are comparable to those that the standard treatment involves. This comprises the standard risk for undergoing a surgical procedure, including risks related to anaesthesia, neurovascular damage and post-operative wound infection. The risks of plaster immobilisation include redisplacement, malunion, loss of function, carpal tunnel syndrome and complex regional pain syndrome. Close follow up and a protocol of treatment, identical to the standard one, will be applied in every subject. Reduction of risks will be done according to inclusion and exclusion criteria. If complications arise, the treating physician will proportionate the adequate treatment according to the current protocols of treatment based on the published literature.

Subjects can leave the study at any time for any reason if they wish to do so without any consequences. The investigator can decide to withdraw a subject from the study for urgent medical reasons. This study will be terminated prematurely if and when patients experience an amount of discomfort or adverse events that is disproportionate to the benefit of the study and presents too great a risk to the participating study subjects. Since the allocated treatment is part of standard treatment of care, no interim analysis, stopping rules or data monitoring was constructed.

Indemnities
The institutional review board at the AMC has waived liability insurance, because no additional risk can be attributed to participation in this study.

Publication plan
The principal investigator, the study designer and the study coordinator will be named author. There will be a limit of ten authors. All others will obtain group authorship in the study group. All authors including group members are allowed to present the results.

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DISCUSSION

The exact moment of inclusion and randomisation of patients with displaced distal radius fractures has proven to be a complicated issue during the design of this trial. Ideally, patients would be randomised before any kind of treatment has been commenced. However, we deem it unethical and moreover not patient-friendly to approach possible participants before adequate reduction has been obtained. Therefore, after careful collaboration and discussion, the research group has decided upon its current format.

REFERENCES

1. Singer BR, McLauchlan GJ, Robinson CM, Christie J. Epidemiology of fractures in 15,000 adults: the influence of age and gender. J Bone Joint Surg Br 1998 Mar;80(2):243-248.

2. Owen RA, Melton LJ,3rd, Johnson KA, Ilstrup DM, Riggs BL. Incidence of Colles' fracture in a North American community. Am J Public Health 1982 Jun;72(6):605-7.

3. Brogren E, Petranek M, Atroshi I. Incidence and characteristics of distal radius fractures in a southern Swedish region. BMC Musculoskelet Disord 2007 May 31;8:48.

4. McQueen M, Caspers J. Colles fracture: does the anatomical result affect the final function? J Bone Joint Surg Br 1988 Aug;70(4):649-651.

5. Villar RN, Marsh D, Rushton N, Greatorex RA. Three years after Colles' fracture. A prospective review. J Bone Joint Surg Br 1987 Aug;69(4):635-638.

6. Edwards BJ, Song J, Dunlop DD, Fink HA, Cauley JA. Functional decline after incident wrist fractures--Study of Osteoporotic Fractures: prospective cohort study. BMJ 2010 Jul 8;341:c3324.

7. Drobetz H, Kutscha-Lissberg E. Osteosynthesis of distal radial fractures with a volar locking screw plate system. Int Orthop 2003;27(1):1-6.

8. DSo S. Guidelines Distal Radius Fractures, diagnosis and treatment. 2010.

9. Mackenney PJ, McQueen MM, Elton R. Prediction of instability in distal radial fractures. J Bone Joint Surg Am 2006 Sep;88(9):1944-1951.

10. Dias JJ, Wray CC, Jones JM, Gregg PJ. The value of early mobilisation in the treatment of Colles' fractures. J Bone Joint Surg Br 1987 May;69(3):463-467.

11. Earnshaw SA, Aladin A, Surendran S, Moran CG. Closed reduction of colles fractures: comparison of manual manipulation and finger-trap traction: a prospective, randomized study. J Bone Joint Surg Am 2002 Mar;84-A(3):354-358.

12. Orbay J. Volar plate fixation of distal radius fractures. Hand Clin 2005 Aug;21(3):347-354.

13. Wong KK, Chan KW, Kwok TK, Mak KH. Volar fixation of dorsally displaced distal radial fracture using locking compression plate. J Orthop Surg (Hong Kong) 2005 Aug;13(2):153-157.

14. Hakimi M, Jungbluth P, Windolf J, Wild M. Functional results and complications following locking palmar plating on the distal radius: a retrospective study. J Hand Surg Eur Vol 2010 May;35(4):283-8.

15. Arora R, Lutz M, Deml C, Krappinger D, Haug L, Gabl M. A prospective randomized trial comparing nonoperative treatment with volar locking plate fixation for displaced and unstable distal radial fractures in patients sixty-five years of age and older. J Bone Joint Surg Am 2011 Dec 7;93(23):2146-2153.

16. Arora R, Gabl M, Gschwentner M, Deml C, Krappinger D, Lutz M. A comparative study of clinical and radiologic outcomes of unstable colles type distal radius fractures in patients older than 70 years: nonoperative treatment versus volar locking plating. J Orthop Trauma 2009 Apr;23(4):237-242.

17. Bartl C, Stengel D, Bruckner T, Rossion I, Luntz S, Seiler C, et al. Open reduction and internal fixation versus casting for highly comminuted and intra-articular fractures of the distal radius (ORCHID): protocol for a randomized clinical multi-center trial. Trials 2011 Mar 22;12:84-6215-12-84.

18. Hanel DP, Jones MD, Trumble TE. Wrist fractures. Orthop Clin North Am 2002 Jan;33(1):35-57, vii.

19. Kwasny O, Fuchs M, Schabus R. Results of a volar approach to plate osteosynthesis of radius shaft fractures. Theoretical basis--clinical results. Unfallchirurgie 1992 Feb;18(1):24-30.

20. Atroshi I, Gummesson C, Andersson B, Dahlgren E, Johansson A. The disabilities of the arm, shoulder and hand (DASH) outcome questionnaire: reliability and validity of the Swedish version evaluated in 176 patients. Acta Orthop Scand 2000 Dec;71(6):613-618.

21. Changulani M, Okonkwo U, Keswani T, Kalairajah Y. Outcome evaluation measures for wrist and hand: which one to choose? Int Orthop 2008 Feb;32(1):1-6.

22. MacDermid JC, Turgeon T, Richards RS, Beadle M, Roth JH. Patient rating of wrist pain and disability: a reliable and valid measurement tool. J Orthop Trauma 1998 Nov-Dec;12(8):577-586.

23. Aaronson NK, Muller M, Cohen PD, Essink-Bot ML, Fekkes M, Sanderman R, et al. Translation, validation, and norming of the Dutch language version of the SF-36 Health Survey in community and chronic disease populations. J Clin Epidemiol 1998 Nov;51(11):1055-1068.

24. Veldman PH, Reynen HM, Arntz IE, Goris RJ. Signs and symptoms of reflex sympathetic dystrophy: prospective study of 829 patients. Lancet 1993 Oct 23;342(8878):1012-1016.

25. Brogren E, Hofer M, Petranek M, Wagner P, Dahlin LB, Atroshi I. Relationship between distal radius fracture malunion and arm-related disability: a prospective population-based cohort study with 1-year follow-up. BMC Musculoskelet Disord 2011 Jan 13;12:9.

CHAPTER 8

COMPUTER-ASSISTED 3D PLANNED CORRECTIVE OSTEOTOMIES IN EIGHT MALUNITED RADIUS FRACTURES

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ABSTRACT

In corrective osteotomy of the radius, detailed preoperative planning is essential to optimising functional outcome. However, complex malunions are not completely addressed with conventional preoperative planning. Computer-assisted preoperative planning may optimise the results of corrective osteotomy of the radius. We analysed the pre- and postoperative radiological result of computerassisted 3D planned corrective osteotomy in a series of patients with a malunited radius and assessed postoperative function. We included eight patients aged 13-64 who underwent a computer-assisted 3D planned corrective osteotomy of the radius for the treatment of a symptomatic radius malunion. We evaluated pre- and postoperative residual malpositioning on 3D reconstructions as expressed in six positioning parameters (three displacements along and three rotations about the axes of a 3D anatomical coordinate system) and assessed postoperative wrist range of motion. In this small case series, dorsopalmar tilt was significantly improved ($p = 0.05$). Ulnoradial shift, however, increased by the correction osteotomy (6 of 8 cases, 75%). Postoperative 3D evaluation revealed improved positioning parameters for patients in axial rotational alignment (63%), radial inclination (75%), proximodistal shift (83%) and volodorsal shift (88%), although the cohort was not large enough to confirm this by statistical significance. All but one patient experienced improved range of motion (88%). Computer-assisted 3D planning ameliorates alignment of radial malunions and improves functional results in patients with a symptomatic malunion of the radius. Further development is required to improve transfer of the planned position to the intra-operative bone.

INTRODUCTION

Malunion of a radial fracture may result in chronic pain and loss of function and occurs in around 5% of the cases.[1-3] A corrective osteotomy for patients with a malunited radius fracture can improve wrist function and reduce stiffness and pain.[4] Previous studies showed that accuracy of the anatomical reconstruction is essential to achieving an optimal outcome.[5-7] Therefore, conscientious preoperative planning of the procedure and accurate surgical repositioning is required.[1,5] Conventionally, planning is based on two orthogonal radiographs depicting lateral and posteroanterior views of the radius.

However, malunion of the radius commonly involves complex three-dimensional (3D) deformations in different planes, which may not be acknowledged on conventional preoperative 2D radiographs.[8-12] Two-dimensional radiographic planning does not always result in adequate restoration of alignment, as was demonstrated by a recent study performed by members of our study group.[7]

A potential solution of the challenge presented by the complex deformity of radius malunions is the use of computer-assisted 3D planning techniques. With these techniques, both physical and virtual models of the deformed radius and the mirrored contralateral radius can be created. The models are used preoperatively to conceptualise the multiple planes of deformity and to preoperatively plan the osteotomy.[4,13] Preoperative 3D planning also provides the possibility to create patient-specific cutting guides to transfer the planned osteotomy plane to the patient's bony anatomy during surgery. Patient-specific guides for cutting or drilling have been successfully introduced before.[14-16] They have proven to enable accurate positioning of surgical instruments or implants with respect to bony anatomy. However, these studies mostly focus on functional results without properly evaluating residual postoperative malpositioning using 3D imaging techniques.

Therefore, the aim of this study was to assess whether computer-assisted 3D planning and the intra-operative use of personalised cutting guides improve the accuracy of bone alignment.

MATERIALS AND METHODS

All patients who underwent a computer-assisted 3D planned corrective osteotomy of the radius for the treatment of symptomatic radius malunion between January 2009 and March 2014 were eligible for inclusion. Only patients who underwent a postoperative computed tomography (CT) scan of both (full length) radii were included. Patients with a previous fracture of the contralateral radius were excluded.

Preoperative planning

Preoperative planning was based on CT scans of both the affected and the contralateral radius. The unaffected contralateral bone served as reference for determining malalignment. All

CT scans were obtained using a Brilliance 64-channel CT scanner (Phillips Healthcare, Best, The Netherlands) reconstructed to a 3D volume with a voxel spacing of 0.45 x 0.45 x 0.45 mm. Data were imported by a dedicated application program which helps quantifying pre- and postoperative malalignment.[17] In short, the program enables segmenting the affected bone using a threshold-connected region growing algorithm that collects voxels that belong to the affected bone, followed by a binary closing algorithm to close residual gaps. A Laplacian level-set segmentation growth algorithm advances the outline towards the boundary of the bone. A polygonal mesh is finally extracted, which is used for visualisation of the bone deformity. It also serves to create a double-contour polygon by sampling the greylevel image 0.3 mm towards the inside (bright) and outside (dark) for each point of the polygonal bone model. This double-contour polygon with image grey levels assigned to each point enables efficient and accurate point-to-image registration.

Next, distal and proximal segments are clipped to exclude the malunited fracture region. The clipped segments are aligned with the mirrored image of the healthy contralateral bone, by point-to-image registration. This procedure provides a position matrix that brings the distal bone segment in a position that agrees with that of the mirrored contralateral bone. The matrix is used to quantify malpositioning in terms of three displacements along and three rotations about the axes of a 3D anatomical coordinate system.[7] The centroid of the clipped bone segment polygons is used as centre of rotation. Translations are determined in the ulnoradial, volodorsal and proximodistal directions. Rotations are expressed in terms of dorsopalmar tilt, radial inclination and axial rotation (pronation and supination). In case of an oblique single-cut rotation osteotomy [14], the matrix is used to determine the orientation of the osteotomy and the rotation angle for aligning the distal and proximal bone segments. The software further enables to create (1) both virtual and physical models of both radii on which the osteotomy planning was simulated (Fig. 1), and (2) patient-specific cutting guides and jigs for intra-operative guidance of the osteotomy (Fig. 2).

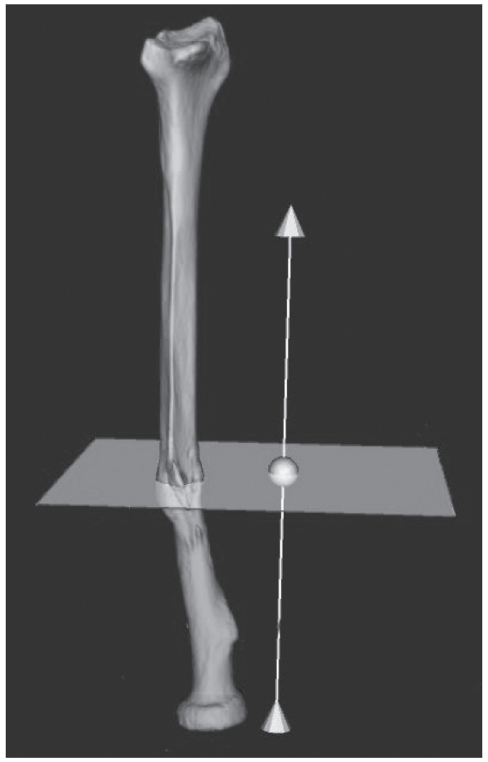


Figure 1. Positioning of cutting plane

Patient-specific bone models and cutting guides

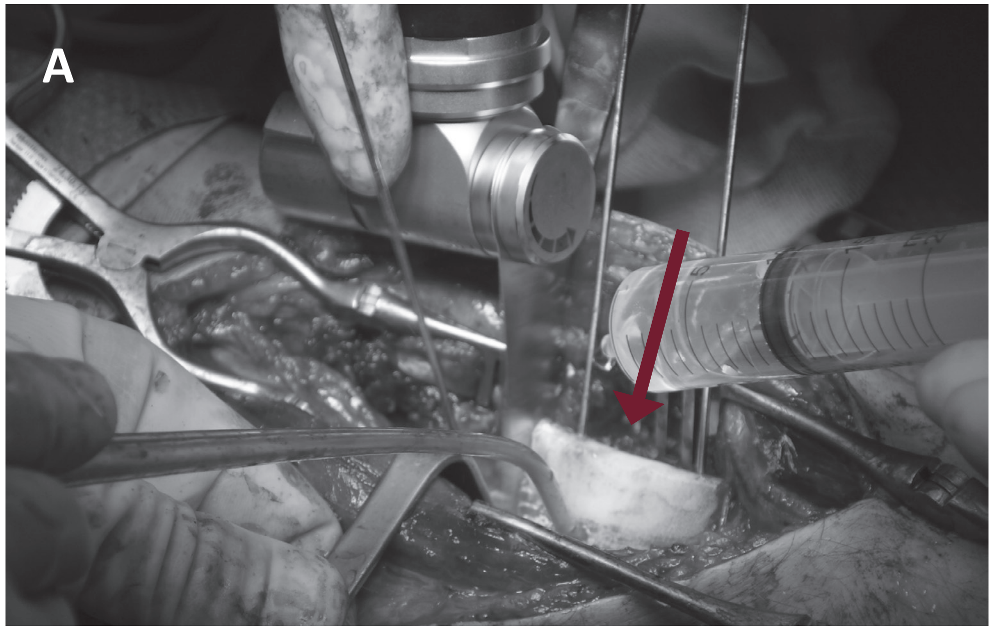
During the preoperative planning, the surgeon was able to interactively set the position and orientation of the cutting plane in the virtual radius (Fig. 1). Synthetic acrylonitrile butadiene styrene (ABS) bone models were created using additive manufacturing technology (SST1200es 3D printer, Dimension Inc, Eden Prairie, MN, USA) with a resolution of 254 lm.

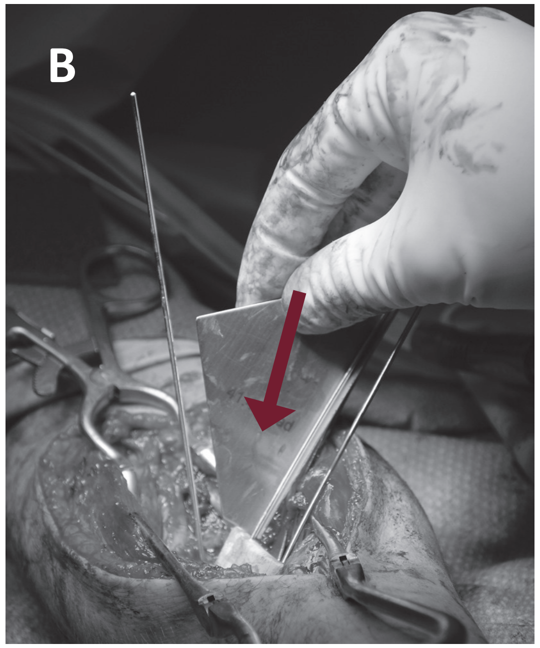
In four patients, a patient-specific cutting guide was used which snugly fitted to the bone geometry (see Fig. 2b). Polyamide cutting guides were manufactured (Materialise, Leuven, Belgium; Sirris, Charleroi, Belgium; Amitek Prototyping, De Meern, The Netherlands) and were sterilised before use in the operating room.

Surgical procedure

Depending on the complexity of the malunion, patients were treated with an open-wedge osteotomy or an oblique single-cut rotation osteotomy (OSCRO).[14] Both osteotomy types were planned by using virtual or physical synthetic models of both radii and/or assisted by intraoperative use of patient-specific cutting guides and jigs (Fig. 2). In the latter method, the sterilised surgical guide was positioned at the specific bone surface and was fixated with Kirschner wires, using the planned fixation holes. In the case of an oblique single-cut rotation osteotomy (OSCRO), the guide was removed after the osteotomy and a stainless steel jig served to set the angle between the proximal and distal bone segment.[14] Rotational alignment was achieved by rotating the malunited distal bone segment over the planned angle. Regular plate and screw fixation was performed to maintain the position. Postoperative management varied from direct mobilisation to 2 weeks of plaster of Paris immobilisation.

Figure 2. a Intra-operative correction of deformation with cutting guide (arrow). b Intra-operative correction of deformation with angled jig (arrow)





Data collection and outcome

Patients were evaluated postoperatively after a minimum follow-up of 6 months. The main outcome was residual 3D malpositioning based on a postoperative CT scan of both forearms. Residual malpositioning was again expressed in terms of six positioning parameters. These residual malpositioning parameters were quantified in exactly the same way as described for preoperative planning, with the one difference that the postoperative image was used for segmentation of the bone instead of the preoperative image. Secondary outcome was the postoperative range of motion of the wrist measured on both sides with a handheld goniometer.

This study was approved by the Medical Ethical Review Committee of the Academic Medical Centre of the University of Amsterdam. All subjects gave informed consent before participation in this study.

Statistical analysis

We reported medians and interquartile range (IQR) for nonparametric variables, and means and standard deviations (SD) for normally distributed variables. The absolute value of each malalignment parameter served to represent the residual error. The Kolmogorov-Smirnov test was used for the determination of the distribution form. The Wilcoxon signed rank test was used to compare the medians of each of the six malpositioning parameters before and after correction.

RESULTS

A total of 16 patients were treated for a symptomatic malunion with a computer-assisted 3D planned corrective osteotomy of the radius.

Five patients were treated recently, and their follow-up was shorter than 6 months. Two patients did not want to participate in postoperative position evaluation, and one patient had moved abroad. This resulted in a total of eight patients who were included in this series.

Of the included patients, three had originally developed a malunion after sustaining an extra-articular distal radius fracture. Five patients had sustained a forearm fracture (three antebrachial fractures and two isolated radius fractures), all of whom developed a diaphyseal malunion of the radius. The demographics of the study group are depicted in Table 1. We performed an opening-wedge osteotomy on four patients, and the other four patients received an oblique single-cut rotation osteotomy (OSCRO). All patients achieved primary osseous union. The median duration of follow-up was 26 months (IQR 12-34). No complications occurred.

Table 1. Demographics of study population

Case	Sex	Age[a]	Location malunion	Dominant hand affected	Indication	Technique[b]	Osteotomy type	Follow-up (months)
1	F	64	Distal, extra articular	Yes	Pain	Cutting guide	Opening	32
2	F	53	Distal, extra articular	Yes	Pain	Simulation	Opening	56
3	F	18	Distal, extra articular	No	Pain, DRUJ instability	Simulation	Opening	8
4	M	32	Diaphyseal	Yes	Restricted supination	Cutting guide	OSCRO	34
5	F	18	Diaphyseal	Yes	Restricted pronation	Simulation	OSCRO	12
6	F	41	Diaphyseal + ulna	No	Restricted ROM (all directions)	Simulation	OSCRO	29
7	M	18	Diaphyseal + ulna	No	Restricted pronation/ supination	Cutting guide	OSCRO	13
8	M	13	Diaphyseal + ulna	Yes	Restricted supination	Cutting guide	Opening	23

Abbreviations: F, female; M, male; ROM, Range of Motion; DRUJ, distal radioulnar joint; Opening, opening-wedge osteotomy; OSCRO, oblique single-cut rotation osteotomy

a. Age in years at time of surgery

b. Technique consisted of either pre- and intra-operative simulation of the osteotomy using virtual or physical 3D models of both radii sometimes with intra-operative use of a custom-made cutting guide and angled jig

The median pre- and postoperative malalignment per dimension is depicted in Table 2. Improvement in dorsopalmar tilt showed statistical significance (p = 0.05, Wilcoxon signed rank test). The median residual malalignment was smallest for radial length (-0.6 mm) and axial rotation (-2.6).

Table 2. Residual malalignment

Malalignment parameter	Median (IQR)			Significance[a]
	Pre-op	Post-op	Difference	
Ulnoradial shift in mm, ulnar (-), radial (+)	3.8 (1.4 - 9.9)	7.0 (1.1 - 11.0)	2.1 (-2.7 - 5.0)	0.327
Volodorsal shift in mm, volar (-), dorsal (+)	7.2 (-5.6 - 30.3)	4.0 (2.8 - 10.3)	-3.2 (-11.6 - 11.2)	0.069
Proximodistal shift in mm shortened (-), lengthened (+)	-5.3 (-17.0 - 13.9)	-0.6 (-3.8 - 0.2)	2.9 (-0.0 - 5.4)	0.123
Dorsopalmar tilt in deg, dorsal (-), volar (-)	-9.0 (-16.8 - 13.9)	-6.4 (-7.9 - 0.4)	5.5 (-6.9 - 10.3)	0.050
Radial inclination in deg, ulnar (-), radial (+)	5.6 (0.4 - 8.8)	3.2 (-1.4 - 8.8)	-1.4 (-9.3 - 5.3)	0.208
Axial rotation in deg, pronation (-), supination (+)	-7.6 (-36.4 - 2.0)	-2.6 (-13.2 - 12.3)	15.0 (1.2 - -30.6)	0.848

a. Related Samples Wilcoxon Signed Rank Test

Abbreviations: IQR, interquartile range; deg, degrees; mm, millimeter;

Bold value indicates statistical significance (p≤0.05)

The individual changes in preoperative and postoperative deformations are depicted in Fig. 3. In two adolescent patients (Cases 7 and 8), the radial length (translation in proximodistal direction) was not reliable due to the patients' growing skeleton between pre- and postoperative CT scans. Volodorsal translation showed improvement (correction towards neutral) in all but one patient (88%). In six patients (75%), ulnoradial shift increased by the correction osteotomy. In two patients, this shift was corrected to nearly neutral.

Dorsopalmar tilt was improved in seven out of eight patients (88%): in one patient (Case 8), tilt was overcorrected from volar to dorsal. In one patient (Case 4), the preoperative neutral position was corrected to dorsal angulation (Fig. 4). Five patients originally had a malunion in pronation. In those five cases, rotations were corrected, although an overcorrection to supination was present in two patients (Cases 6 and 8). Radial inclination was improved in six out of eight patients (88%).

Figure 3. Pre- and postoperative positioning

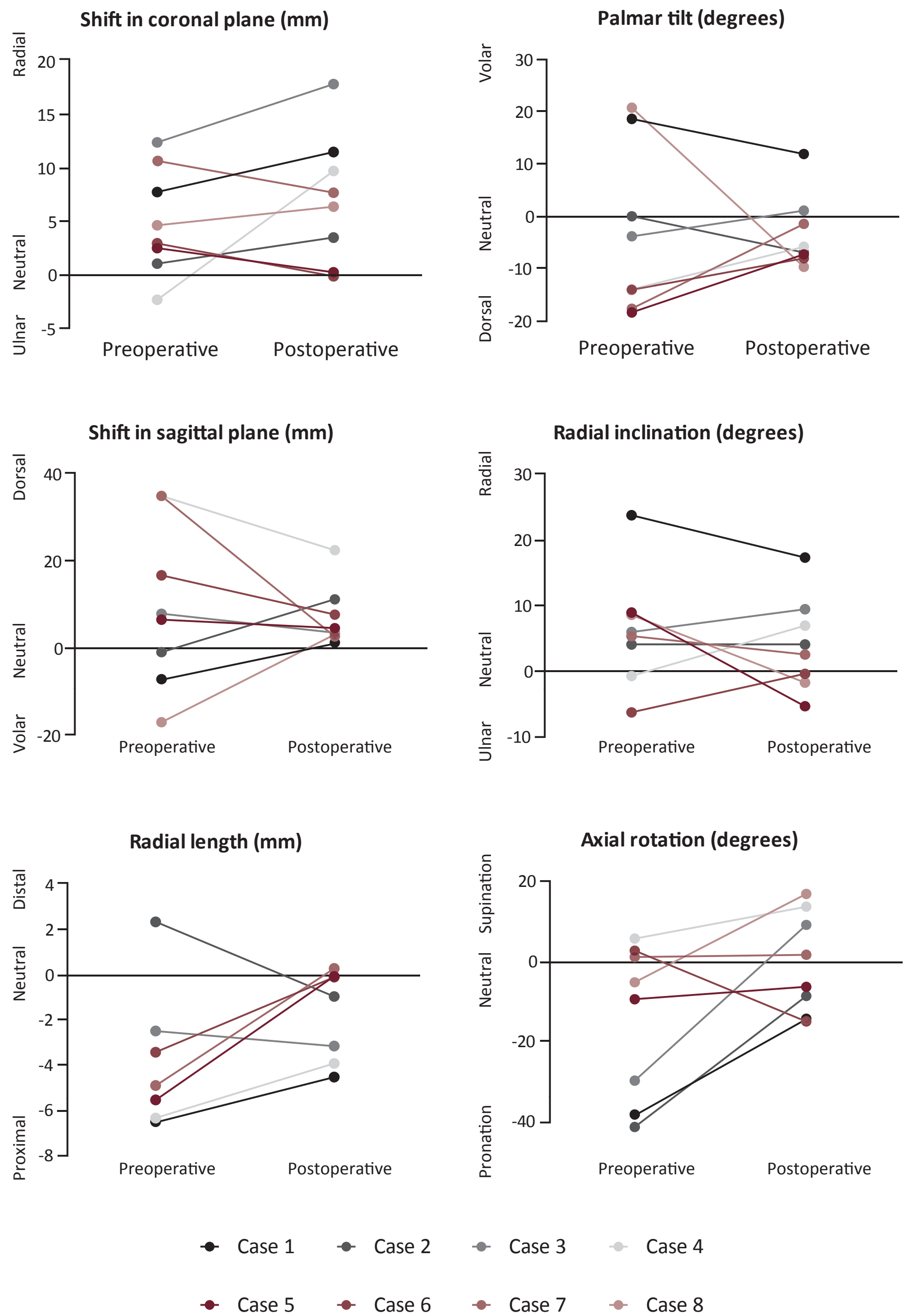
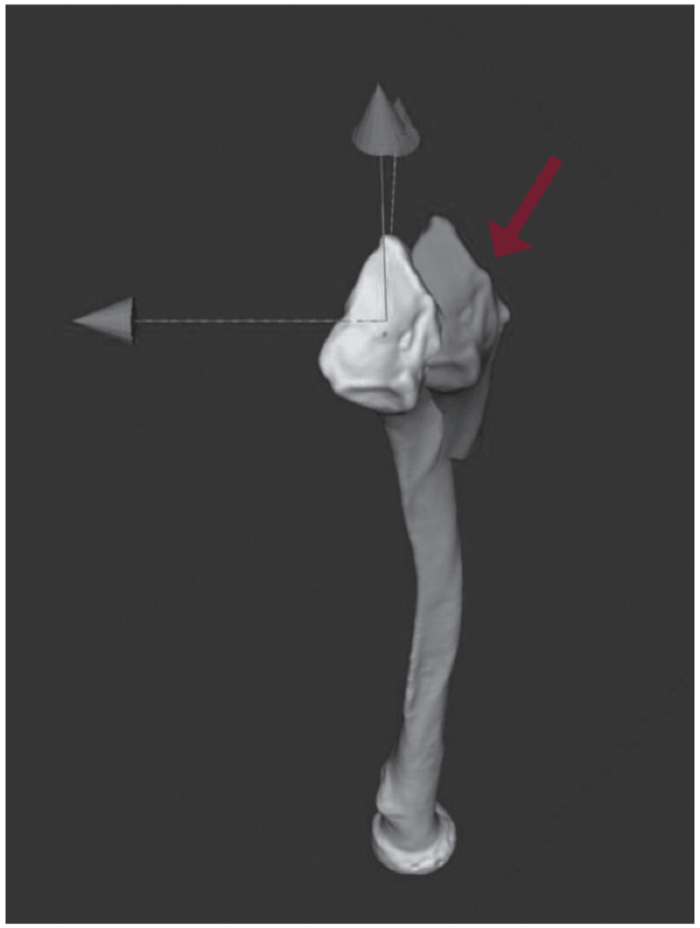


Fig. 4 Postoperative alignment in virtual model. Postoperative malalignment of the distal radius segment (arrow) of Case 4 compared to the mirrored contralateral radius.



Six patients (88%) experienced a postoperative increased range of motion (Table 3). One patient (Case 3) slightly deteriorated. In addition to a distal radius fracture, this patient had sustained a triangular fibrocartilage complex (TFCC) tear that resulted in instability of the distal radioulnar joint (DRUJ). The performed correction osteotomy itself did not provide enough stability, and reinsertion of the TFCC was attempted 2 months after the corrective osteotomy, but was not successful. In one patient (Case 2), the indication for treatment was based on pain, instead of restricted ROM. The preoperative range of motion (ROM) was therefore not measured. There was no statistically significant difference in terms of malalignment parameters between the cases that were corrected with use of a cutting guide versus the corrections that were visualised (Table 4).

Table 3. Functional results

Case	Preoperative		Preoperative	
	Range of wrist[a]		Range of wrist[a]	
	Pronation/ supination	Flexion/ extension	Pronation/ supination	Flexion/ extension
1	150	150	165	135
2	NA	NA	180	175
3	180	155	180	150
4	115	100	145	180
5	90	NA	155	180
6	40	55	175	175
7	80	NA	135	180
8	125	180	180	180
Average	111	128	164	169

NA, not available

a. Expressed in degrees and measured with a handheld goniometer

Table 4. Differences in malalignment parameters compared to pre-op for patients treated with cutting guide versus visualisation

Malalignment parameter	Difference compared to pre-op, median (IQR)		Significance[a]
	Cutting guide (n = 4)	Visualisation (n = 4)	
Ulnoradial shift in mm, ulnar (-), radial (+)	3.1 (1.9 to 10.0)	-2.6 (-3.0 to 3.5)	0.200
Volodorsal shift in mm, volar (-), dorsal (+)	10.2 (-7.3 to 18.1)	-6.7 (-26.4 to -2.6)	0.200
Proximodistal shift in mm, shortened (-), lengthened (+)	2.2 (-2.0 to 15.7)	4.3 (0.3 to 5.4)	0.686
Dorsopalmar tilt in deg, dorsal (-), volar (-)	-6.8 (-24.5 to 4.4)	8.5 (5.2 to 14.9)	0.114
Radial inclination in deg, ulnar (-), radial (+)	-3.2 (-9.3 to 5.7)	0.3 (-11.4 to 5.3)	1.000
Axial rotation in deg, pronation (-), supination (+)	23.0 (11.5 to 30.6)	1.8 (-13.1 to 30.0)	0.343

Abbreviations: IQR, interquartile range; deg, degrees, mm, millimetre

a. Independent samples Mann-Whitney U test

DISCUSSION

Postoperative 3D evaluation revealed improved positioning parameters for most patients in dorsopalmar tilt, axial rotation (pronation and supination), radial inclination, proximodistal shift and volodorsal shift. Dorsopalmar tilt significantly improved. However, ulnoradial translation was worsened by the correction osteotomy. Both over- and undercorrection occurred in individual patients. All but one patient experienced improved range of motion.

Computer-assisted 3D planning techniques are expected to optimise preoperative treatment plans and therefore minimise residual malalignment.[7] In our study, alignment improved in five of the six positioning parameters, of which improvement in dorsopalmar tilt reached significance despite the small number of patients.

There are several explanations for the residual malalignment. Firstly, the transfer from the virtual plan to the actual realignment and fixation might leave room for error. Although in half of the patients, we used patientspecific cutting jigs to transfer the planned correction onto the patients' radius and used a jig to indicate the angle of the osteotomy, reduction and fixation were done in a freehand manner with K-wires. Although cutting guides generally show beneficial in reconstructive surgery[18], based on our results we cannot yet draw conclusions on its added value. For accurate bone repositioning in future corrective osteotomy treatment, we recommend using reduction guides[15] or patient-specific fixation plates.[19]

The advantage of using an oblique single-cut rotation osteotomy is the correction of angular deformities in three dimensions while maintaining optimal bone contact. However, the method does not aim to correct translational displacements. Small rotational errors after corrective osteotomy of a diaphyseal malunion may scale to relatively large translational displacements at the distal articular level. This could partly explain the residual displacements in ulnoradial and volodorsal shifts.

Secondly, the preoperative plan does not take into account the soft tissue issues many of these deformed forearms have. Earlier (surgical) trauma often causes scar formation to structures like the interosseous membrane and makes the planned repositioning difficult to realise. Additionally, full geometric restoration of bony structures may hamper full mobility if there is too much stress on the soft tissue. Therefore, in some cases, complete correction was not obtained. Despite this issue, previously published data suggest a statistically significant correlation between residual malalignment and clinical outcome.[7] When soft tissue allows, we expect that increased precision in radiological outcome will further optimise postoperative functional results.

The strength of this study is that we examined the postoperative positioning using 3D techniques. Only a few previous studies assessed postoperative results in 3D.[7,20,21] However, they focussed on intra-articular distal radius malunions and expressed their findings in terms of postoperative articular displacement. Another study by Vroemen et al.[7] evaluated the postoperative malalignment in 25 patients after a 2D planned corrective osteotomy using 3D imaging techniques. The median residual malalignments we presented in this study are comparable, but not per se superior to their results after a 2D planned corrective osteotomy. However, due to the lack of preoperative 3D malpositioning of their series and a potential selection of relatively complex cases in ours, full comparison is not possible.

The postoperative range of motion we found is better than previous studies with computer-assisted 3D planned corrective osteotomy in radial malunions.[22,23] Athwal et al.[22] included six patients with a distal radius malunion. They found an average postoperative range of motion of 89 of flexion-extension, 78% of pronation and 74% of supination after a mean follow-up of 25 months. Miyake et al. included 20 patients and reported a range of motion of 152 pronation and supination after a mean follow-up of 24 months.

Our functional results are also superior to published results of conventional 2D planned corrective osteotomies. A previous study that investigated the long-term results after 2D planned corrective osteotomy of distal malunions demonstrated a range of motion of 109 degrees of flexion-extension and 142 of pronation and supination after a mean follow-up of 13 years.[24]

This study has several limitations. Due to the retrospective nature of this study, there was no predefined protocol for selecting patients. The decision to perform a computer-assisted 3D planned corrective osteotomy was made by the surgeon. Only patients with complex malunions were selected for this type of treatment. This approach has resulted in a selection bias and potentially limits the generalisability of our results. Due to the retrospective nature of this study, we were not able to acquire preoperative grip strength or functional questionnaires (e.g. DASH, PRWE), thus limiting the evaluation of functional outcome of the procedure. Another limitation is the heterogeneity of the population. We included subjects with both diaphyseal and extra-articular distal radius malunions. Distal malunions commonly show axial malalignment in pronation[25], whereas diaphyseal malunions typically involve angular deformation.[23] Individual cases require different goals of correction. As mentioned, an oblique single-cut rotation osteotomy (OSCRO) aims to correct rotational deformities and is limited in providing ulnoradial or volodorsal shifts. This phenomenon—in combination with the low number of cases—may explain the lack of statistically significant improvement in individual directional parameters.

Some patients may benefit more from this 3D planned osteotomy than others. Future studies should focus on determining the appropriate indication for the use of 3D planning techniques in corrective osteotomy. This study suggests that virtual 3D planning of corrective osteotomies of radial malunions ameliorates alignment. Further enhancement of this technique is required to improve transfer of the preoperatively planned position to the intraoperative bone.

REFERENCES

1. Cooney WP,3rd, Dobyns JH, Linscheid RL. Complications of Colles' fractures. J Bone Joint Surg Am 1980;62(4):613-619.

2. McKay SD, MacDermid JC, Roth JH, Richards RS. Assessment of complications of distal radius fractures and development of a complication checklist. J Hand Surg 2001 sep;26(5):916-922.

3. Crisco JJ, Moore DC, Marai GE, Laidlaw DH, Akelman E, Weiss AP, et al. Effects of distal radius malunion on distal radioulnar joint mechanics--an in vivo study. J Orthop Res 2007 Apr;25(4):547-555.

4. Buijze GA, Prommersberger KJ, Gonzalez Del Pino J, Fernandez DL, Jupiter JB. Corrective osteotomy for combined intra- and extra-articular distal radius malunion. J Hand Surg Am 2012 Oct;37(10):2041-2049.

5. Fernandez DL. Correction of post-traumatic wrist deformity in adults by osteotomy, bone-grafting, and internal fixation. J Bone Joint Surg Am 1982 Oct;64(8):1164-1178.

6. Prommersberger KJ, Van Schoonhoven J, Lanz UB. Outcome after corrective osteotomy for malunited fractures of the distal end of the radius. J Hand Surg Br 2002 Feb;27(1):55-60.

7. Vroemen JC, Dobbe JG, Strackee SD, Streekstra GJ. Positioning evaluation of corrective osteotomy for the malunited radius: 3-D CT versus 2-D radiographs. Orthopedics 2013 Feb;36(2):e193-9.

8. Miyake J, Murase T, Yamanaka Y, Moritomo H, Sugamoto K, Yoshikawa H. Comparison of three dimensional and radiographic measurements in the analysis of distal radius malunion. J Hand Surg Eur Vol 2013 Feb;38(2):133-143.

9. Bilic R, Zdravkovic V, Boljevic Z. Osteotomy for deformity of the radius. Computer-assisted three-dimensional modelling. J Bone Joint Surg Br 1994 Jan;76(1):150-154.

10. Cirpar M, Gudemez E, Cetik O, Turker M, Eksioglu F. Rotational deformity affects radiographic measurements in distal radius malunion. European Journal of Orthopaedic Surgery & Traumatology 2010 Jun;21(1):13-20.

11. Capo JT, Accousti K, Jacob G, Tan V. The effect of rotational malalignment on X-rays of the wrist. J Hand Surg Eur Vol 2009 Apr;34(2):166-172.

12. Pennock AT, Phillips CS, Matzon JL, Daley E. The effects of forearm rotation on three wrist measurements: radial inclination, radial height and palmar tilt. Hand Surg 2005 Jul;10(1):17-22.

13. Leong NL, Buijze GA, Fu EC, Stockmans F, Jupiter JB, Distal Radius Malunion (DiRaM) collaborative group. Computer-assisted versus non-computer-assisted preoperative planning of corrective osteotomy for extra-articular distal radius malunions: a randomized controlled trial. BMC Musculoskelet Disord 2010 Dec 14;11:282-2474-11-282.

14. Dobbe JG, Pre KJ, Kloen P, Blankevoort L, Streekstra GJ. Computer-assisted and patient-specific 3-D planning and evaluation of a single-cut rotational osteotomy for complex long-bone deformities. Med Biol Eng Comput 2011 Dec;49(12):1363-1370.

15. Murase T, Oka K, Moritomo H, Goto A, Yoshikawa H, Sugamoto K. Three-dimensional corrective osteotomy of malunited fractures of the upper extremity with use of a computer simulation system. J Bone Joint Surg Am 2008 Nov;90(11):2375-2389.

16. Stockmans F, Dezillie M, Vanhaecke J. Accuracy of 3D Virtual Planning of Corrective Osteotomies of the Distal Radius. J Wrist Surg 2013 Nov;2(4):306-314.

17. Dobbe JGG, Strackee SD, Schreurs aW, Jonges R, Carelsen B, Vroemen JC, et al. Computer-assisted planning and navigation for corrective distal radius osteotomy, based on pre- and intraoperative imaging. IEEE Trans Biomed Eng 2011 jan;58(1):182-190.

18. Krishnan SP, Dawood A, Richards R, Henckel J, Hart AJ. A review of rapid prototyped surgical guides for patient-specific total knee replacement. J Bone Joint Surg Br 2012 Nov;94(11):1457-1461.

19. Dobbe JG, Vroemen JC, Strackee SD, Streekstra GJ. Patient-specific distal radius locking plate for fixation and accurate 3D positioning in corrective osteotomy. Strategies Trauma Limb Reconstr 2014 Nov;9(3):179-183.

20. Schweizer A, Furnstahl P, Nagy L. Three-dimensional correction of distal radius intra-articular malunions using patient-specific drill guides. J Hand Surg Am 2013 Dec;38(12):2339-2347.

21. Vroemen JC, Dobbe JG, Sierevelt IN, Strackee SD, Streekstra GJ. Accuracy of distal radius positioning using an anatomical plate. Orthopedics 2013 Apr;36(4):e457-62.

22. Athwal GS, Ellis RE, Small CF, Pichora DR. Computer-Assisted Distal Radius Osteotomy. J Hand Surg 2003;28:951-958.

23. Miyake J, Murase T, Oka K, Moritomo H, Sugamoto K, Yoshikawa H. Computer-assisted corrective osteotomy for malunited diaphyseal forearm fractures. J Bone Joint Surg Am 2012 Oct 17;94(20):e150.

24. Lozano-Calderon SA, Brouwer KM, Doornberg JN, Goslings JC, Kloen P, Jupiter JB. Long-term outcomes of corrective osteotomy for the treatment of distal radius malunion. J Hand Surg Eur Vol 2010 Jun;35(5):370-380.

25. Miyake J, Murase T, Yamanaka Y, Moritomo H, Sugamoto K, Yoshikawa H. Three-dimensional deformity analysis of malunited distal radius fractures and their influence on wrist and forearm motion. J Hand Surg Eur Vol 2012 Jul;37(6):506-512.

PART 3

PROGNOSIS

CHAPTER 9

PREDICTORS OF UNSTABLE DISTAL RADIUS FRACTURES: A SYSTEMATIC REVIEW AND META-ANALYSIS

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ABSTRACT

The aim of this study was to perform a systematic review in order to identify predictors of secondary displacement in distal radius fractures. We performed a systematic review to identify all studies that reported secondary displacement following distal radius fractures. Where possible, we pooled the odds ratios of predictors. The initial search yielded 3178 studies of which 27 were included. Multiple studies found that age, shortening, volar comminution, loss of radial inclination, the presence of a volar hook, AO type 3 fractures (A3, B3, C3) and the Older classification were significant predictors of secondary displacement. Pooling revealed a significantly increased risk of secondary displacement in fractures with dorsal comminution, in women and in patients aged >60 years. An associated ulna fracture or intra-articular involvement does not result in an increased risk of secondary displacement. The overview provided in this study can help surgeons to inform patients of the chances of success of closed treatment regarding the radiological outcome and facilitate shared-decision making.

INTRODUCTION

Initial treatment of patients with distal radius fractures generally consists of closed reduction and plaster immobilization.[1-4] However, fracture re-displacement following closed reduction occurs in up to 64% of the patients (in part depending upon the definition).[3,5,6] Most surgeons would agree that distal radius fractures with re-displacement outside acceptable parameters (>10° dorsal angulation, radial shortening >3mm or intra-articular step-off >)[7] benefit from surgical fixation, taking into account patient-related factors. Patients with a distal radius fracture with a perceived high risk of re-displacement may be recommended primary surgical treatment. Unfortunately, patients with these potentially more unstable distal radius fractures are difficult to identify. In 1989, Lafontaine et al. identified five factors predictive of fracture instability: dorsal angulation exceeding 20° at presentation; dorsal comminution; extension of the fracture into the radiocarpal joint; an associated ulnar fracture; and age over 60 years.[8] According to Lafontaine et al. a fracture can be considered potentially unstable if three or more factors are present.

Since then, several studies have confirmed and refuted the importance of these five risk factors, and new clinical and radiological predictors have been identified.[9-12] Other authors have quantified predictors and presented scoring systems to predict the risk of secondary displacement based on clinical and radiological variables.[3,13] Although several risk factors of secondary displacement are commonly accepted, the evidence for some predictors is limited. An overview of all known predictors of fracture instability in literature, and their relative weight (pooled odds ratios), could assist physicians in decision-making regarding the optimal method of treatment for patients with distal radius fractures. The aim of this study was to perform a systematic review in order to identify predictors of secondary displacement in distal radius fractures.

METHODS

This review was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[14] A review protocol was drafted and registered on PROSPERO with number CRD42014010828. All of the following steps were performed by two independent reviewers (SA and MMJW). Disagreements between the two reviewers were discussed until a consensus was reached.

Eligibility criteria systematic review

Any study that could potentially provide information on predictors of secondary displacement was eligible for inclusion. Therefore, studies describing non-operative treatment in patients with distal radius fracture were also included. We anticipated that these studies would report secondary displacement during follow-up. Inclusion criteria were studies that addressed adult (18 years and older) patients with distal radius fractures initially treated with plaster immobilization, with or without closed reduction of the fracture. Reviews, animal studies, cadaver studies, case reports, surveys, current (management) concepts, editorials, commentaries, conference abstracts and letters were excluded. Since there are numerous definitions of displacement and instability, we did not predetermine a definition that should have been used for a study to be included. For the same reason we did not define what constitutes a displaced, undisplaced or minimally displaced fracture.

Eligibility criteria meta-analysis
For the meta-analysis, an additional inclusion criterion was studies that reported odds ratios of predictors of secondary displacement, or provided sufficient information to calculate odds ratios. We required studies to have had a minimal radiological follow-up of 4 weeks for the assessment of secondary displacement.

Literature search and study selection
We conducted a systematic search of the MEDLINE and EMBASE databases on August 28, 2013, and updated the search on March 19, 2015 (Appendix 1), to identify all studies on patients with distal radius fractures and reporting displacement or fracture instability. To ensure proper interpretation of the results by our team, publication language was restricted to English, German, Spanish, French, Turkish or Dutch. The resulting titles and abstracts were reviewed. If the eligibility criteria were met full manuscripts were procured and reviewed. The bibliographies of all included studies were manually screened for additional articles of interest.

Data extraction
Data were extracted using a standardized data collection form that was developed according to the Cochrane guidelines.[15] Items collected included publication details, study type, numbers of patients, fracture types, the definition of displacement, the type of statistical analysis and details regarding treatment. For each study we determined which predictors of secondary displacement were found statistically significant ($p<0.05$). Additionally, we assessed if the predictor was tested in a univariate or a multivariable analysis. For the meta-analysis, predictors and odds ratios or coefficients of predictors of secondary displacement were obtained and collected in a database.

Quality assessment
Quality and heterogeneity across studies was assessed using the Quality in Prognostic Studies (QUIPS) tool.[16,17] (Table 1 and appendix 2) The QUIPS tool rates individual studies according to the potential risk of bias associated with six domains: (1) study participation; (2) study attrition; (3) prognostic factor measurement; (4) outcome measurement; (5) confounding measurement and account; and (6) analysis. Two reviewers (SA and MMJW) independently assessed the potential risk of basis of each study based on information available in the manuscripts. Disagreements were discussed by the reviewers until a consensus was reached.

Synthesis of results of meta-analysis
For the meta-analysis, univariate odds ratios were pooled using the random effects model. The random effects model involves an assumption that the effects being estimated in the different studies are not identical, but follow some distribution.[15] If coefficients from a logistic regression analysis were reported, odds ratios were calculated by taking the exponential. Odds ratios for instability or displacement at any point during follow-up (early or late) were added as separate odds ratios to the analysis. Data were pooled with the log odds ratio and the standard error (SE) with the generic inverse variance.

To test the robustness of the results, sensitivity analyses were performed by comparing the results obtained with the random effects model with the fixed effects models. 15 Similar results imply that the results are robust.

Statistical heterogeneity for each analysis was tested with I^2. The I^2 is a statistic that indicates the percentage of variance and is qualified as follows: 0% to 40% (might not be important); 30% to 60% (may represent moderate heterogeneity); 50% to 90% (may represent substantial heterogeneity); 75% to 100% (considerable heterogeneity).[15]

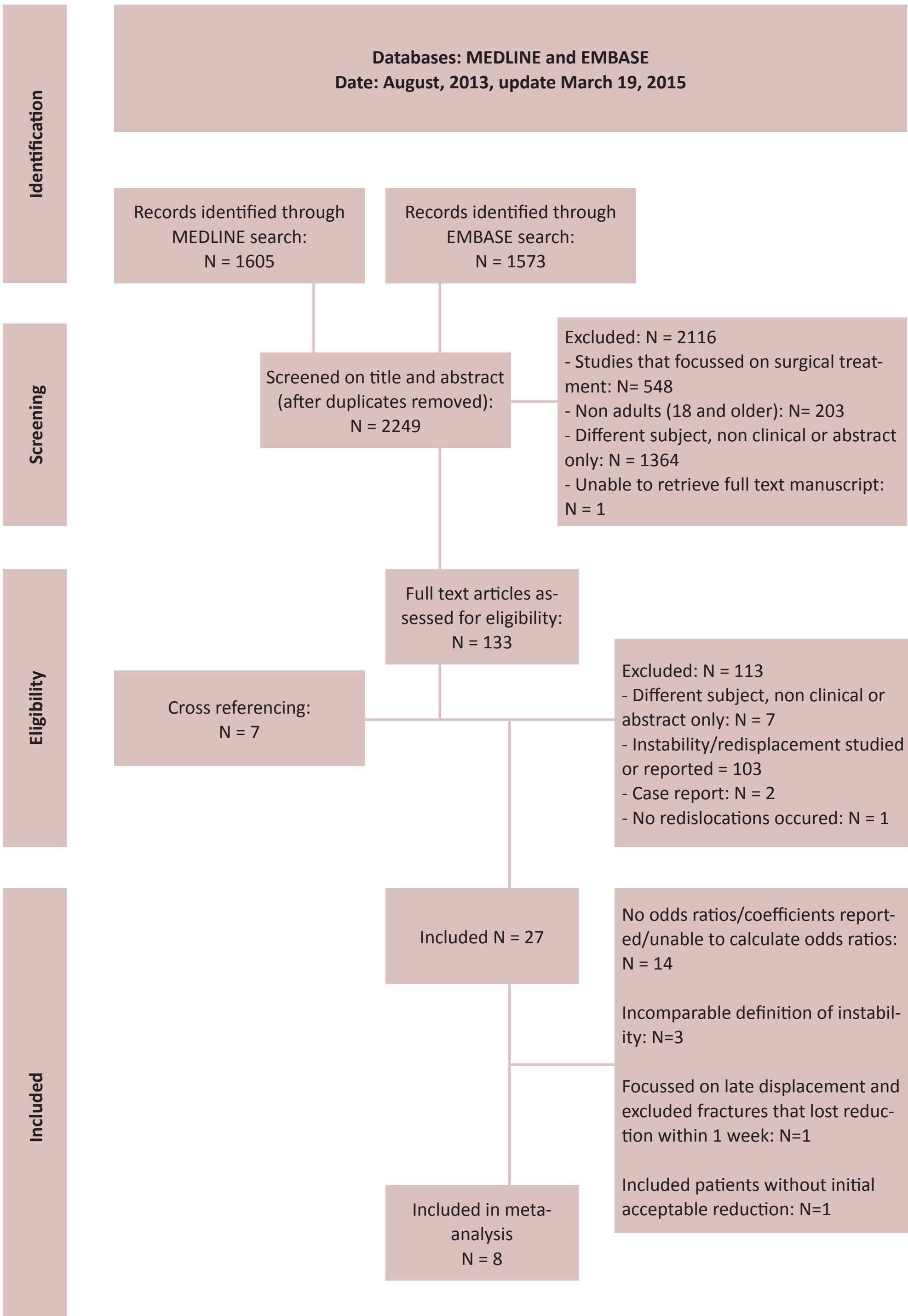
RESULTS

Search results
The initial search yielded a total of 3178 studies, of which 2249 remained after excluding the duplicates. The full text manuscripts of 133 studies were evaluated and 27 studies were included in the systematic review (Fig 1).[3,6,8-11,13,18-37] The full text manuscript of one study could not be procured, even after contacting the authors.[38]

Systematic review
The characteristics of the studies included are outlined in Table 2. All but three studies focused primarily on secondary displacement or radiographic outcome.[20,33,35] One study excluded fractures that lost reduction within one week and assessed late secondary displacement at two months.[32] Quality and risk of bias were variable (Table 1 and appendix 2).

A total of 7574 patients were included. Secondary displacement occurred in 10% to 89% of the fractures. Forty-four different predictors of secondary displacement were reported. An overview of the most common predictors and in which study they were assessed is outlined in Table 3.

Figure 1. Flow chart



Only a few predictors were also tested in a multivariable analysis, adjusting for other covariates. Of these, age, shortening, volar comminution, loss of radial inclination, the presence of a volar hook, AO type 3 fractures (A3, B3, C3) and the Older classification were found to be significant predictors in one or more studies.

The mechanism of the injury, the forces involved i.e. the estimated energy of the injury, the independence of a patient (defined as being able to go shopping), initial dorsal angulation >20° from neutral, the initial radial shift, the presence of an associated ulnar styloid fracture and the Frykman classification were revealed not to be significant predictors of secondary displacement in one or more studies that adjusted for other covariates.

For gender, initial ulnar variance, comminution and intra-articular involvement, there were studies that found a significantly increased risk of secondary displacement and others that did not.

Meta-analysis

We were able to extract or calculate odds ratios from 11 articles.[3,6,8,9,11,18,20,23,28,31,32] We contacted the corresponding authors of four additional articles that reported p-values without odds ratios or only adjusted odds ratios to request additional information.[24,30,34,37] The authors of two studies provided further data[34,37] so we could extract or calculate odds ratios from 13 studies. Ten of these studies used a comparable definition for secondary displacement and were therefore eligible for pooling.[3,6,9,11,18,23,31,32,34,37] Myderrizi et al. (2011) excluded patients with loss of reduction at one week and this study was therefore not included in the analysis. Wadsten et al. (2014) also analysed the 92 patients who went on to surgery because their post reduction films revealed an unacceptable position and therefore we did not include this study. From the remaining eight articles we were able to pool the odds ratios of seven predictors. A total of 3807 patients were analysed. Female gender, age >60-65 years and dorsal comminution were significant predictors of secondary displacement (Figs 2-4). An associated ulnar styloid fracture, intra-articular involvement, dorsal angulation >15° from neutral and dorsal angulation >20° from neutral were not significantly associated with secondary displacement (Figure 5- 8). A sensitivity analysis showed similar estimates in the random and fixed effects models (Table 4). The odds ratio of intra-articular involvement and dorsal angulation >15° from neutral were both significant only in the fixed effects model.

Figure 2. Forest plot of comparison female versus male. The four odds ratios from Mackenney et al. represent early and late instability in minimally displaced and displaced fractures. The odds ratios from Leone at al represent early and late instability in all fractures.

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Fixed, 95% CI
Alemdaroglu, 2010	1.4255	0.8043	1.2%	4.16 [0.86, 20.12]
Leone early	1.737	1.4815	0.3%	5.68 [0.31, 103.62]
Leone late	−0.5188	0.7237	1.4%	0.60 [0.14, 2.46]
Mackenney displaced early	0.6643	0.1513	32.7%	1.94 [1.44, 2.61]
Mackenney displaced late	0.1606	0.1746	24.5%	1.17 [0.83, 1.65]
Mackenney min displ late	0.7883	0.1861	21.6%	2.20 [1.53, 3.17]
Mackenney min-displ early	0.6244	0.2413	12.8%	1.87 [1.16, 3.00]
Makhni, 2008	1.1299	0.4236	4.2%	3.10 [1.35, 7.10]
Nesbitt, 2004	0.9821	1.0293	0.7%	2.67 [0.36, 20.08]
Phillips 2014	0.3691	1.1136	0.6%	1.45 [0.16, 12.83]
Total (95% CI)			**100.0%**	**1.78 [1.50, 2.11]**

Heterogeneity: Chi² = 13.26, df = 9 (P = 0.15); I² = 32%
Test for overall effect: Z = 6.68 (P < 0.00001)

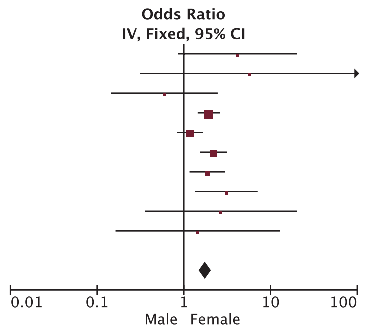


Figure 3. Forest plot of comparison age >60y versus <60-65y. Mackenney et al. represent early and late instability in minimally displaced and displaced fractures

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Random, 95% CI
Mackenney displaced early	1.0438	0.1098	32.7%	2.84 [2.29, 3.52]
Mackenney displaced late	0.7514	0.1436	23.1%	2.12 [1.60, 2.81]
Mackenney min displ late	1.0784	0.1503	21.7%	2.94 [2.19, 3.95]
Mackenney min-displ early	1.1817	0.1869	15.5%	3.26 [2.26, 4.70]
Makhni, 2008	0.4637	0.4042	3.9%	1.59 [0.72, 3.51]
Nesbitt, 2004	1.3397	0.6235	1.7%	3.82 [1.12, 12.96]
Phillips 2014	0.3131	0.6916	1.4%	1.37 [0.35, 5.30]
Total (95% CI)			**100.0%**	**2.66 [2.26, 3.12]**

Heterogeneity: Tau² = 0.01; Chi² = 7.36, df = 6 (P = 0.29); I² = 18%
Test for overall effect: Z = 11.90 (P < 0.00001)

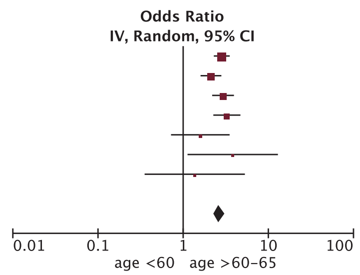


Figure 4. Forest plot of comparison dorsal comminution versus no comminution. The four odds ratios from Mackenney et al. represent early and late instability in minimally displaced and displaced fractures. The odds ratios from Leone at al represent early and late instability in all fractures.

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Fixed, 95% CI
Alemdaroglu, 2010	−0.0408	0.5004	3.3%	0.96 [0.36, 2.56]
Leone early	1.4012	0.81	1.2%	4.06 [0.83, 19.86]
Leone late	0.1222	0.5299	2.9%	1.13 [0.40, 3.19]
Mackenney displaced early	0.5539	0.2157	17.6%	1.74 [1.14, 2.66]
Mackenney displaced late	0.5653	0.2684	11.3%	1.76 [1.04, 2.98]
Mackenney min displ late	1.361	0.1582	32.7%	3.90 [2.86, 5.32]
Mackenney min-displ early	1.9824	0.1995	20.5%	7.26 [4.91, 10.73]
Makhni, 2008	1.0332	0.5924	2.3%	2.81 [0.88, 8.97]
Nesbitt, 2004	0.9066	1.2588	0.5%	2.48 [0.21, 29.19]
Phillips 2014	−0.0886	1.1379	0.6%	0.92 [0.10, 8.51]
Tahririan, 2013	0.4731	0.3414	7.0%	1.60 [0.82, 3.13]
Total (95% CI)			**100.0%**	**2.99 [2.50, 3.56]**

Heterogeneity: Chi² = 45.90, df = 10 (P < 0.00001); I² = 78%
Test for overall effect: Z = 12.10 (P < 0.00001)

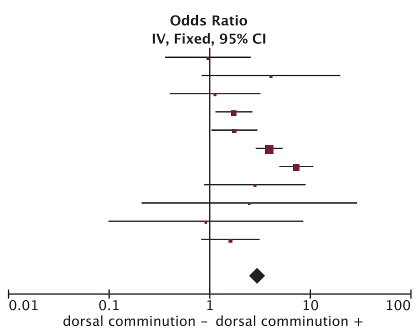


Figure 5. Forest plot of comparison presence of associated ulnar styloid fracture versus intact ulnar styloid. The odds ratios from Leone et al. represent early and late instability in all fractures

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Fixed, 95% CI
Alemdaroglu, 2010	0.5481	0.5074	19.2%	1.73 [0.64, 4.68]
Leone early	0.8961	0.7039	10.0%	2.45 [0.62, 9.73]
Leone late	0.408	0.6485	11.8%	1.50 [0.42, 5.36]
Nesbitt, 2004	−0.8651	0.6848	10.5%	0.42 [0.11, 1.61]
Phillips 2014	−0.6466	0.7372	9.1%	0.52 [0.12, 2.22]
Tahririan, 2013	−0.2829	0.3542	39.4%	0.75 [0.38, 1.51]
Total (95% CI)			**100.0%**	**0.98 [0.63, 1.52]**

Heterogeneity: Chi² = 6.18, df = 5 (P = 0.29); I² = 19%
Test for overall effect: Z = 0.08 (P = 0.93)

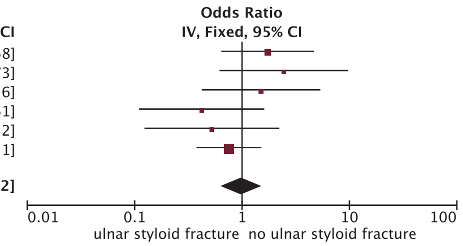


Figure 6. Forest plot of comparison intra-articular fracture involvement versus no involvement.

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Fixed, 95% CI
Nesbitt, 2004	−0.0284	0.6847	17.2%	0.97 [0.25, 3.72]
Phillips 2014	0.5355	0.6827	17.3%	1.71 [0.45, 6.51]
Tahririan, 2013	−0.8636	0.3514	65.4%	0.42 [0.21, 0.84]
Total (95% CI)			**100.0%**	**0.62 [0.36, 1.08]**

Heterogeneity: Chi² = 3.84, df = 2 (P = 0.15); I² = 48%
Test for overall effect: Z = 1.68 (P = 0.09)

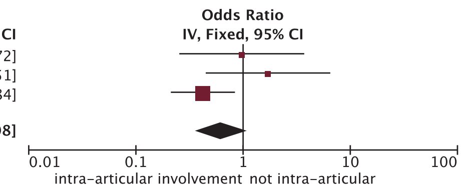


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Figure 7. Forest plot of comparison dorsal angulation >15° from neutral versus dorsal angulation ≤15° from neutral

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Random, 95% CI
Blakeney 2009	1.9943	0.5685	72.9%	7.35 [2.41, 22.39]
Phillips 2014	−0.1902	1.5846	27.1%	0.83 [0.04, 18.46]
Total (95% CI)			**100.0%**	**4.07 [0.61, 27.26]**

Heterogeneity: Tau² = 0.97; Chi² = 1.68, df = 1 (P = 0.19); I² = 41%
Test for overall effect: Z = 1.45 (P = 0.15)

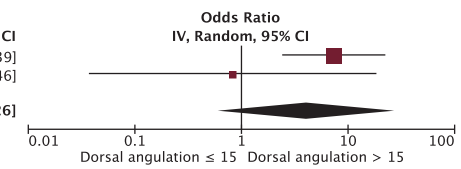
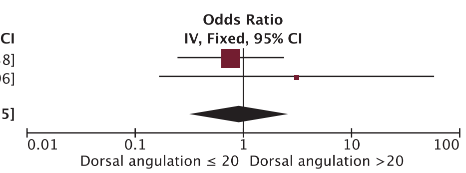


Figure 8. Forest plot of comparison dorsal angulation >20° from neutral versus dorsal angulation ≤20° from neutral

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Fixed, 95% CI
Nesbitt, 2004	−0.2679	0.5789	86.9%	0.76 [0.25, 2.38]
Phillips 2014	1.1328	1.4934	13.1%	3.10 [0.17, 57.96]
Total (95% CI)			**100.0%**	**0.92 [0.32, 2.65]**

Heterogeneity: Chi² = 0.76, df = 1 (P = 0.38); I² = 0%
Test for overall effect: Z = 0.16 (P = 0.87)



DISCUSSION

This systematic review provides an overview of all predictors of secondary displacement of distal radius fractures in literature. We have demonstrated that not all popular predictors of instability that are persistently used in the literature have indeed been identified as significantly associated with secondary displacement. For instance, several studies that also adjusted for other covariates in their analyses did not find an increased risk of secondary displacement in fractures with an initial dorsal angulation exceeding 20° from neutral and neither in fractures with an associated ulnar styloid fracture.

For other popular risk factors such as the female gender, dorsal comminution and intra-articular involvement, the results were inconclusive. Some studies with adjusted analyses did find a significant influence on secondary displacement and others did not.
In an attempt to provide a definite answer, we pooled the odds ratios of seven predictors including gender, age >60-65, dorsal comminution, associated ulnar styloid fracture, intra-articular involvement and dorsal angulation exceeding 15° and 20° from neutral. Our results show a significantly increased risk of secondary displacement in fractures with dorsal comminution and in women. Additionally, the pooled results confirm the importance of age demonstrating a significantly increased risk of secondary displacement of distal radius fractures in patients older than 60-65 years.

Conversely, our analysis reveals no significantly increased risk of secondary displacement in fractures with a dorsal angulation exceeding 15° or 20° from neutral, an associated ulna fracture or intra-articular involvement.

Intra-articular involvement is often mentioned as an indication for surgery and is one of Lafontaine's often cited risk factors.[3,6,7] Nevertheless, we found no significant effect on secondary displacement of intra-articular fractures (0.52, p=0.07). When the fixed effects model was used, risk of secondary displacement in intra-articular fractures was significantly lower (OR: 0.5, p=0.03). An explanation for this is that in the fixed-effects analyses, studies are weighted less equally than in the random-effects. Therefore, the larger study of the two (that found a significant OR) has greater weight.[15] Another possible reason could be that patients with more severe intra-articular fractures received primary operative treatment, resulting in less severe intra-articular fractures in the study population. The same reason may explain why dorsal angulation >15° from neutral was significant in the fixed-effects model and not in the random-effects model.

Another of Lafontaine's risk factors is the presence of an associated ulnar styloid fracture, which is believed to result in injuries of the ulnocarpal ligaments and therefore constitute fracture instability.[12,39] However, despite its popularity, this predictor was not identified as significantly associated with secondary fracture displacement in multiple studies. This is confirmed by the results of our meta-analysis that do not show an increased risk of secondary displacement for an associated ulnar styloid fracture.

The strength of this study is that it provides a complete and comprehensive overview of all predictors known in literature. There is a considerable advantage to the novel approach we took in this study to pool odds ratios of predictors. This is especially demonstrated by the pooled results for gender and dorsal comminution. Table 3 shows evidence for both predictors seems inconclusive; however, by pooling we found that both are significantly associated with secondary displacement. Gender is not commonly addressed in popular definitions of an unstable distal radius fracture.[8,12,40] Moreover, gender has been refuted as a predictor by several studies (Table 3). It is possible that by pooling, we identified a predictor that did not previously reach significance due to small study sizes. Nevertheless, the effect of female gender could be mitigated when accounting for age because women reach a higher age than men and are more prone to suffer from osteoporosis Thus the association between gender and fracture instability is probably indirect and should not be interpreted as direct causality.

This study has several limitations. The majority of studies that we included focused primarily on secondary displacement. Consequently, these studies only described patients who were treated conservatively. Patients treated initially with an operation were probably not included. This last group is likely to include the most unstable fractures. In our opinion, this limitation mostly applies to studies performed after the introduction of volar locking plates in 2000. Conversely, some patients might have been treated operatively who would have achieved excellent results with conservative treatment. Unfortunately, the decisions to perform primary surgical fixation and exclude these patients were only reported in a few studies. Intra-articular involvement, volar fracture displacement or open fractures were most commonly mentioned.

A limitation regarding the meta-analysis is the variation among study populations: four studies provided one common odds ratio for both non-displaced and displaced fractures; one study only provided odds ratios for displaced fractures; and one study reported separate odds ratios for displaced and minimally displaced fractures. We were unable to extract separate odds ratios for non-displaced and displaced fractures and therefore combined these data.

Of particular note is the definition of secondary displacement varied considerably across studies (Table 2). All studies included an alteration in dorsal angulation as a criterion of displacement in their definition. However, cut-off values varied from an absolute dorsal angulation of 10° or 15° from neutral to a change of 5°. The pooled odds ratios we found should therefore be interpreted with some caution.

Despite the obvious variability among studies, the statistical heterogeneity tests showed an I^2 of 48% or less for all analyses but one. The heterogeneity for dorsal comminution was considerable (I^2 =78%). A possible explanation for this could be that the assessment of the presence of dorsal comminution was more subjective and variable across studies than other predictors such as age and gender.

These limitations emphasize the need for consistency of definitions, measurement methods and a structured follow-up for patients with distal radius fractures. Standardization would allow easier comparison of studies and contribute to a higher level of evidence.

This systematic review provides a comprehensive overview of all known predictors and non-predictors of secondary displacement in patients with distal radius fractures. We have demonstrated that, despite their popularity as predictors of secondary displacement, distal radius fractures with an associated ulna fracture, a dorsal angulation >15° or >20° from neutral, and intra-articular fractures do not have an increased risk of secondary displacement. We did find a significantly increased risk of secondary displacement for patients older than 60-65, women and fractures with dorsal comminution. Our results can provide a good basis for surgeons to inform patients on the probability of secondary displacement and therefore the chances of success from conservative treatment. This will facilitate shared-decision making between patient and surgeon. Nevertheless, since secondary displacement does not always entail poor functional results after conservative treatment, especially in elderly patients (Bartl et al., 2014) future studies should focus on pooling important predictors of functional outcome.

REFERENCES

1. Arora R, Lutz M, Deml C, Krappinger D, Haug L, Gabl M. A prospective randomized trial comparing nonoperative treatment with volar locking plate fixation for displaced and unstable distal radial fractures in patients sixty-five years of age and older. Orthopedics 2012;35(1):50-51.

2. Earnshaw SA, Aladin A, Surendran S, Moran CG. Closed reduction of colles fractures: comparison of manual manipulation and finger-trap traction: a prospective, randomized study. J Bone Joint Surg Am 2002 Mar;84-A(3):354-358.

3. Mackenney PJ, McQueen MM, Elton R. Prediction of instability in distal radial fractures. J Bone Joint Surg Am 2006 Sep;88(9):1944-1951.

4. Kumar S, Penematsa SR, Sadri M, Deshmukh SC. How many clinic visits does it take to treat distal radial fractures? Int Orthop 2008 Feb;32(1):91-96.

5. Jenkins NH. The unstable Colles' fracture. J Hand Surg Br 1989 May;14(2):149-154.

6. Makhni EC, Ewald TJ, Kelly S, Day CS. Effect of Patient Age on the Radiographic Outcomes of Distal Radius Fractures Subject to Nonoperative Treatment. J Hand Surg 2008;33(8):1301-1308.

7. American Academy of Orthopaedic Surgeons Board of Directors, December 5, 2009. THE TREATMENT OF DISTAL RADIUS FRACTURES, GUIDELINE AND EVIDENCE REPORT. Available at: http://www.aaos.org/research/guidelines/drfguideline.pdf. Accessed July, 8, 2014.

8. Lafontaine M, Hardy D, Delince P. Stability assessment of distal radius fractures. Injury 1989;20(4):208-210.

9. Nesbitt KS, Failla JM, Les C. Assessment of instability factors in adult distal radius fractures. J Hand Surg 2004 nov;29(6):1128-1138.

10. Abbaszadegan H, Jonsson U, Sivers KV. Prediction of instability of Colles' fractures. Acta Orthop Scand 1989;60(6):646-650.

11. Tahririan MA, Javdan M, Nouraei MH, Dehghani M. Evaluation of instability factors in distal radius fractures. Journal of Research in Medical Sciences 2013;18:892-896.

12. Poigenfürst J. Brüche am distalen Unterarmende. Einteilung der Bruchformen und Indikation. Hefte Unfallheilkd 1980;148:53-59.

13. Adolphson P, Abbaszadegan H, Jonsson U. Computer-assisted prediction of the instability of Colles' fractures. Int Orthop 1993;17(1):13-15.

14. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int J Surg 2010;8(5):336-341.

15. Higgins JPT, Green S editors. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. : The Cochrane Collaboration; 2011.

16. Hayden JA, van der Windt DA, Cartwright JL, Cote P, Bombardier C. Assessing bias in studies of prognostic factors. Ann Intern Med 2013 Feb 19;158(4):280-286.

17. Huguet A, Hayden JA, Stinson J, McGrath PJ, Chambers CT, Tougas ME, et al. Judging the quality of evidence in reviews of prognostic factor research: adapting the GRADE framework. Syst Rev 2013 Sep 5;2:71-4053-2-71.

18. Alemdaroglu KB, Iltar S, Aydogan NH, Say F, Kilinc CY, Tiftikci U. Three-point index in predicting redisplacement of extra-articular distal radial fractures in adults. Injury 2010;41(2):197-203.

19. Altissimi M, Mancini GB, Azzara A, Ciaffoloni E. Early and late displacement of fractures of the distal radius: The prediction of instability. Int Orthop 1994;18(2):61-65.

20. Bartl C, Stengel D, Bruckner T, Gebhard F, ORCHID Study Group. The treatment of displaced intra-articular distal radius fractures in elderly patients. Dtsch Arztebl Int 2014 Nov 14;111(46):779-787.

21. Benoist LA, Freeland AE. The shelf sign indicating instability in minimally displaced extraarticular distal radial fractures. Orthopedics 1995;18(11):1125-1126.

22. Beumer A, McQueen MM. Fractures of the distal radius in low-demand elderly patients: Closed reduction of no value in 53 of 60 wrists. Acta Orthop Scand 2003;74(1):98-100.

23. Blakeney W, Webber L. Emergency department management of Colles-type fractures: A prospective cohort study. EMA - Emergency Medicine Australasia 2009 aug;21(4):298-303.

24. Camelot C, Ramare S, Lemoine J, Saillant G. Orthopedic treatment of fractures of the lower extremity of the radius by the Judet technique. Anatomic results in function of the type of lesion: apropos of 280 cases. Rev Chir Orthop Reparatrice Appar Mot 1998 Apr 1998;84(2):124-135.

25. Clayton RA, Gaston MS, Ralston SH, Court-Brown CM, McQueen MM. Association between decreased bone mineral density and severity of distal radial fractures. J Bone Joint Surg Am 2009 Mar 1;91(3):613-619.

26. Einsiedel T, Freund W, Sander S, Trnavac S, Gebhard F, Kramer M. Can the displacement of a conservatively treated distal radius fracture be predicted at the beginning of treatment?. Int Orthop 2009;33(3):795-800.

27. Fenyo G, Johansson O. Secondary displacement of reduced distal radius fractures. Acta Orthop Scand 1974;45(1):76-81.

28. Hove LM, Solheim E, Skjeie R, Sorensen FK. Prediction of secondary displacement in Colles' fracture. Journal of hand surgery (Edinburgh, Scotland) 1994 dec;19(6):731-736.

29. Kulej M, Dragan S, Dragan SL, Krawczyk A, Plochowski J, Orzechowski W, et al. Efficacy of closed reduction and maintenance of surgical outcome in plaster cast immobilization in different types of distal radius fractures. Ortopedia Traumatologia Rehabilitacja 2007;9(6):577-590.

30. LaMartina J, Jawa A, Stucken C, Merlin G, Tornetta P,3rd. Predicting Alignment After Closed Reduction and Casting of Distal Radius Fractures. J Hand Surg Am 2015 Mar 12;40(5):934-939.

31. Leone J, Bhandari M, Adili A, McKenzie S, Moro JK, Dunlop RB. Predictors of early and late instability following conservative treatment of extra-articular distal radius fractures. Arch Orthop Trauma Surg 2004;124(1):38-41.

32. Myderrizi N. Factors predicting late collapse of distal radius fractures. Malays Orthop J 2011 Nov;5(3):3-7.

33. Oskarsson GV, Aaser P, Hjall a. Do we underestimate the predictive value of the ulnar styloid affection in Colles fractures? Arch Orthop Trauma Surg 1997 jan;116(6-7):341-344.

34. Phillips AR, Al-Shawi A. Restoration of the volar cortex: predicting instability after manipulation of distal radial fractures. Injury 2014 Dec;45(12):1896-1899.

35. Porter M, Stockley I. Fractures of the distal radius. Intermediate and end results in relation to radiologic parameters. Clin Orthop Relat Res 1987 Jul;220(220):241-252.

36. Robin BN, Ellington MD, Jupiter DC, Brennan ML. Relationship of bone mineral density of spine and femoral neck to distal radius fracture stability in patients over 65. J Hand Surg Am 2014 May;39(5):861-6.e3.

37. Wadsten MA, Sayed-Noor AS, Englund E, Buttazzoni GG, Sjoden GO. Cortical comminution in distal radial fractures can predict the radiological outcome: a cohort multicentre study. Bone Joint J 2014 Jul;96-B(7):978-983.

38. Plaweski S., Lantuejoul J.P., Verjux T., Eid A., Rachidi I., Faure C., et al. Articular fractures of the distal radius: Results according to anatomy and treatment. Main 1997;2(1):11-18.

39. Poigenfuerst J, Tuchmann A. The significance of injuries to the ulnar ligaments of the wrist in Colles' fractures. Handchirurgie 1978 1978;10(3):121-125.

40. Cooney WP,3rd, Linscheid RL, Dobyns JH. External pin fixation for unstable Colles' fractures. J Bone Joint Surg Am 1979 Sep;61(6A):840-845.

CHAPTER 10

VALIDATION OF A PREDICTION MODEL FOR INSTABILITY IN DISTAL RADIAL FRACTURES

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Submitted

ABSTRACT

Background
Mackenney et al. published a prediction model to predict early loss of reduction in displaced distal radius fractures. If the model were reliable, it could assist in decision-making regarding the treatment of choice. However, Mackenney's model was never externally validated, a requirement before implementation in clinical practice. The purpose of this study was to externally validate the model.

Patients and Methods
We performed a retrospective cohort study and included all consecutive adult patients with a displaced distal radius fracture who were treated conservatively between 2009 and 2014. The primary outcome was early (<2 weeks) instability. The validity of the model was assessed by comparing the predicted probabilities of early instability with the observed early instability. We calculated the ability of the model to discriminate between patients with and without early instability (Area under the Receiver Operating Characteristics Curve [AUC]). Additionally, we determined its sensitivity and specificity.

Results
Ninety-nine patients were included and early instability occurred in 61 patients (62%). The AUC of the model was 0.53 (95% CI: 0.41 - 0.64), indicating poor discrimination. The sensitivity and specificity for correctly identifying an unstable fracture were 1.6% (95% CI: 0.9% - 9.9%) and 94.7% (95% CI: 80.9% - 99.1%) respectively.

Conclusions
External validation of Mackenney's prediction model for early instability in displaced distal radius fractures revealed a disappointing performance. Therefore we conclude that the model in its current form is unsuitable for a population other than the population from which it was derived.

INTRODUCTION

Instability of distal radius fractures has often been subject of investigation in an attempt to timely select those patients requiring surgery.[1,2] Non-displaced fractures generally tend to be stable and can be managed conservatively.[3,4] However, treatment of displaced and potentially unstable fractures continues to stimulate debate.[2] Preferably, patients with a displaced distal radius fracture with a high risk of early loss of reduction are selected for preemptive surgical treatment. Unfortunately, these potential unstable distal radius fractures are difficult to identify.

Mackenney et al. published a prediction model to predict early instability in distal radius fractures.[2] Based on age, the presence of comminution and ulnar variance, the model predicts the probability of instability occurring within the first two weeks after the injury. The study was very well-designed and the model was based on data of over 4,000 patients. However, although the model is available as an online calculator and can thus be used in clinical practice, it has never been externally validated. External validation, or evaluating the performance of a prediction model in a new patient population, is essential before its implementation elsewhere.

The aim of this study was to externally validate this model in a different patient population with displaced distal radius fractures. We sought to examine how the model would perform in a new patient population and what its sensitivity and specificity for correctly identifying an unstable fracture would be.

METHODS

Source of data and participants

For this retrospective cohort study, we included all consecutive conservatively treated adult patients with a displaced distal radius fracture who visited the outpatient clinic between January 1st, 2009 and August 4th, 2014. Patients were retrospectively identified using the hospital administration code (in Dutch: DBC, Diagnosis and Treatment Combination) for distal radius fractures. Fractures were considered displaced when there was dorsal or volar angulation of >10˚and/or an ulnar variance of >3 mm. Acceptable reduction was defined according to Mackenney et al. as a fracture with dorsal angulation of ≤0° and an ulnar variance of ≤3 mm. An unacceptable reduction was defined as a position with dorsal angulation of >0° and/or an ulnar variance of >3 mm following closed reduction. The exclusion criteria were similar to Mackenney's protocol: (1) skeletal immaturity; (2) primary operative treatment; (2) prior fracture malunion; and (4) missing data. Patients with missing radiographic data from the evaluation after reduction were excluded from the analyses.

Study outcomes measures

The primary outcome was early instability. Early instability was defined as a fracture that was radiographically redisplaced into an unacceptable position within two weeks after the injury. Because Mackenney's criteria for an unacceptable position differ from Dutch guidelines, we evaluated two definitions of early instability: According to Mackenney et al., an unacceptable position is a fracture with dorsal angulation of >0° and/or an ulnar variance of >3 mm. According to Dutch guidelines, an unacceptable position is defined as ≥15˚dorsal angulation or ≥20˚volar angulation of the distal fracture fragment, ≥5mm shortening or <15˚radial inclination.[6]

Predictors

According to hospital protocol, patients were evaluated clinically and radiographically at presentation, following closed reduction, and at approximately one week and six weeks after injury. Radiographic evaluation comprised standard posteroanterior and lateral radiographs. The first author retrospectively determined the following criteria on all X-rays: AO fracture classification, dorsal or volar angle, radial inclination, radial height, ulnar variance and radial shift (in millimetres), and the presence of any comminution. Mackenney et al. expressed ulnar variance as difference between the injured side and the normal (uninjured) side. However, since we do not regularly image the uninjured wrist, ulnar variance was calculated as the difference between the injured side and the normal value (0.49 mm).[5]
All radiographs were measured using the functions available on the computerised radiographical system (IMPAX) with a digital ruler and protractor.

Analysis

We reported medians and interquartile range (IQR) for non-parametric variables, and means and standard deviations (SD) for normally distributed variables. The Shapiro-Wilk test was used for testing normality.

For each patient, the probability of early instability was calculated according to the published formula: X = 0.03 * age + 0.38 * (if comminution is present) + 0.21 * ulnar variance -3.12. The probability of instability equals (ex / [1 + ex]) * 100.

To estimate the ability of the model to discriminate between patients with and without instability, we calculated the Area under the Receiver Operating Characteristics Curve (AUC). The AUC ranges from 0.5 to 1, with higher score indicating better discrimination. The calibration of the model (the agreement between observed outcomes and predictions) was assessed by plotting the predicted probability of instability and the observed frequency of occurrence of instability. The ideal is a slope of 1 for the observed versus predicted risks.[7]

Decision-making in the treatment of displaced distal radius fractures requires a binary outcome: is the fracture stable or unstable? The predictive formula of Mackenney et al. generates a percentage risk of instability. The authors demonstrated that for the prediction of malunion in displaced fractures, the cut-off is best set at approximately 70% (<70% probability of instability constitutes a stable fracture, ≥70% probability constitutes an unstable

fracture).[8] Therefore, we calculated the sensitivity and specificity for a cut-off of 70%.

Data entry and analysis were performed with the Statistical Package for Social Sciences (SPSS) version 20.0 for Windows (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) and R Gui version 3.1.2 (R Development Core Team (2008,R Foundation for Statistical Computing, Vienna, Austria). A p-value of ≤0.05 was considered statistically significant.

RESULTS

During the study period there were 515 patients with a distal radius fracture. A total of 99 patients were eligible and included in the analysis (Figure 1). The characteristics of the study population are outlined in Table 1. The probability of early instability according to the model ranged from 5% to 89% with a median probability of 33%. Early instability occurred in 61 patients (62%).

Figure 1. Flowchart

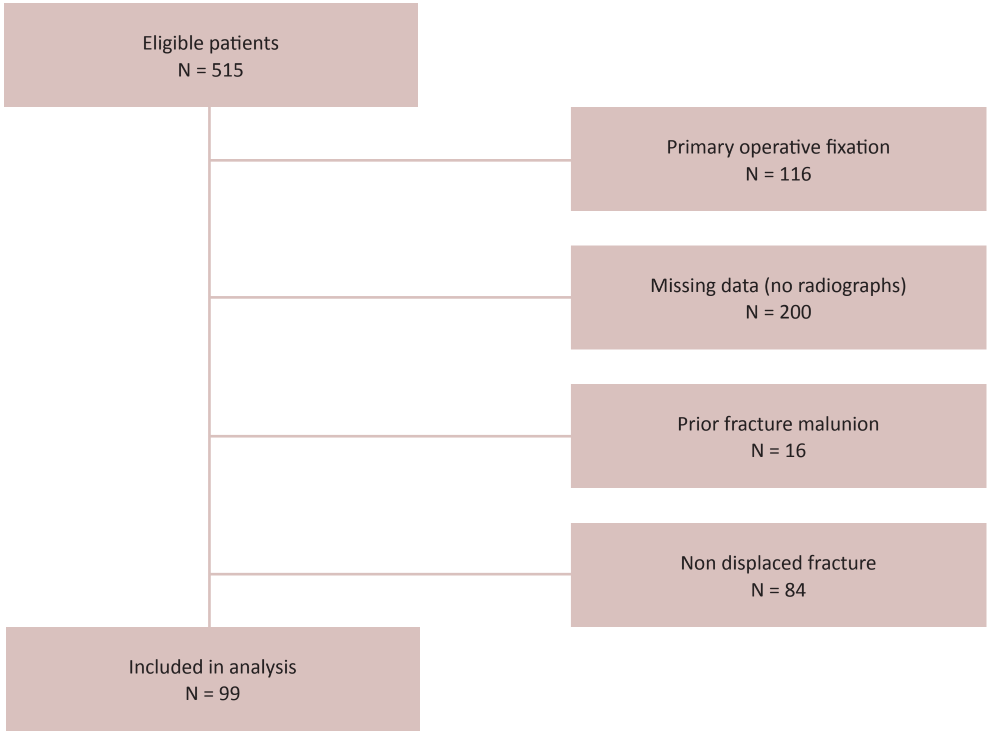

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Table 1. Characteristics of study population (N=99)

Age (median, IQR)	63 (54 - 74)
Sex (female), No. (%)	73 (74)
AO fracture classification, No. (%)	
A	55 (56)
B	20 (20)
C	24 (24)
Early instability, Number (%)	61 (62)
Early instability Dutch[a], Number (%)	18 (18)

a. Instability according to the Dutch guidelines: 15˚dorsal angulation or ≥20˚volar angulation of the distal fracture fragment, ≥5mm shortening or <15˚radial inclination.

The ability of the model to discriminate between patients with and without early instability expressed as the AUC was 0.53 (95% CI: 0.41 - 0.64). The calibration slope of the model was -0.10 (95% CI: -0.62 - 0.41).

When applying the suggested 70% cut-off (<70% probability of instabiliy constitutes a stable fracture, ≥70% probability constitutes an unstable fracture), the model showed a sensitivity of 1.6% (95% CI: 0.9% - 9.9%) and a specificity of 94.7% (95% CI: 80.9% - 99.1%) for correctly identifying an unstable fracture (Table 2).

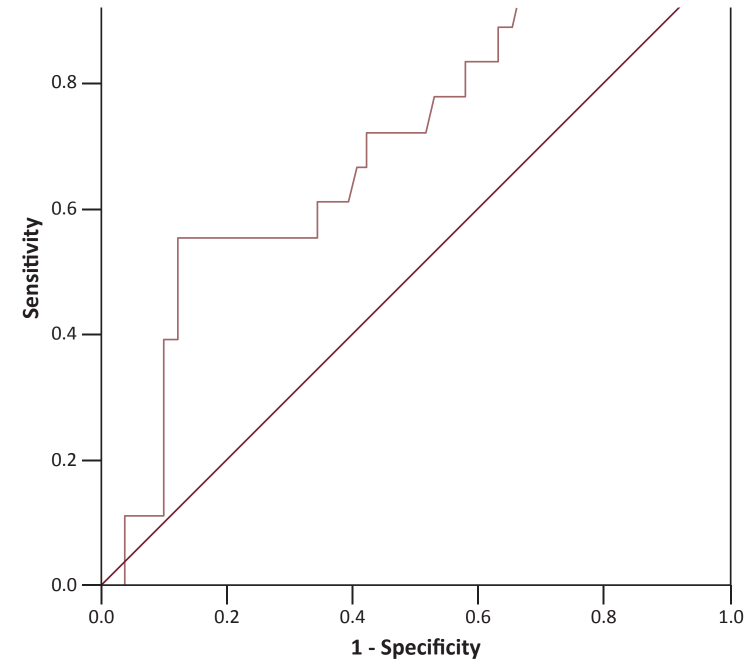
Table 2. Performance of the model to when cut-off was applied (N=99)

	Early instability occurred	Early instability did not occur	Total
Unstable fracture[a]	1	2	3
Stable fracture[b]	60	36	96
Total	61	38	99
Sensitivity (95% CI)	1.6% (0.9% - 9.9%)		
Specificity (95% CI)	94.7% (80.9% - 99.1%)		

a. Predicted probability ≥70%
b. Predicted probability <70%)
Abbreviations: CI, Confidence Interval

According to the more liberal Dutch guidelines, only 18 patients (18%) showed early fracture instability. Using this definition as the predicted outcome, the AUC of the model was 0.71 (95% CI: 0.58 - 0.84) for predicting this type of instability (Figure 2). The calibration slope was 0.85 (95% CI: 0.14 - 1.6). The model showed a sensitivity of 0% (95% CI: 0% - 21.9%) and a specificity of 96.3% (95% CI: 88.9% - 99.0%) for correctly identifying an unstable fracture.

Figure 2. Receiver operating characteristics curve. The area under the curve is 0.53 (95% CI: 0.41 - 0.64). The green line represents an area under the curve of 0.5, which is equal to a coin toss.



DISCUSSION

External validation of Mackenney's prediction rule for early instability showed poor discrimination and calibration. The AUC of 0.53 represents a discriminative ability that is equal to a coin toss. Applying a 70% cut-off for the predicted probability (a probability of <70% constitutes a stable fracture, a probability of ≥70% constitutes an unstable fracture) resulted in good specificity (95%) but very low sensitivity (<2%) for predicting instability.

This study has several limitations. Due its retrospective nature, selection of patients for surgery did not follow a protocol. As discussed above, this has resulted in a study population that is not clearly defined and therefore limits the generalizability of our results. We also had to exclude a considerable number of patients due to missing radiographs. Our hospital is situated in a city that is frequently visited by tourists who are followed up elsewhere. The follow-up evaluation radiographs of these patients were missing and therefore the occurrence of early instability could not be determined.
Another study limitation and possible reason for the model's poor performance is the method we used to determine the ulnar variance. Mackenney et al. calculated the ulnar variance

as difference between the injured side and the normal (uninjured) side. However, since we do not regularly image the uninjured wrist, we were forced to use the published normal value for ulnar variance. We recognize that this approach is not optimal and might have negatively influenced our results. Nevertheless, we believe that obtaining x-rays from both sides is not standard practise in most institutions, rendering the model impractical to use.

The poor performance of the model could also be explained by the differences between the study populations. In our population, primary operative treatment was selected for most displaced intra-articular fractures, and some displaced extra-articular distal radius fractures based on surgeons' preference. In Mackenney's population, primary operative treatment was selected for all intra-articular fractures or volarly displaced fractures. Of the 1595 displaced fractures they included, early instability occurred in 682 (43%). Our more conservative selection of patients for operative treatment may have resulted in a less favourable population with a higher a priori probability of instability. The higher percentage of patients with early instability in our sample (62% versus 43%) supports this theory.

Predictors of loss of reduction or instability in distal radius fractures have been studied extensively.[9-17] However, the definition of loss of acceptable reduction varies across studies. In general, the Dutch definition is more liberal, allowing up to 15 degrees of dorsal angulation or 20 degrees of volar angulation, and 5 mm of shortening. Surprisingly, the model performed better when it was used to predict early instability according to the Dutch guidelines. Although the model was not designed to predict this outcome, both the discrimination and the calibration were higher. Nevertheless, decision-making in the treatment of displaced distal radius fractures requires a binary outcome: is the fracture stable or unstable? When applying the cut-off of 70% (<70% stable, ≥70% unstable), specificity of the model was good (96%), but its sensitivity was very low (0%).

Clinical prediction models can assist and support shared decision making between patients and physicians. Especially well-designed models derived from large samples such as the model from Mackenney, can provide a useful tool. However, evaluating the validity of a prediction model in a new patient population is essential before its implementation. The validity of a model can be assessed by comparing the observed outcomes with the predicted probabilities. Subsequently, the model may be updated to improve predictions in the population examined.[18]

CONCLUSION

Unfortunately, external validation of Mackenney's prediction rule for early instability in a different population showed poor discrimination and calibration. Recalibration of the model by adjusting the intercept for a new population would not have led to better results. Our results do not discredit the model itself, merely its performance in another patient population. Surprisingly, the model performed better when it was used to predict early instability according to the more liberal Dutch guidelines. Nevertheless, its sensitivity remained equally low. Therefore we conclude that the model in its current form is unsuitable for a population other than the population from which it was derived.

REFERENCES

1. Alemdaroglu KB, Iltar S, Aydogan NH, Say F, Kilinc CY, Tiftikci U. Three-point index in predicting redisplacement of extra-articular distal radial fractures in adults. Injury 2010 Feb;41(2):197-203.

2. Mackenney PJ, McQueen MM, Elton R. Prediction of instability in distal radial fractures. J Bone Joint Surg Am 2006 Sep;88(9):1944-1951.

3. McQueen M, Caspers J. Colles fracture: does the anatomical result affect the final function? J Bone Joint Surg Br 1988 Aug;70(4):649-651.

4. Cooney WP. Management of Colles' fractures. J Hand Surg Br 1989 May;14(2):137-139.

5. Parker AS, Nguyen M, Minard CG, Guffey D, Willis MH, Reichel LM. Measurement of ulnar variance from the lateral radiograph: a comparison of techniques. J Hand Surg Am 2014 Jun;39(6):1114-1121.

6. DSo S. Guidelines Distal Radius Fractures, diagnosis and treatment. 2010.

7. Steyerberg E. Evaluation of performance. Clinical Prediction Models, a Practical Approach to Development, Validation, and Updating. New York: Springer; 2009. p. 270--279.

8. Mackenney PJ. Re: An evaluation of two scoring systems to predict instability in fractures of the distal radius. J Trauma 2005 Dec;59(6):1535; author reply 1535.

9. Abbaszadegan H, Jonsson U, von Sivers K. Prediction of instability of Colles' fractures. Acta Orthop Scand 1989 Dec;60(6):646-650.

10. Adolphson P, Abbaszadegan H, Jonsson U. Computer-assisted prediction of the instability of Colles' fractures. Int Orthop 1993;17(1):13-15.

11. Einsiedel T, Freund W, Sander S, Trnavac S, Gebhard F, Kramer M. Can the displacement of a conservatively treated distal radius fracture be predicted at the beginning of treatment? Int Orthop 2009 Jun;33(3):795-800.

12. Lafontaine M, Hardy D, Delince P. Stability assessment of distal radius fractures. Injury 1989 Jul;20(4):208-210.

13. Hove LM. Simultaneous scaphoid and distal radial fractures. J Hand Surg Br 1994 Jun;19(3):384-388.

14. Leone J, Bhandari M, Adili A, McKenzie S, Moro JK, Dunlop RB. Predictors of early and late instability following conservative treatment of extra-articular distal radius fractures. Arch Orthop Trauma Surg 2004 Jan;124(1):38-41.

15. Makhni EC, Ewald TJ, Kelly S, Day CS. Effect of patient age on the radiographic outcomes of distal radius fractures subject to nonoperative treatment. J Hand Surg Am 2008 Oct;33(8):1301-1308.

16. Nesbitt KS, Failla JM, Les C. Assessment of instability factors in adult distal radius fractures. J Hand Surg Am 2004 Nov;29(6):1128-1138.

17. Tahririan MA, Javdan M, Nouraei MH, Dehghani M. Evaluation of instability factors in distal radius fractures. J Res Med Sci 2013 Oct;18(10):892-896.

18. Steyerberg EW, Borsboom GJ, van Houwelingen HC, Eijkemans MJ, Habbema JD. Validation and updating of predictive logistic regression models: a study on sample size and shrinkage. Stat Med 2004 Aug 30;23(16):2567-2586.

CHAPTER 11

THE MINIMUM CLINICALLY IMPORTANT DIFFERENCE OF THE PATIENT-RATED WRIST EVALUATION SCORE FOR PATIENTS WITH DISTAL RADIUS FRACTURES

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ABSTRACT

Background
The Patient-rated Wrist Evaluation (PRWE) is a commonly used instrument in upper extremity surgery and in research. However, to recognize a treatment effect expressed as a change in PRWE, it is important to be aware of the minimum clinically important difference (MCID) and the minimum detectable change (MDC). The MCID of an outcome tool like the PRWE is defined as the smallest change in a score that is likely to be appreciated by a patient as an important change, while the MDC is defined as the smallest amount of change that can be detected by an outcome measure. A numerical change in score that is less than the MCID, even when statistically significant, does not represent a true clinically relevant change. To our knowledge, the MCID and MDC of the PRWE have not been determined in patients with distal radius fractures.

Questions/Purposes
We asked: (1) What is the MCID of the PRWE score for patients with distal radius fractures? (2) What is the MDC of the PRWE?

Methods
Our prospective cohort study included 102 patients with a distal radius fracture and a median age of 59 years (interquartile range [IQR], 48-66 years). All patients completed the PRWE questionnaire during each of two separate visits. At the second visit, patients were asked to indicate the degree of clinical change they appreciated since the previous visit. Accordingly, patients were categorized in two groups: (1) minimally improved or (2) no change. The groups were used to anchor the changes observed in the PRWE score to patients' perspectives of what was clinically important. We determined the MCID using an anchor-based receiver operator characteristic method. In this context, the change in the PRWE score was considered a diagnostic test, and the anchor (minimally improved or no change as noted by the patients from visit to visit) was the gold standard. The optimal receiver operator characteristic cutoff point calculated with the Youden index reflected the value of the MCID. Results In our study, the MCID of the PRWE was 11.5 points. The area under the curve was 0.54 (95% CI: 0.37 - 0.70) for the pain subscale and 0.71 (95% CI: 0.57 - 0.85) for the function subscale. We determined the MDC to be 11.0 points.

Conclusions
We determined the MCID of the PRWE score for patients with distal radius fractures using the anchor-based approach and verified that the MDC of the PRWE was sufficiently small to detect our MCID.

Clinical Relevance
We recommend using an improvement on the PRWE of more than 11.5 points as the smallest clinically relevant difference when evaluating the effects of treatments and when performing sample-size calculations on studies of distal radius fractures.

INTRODUCTION
A frequently used outcome measure in distal radius fracture studies is the Patient-rated Wrist Evaluation (PRWE) score.[1,2] The PRWE is a 15-item questionnaire designed to measure a patient's wrist pain and disability. It consists of two subscales (pain and function) and has a score range from 0 (no disability) to 100 (severe disability).

To recognize a treatment effect expressed as a change in PRWE score, it is important to be aware of the minimum clinically important difference (MCID) of the PRWE score. The MCID represents the smallest change in score that would be perceived by the patient as beneficial.[3-5] Consequently, a numeric change in score that is less than the MCID, even if statistically significant, does not represent a true clinically relevant change. Because the MCID defines a difference that is considered important to patients, the MCID also serves as the basis for estimating the necessary sample size in designing future studies.[6]

Another important instrument is the minimum detectable change (MDC). The MDC is the smallest amount of change that falls outside the measurement error of an instrument. Therefore, any change smaller than the MDC could be the result of the variability of the questionnaire. To ensure that the MDC is sufficiently small to detect the MCID, the MCID should be greater than the MDC.

The MCID and the MDC of the PRWE have been examined in patients with chronic wrist conditions[6-8]; however, to our knowledge, they have not been determined in patients with a distal radius fracture. Therefore, the purpose of our study was to determine the MCID and MDC of the PRWE score in patients with distal radius fractures.

PATIENTS AND METHODS
Our prospective cohort study was conducted alongside two ongoing clinical trials that are coordinated from our institution, an academic Level-1 trauma center in The Netherlands. The medical ethical review committee granted approval before initiation of this parallel study, without the need for informed consent from patient participants.

Patients for our cohort study were recruited from the two ongoing clinical trials between January 2011 and July 2014, during their first visit to the outpatient clinic. To increase the size of our cohort study population, we also recruited patients with distal radius fractures at the outpatient clinic who were not enrolled in the clinical trials. The patients who were not participants of the clinical trial were enrolled in our study between January 2014 and July 2014.

Our study population consisted of 102 patients with distal radius fractures. Patients were excluded if they: (1) did not want to complete the questionnaire at the outpatient clinic; (2) did not complete the anchor questions; (3) were unable to understand the study information; or (4) had sustained their distal radius fracture more than 1 year before their visit to the outpatient clinic.

Of the two concurrent clinical trials occurring during our prospective cohort study, the first trial[9] included 42 patients who underwent a study of two- and three-dimensional imaging. This trial provided 42 adult patients with intraarticular distal radius fractures who were treated with open reduction and internal fixation with a volar locking plate.

The second trial[10] randomized patients with displaced extraarticular distal radius fractures (AO types A2 and A3[11]) between treatment with either open reduction and internal fixation with a volar locking plate or plaster immobilization. This trial provided 39 patients.

Additionally, during the first 6 months of 2014, we identified 55 patients who were not enrolled in either clinical trial but who were eligible for participation in our study. All adult patients with a distal radius fracture were eligible for inclusion, regardless of the type of treatment they received. After exclusion, an additional 21 patients with a distal radius fracture who were not enrolled in either of the two trials were included in our study cohort.

There are two methods to define the MCID: (1) a distribution-based and (2) an anchor-based approach.[12] The distribution-based approach is used to evaluate if the observed effect is attributable to true change or simply the variability of the questionnaire. It examines the distribution of observed scores in a group of patients. The magnitude of the effect is interpreted in relation to variation of the instrument.[13] In other words, is the observed effect attributable to true change or simply the variability of the questionnaire?

The anchor-based approach uses an external criterion (the anchor) to determine the MCID. Possible anchors include objective measurements, such as prehensile grip strength and ROM, or patient-reported anchor questions. The purpose of a patient-reported anchor question is to ''anchor'' the changes observed in the PRWE score to patients' perspectives of what is clinically important.[14]

Anchor-based methods to determine the MCID are preferred because an external criterion is used to define what is clinically important[15]; however, the anchor-based method does not take into account the measurement error of the instrument, so it is valuable to use the anchor- and distribution-based approaches.[15] To avoid confusion, the distribution-based method generally is referred to as minimum detectable change (MDC), and the anchor-based method as MCID.[15] We use the same terms to identify the methods.

Data were collected prospectively. Patients completed the Dutch version of the PRWE questionnaire during two visits at approximately 6 to 12 weeks and approximately 12 to 52 weeks after distal radius fracture injury.

At the second visit, patients were asked to indicate the degree of clinical change they had noticed since the previous visit for each domain (pain and function). Patients noted their

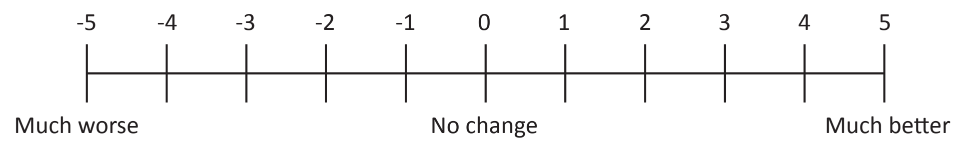
answers on a global rating of change scale (GRC) from -5 (much worse) to +5 (much better) (Fig. 1).[16] The purpose of this question was to ''anchor'' the changes observed in the PRWE score to patients' perspectives regarding what is clinically important.[14]

There is no consensus regarding the required sample size to determine the MCID.[17] We made a sample size estimation based on a conservatively estimated MCID of 12 points, with a SD of ± 14.[6-8] To achieve an a of 0.05 and a power of 80%, we required 18 data points representing no change, and 18 data points representing minimal improvement.

Fig. 1 The global rating of change (GRC) scale used in the Patient-rated Wrist Evaluation (PRWE) questionnaire is shown. The anchor questions allowed patients to assess their current health status regarding wrist function and wrist pain, and compare their status with that of their previous visit.

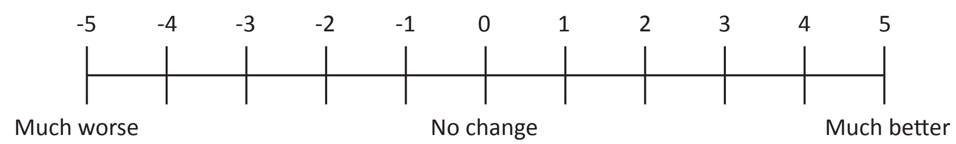
1. Pain

Rate the pain in your wrist compared to your previous visit. Please indicate your answer on the scale below.



2. Function

Rate your wrist function compared to your previous visit. Please indicate your answer on the scale below.



Statistical Methods

The number of questions not answered by patients comprised less than 5% for all items and were replaced with the mean score of the subscale according to the PRWE user manual.[18] PRWE scores were calculated for both subscales (pain and function) using the published algorithm.[18] The change in outcome was calculated as the difference between the last and the first scores. The change in score between visits was transformed such that improvement was indicated by a positive value. We reported medians and interquartile ranges (IQR) for nonparametric variables, and means (± SD) for normally distributed variables. The Kolmogorov-Smirnov test was used to determine if a variable was normally distributed. A p value of 0.05 or less was considered statistically significant. Data entry and analysis were performed using SPSS1 (Version 20.0; IBM Corp, Armonk, NY, USA) and R Studio Version 3.1.2; R Studio, Boston, MA, USA), with the package coefficient alpha.

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Determination of MDC

We calculated the MDC for the pain and function subscales separately and summed them to obtain the total MDC.[15] The MDCs were calculated as:

$$z\ score_{90\%} * \sqrt{2} * \text{Standard Error of Measurement}_{PRWE}$$

A z score of 1.65 was chosen to reflect a 90% one-sided CI, similar to previous studies.[6,7] The standard error of measurement is a measure of the instrument variability and takes into account the distribution of repeated measures on a questionnaire around the ''true'' score of a patient. For our study, the standard error of measurement was calculated by multiplying the SD (σ) of the PRWE score at the second followup, by the square root of 1, minus the reliability coefficient (r) of the instrument, or, in formula[15,19]:

$$\text{Standard Error of Measurement} = \sigma * \sqrt{(1 - r)}$$

The reliability coefficient is the overall consistency of an instrument. We used Cronbach's alpha as a parameter of reliability.[20] Cronbach's alpha is used to measure the internal consistency of a (sub)scale. Its value can range from 0 to 1.0, where greater than 0.7 indicates good internal consistency.[20]

Determination of the MCID

We calculated the MCID according the receiver operating characteristic (ROC) curve method[7,21] In this context, the change in PRWE score was considered a diagnostic test and the anchor was the gold standard.[21] The ROC curve plots the sensitivity against 1-specificity for all possible cutoff points of the change in PRWE score. The optimal ROC cutoff point is the value for which the sum of percentages of false positive and false negative classifications is smallest ([1-sensitivity] + [1-specificity]).[21] This value represents the MCID. The area under the ROC curve reflects the ability of the change in PRWE score to differentiate between patients with and without clinically important change. The area under the ROC curve ranges from 0.5 to 1; a higher score indicates better discrimination.

Consistent with previous studies[8,22], patients were categorized in five groups according to their answer to the anchor question: -5 to -4 (marked worsening); -3 to -2 (minimal worsening); -1 to 1 (no change); 2 to 3 (minimal improvement); and 4 to 5 (marked improvement). We calculated the MCID by plotting the ROC of the change in PRWE score for patients in the minimal-improvement group compared with patient scores in the no-change group.

We tested for significant score changes among patients who indicated they had experienced marked worsening, minimal worsening, no change, minimal improvement, and marked improvement, using the Kruskal-Wallis test. Nonsignificant differences among the five patient categories could suggest that the improvement categories were not sufficiently discrimi-

native. The adequateness of the GRC scale was explored by quantifying the correlation between change in PRWE scores and the anchor questions using Spearman's rho. Correlation coefficients were interpreted as negligible correlation (0 - 0.3); low correlation (0.3 - 0.5); moderate correlation (0.5 - 0.7); high correlation (0.7 - 0.9); or very high correlation (0.9 - 1.0).[23] A total 102 patients were included in our study (Fig. 2). Patient characteristics are provided (Table 1).

Figure 2. The flowchart shows patient selection methods used for the study

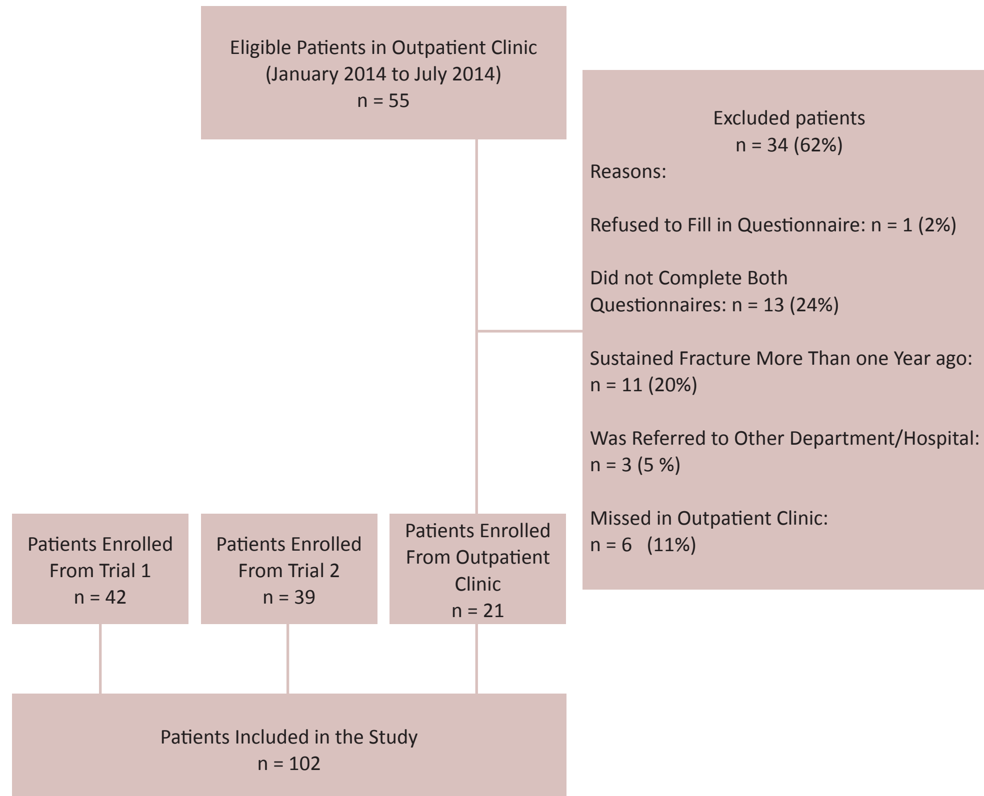

Table 1. Characteristics of study population (n = 102)

Characteristic	Numbers
Age, median year (IQR)	59 (48 - 66)
Women, n (%)	71 (70)
Dominant hand affected, n (%)	50 (49)
AO fracture classification, n (%)	
A	56 (55)
B	11 (11)
C	35 (34)
Type of treatment, n (%)	
Open reduction and volar locking plate, n (%)	65 (64)
Plaster, n (%)	36 (35)
Nonea, n (%)	1 (1)
Weeks from trauma to first measurement, median (IQR)	8 (6 - 13)
Weeks between measurements, median (IQR)	8 (6 - 39)
Weeks from trauma to second measurement, median (IQR)	16 (13 - 52)
PRWE score at first measurement, median (IQR)	44 (21 - 63)
PRWE score at second measurement, median (IQR)	17 (4 - 45)

a. Patient was treated elsewhere and the fracture was missed; IQR = interquartile range; PRWE = patient-rated wrist evaluation.

RESULTS

MCID of the PRWE for Patients with Distal Radius Fractures

The overall MCID was 11.5 points on the PRWE (Table 2). For the pain subscale, 20% of the patients (20/102) indicated they had experienced minimal improvement and 37% (38/102) experienced no change. The area under the ROC curve of the change in PRWE score to differentiate between patients with minimal improvement in pain and patients with no change in pain was 0.54 (95% CI: 0.37-0.70). For the function subscale, 24% of the patients (24/102) reported minimal improvement in function and 34% (35/102) experienced no change. The area under the ROC curve of the change in PRWE score to differentiate between patients with minimal improvement in function and no change in function was 0.71 (95% CI: 0.57-0.85).

Table 2. The MCID of the PRWE score

Subscale	MCID[a]
PRWE pain	1.5
PRWE function	10
PRWE total	11.5

a. Units are expressed in points on the PRWE score.

Abbreviations: MCID, minimal clinically important difference; PRWE, patient-rated wrist evaluation.

MDC of the PRWE

The MDC was 11.0 points. The majority of patients reported marked improvement (Table 3) and the PRWE scores between the first and the second measurements differed ($p< 0.001$; Wilcoxon signed rank test). For the pain subscale, 40 patients reported marked improvement (change in PRWE, 9.5; IQR, 5.0 - 16.0), and 20 patients had minimal improvement (change in PRWE, 5.0; IQR, -1.8 to 10.7). For the function subscale, 41 patients reported marked improvement (change in PRWE, 12.5; IQR, 5.8 - 19.7), and 24 patients had minimal improvement (change in PRWE, 10.8; IQR, 3.6 - 18.8).

There were significant differences in the changes in PRWE scores among patients who indicated they had experienced marked worsening, minimal worsening, no change, minimal improvement, or marked improvement in pain ($p = 0.001$, Kruskal-Wallis test), suggesting sufficiently discriminative categories (Table 3). There also were significant differences in the changes in PRWE scores among the categories of the function subscale ($p<0.001$, Kruskal-Wallis test).

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There was correlation between the change in PRWE scores for the pain subscale and the GRC categories, confirming the adequacy of the GRC (correlation coefficient = 0.39; two-tailed $p<0.001$). The correlation between the change in PRWE score and GRC categories for function was similar (correlation coefficient = 0.34; two-tailed $p = 0.001$). Reliability coefficients (Cronbach's alpha) were 0.98 for the pain subscale and 0.95 for the function subscale, indicating good internal consistency of the questionnaire.

DISCUSSION

The PRWE score is a well-accepted measure of patient functional outcome after distal radius fracture.[1] Knowledge of the MCID of the PRWE provides a useful benchmark to interpret study results and a basis for sample size calculations. Three previous studies have examined the MCID of the PRWE; however, to our knowledge, no such study has examined patients with distal radius fractures.[6-8] Some authors advocate that the MCID is not a universal fixed attribute and cannot be applied across patient populations or disease-specific states.[3,17,24,25] The MCID can fluctuate based on what is interpreted as important to the patient; therefore, patients with chronic wrist conditions may have other expectations from treatment than patients with an acute condition. Patients who sustain a distal radius fracture generally have their healthy wrist become immobilized, are in pain, and experience a (temporary) complete loss of wrist function. Their standard of comparison is likely not the painful situation at the beginning of treatment for the fracture, but their status before the injury.[26] In general, these patients expect complete recovery, which could entail that they require different changes in PRWE scores to appreciate clinical improvement.

In our patients, the MCID was 11.5 points, which was just outside the measurement error (MDC) of the PRWE score.

Our study had several limitations. The majority of patients were selected from one of two ongoing clinical trials coordinated from our institution. Owing to the nature of the trials, the patients in our study were part of a more selective group of patients. All patients had a sustained displaced distal radius fracture and consented to participate in a randomized controlled trial. Such a select group of patients may limit the generalizability of our results. Other limitations pertain to the various approaches for determining the MCID. For example, a limitation of the anchor-based approach is that it does not take measurement precision into account[12,15]; therefore, the MCID determined potentially can be within the measurement error of the questionnaire. By determining the MDC, it becomes possible to judge whether the MDC of a measurement instrument is sufficiently small to detect the MCID.[15] In our study, the MDC was 11 points, therefore the MCID we determined was outside the measurement error of the questionnaire. Another limitation of the anchor-based method is the possibility of recall bias.[27] Recall bias implies that patients are unable to recall their initial state at the time of injury. Recall bias was present in our study, illustrated by the low correlation we found between the change in scores and the anchor questions; however, none of the patients gave contradicting answers (indicating worsening status in response to the anchor questions while their PRWE score had improved, or vice versa). The relatively short duration between measurements (8 weeks) might have contributed to this. An increased duration of followup in a study is associated with larger estimates of the MCID[22], therefore we chose to limit the followup to 1 year, similar to that in a previous study on the MCID of the PRWE in patients with traumatic upper-extremity conditions.[8]

The MCID for our patients was 11.5 points, which was lower than previously determined MCIDs. Three previous studies have examined the MCID of the PRWE. Schmitt and Di Fabio[6] reported a MCID of 24 points in a cohort of 211 patients, however their patients predominantly had shoulder pain, and the PRWE is not intended for patients with shoulder injuries. The second study, by Sorensen et al.[8], included 102 patients with a traumatic upper-extremity conditions such as isolated tendinitis, arthritis, and nerve compression syndrome. The MCID in that study was 14 points. The third study included 31 patients who underwent ulnar-shortening osteotomy for ulnar impaction syndrome and the MCID was 17 points.[7]

The MDC is the smallest change in score that likely reflects true change rather than measurement error. It shows which changes fall outside the measurement error of the health status measurement (based on, for instance, internal validity or test-retest reliability).[15] To ensure that the MDC is sufficiently small to detect the MCID, it should be greater than the MDC. We found an MDC of 11.0 points, similar to the MDCs reported by Kim and Park (7.7 points)[7] and Schmitt and Di Fabio (12.2 points).[6] This value for the MDC indicates that the PRWE questionnaire is able to detect changes as small 11.0 points, therefore the PRWE should be able to detect the MCID we determined.

In our prospective cohort study, we determined the MCID of the PRWE for patients with distal radius fractures using the anchor-based approach and verified that the MDC of the PRWE was sufficiently small to detect our MCID.

The MCID is not a value that can be used to classify individual treatment results, but rather a method to put group level treatment effects in perspective. We recommend using an improvement on the PRWE of more than 11.5 points as the smallest clinically relevant difference when evaluating the effects of treatments and when performing sample-size calculations on studies of distal radius fractures.

REFERENCES

1. Gupta S, Halai M, Al-Maiyah M, Muller S. Which measure should be used to assess the patient's functional outcome after distal radius fracture? Acta Orthop Belg 2014 Mar;80(1):116-118.

2. MacDermid JC, Turgeon T, Richards RS, Beadle M, Roth JH. Patient rating of wrist pain and disability: a reliable and valid measurement tool. J Orthop Trauma 1998 Nov-Dec;12(8):577-586.

3. Calfee RP, Adams Aa. Clinical research and patient-rated outcome measures in hand surgery. J Hand Surg 2012 Apr;37(4):851-855.

4. Jaeschke R, Singer J, Guyatt GH. Measurement of health status. Ascertaining the minimal clinically important difference. Control Clin Trials 1989 Dec;10(4):407-415.

5. Smith MV, Calfee RP, Baumgarten KM, Brophy RH, Wright RW. Upper extremity-specific measures of disability and outcomes in orthopaedic surgery. J Bone Joint Surg Am 2012 Feb 1;94(3):277-285.

6. Schmitt JS, Di Fabio Richard P. Reliable change and minimum important difference (MID) proportions facilitated group responsiveness comparisons using individual threshold criteria. J Clin Epidemiol 2004 Oct;57(10):1008-1018.

7. Kim JK, Park ES. Comparative responsiveness and minimal clinically important differences for idiopathic ulnar impaction syndrome. Clin Orthop Relat Res 2013 May;471(5):1406-1411.

8. Sorensen AA, Howard D, Tan WH, Ketchersid J, Calfee RP. Minimal clinically important differences of 3 patient-rated outcomes instruments. J Hand Surg Am 2013 Apr;38(4):641-649.

9. Beerekamp MS, Ubbink DT, Maas M, Luitse JS, Kloen P, Blokhuis TJ, et al. Fracture surgery of the extremities with the intra-operative use of 3D-RX: a randomized multicenter trial (EF3X-trial). BMC Musculoskelet Disord 2011 Jul 6;12:151-2474-12-151.

10. Walenkamp MM, Goslings JC, Beumer A, Haverlag R, Leenhouts PA, Verleisdonk EJ, et al. Surgery versus conservative treatment in patients with type A distal radius fractures, a randomized controlled trial. BMC Musculoskelet Disord 2014 Mar 19;15:90-2474-15-90.

11. Müller ME, Nazarian S, Koch P, Schatzker J. The comprehensive classification of fractures of long bones. Berlin: Springer; 1990.

12. Crosby RD, Kolotkin RL, Williams GR. Defining clinically meaningful change in health-related quality of life. J Clin Epidemiol 2003 May;56(5):395-407.

13. Guyatt GH, Osoba D, Wu AW, Wyrwich KW, Norman GR, Clinical Significance Consensus Meeting Group. Methods to explain the clinical significance of health status measures. Mayo Clin Proc 2002 Apr;77(4):371-383.

14. Lydick E, Epstein RS. Interpretation of quality of life changes. Qual Life Res 1993 Jun;2(3):221-226.

15. de Vet HC, Terwee CB, Ostelo RW, Beckerman H, Knol DL, Bouter LM. Minimal changes in health status questionnaires: distinction between minimally detectable change and minimally important change. Health Qual Life Outcomes 2006 Aug 22;4:54.

16. Kamper SJ, Maher CG, Mackay G. Global rating of change scales: a review of strengths and weaknesses and considerations for design. J Man Manip Ther 2009;17(3):163-170.

17. Revicki D, Hays RD, Cella D, Sloan J. Recommended methods for determining responsiveness and minimally important differences for patient-reported outcomes. J Clin Epidemiol 2008 Feb;61(2):102-109.

18. MacDermid JC. The Patient-Rated Wrist Evaluation (PRWE) User Manual. 2007; Available at: http://srs-mcmaster.ca/wp-content/uploads/2015/05/English-PRWE-User-Manual.pdf. Accessed September 18, 2014.

19. Beaton DE, Boers M, Wells GA. Many faces of the minimal clinically important difference (MCID): a literature review and directions for future research. Curr Opin Rheumatol 2002 Mar;14(2):109-114.

20. Beaton DE, Bombardier C, Katz JN, Wright JG, Wells G, Boers M, et al. Looking for important change/differences in studies of responsiveness. OMERACT MCID Working Group. Outcome Measures in Rheumatology. Minimal Clinically Important Difference. J Rheumatol 2001 Feb;28(2):400-405.

21. de Vet HCW, Ostelo RWJG, Terwee CB, van der Roer N, Knol DL, Beckerman H, et al. Minimally important change determined by a visual method integrating an anchor-based and a distribution-based approach. Quality of life research : an international journal of quality of life aspects of treatment, care and rehabilitation 2007 Feb;16(1):131-142.

22. Tashjian RZ, Deloach J, Green A, Porucznik Ca, Powell AP. Minimal clinically important differences in ASES and simple shoulder test scores after nonoperative treatment of rotator cuff disease. The Journal of bone and joint surgery.American volume 2010 Feb;92(2):296-303.

23. Mukaka MM. Statistics corner: A guide to appropriate use of correlation coefficient in medical research. Malawi Med J 2012 Sep;24(3):69-71.

24. Wang YC, Hart DL, Stratford PW, Mioduski JE. Baseline dependency of minimal clinically important improvement. Phys Ther 2011 May;91(5):675-688.

25. Wright JG. The minimal important difference: who's to say what is important? J Clin Epidemiol 1996 Nov;49(11):1221-1222.

26. Norman GR, Sloan JA, Wyrwich KW. Interpretation of changes in health-related quality of life: the remarkable universality of half a standard deviation. Med Care 2003 May;41(5):582-592.

27. Stratford PW, Binkley JM, Riddle DL, Guyatt GH. Sensitivity to change of the Roland-Morris Back Pain Questionnaire: part 1. Phys Ther 1998 Nov;78(11):1186-1196.

APPENDIX

Chapter 2

Number of patients with missings according to variable

Variables	Derivation cohort[a] (n = 487), No. (%)	Validation cohort[b] (n = 395), No. (%)
Complete cases	407 (83.6)	320 (81.0)
Age	0	0
Sex	0	0
Mechanism of injury	0	0
Swelling of distal radius	1 (0.2)	2 (0.5)
Visible deformation	4 (0.8)	7 (1.8)
Distal radius tender to palpation	0 (0.6)	1 (0.3)
Dorsiflexion	3 (0.6)	2 (0.5)
Palmar flexion	3 (0.6)	7 (1.8)
Supination	3 (0.6)	3 (0.8)
Pronation	3 (0.6)	4 (1.0)
Ulnar deviation	3 (0.6)	5 (1.3)
Radial deviation	3 (0.6)	8 (2.0)
Radioulnar ballottement test	16 (3.3)	17 (4.3)
Axial compression of forearm	11 (2.3)	14 (3.5)
Prehensile grip strength	55 (11.3)	45 (11.4)
Distal radius fracture (outcome)	0	0

a. Data from the academic hospital.

b. Data from the other four hospitals.

Characteristics of patients with and without prehensile grip strength as missing variable

Characteristics	Missing (N=100)	Non-missing (N=782)
Age	55 (39-68)	49 (31-63)
Female, No. (%)	59 (59.0)	473 (60.5)
Patients with distal radius fracture, No. (%)	57 (57.0)	327 (41.8)
Patients with other wrist fracture than distal radius No. (%)[a]	13 (13.0)	73 (9.3)
Patients with multiple wrist fractures No. (%)[b]	2 (2.0)	9 (1.2)
Complete cases	92 (92.0)	753 (96.3)
Treatment[c]		
Expectant	5 (5.0)	61 (7.8)
Compression bandage	8 (8.0)	159 (20.3)
Plaster immobilisation	48 (48.0)	385 (49.2)
Reduction and plaster immobilisation	30 (30.0)	146 (18.7)
Primary operative	9 (9.0)	26 (3.4)
Unknown[d]	0	5 (0.6)

a. Patient without a distal radius fracture but with an isolated fracture of the ulna or one of the carpal bones.

b. Patients that sustained a fracture of distal radius and one of the carpal bones.

c. Patients with and without fractures

d. Not recorded in patients files

Chapter 3

Appendix 1: Clinical Variables of the CRF

Sex
Age
Swelling of distal radius
Swelling of distal ulna
Swelling of anatomical snuff box
Visible deformation
Bone tenderness distal radius distal ulna anatomical snuff box
Active mobility painful[a] dorsiflexion palmar flexion supination pronation ulnar deviation radial deviation
Functional tests painful[a] radio ulnar ballottement test[b] axial compression of forearm
Prehensile grip strength[c]

a. Items were scored positive if the patient experienced pain, if they were unable to perform the test or if they refused to perform the test.

b. Test is positive if pain or tenderness occurs when the ulna is translated from volar to dorsal while the radius manually fixated.

c. Both sides assessed three times with a Baseline Hydraulic Hand Dynamometer, expressed in percentage of decrease in grip strength between the healthy and the mean affected side.

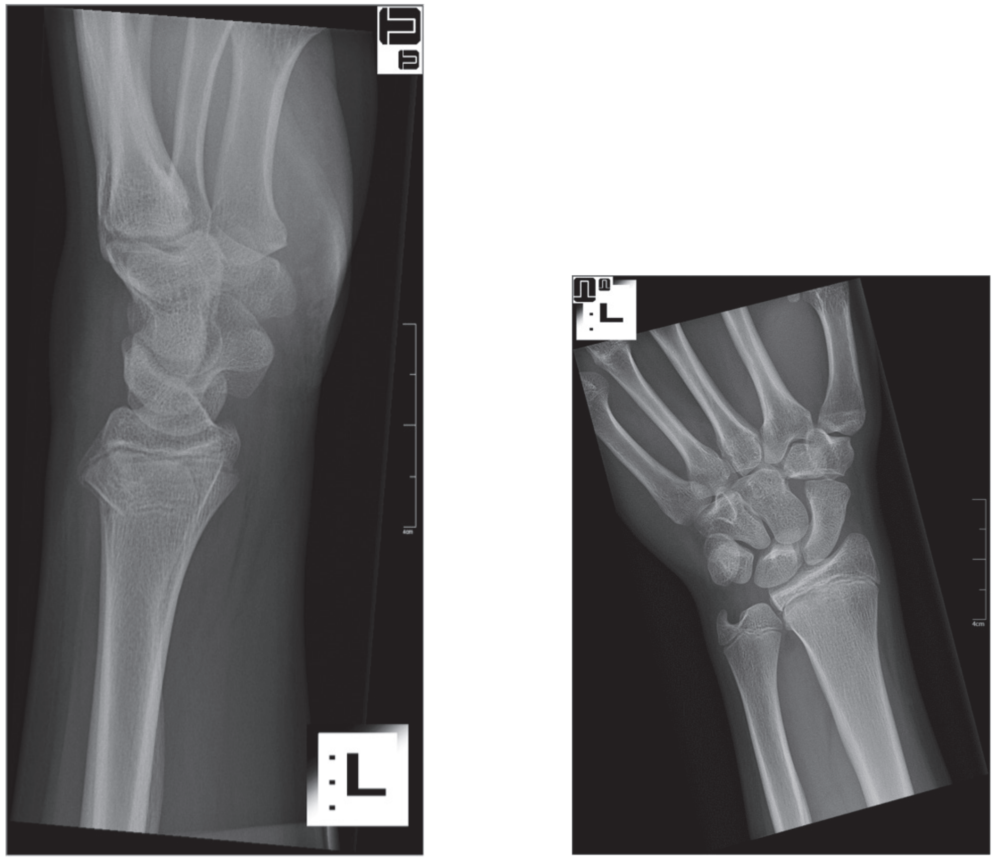
Appendix 2: Missing variables

Missing variables	Amount (%)
Swelling of distal radius present	1 (0.1)
Swelling of distal ulna present	32 (4.1)
Swelling of anatomical snuffbox	2 (0.3)
Visible deformation	0
Bone tenderness distal radius	2 (0.3)
Bone tenderness distal ulna	3 (0.4)
Bone tenderness anatomical snuffbox	3 (0.4)
Dorsiflexion painful	3 (0.4)
Palmar flexion painful	4 (0.5)
Supination painful	3 (0.4)
Pronation painful	3 (0.4)
Ulnar deviation painful	4 (0.5)
Radial deviation painful	5 (0.6)
Radioulnar ballottement test painful	25 (3.2)
Axial compression of forearm	25 (3.2)
Prehensile grip strength	98 (12.5)

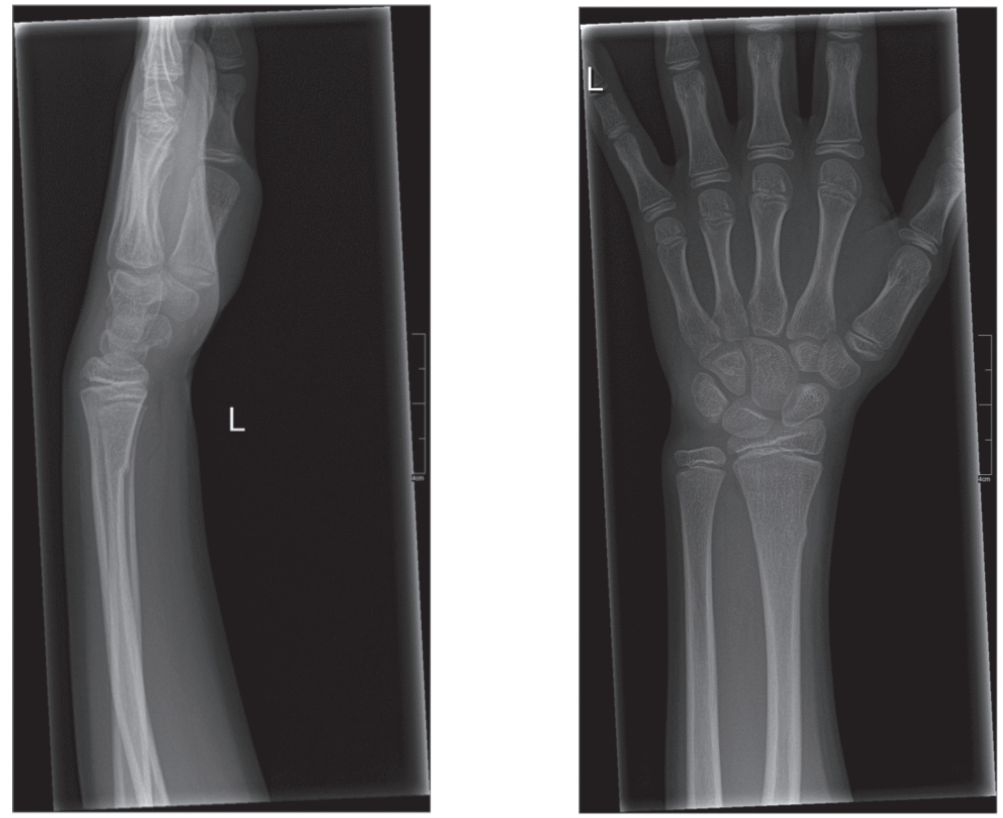
Appendix 3: Interaction of the variables

	Swelling of distal radius	Swelling of distal ulna	Swelling of anatomical snuff box	Defor-mation	Bone tenderness distal radius	Bone tenderness distal ulna	Bone tenderness anatomical snuff box	Dorsi flexion	Palmar flexion	Supination	Pronation	Ulnar deviation	Radial deviation	Radio ulnar ballottement test
Swelling of distal ulna	141													
Swelling of anatomical snuff box	48	22												
Deformation	50	35	11											
Bone tenderness distal radius	342	146	56	55										
Bone tenderness distal ulna	175	147	32	43	346									
Bone tenderness anatomical snuff box	90	33	59	15	178	102								
Dorsiflexion	319	162	65	55	561	351	193							
Palmar flexion	267	137	60	48	487	307	176	531						
Supination	274	141	51	55	489	306	154	490	439					
Pronation	258	131	47	49	464	291	148	465	426	489				
Ulnar deviation	295	144	54	52	453	311	167	485	451	427	416			
Radial deviation	294	141	61	54	510	301	182	524	479	450	433	471		
Radio ulnar ballottement test	263	135	54	49	464	295	148	446	400	391	377	383	405	
Axial compression of forearm	253	121	50	48	450	277	161	442	405	372	364	387	417	369

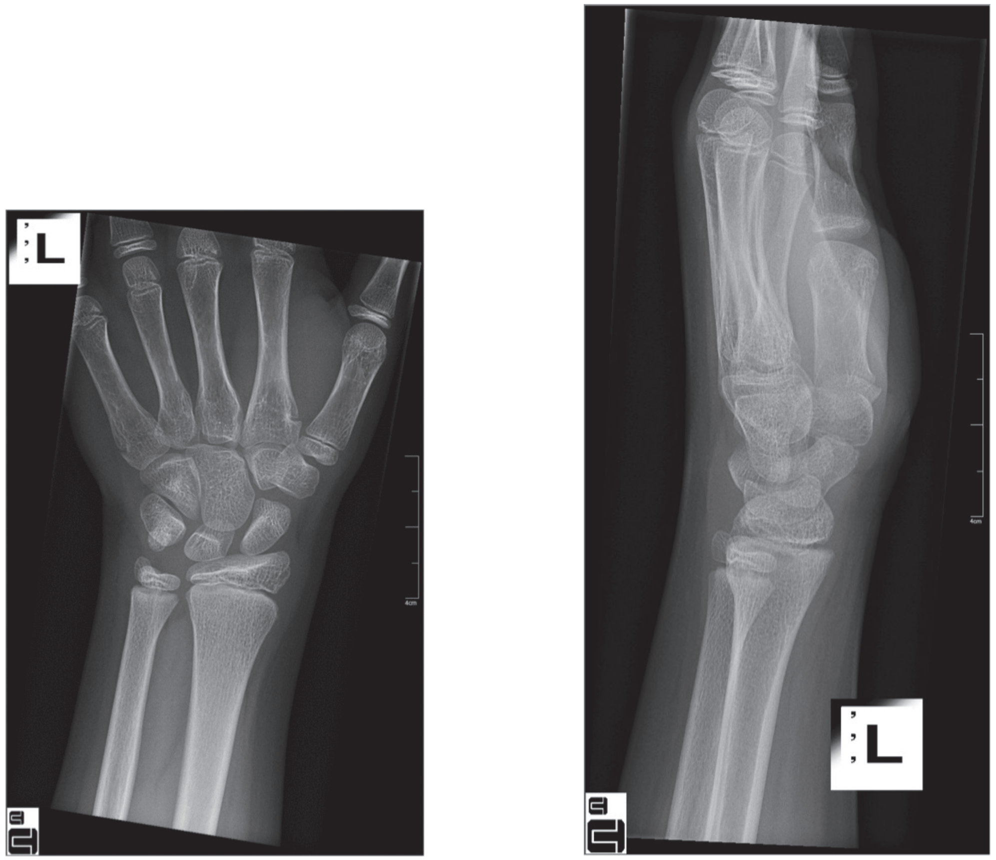
Appendix 4:
Radiographs of patients with a potentially missed fracture after applying the Amsterdam Paediatric Wrist Rules in the external validation cohort.



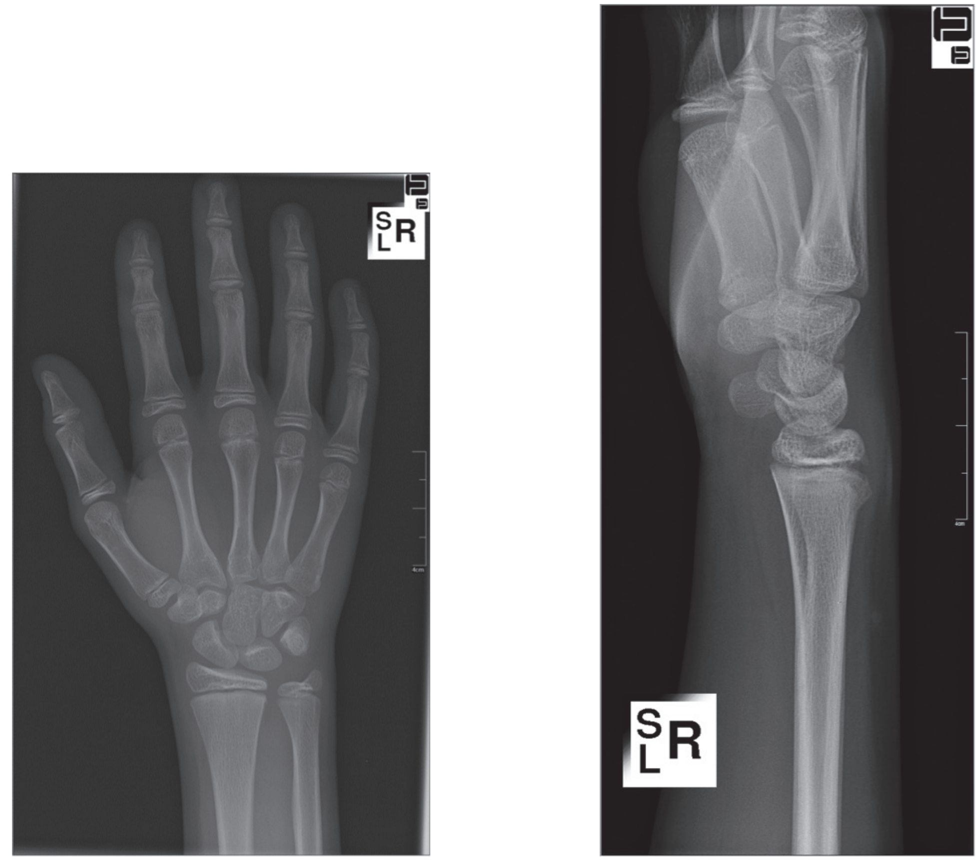
Patient 1: boy, 15 years old, buckle fracture of the distal radius.



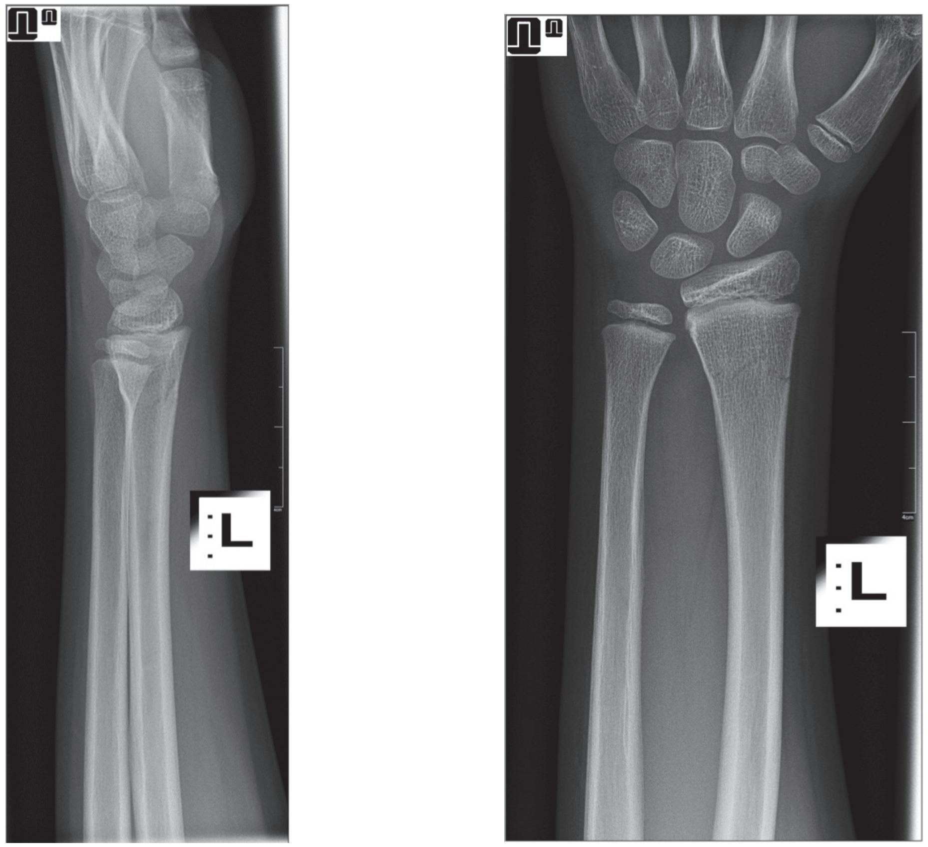
Patient 2: boy, 10 years old, buckle fracture of the distal radius.



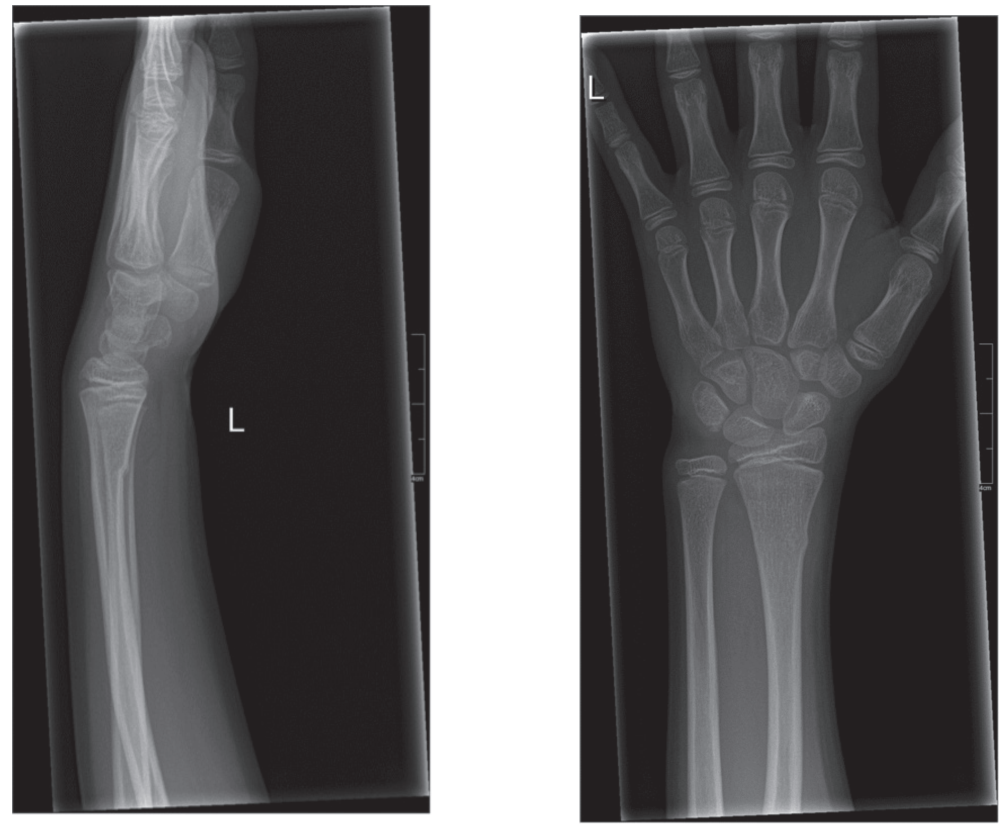
Patient 3: boy, 12 years old, subtle buckle fracture of the distal radius.



Patient 4: boy, 10 years old, buckle fracture of the distal radius.



Patient 5: boy, 11 years old, fracture of the distal radius with buckle component dorsal.



Patient 6: boy, 10 years old, buckle fracture of the distal radius.

Patient 7: boy, 9 years old, buckle fracture of the distal radius.

Chapter 4

Box 1. Search string

Medline:

(((radius[Title/Abstract]) OR radial[Title/Abstract]) AND ((distal[Title/Abstract]) AND fracture*[Title/Abstract])) OR ((radius fracture[MeSH Terms]) AND distal[Title/Abstract]) OR (colles fracture[MeSH Terms]) OR (((((((((((((((colles'[Title/Abstract] OR colles[Title/Abstract]) OR barton[Title/Abstract]) OR bartons[Title/Abstract]) OR barton's[Title/Abstract]) OR hutchinson[Title/Abstract]) OR hutchinsons[Title/Abstract]) OR hutchinson's[Title/Abstract]) OR chauffeur[Title/Abstract]) OR chauffeurs[Title/Abstract]) OR chauffeur's[Title/Abstract]) OR smith[Title/Abstract]) OR smiths[Title/Abstract]) OR smith's[Title/Abstract]) OR wrist[Title/Abstract]) AND (fracture*[Title/Abstract]))) AND (((unstable) OR instability) OR instable)

EMBASE:

radius.ti,ab OR radial.ti,ab AND distal.ti,ab AND fracture OR colles.ti,ab OR colles'.ti,ab OR barton.ti,ab OR bartons.ti,ab OR barton's.ti,ab OR Hutchinson.ti,ab OR hutchinsons.ti,ab OR hutchinson's.ti,ab OR chauffeur.ti,ab OR chauffeurs.ti,ab OR chauffeur's.ti,ab OR smith.ti,ab OR smiths.ti,ab OR smith's.ti,ab OR wrist.ti,ab AND fracture.ti,ab OR Exp wrist fracture/ Exp colles fracture/Exp radius fracture/ AND distal AND (instable or unstable or instability).af

Cochrane:

radius.ti,ab,kw OR radial.ti,ab,kw AND distal.ti,ab,kw AND fracture OR Colles fracture*.ti,ab,kw OR colles' fracture*.ti,ab,kw OR barton fracture*.ti,ab,kw OR bartons fracture*.ti,ab,kw OR barton's fracture*.ti,ab,kw OR Hutchinson fracture*.ti,ab,kw OR hutchinsons fracture*.ti,ab,kw OR hutchinson's fracture*.ti,ab,kw OR chauffeur fracture*.ti,ab,kw OR chauffeurs fracture*.ti,ab,kw OR chauffeur's fracture*.ti,ab,kw OR smith fracture*.ti,ab,kw OR smiths fracture*.ti,ab,kw OR smith's fracture*.ti,ab,kw OR wrist fracture*.ti,ab,kw OR distal radius fracture* AND (instable or unstable or instability)

Search string

MEDLINE

((((((((displac*[tiab] OR redisplac*[tiab] OR dislocat*[tiab] OR redislocat*[tiab] OR instab*[tiab] OR unstab*[tiab] OR loss of reduction[tiab] OR loss of posit*[tiab])))))))) AND (((((((("Colles' Fracture"[Mesh] OR colles fracture*[tiab] OR wrist fracture*[tiab] OR (oblique fracture*[tiab] AND radial[tiab]) OR barton fracture*[tiab] OR smith fracture*[tiab] OR hutchinson fracture*[tiab] OR chauffeur fracture*[tiab]))))))OR (((((radius[Title/Abstract]) OR radial[Title/Abstract])) AND (((((distal[Title/Abstract]) AND fracture*[Title/Abstract])) OR ((distal[Title/Abstract]) AND radius fracture[MeSH Terms])))))))))

EMBASE

((displac* or redisplac* or dislocat* or redislocat* or instab* or unstab* or loss of reduction or loss of posit*).ti,ab.) and ((((radius or radial).ti,ab.) and (((distal and fracture*).ti,ab.) or (distal.ti,ab. and radius fracture/))) or ("Colles' Fracture"/ or colles fracture*.ti,ab. or wrist fracture*.ti,ab. or (oblique fracture* and radial).ti,ab. or barton fracture*.ti,ab. or smith fracture*.ti,ab. or hutchinson fracture*.ti,ab. or chauffeur fracture*.ti,ab.)) ((displac* or redisplac* or dislocat* or redislocat* or instab* or unstab* or loss of reduction or loss of posit*).ti,ab.)

Table 1. Quality assessment according to QUIPS tool

First author	Bias due to study participation	Bias due to study attrition	Bias due to prognostic factor measurement	Bias due to confounding	Bias due to analysis	Bias due to outcome measurement
Abbaszadegan	Moderate (eligibility criteria and recruitment not described. Not clear if patients without initial anatomical reduction were excluded)	Moderate (attrition not reported)	Low (measurements illustrated, although definition of dorsal compression is unclear)	Low (all major predictors were tested)	Moderate (only univariate analyses were performed, analysis done seems linear regression although outcome was binary)	Moderate (used combined outcome and did not clearly describe definitions, duration of follow-up adequate)
Adolphson	Moderate (eligibility criteria and recruitment not described. Not clear if patients without initial anatomical reduction were excluded)	Moderate (attrition not reported)	Low (measurements illustrated)	Low (all major predictors were tested)	Moderate (an algorithm was tested that was not described)	Moderate (used combined outcome and did not clearly describe definitions, duration of follow-up adequate)
Alemdaroglu	Moderate (not clear if patients without initial anatomical reduction were excluded)	Low	Low (measurements described)	Low (all major predictors were considered)	Moderate (univariate analysis not adjusted for other factors)	Low (outcome clearly defined and adequate follow-up)
Altissimi	Moderate (eligibility and recruitment not described)	Moderate (attrition not reported)	Moderate (measurements partly described)	Moderate (age was not considered)	Moderate (univariate analysis not adjusted for other factors)	High (outcome was not defined)
Bartl	Low	Low	Moderate (prognostic factor was AO fracture type determined by a single surgeon)	Moderate (predictors were not investigated in this study but observed in the conservative treatment arm)	Moderate (unadjusted relative risk)	High (outcome was not defined)
Benoist	NA (no clinical data described)	NA (no clinical data described)	NA (no clinical data described)	High (prognostic factor was merely described)	NA (no clinical data described)	NA (no clinical data described)
Beumer	Moderate (eligibility not described)	Low	Moderate (measurements not defined or described)	Moderate (age was not considered)	Moderate (analysis not clearly described)	Moderate (outcome defined but follow-up not reported)
Blakeney	Low	Low	Low	Moderate (only inadequate reduction was considered)	Moderate (univariate analysis not adjusted for other factors)	Moderate (combined outcome as either poor radiologic result or progression to surgery)
Camelot	Low	Low	Low	Low (most important predictors were considered)	Moderate (type of analysis not reported)	Low
Clayton	Moderate (not clear if patients without initial anatomical reduction were excluded)	Low	Low	Low	Low	High (outcome was not observed instability but instability calculated with algorithm)
Einsiedel	High (eligibility criteria, recruitment and treatment not described. Not clear if patients without initial anatomical reduction were excluded)	Not reported	Low	Low (most important predictors were considered)	Moderate (univariate correlations without adjusting for other factors)	Low
Fenyo	Moderate (not clear if patients without initial anatomical reduction were excluded)	Not reported	High (investigated result of primary reduction as predictor but this was not defined)	High (only result of primary reduction and immobilisation technique were considered)	High (analyses not described)	High (outcome not defined)
Hove	High (excluded patients with a second reduction during the immobilisation period)	Not reported	Low	Low (most important predictors were considered)	Low (multivariate analyses)	Low

First author	Bias due to study participation	Bias due to study attrition	Bias due to prognostic factor measurement	Bias due to confounding	Bias due to analysis	Bias due to outcome measure-ment
Kulej	Moderate (eligibility criteria and recruitment not described)	Not reported	Moderate (measure-ments partly described)	Moderate (only AO type was considered)	Moderate (univariate analysis not adjusted for other factors)	High (outcome undefined, dura-tion of follow-up not reported)
Lafontaine	Moderate (eligibility criteria not described)	Low	Low	Low (several important predictors considered)	Moderate (univariate analysis not adjusted for other factors)	High (outcome was result on Stewart score [a summation of points for DA, radial angle and radial length])
LaMartina	Low	Low	Low	Low (several important predictors considered)	Moderate (multivariate analysis but unclear with which factors, coefficients not reported and referred to as correlations)	Low
Leone	Low	Not reported	Moderate (meas-urements were not defined)	Low (several important predictors considered)	Moderate (type of regression analysis unclear)	Low
Mackenney	Low	Low	Low	Low	Low	Low
Makhni	Moderate (not clear if patients without initial anatomical reduc-tion were excluded)	Not reported	Low	Low (several important predictors considered)	Moderate (univariate analysis not adjusted for other factors)	Low
Myderrizi	Moderate (excluded early unsta-ble fractures that lost reduction within one week)	Not reported	Moderate (measure-ments not described)	Low (several important predictors considered)	Moderate (univariate analysis not adjusted for other factors)	High (outcome not clearly defined)
Nesbitt	Moderate (patients with <3 insta-bility factors were excluded)	Low	Low	Low	Low	Low
Oskarsson	Low	Low	Moderate (measure-ments not described)	High (several important predictors not considered)	High (univariate analysis not adjusted for other factors, signifi-cance reported but corresponding p-values not)	High (outcome was defined as poor functional outcome)
Phillips	Moderate (inclusion criteria unclear)	Not reported	Moderate (measure-ments not described)	Low	Moderate (univariate analysis not adjusted for other factors)	High (outcome unclear, seems combined outcome of early insta-bility or need for surgery [unde-fined]. Not clear to which outcome the reported results refer)
Porter	Low	Low	Low	Moderate (only a few predictors considered)	High (predictors studied are reported to not predispose to redisplacement, but no mentioned of the statistical tests or results is made	Moderate (instability was not primary outcome of study)
Robin	Moderate (not clear if patients without initial anatomical reduc-tion were excluded)	Low	Moderate (measure-ments not described)	Moderate (only T-scores were considered)	Moderate (univariate analysis not adjusted for other factors)	Moderate (loss of reduction was expressed as formula proposed by the authors and therefore not validated)
Tahririan	Moderate (patients with <3 insta-bility factors were excluded, dura-tion of immobilisation unclear)	Low	Moderate (measure-ments not described and unclear if loss of radial height and incli-nation were defined as relative to uninjured side)	Low (most important predictors were considered)	Low	Low
Wadsten	High (it seems that patients with-out initial anatomical reduction who went on to surgery were included and analyzed, duration of immobilisation unclear)	Low	Moderate (not all predictors defined)	Moderate (age was not consid-ered)	Low	Moderate (definition of outcome is not described)

THESIS SUMMARY & FUTURE PERSPECTIVES

THESIS SUMMARY

Wrist trauma is one of the most common Emergency Department attendances. Around 40%-50% of the patients with wrist trauma has sustained a distal radius fracture. Annually, this amounts to 286 distal radius fractures per 100,000 persons. Although a distal radius fracture might appear to be a quite innocent condition, immobilisation of the wrist causes substantial disability. This does not only affect the patient but also their family and friends. Moreover, insufficient treatment may result in definitive impairment of the wrist.

This thesis aimed to improve diagnosis, treatment and prognosis of patients with wrist injury. To this end, we performed several multicentre prospective and retrospective studies that focussed on diagnosing wrist fractures, treating distal radius fractures and determining the prognosis of distal radius fractures.

PART 1: DIAGNOSIS

In **Chapter 1**, we performed a multicentre cross-sectional observational study in five Emergency Departments and included all consecutive adult patients with wrist trauma. Physicians were asked to perform a standardized examination of the wrist and to subsequently indicate the probability of a distal radius fracture. We found that physicians were able to accurately discriminate between patients with and without a distal radius fracture based on their physical findings. Despite this, the majority of the 924 included patients were referred for radiography (99.6%). We concluded that a validated clinical decision rule could reinforce physician's clinical judgment and support them in their decision not to routinely request radiography.

The aim of **Chapter 2** was to derive and externally validate such a clinical decision rule for adult patients with wrist trauma. We performed a multicentre prospective study that consisted of three components: (1) derivation of a clinical prediction model for detecting wrist fractures in patients following wrist trauma; (2) external validation of this model; and (3) design of a clinical decision rule. A total of 882 patients was analysed; 487 in the derivation cohort and 395 in the validation cohort. Subsequently, we derived a clinical prediction model with eight variables: age; sex, swelling of the wrist; swelling of the anatomical snuffbox, visible deformation; distal radius tender to palpation; pain on radial deviation and painful axial compression of the thumb. The Area Under the Curve (AUC) at external validation of this model was 0.81 (95% CI: 0.77 - 0.85).

We named this clinical decision rule the Amsterdam Wrist Rules (AWR). If the AWR had been applied in the external validation cohort, its sensitivity for detecting fractures of the wrist would be 98% (95% CI: 95% - 99%) and its specificity 21% (95% CI: 15% - 28%). The negative predictive value would be 90% (95% CI: 81% - 99%). Use of the AWR could result in a 10.4% absolute reduction in X-rays requested. We concluded that the Amsterdam Wrist Rules can provide physicians in the Emergency Department with a useful screening tool to select patients with acute wrist trauma for radiography.

In **Chapter 3**, we aimed to derive and externally validate a similar clinical decision rule for paediatric patients with wrist trauma and named it the Amsterdam Paediatric Wrist Rules (APWR). We analyses a total of 787 children; 408 in the derivation cohort and 379 in the validation cohort. A prediction model was derived with six variables: age; swelling of the wrist; visible deformation; distal radius tender to palpation; anatomical snuffbox tender to palpation and painful or abnormal supination. The model showed good discriminative ability (AUC 0.79, 95% CI: 0.76- 0.83) at external validation. If the APWR had been applied to the external validation cohort, its sensitivity and specificity would be 95.9% (95% CI: 91.7% - 98.0%) and 37.3% (95% CI: 31.0% - 44.1%) respectively. The use of the APWR would have resulted in a 22% absolute reduction of radiographs, however at the cost of missing a fracture (without therapeutic consequences) in 4.3% of the patients. We concluded that the Amsterdam Pediatric Wrist Rules can provide a valuable tool for physicians to decide if radiography in children after wrist trauma is required. Implementation of the APWR may avoid unnecessary waiting time for children and result in a reduction of radiation exposure.

PART 2: TREATMENT

Treatment of distal radius fractures is a popular area of research, especially in patients with unstable distal radius fractures for whom the optimal treatment remains inconclusive. However, to appreciate the findings of studies that enrolled patients with unstable distal radius fractures, it should be clear how the authors defined an unstable distal radius fracture. In **Chapter 4**, we described a comprehensive systematic review to assess what the most common definition of an unstable distal radius fracture was in literature, and to examine if there is one preferred evidence-based definition for future authors. The search yielded 2489 citations of which 479 studies were included. We found that of the 149 studies in which it was explicitly stated that patients with unstable distal radius fractures were enrolled, the authors only provided a definition of what they considered an unstable distal radius fracture in 81 studies (54%). Moreover, there was an abundance of definitions circulating in literature: overall we found 143 different definitions for unstable distal radius fractures. The seven most common definitions were: displacement following adequate reduction; Lafontaine's definition; irreducibility; an AO type C2 fracture; a volarly displaced fracture; Poigenfürst's criteria and Cooney's criteria. Only Lafontaine's definition originated from a clinical study (Level of Evidence IIIb). We concluded that none of the definitions stood out as the preferred choice.

In addition to a substantial amount of variation in definitions used in literature, variation is also present in the actual treatment of distal radius fractures. In **Chapter 5** we performed a study to examine the variation in surgical treatment rate across all Dutch hospitals. Therefore we obtained all reimbursement data for the treatment of distal radius fractures categorised by hospital for a period of two years. This resulted in a total of 95,754 reimbursements;

49,615 in 2012 and 46,139 in 2013. We found that the operative rate across hospitals ranged from 0% to 23%. Hospital type, the percentage of females, the percentage of patients over 65, the mean age, the average socioeconomic status of the patients treated and the total number of patients treated explained only 2.6% of the observed differences in the operative rate among hospitals in 2012, and 11.6% in 2013 (adjusted R squared = 0.026 and 0.116). Except for the mean age in 2013, none of these variables was independently related to the operative rate. We concluded that there is a considerable variation in the treatment of distal radius fractures across the country, which cannot completely be explained by the hospital type and characteristics of the patient population.

One of the surgical treatment methods for distal radius fractures is a bridging external fixation. This technique relies on ligamentotaxis to obtain and maintain fracture alignment. In **Chapter 6**, we performed a meta-analysis that compared functional outcome after bridging external fixation with volar locked plating in patients with unstable distal radius fractures. Functional outcome was defined by the Disability of the Arm Shoulder and Hand Score (DASH). The literature search yielded 197 results, of which three studies involving 174 patients were included. We found that patients treated with a volar locking plate showed significantly lower (better) DASH scores at all times. This was a difference of 16 ($p = 0.006$), six ($p = 0.008$) and eight points ($p = 0.06$) was found at three, six and 12 months follow-up, respectively. We concluded that patients treated with a volar locking plate showed significantly better functional outcome scores throughout the entire follow-up than patients treated with bridging external fixation.

Another treatment option for displaced distal radius fractures is closed reduction and plaster immobilisation. Although, recently the use of internal fixation (ORIF) with a volar locking plate plates has become more popular, no evidence yet exists to support volar locking plates over closed reduction and plaster immobilisation. Therefore, we started the VIPER-trial and described its design in **Chapter 7**. The VIPER-trial is a multicentre randomised controlled trial designed to compare functional outcome after closed reduction followed by plaster immobilisation versus internal fixation (ORIF) with a volar locking plate for patients with displaced extra-articular distal radius fractures. The VIPER-trial is currently running in 19 Dutch hospitals and more than two thirds of required sample-size has been included. The primary outcome measure is wrist function, assessed with the DASH score and the Patient-Rated Wrist Evaluation score (PRWE). The results of the VIPER-trial will finally provide a definite answer for the optimum treatment of patients with displaced extra-articular distal radius fractures. If similar functional results are achieved with both treatment types, the results of the parallel economic evaluation study might prove to be decisive.

A possible compilations following inadequate treatment of a distal radius fracture is a malunion, resulting in pain and loss of function. Careful preoperative planning of a correction osteotomy to restore anatomy is essential to optimise functional outcome. In **Chapter 8**, we described a case series of eight patients who were treated with a computer-assisted 3-D planned corrective osteotomy. We analysed the postoperative residual malpositioning on 3-D reconstructions that were expressed in six positioning parameters (three translations along three orthogonal axes and three rotations about these axes). In this small case series, dorsopalmar tilt was significantly improved ($p = 0.05$). However, ulnoradial shift was worsened by the correction osteotomy (in 6 of 8 cases). Postoperative 3-D evaluation revealed improved positioning parameters for patients in axial rotational alignment radial inclination, proximodistal shift and volodorsal shift, although the group was not large enough to reach statistical significance. All but one patient experienced improved range of motion. We concluded that computer assisted 3-D planning can ameliorate alignment of radial malunions, especially in rotational deformity.

PART 3: PROGNOSIS

To help surgeons to inform patients on chances of success of closed treatment and facilitate shared-decision making, it is important to consider prognostic factors for patients with distal radius fractures. In **Chapter 9**, we performed a systematic review and meta-analysis to provide an overview of risk factors secondary displacement in distal radius fractures. The initial search yielded 3178 studies of which 27 were included in the systematic review. Multiple studies found that age, shortening, loss of radial inclination and AO type 3 fractures (A3, B3, C3) were significant predictors of secondary displacement. Conversely, the mechanism of trauma, energy of the injury, the Frykman classification, intra-articular involvement, radial shift and an associated ulnar styloid fracture were found non-significant predictors of secondary displacement. For sex, dorsal comminution and dorsal angulation, the studies seem inconclusive.

Because the majority of studies in distal radius fracture research regard relatively small sample-sizes, we decided to pool the odds ratios of the predictors in a meta-analysis. We were able to pool the odds ratios of seven predictors and found a significantly increased risk of secondary displacement in fractures with dorsal comminution and in female patients. Additionally, the pooled results confirmed the importance of age demonstrating a significantly increased risk of secondary displacement of distal radius fractures in patients older than 60-65 years. Our results did not show an increased risk of secondary displacement for fractures with intra-articular involvement, nor for fractures with an associated ulnar styloid fracture.

Another method to review the radiological prognosis of a patient is by using a clinical prediction model that predicts the probability of secondary displacement. In **Chapter 10**, we performed a retrospective cohort study to externally validate an existing clinical prediction model in our patient population with displaced distal radius fractures. We included 99 patients who had been treated conservatively. Early secondary displacement (within two weeks) occurred in 61 patients (62%). Unfortunately, the performance of the model was disappointing with an AUC of 0.53 (95% CI: 0.41 - 0.64), indicating poor discrimination. The sensitivity and specificity were 1.6% (95% CI: 0.9% - 9.9%) and 94.7% (95% CI: 80.9% - 99.1%) for correctly identifying an unstable fracture. We concluded that the model in its current form is unsuitable for a population other than the population from which it was derived.

Ultimately, secondary displacement does not always result in poor functional outcome. For this reason it is important to regard patient-reported outcome measures such as the DASH and the PRWE score. To interpret results expressed in patient-reported outcome scores, one should be aware of the minimal numeric change in score that constitutes a clinical change for the patient. This value is called the minimum clinically important difference (MCID). In **Chapter 11**, we determined the MCID of the PRWE for patients with distal radius fractures. We included 102 patients with a distal radius fracture and asked them to complete the PRWE questionnaire during each of two separate visits. At the second visit, patients were asked to indicate the degree of clinical change they appreciated since the previous visit. Accordingly, patients were categorized in two groups: (1) minimally improved or (2) no change. The groups were used to anchor the changes observed in the PRWE score to patients' perspectives of what was clinically important. We found that the MCID of the PRWE for patients with distal radius fractures is 11.5 points. We recommend using this value as the smallest clinically relevant difference when evaluating the effects of treatments and when performing sample-size calculations on studies of distal radius fractures.

FUTURE PERSPECTIVES

The true effect of the clinical decision rules that were designed in Chapter 2 and Chapter 3 can only be evaluated after their implementation. Do the Amsterdam Wrist Rules and the Amsterdam Paediatric Wrist Rules really result in a reduction of X-rays requested? Will patients still be satisfied with the care they have received? And will physicians be content with using the AWR and the APWR? These and other questions are the subject of the Amsterdam Wrist Rules implementation study that is currently being conducted. Should the AWR and APWR prove to be effective, a nationwide implementation in both General Practitioners' office and Emergency Departments is indicated. We expect to have the results of the implementation study at the end of 2016.

Not only diagnosis, but also the treatment of distal radius fracture also requires further clarification. First, a general consensus definition of what constitutes an unstable distal radius fracture could help to standardize future research. We are planning on conducting a Delphi study in an attempt to reach such a conclusion among experts in the field of upper extremity surgery.

Second, the substantial variation in treatment of patients with distal radius fractures in the Netherlands is a phenomenon that is hard to explain to the public. For an individual patient, the probability of receiving operative treatment seems to be driven more by a surgeon's local beliefs and preferences than by scientific influences. This variation across the country calls for a standardized and transparent reporting of outcomes of different health care providers. Health care insurance companies already require some providers to transparently report the clinical outcomes they achieve. The considerable variation in the treatment of distal radius fractures should especially urge providers to systematically collect patient-reported outcomes of their patient population in order to benchmark their quality of care.

Third, the results of the VIPER-trial will solve many of the so far unanswered questions regarding the treatment of patients with displaced extra-articular distal radius fractures. The results of its sequel and equivalent study, the VIPAR trial, will provide these answers for patients with intra-articular distal radius fractures. Should both surgical and conservative treatment turn out to achieve similar acceptable results, the costs might prove to be of paramount importance. Since the direct costs of operative fixation of distal radius fractures are approximately tenfold that of conservative treatment, health insurance companies might narrow the indications for which they reimburse surgical treatment. Nevertheless, a possible earlier return to work after operative fixation should also be considered when evaluating costs. These costs could surmount the direct costs of surgical fixation from a societal point of view. The economic evaluation that runs parallel to both the VIPER-trial and the VIPAR-trial will provide more insight into these issues.

Fourth, the use of computer-assisted 3-D planned corrective osteotomies for treatment of malunions of the radius is still in its infancy. Accurate pre-operative planning does not always result in equally accurate post-operative reconstruction. Further development is required to improve transferral of the planned position into post-operative results. Moreover, computer-assisted technology is currently mainly applied in patients with complex deformations. This renders comparison of clinical outcomes to the results of conventional corrective osteotomies for less complex malunions an intricate endeavour. Once the technique has been optimised, a computer-assisted 3-D planning might become standard of care for all patients with corrective osteotomies.

Finally, as the importance of patient-reported outcome measures is increasing, so should the number of studies that have determined the minimum clinically important difference (MCID) in various populations. Future sample-size calculations on studies with distal radius fractures should not be based on predetermined arbitrary differences in PRWE score, but rather on the minimum clinically important difference. The MCID should also be used as a tool when comparing health care outcomes among providers. Therefore, health care insurance companies should encourage providers and researchers to determine the MCIDs for various patient populations. This will help ensure that not statistics, but rather patients' perception of the quality of the health care they received is of paramount importance.

SAMENVATTING & TOEKOMSTPERSPECTIEVEN

SAMENVATTING

Polstrauma is een van de meest voorkomende redenen voor een bezoek aan de Spoedeisende Hulp. Ongeveer 40% tot 50% van de patiënten met polstrauma heeft een distale radius fractuur opgelopen. Jaarlijks resulteert dit in 286 distale radius fracturen per 100.000 personen. Hoewel een distale radius fractuur ogenschijnlijk een onschuldige aandoening is, veroorzaakt immobilisatie van de pols een aanzienlijke belemmering. Bovendien kan onjuiste of onvoldoende behandeling leiden tot blijvende schade aan het polsgewricht.

Het doel van dit proefschrift was om de diagnose, behandeling en prognose van patiënten met polstrauma te verbeteren. Daartoe hebben wij verschillende multicenter prospectieve en retrospectieve studies uitgevoerd die zich richtten op de diagnose, de behandeling en de prognose van distale radius fracturen.

DEEL 1: DIAGNOSE

In **Hoofdstuk 1** hebben wij een multicenter cross-sectionele observationele studie op vijf Spoedeisende Hulp afdelingen uitgevoerd en alle opeenvolgende volwassen patiënten met polstrauma geïncludeerd. Artsen werden gevraagd een gestandaardiseerd lichamelijk onderzoek van de pols te verrichten en aansluitend de waarschijnlijkheid op een distale radius fractuur aan te geven. Wij vonden dat artsen op basis van het lichamelijk onderzoek goed in staat waren om een onderscheid te maken tussen patiënten met en patiënten zonder een distale radius fractuur. Desondanks bleek het merendeel (99,6%) van de 924 patiënten doorverwezen voor een Röntgenfoto van de pols. Wij concludeerden dat een gevalideerde klinische beslisregel artsen kan ondersteunen bij de beslissing om niet routinematig voor iedere patiënt een Röntgenfoto aan te vragen.

Het doel van **Hoofdstuk 2** was om een dergelijke klinische beslisregel voor volwassen patienten met polstrauma te ontwikkelen en extern te valideren. Wij verrichtten een multicenter prospectieve studie die bestond uit drie onderdelen: (1) ontwikkeling van een klinische predictiemodel; (2) externe validatie van dit model; en (3) formuleren van een klinische beslisregel. In totaal werden er 882 patiënten geanalyseerd, waarvan 487 in het ontwikkelingscohort en 395 in het validatiecohort. Vervolgens leidden wij een klinisch predictiemodel af dat bestond uit acht variabelen: leeftijd; geslacht; zwelling van de pols; zwelling van de tabatière anatomique, standsafwijking, drukpijn over de distale radius, pijnlijke radiale deviatie en pijnlijke axiale compressie van de eerste straal. Bij de externe validatie bedroeg de oppervlakte onder de Receiver Operator Characteristics Curve (AUC), een maat voor hoe goed het model onderscheid kan maken tussen patiënten met en patiënten zonder een fractuur, 0.81 (95% Betrouwbaarheids Interval [BI]: 0.77 - 0.85).

Wij noemden deze beslisregel de Amsterdam Wrist Rules (AWR). Het externe validatiecohort toonde een sensitiviteit van 98% (95% BI: 95% - 99%) en een specificiteit van 21% (95% BI: 15% - 28%) voor het detecteren van polsfracturen. De negatief voorspellende was 90% (95% BI: 81% - 99%). Het gebruik van de AWR zou geresulteerd hebben in een absolute vermindering van het aantal aangevraagde Röntgenfoto's van 10,4%. Wij concludeerden dat de Amsterdam Wrist Rules een nuttig instrument is voor artsen om patiënten met acuut polstrauma te selecteren voor een Röntgenfoto.

In **Hoofdstuk 3** beschreven wij een vergelijkbare studie voor kinderen met polstrauma en noemden deze beslisregel de Amsterdam Paediatric Wrist Rules (APWR). Wij analyseerden in totaal 787 kinderen; 408 in het ontwikkelingscohort en 379 in het validatiecohort. Vervolgens leidden wij een klinisch predictiemodel af met zes variabelen: leeftijd; zwelling van de pols; standsafwijking, drukpijn over de distale radius, drukpijn over het tabatière anatomique en pijnlijke of abnormale supinatie. Dit model toonde bij externe validatie een goed discriminerend vermogen (AUC 0.79, 95% BI: 0.76- 0.83). De regel had in het externe validatie cohort een sensitiviteit van 95.9% (95% BI: 91.7% - 98.0%) en een specificiteit van 37.3% (95% BI: 31.0% - 44.1%). Het gebruik van de APWR zou geresulteerd hebben in een vermindering van het aantal aangevraagde Röntgenfoto's van 22%. Daarentegen zou gelijktijdig 4,3% van de fracturen zijn gemist. Dit betroffen echter klinisch niet relevante fracturen en onderbehandeling zou geen therapeutische consequenties hebben gehad.

Wij concludeerden dat ook de Amsterdam Pediatric Wrist Rules een nuttig screeningsinstrument is om kinderen met polstrauma te selecteren voor een Röntgenfoto. Implementatie van de APWR heeft de potentie om de wachttijd voor kinderen te doen verminderen en resulteert in een vermindering van de stralenbelasting.

DEEL 2: BEHANDELING

De behandeling van distale radius fracturen is een populair onderzoeksgebied. In het bijzonder geldt dit voor patiënten met een instabiele distale radius fractuur. Voor deze groep patiënten bestaat nog geen overtuigend bewijs van de optimale behandeling. Echter, om de bevindingen van de vele studies, die patiënten met een instabiele distale radius fractuur hebben geïncludeerd op waarde te kunnen schatten, is het van belang dat auteurs het begrip "instabiele distale radius fractuur" duidelijk hebben gedefinieerd. In **Hoofdstuk 4** beschreven wij een grootscheeps literatuuronderzoek, waarin wij trachtten te bepalen wat de meest gebruikte definitie van een instabiele distale radius fractuur was in de literatuur. Daarnaast onderzochten wij of er een definitie werd gebruikt, die de voorkeur geniet voor toekomstige auteurs. De zoektocht leverden 2489 citaties op, waarvan 479 studies werden geïncludeerd. Wij vonden dat van de 149 studies, waarin expliciet werd vermeld dat patiënten met een instabiele distale radius fractuur waren geïncludeerd, de auteurs slechts in 81 studies (54%) een definitie gaven van wat zij als een instabiele distale radiusfractuur beschouwden. Bovendien was er een grote verscheidenheid aan definities: wij 143 verschillende definities van een instabiele distale radius fractuur. De zeven meest voorkomende definities waren: dislocatie van de fractuur na adequate repositie, Lafontaine's definitie, een niet reduceerbare fractuur, aan AO type C2 fractuur, een volair gedisloceerde fractuur, Poigenfürst's criteria en Cooney's criteria. Van deze zeven definities was alleen Lafontaine's definitie afkomstig uit een klinische studie (Level of Evidence IIIb). Wij concludeerden dat geen van de gevonden definities een goede beschrijving geeft van een instabiele distale radius fractuur.

Naast een aanzienlijke variatie in verschillende definities die worden gebruikt in de literatuur, is variatie ook aanwezig in de behandeling van distale radius fracturen. In **Hoofdstuk 5** onderzochten wij de variatie in het percentage operatief behandelde patiënten met een distale radius fractuur in alle Nederlandse ziekenhuizen. Daartoe verkregen wij alle vergoedingsdata voor de behandeling van distale radius fracturen in Nederland voor een periode van twee jaar, gecategoriseerd per ziekenhuis. Dit resulteerde in 95.754 vergoedingen; 49.615 in 2012 en 46.139 in 2013.

Wij constateerden dat de ratio's patiënten die geopereerd werd per ziekenhuis varieerden van 0% tot 23%. Het type ziekenhuis, het percentage vrouwelijke patiënten, het percentage patiënten boven de 65, de gemiddelde leeftijd, de gemiddelde sociaal economische status en het totaal aantal behandelde patiënten verklaarden slechts 2,6% van de geobserveerde verschillen tussen ziekenhuizen in 2012 en 11.6% in 2013 (adjusted R squared = 0,026 en 0,116). Behoudens de gemiddelde leeftijd van de patiënten in 2013, was geen van de bovengenoemde variabelen onafhankelijk gerelateerd aan de ratio geopereerde patiënten. Wij concludeerden dat er een aanzienlijke variatie is in de behandeling van patiënten met distale radius fracturen in Nederland, die niet volledig kan worden verklaard door het type ziekenhuis en karakteristieken van de patiëntpopulatie.

Een van de chirurgische behandelmethoden voor distale radius fracturen is fixatie met een overbruggende fixateur externe. De werking van deze techniek berust op ligamentotaxis, waardoor de fractuurdelen in positie blijven. In **Hoofdstuk 6** beschreven wij een meta-analyse waarin wij de functionele uitkomst na overbruggende fixateur externe vergeleken met een hoekstabiele volaire plaat in patiënten met een instabiele distale radius fractuur. De functionele uitkomst was uitgedrukt in the Disability of the Arm Shoulder and Hand Score (DASH). De zoektocht van de literatuur leverde 197 citaties op, waarvan drie studies konden worden geïncludeerd. Deze studies beschreven 174 patiënten.
Wij constateerden dat patiënten die behandeld waren met een hoekstabiele volaire plaat op alle meetmomenten een significant lagere (betere) DASH score hadden. Dit verschil was 16 punten (p = 0.006), zes punten (p = 0.008) en acht punten (p = 0.06) na drie, zes en 12 maanden follow-up. Wij concludeerden dat patiënten die behandeld werden met een hoekstabiele volaire plaat een significant betere functie hadden gedurende de gehele follow-up dan patiënten die behandeld werden met een overbruggende fixateur externe.

Een andere behandelingsoptie voor patiënten met een gedisloceerde distale radiusfractuur is gesloten repositie gevolgd door gipsimmobilisatie. Hoewel de hoekstabiele volaire plaat de laatste jaren aan populariteit heeft gewonnen, bestaat er nog geen overtuigend bewijs dat behandeling met hoekstabiele volaire platen beter is dan gesloten repositie en gipsimmobilisatie. Om deze reden hebben wij de VIPER-trial opgezet, waarvan het ontwerp werd beschreven in **Hoofdstuk 7**. De VIPER-trial is een multicenter gerandomiseerd gecontroleerde trial, ontworpen om de functionele uitkomst na gesloten repositie gevolgd door gipsimmobilisatie, te vergelijken met interne fixatie met een hoekstabiele volaire plaat in patiënten met een gedisloceerde extra-articulaire distale radius fractuur. De VIPER-trial loopt momenteel in 19 Nederlandse ziekenhuizen en meer dan twee-derde van de benodigde sample-size werd inmiddels geïncludeerd. De primaire uitkomstmaat is polsfunctie, gemeten met de DASH score en de Patient-Rated Wrist Evaluation score (PRWE). De resultaten van de VIPER-trial zullen een definitief antwoord geven op de vraag wat de optimale behandeling is voor patiënten met een gedisloceerde extra-articulaire distale radius fractuur. Als beide behandelingen gelijke functionele resultaten bereiken, zullen de resultaten van de parallelle economische evaluatie mogelijk doorslaggevend zijn.

Een mogelijk gevolg van inadequate behandeling van een distale radius fractuur is een malunion, welke kan resulteren in pijn en functieverlies. Een nauwkeurige preoperatieve planning is essentieel om de functionele uitkomsten na een correctie-osteotomie te optimaliseren. In **Hoofdstuk 8** beschreven wij een serie van acht patiënten die werden behandeld met een computer-geassisteerde 3-D geplande correctie-osteotomie. Wij analyseerden de postoperatieve resterende malpositionering op 3-D reconstructies en drukten deze uit in zes positionerings parameters (drie translaties langs drie orthogonale assen en drie rotaties om deze assen). Wij constateerden in het merendeel van de patiënten een verbetering in de positionering parameters volaire kanteling, radiale inclinatie, radiale lengte en sagittale shift (volair - dorsaal), hoewel niet statistisch significant. De dorsopalmaire tilt afwijking was wel significant verbeterd na de ingreep (p=0.05). De ulnoradiale shift werd juist verslechterd door de correctie-osteotomie (in 6 van de 8 casus). Behoudens één, hadden alle patiënten een verbeterde range of motion. Wij concludeerden dat computer-geassisteerde 3-D planning de postoperatieve stand bij radiale malunions kan verbeteren, en in het bijzonder bij rotatieafwijkingen.

DEEL 3: PROGNOSE

Om chirurgen te ondersteunen bij het informeren van patiënten over de kans op een succesvolle conservatieve behandeling is het van belang verschillende prognostische factoren in ogenschouw te nemen. In **Hoofdstuk 9** beschreven wij een literatuuronderzoek en meta-analyse waarin wij een overzicht gaven van belangrijke risicofactoren voor secundaire dislocatie in distale radius fracturen. De initiële zoektocht leverden 3178 citaten op waarvan 27 studies werden geïncludeerd in het literatuuronderzoek. Meerdere studies hadden aangetoond dat leeftijd, verkorting, verlies van radiale inclinatie en AO type 3 fracturen (A3 ,B3, C3) significante voorspellers waren van secundaire dislocatie. Daarentegen waren het traumamechanisme, hoog energetisch trauma, de Frykman classificatie, intra-articulaire betrokkenheid, radiale shift en een geassocieerde fractuur van het processus styloideus ulnae geen significante voorspellers. Voor de factoren het vrouwelijk geslacht, dorsale comminutie en dorsale angulatie waren de studies onbeslist.

Omdat de meerderheid van de studies met patiënten met distale radius fracturen relatief kleine groepen betreft, besloten wij de odds ratios van de risicofactoren gezamenlijk te analyseren in een meta-analyse. We waren in staat om de odds ratios van zeven risicofactoren samen te voegen en een gewogen gemiddelde te berekenen. Hieruit bleek date er een significant verhoogd risico is op secundaire dislocatie in patiënten met dorsale comminutie en in vrouwelijke patiënten. Bovendien bevestigde deze analyse het belang van leeftijd als risicofactor, want wij vonden ook dat patiënten ouder dan 60-65 jaar een verhoogd risico hadden op secundaire dislocatie. Daarnaast toonden onze resultaten dat er geen verhoogd risico is bij fracturen met intra-articulaire betrokkenheid en ook niet bij aanwezigheid van een geassocieerde fractuur van het processus styloideus ulnae.

Een andere methode om de radiologische prognose van patiënten te bepalen, is met behulp van een klinisch predictiemodel dat de kans op secundaire dislocatie voorspelt. In **Hoofdstuk 10** beschreven wij een retrospectieve cohortstudie waarin wij een bestaande klinisch predictiemodel extern valideerden in onze patiëntenpopulatie met gedisloceerde distale radius fracturen. Hiervoor includeerden wij 99 conservatief behandelde patiënten. In deze groep trad in 61 patiënten (62%) binnen 2 weken secundaire dislocatie op. Helaas presteerde het predictiemodel teleurstellend in onze populatie. De AUC was 0,53 (95% CI: 0,41 - 0,64), een waarde die aangeeft dat het model slecht kan discrimineren tussen patiënten waarin secundaire dislocatie zal optreden en patiënten waarbij dit niet zal optreden. De sensitiviteit en specificiteit van het correct identificeren van een instabiele fractuur waren 1,6% (95% CI: 0,9% - 9,9%) and 94,7% (95% CI: 80,9% - 99,1%) respectievelijk. Wij concluderen dat het model in zijn huidige vorm niet geschikt is voor een populatie anders dan de populatie waaruit het is afgeleid.

Uiteindelijk resulteert secundaire dislocatie niet altijd in een slechte functionele uitkomst. Om deze reden is het van belang ook patient-reported outcome measures zoals de DASH en de PRWE score in ogenschouw te nemen. Interpretatie van studieresultaten uitgedrukt in patient-reported outcome measures vereist echter bewustzijn van de minimale numerieke verandering in score die een klinisch verschil voor de patiënt vormt. Deze waarde wordt ook wel het minimaal klinisch relevante verschil genoemd (Engelse afkorting: MCID). In **Hoofdstuk 11** bepaalden wij de MCID van de PRWE voor patiënten met distale radius fracturen. Wij includeerden 102 patiënten met een distale radius fractuur en legden hen op twee afzonderlijke momenten tijdens de follow-up de PRWE vragenlijst voor. Tijdens het tweede meetmoment vroegen wij patiënten om hun klinische voor- of achteruitgang sinds het vorige bezoek aan te geven. Overeenkomstig werden patiënten in twee groepen ingedeeld: (1) minimaal verbeterd of (2) geen verandering. Deze groepen werden gebruikt om de geobserveerde verandering in PRWE score te verankeren aan wat klinisch belangrijk was vanuit het perspectief van patiënten. Wij constateerden dat de MCID van de PRWE voor patiënten met distale radius fracturen 11.5 punten is. Deze waarde is het kleinste verschil in de PRWE score die door patiënten als klinisch relevant wordt beschouw. Wij adviseren dan ook om dit getal in gedachte te houden bij het interpreteren van studieresultaten, en te hanteren als basis voor sample-size berekening van toekomstige studies.

TOEKOMSTPERSPECTIEVEN

De ware effecten van de klinische beslisregel die in Hoofdstuk 2 en Hoofdstuk 3 zijn beschreven kunnen pas geëvalueerd worden na hun implementatie. Resulteert het gebruik van de Amsterdam Wrist Rules en de Amsterdam Paediatric Wrist Rules werkelijk in een reductie van het aantal aangevraagde Röntgenfoto's? Zijn patiënten nog steeds tevreden met de zorg die zij ontvangen? En zijn artsen die de AWR en de APWR gebruiken ook tevreden? Deze en andere vragen zijn het onderwerp van de Amsterdam Wrist Rules implementatie studie die momenteel loopt. Indien blijkt dat de AWR en de APWR effectief zijn, is een landelijke implementatie van de beslisregels op zowel de Spoedeisende Hulp als in de huisartsenpraktijk aangewezen. Wij verwachten eind 2016 de resultaten van de implementatiestudie te kunnen presenteren.

Niet alleen de diagnose, maar ook de behandeling van distale radiusfracturen vereist in de toekomst meer verduidelijking. Ten eerste zou een algemene consensus definitie van een instabiele distale radius fractuur kunnen bijdragen aan het standaardiseren van toekomstige studies. Wij werken momenteel aan een Delphi studie in een poging een dergelijke consensus definitie onder experts op het gebied van de bovenste extremiteit te bereiken.

Ten tweede is de aanzienlijke variatie in de behandeling van patiënten met distale radiusfracturen een fenomeen dat lastig uit te leggen is aan de maatschappij. Voor een individuele patiënt is de kans om geopereerd te worden aan een distale radiusfractuur meer gebaseerd op lokale gebruiken en voorkeuren van de chirurg dan op wetenschappelijke invloeden. Deze variatie in Nederland vereist een gestandaardiseerde en transparante rapportage van de uitkomstem van verschillende zorgaanbieders. Zorgverzekeraars vragen momenteel al enkele zorgaanbieders hun klinische resultaten transparant te maken. Juist de aanzienlijke variatie in de behandeling van patiënten met distale radiusfracturen zou zorgaanbieders moeten aanzetten tot het systematisch verzamelen van patient-reported outcome measures van hun patiëntenpopulatie om zo een benchmark te creëren van de kwaliteit van de door hun geleverde zorg.

Ten derde zullen de resultaten van de VIPER-trial een oplossing bieden voor de vele, tot op heden onbeantwoorde, vragen over de optimale behandeling van patiënten met een gedisloceerde extra-articulaire distale radius fractuur. De resultaten van haar opvolger, de VIPAR-trial, zullen deze vagen voor patiënten met intra-articulaire distale radius facturen beantwoorden. Indien zowel chirurgische als conservatieve behandeling gelijke en acceptabele resultaten bereiken, zullen de kosten doorslaggevend zijn. Gezien de directe kosten van operatieve fixatie van distale radiusfracturen ongeveer het tienvoudige zijn van de conservatieve behandeling, zullen zorgverzekeraars mogelijk de indicaties vernauwen waarvoor zij chirurgische therapie vergoeden. Echter, bij het evalueren van de kosten moet ook de mogelijk snellere hervatting van betaald werk na operatieve fixatie overwogen worden. Deze kosten zouden vanuit een maatschappelijk oogpunt de directe kosten van chirurgische fixatie kunnen overstijgen. De economische evaluatie die parallel loopt aan zowel de VIPER-trial als de VIPAR-trial biedt mogelijk meer inzicht in dit vraagstuk.

Ten vierde staat het gebruik van computer-geassisteerde 3-D geplande correctie-osteotomie voor behandeling van malunions van de radius nog in de kinderschoenen. Een accurate preoperatieve planning leidt niet altijd tot even accurate postoperatieve reconstructie. Er is behoefte aan nieuwe ontwikkelingen die zich richten op het verbeteren van de overdracht van de geplande positie naar de postoperatieve resultaten. Dit kan bijvoorbeeld geeffectueerd worden met aparte reductie mallen. Daarnaast wordt deze techniek momenteel voornamelijk toegepast bij patiënten met complexe deformaties. Dit bemoeilijkt de vergelijking met conventionele correctie osteotomieën. Zodra de techniek geoptimaliseerd is zou een computer-geassisteerde 3-D geplande correctie-osteotomieën de standaard kunnen worden voor alle patiënten met een malunion.

Tot slot, met het toenemende belang van de patient-reported outcome measures in wetenschappelijk onderzoek zou ook het aantal studies dat zich richt op het bepalen van de MCID in verschillende populaties moeten stijgen. Toekomstige sample-size berekeningen voor patiënten met distale radius fracturen kunnen niet meer slechts gebaseerd zijn op een vooraf bepaald arbitrair verschil in PRWE score, maar op het minimaal klinisch relevante verschil voor patiënten. De MCID zou daarnaast ook gebruikt moeten worden als instrument om zorguitkomsten onder verschillende zorgaanbieders te vergelijken. Hiertoe moeten zorgverzekeraars zorgaanbieders stimuleren de MCIDs te bepalen voor verschillende patiënten populaties. Dit zal ervoor zorgen dat niet statistieken, maar vooral de perceptie van patiënten van de kwaliteit van zorg doorslaggevend is.

LIST OF PUBLICATIONS

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PEER-REVIEWED PUBLICATIONS

Internal plate fixation versus plaster in displaced complete articular distal radius fractures, a randomised controlled trial.
Mulders MA, Walenkamp MM, Goslings JC, Schep NW.
BMC Musculoskelet Disord. 2016 Feb

The Amsterdam wrist rules: the multicenter prospective derivation and external validation of a clinical decision rule for the use of radiography in acute wrist trauma
Walenkamp MM, Bentohami A, Slaar A, Beerekamp MS, Maas M, Jager LC, Sosef NL, van Velde R, Ultee JM, Steyerberg EW, Goslings JC, Schep NW.
BMC Musculoskelet Disord. 2015 Dec

Mason Type I Fractures of the Radial Head.
de Muinck Keizer RJ, Walenkamp MM, Goslings JC, Schep NW.
Orthopedics. 2015 Dec

The Unstable Distal Radius Fracture-How Do We Define It? A Systematic Review.
Walenkamp MM, Vos LM, Strackee SD, Goslings JC, Schep NW.
J Wrist Surg. 2015 Nov

Predictors of unstable distal radius fractures: a systematic review and meta-analysis.
Walenkamp MM, Aydin S, Mulders MA, Goslings JC, Schep NW.
J Hand Surg Eur Vol. 2015 Sep

Computer-assisted 3D planned corrective osteotomies in eight malunited radius fractures.
Walenkamp MM, de Muinck Keizer RJ, Dobbe JG, Streekstra GJ, Goslings JC, Kloen P, Strackee SD, Schep NW.
Strategies Trauma Limb Reconstr. 2015 Aug

A clinical decision rule for the use of plain radiography in children after acute wrist injury: development and external validation of the Amsterdam Pediatric Wrist Rules.
Slaar A, Walenkamp MM, Bentohami A, Maas M, van Rijn RR, Steyerberg EW, Jager LC, Sosef NL, van Velde R, Ultee JM, Goslings JC, Schep NW.
Pediatr Radiol. 2016 Jan

The Minimum Clinically Important Difference of the Patient-rated Wrist Evaluation Score for Patients With Distal Radius Fractures.
Walenkamp MM, de Muinck Keizer RJ, Goslings JC, Vos LM, Rosenwasser MP, Schep NW.
Clin Orthop Relat Res. 2015 Oct

A multicentre cross-sectional study to examine physicians' ability to rule out a distal radius fracture based on clinical findings.
Walenkamp MM, Rosenwasser MP, Goslings JC, Schep NW.
Eur J Trauma Emerg Surg. 2015 Apr

Surgery versus conservative treatment in patients with type A distal radius fractures, a randomized controlled trial.
Walenkamp MM, Goslings JC, Beumer A, Haverlag R, Leenhouts PA, Verleisdonk EJ, Liem RS, Sintenie JB, Bronkhorst MW, Winkelhagen J, Schep NW.
BMC Musculoskelet Disord. 2014 Mar

Multiple testing in orthopedic literature: a common problem?
Walenkamp MM, Roes KC, Bhandari M, Goslings JC, Schep NW.
BMC Res Notes. 2013 Sep

Functional outcome in patients with unstable distal radius fractures, volar locking plate versus external fixation: a meta-analysis.
Walenkamp MM, Bentohami A, Beerekamp MS, Peters RW, van der Heiden R, Goslings JC, Schep NW.
Strategies Trauma Limb Reconstr. 2013 Aug

Amsterdam wrist rules: clinical decision aid.
Bentohami A, Walenkamp MM, Slaar A, Beerekamp MS, de Groot JA, Verhoog EM, Jager LC, Maas M, Bijlsma TS, van Dijkman BA, Schep NW, Goslings JC.
BMC Musculoskelet Disord. 2011 Oct

NON PEER-REVIEWED PUBLICATIONS

State of the Art: correctie van malunions van de radius met behulp van 3-D modellen
Walenkamp MM, de Muinck Keizer RJO, Dobbe JCG, Strackee SD, Schep NW
Nederlands Tijdschrift voor Traumachirurgie, 2015 okt

In ’t Kort: Osteoporose komt ook voor bij oudere mannen
Walenkamp MM, Goslings JC.
Ned Tijdschr Geneeskd. 2015;159:A8696

Een pijnlijke smalle pols na val van paard: traumatische volaire dislocatie van het distale radio-ulaire gewricht
Walenkamp MM, Vos L, Liem, RSL, Schep, NW.
Nederlands Tijdschrift voor Traumachirurgie, 2015 feb

De VIPER trial
Walenkamp MM, Goslings JC, Schep NW.
Nederlands Tijdschrift voor Traumachirurgie, 2014 aug

Aankondiging van Onderzoek: De VIPER studie
Walenkamp MM, Goslings JC, Schep NW.
Ned Tijdschr Geneeskd. 2014;158:A7762

In ’t Kort: Het ondergeschoven kindje van de chirurgie: de visite
Walenkamp MM, Goslings JC.
Ned Tijdschr Geneeskd. 2014;158:A7491

Re: is there a need for a clinical decision rule in blunt wrist trauma?
Walenkamp MM, Schep NW.
Injury, 2014 Nov

Ulnaire pijn na een polsfractuur, differentiaaldiagnose, onderzoek en behandeling
Smits FV, Walenkamp MM, Strackee SD, Schep NW.
Nederlands Tijdschrift voor Traumachirurgie, 2013 aug

Correctie van malunion van de radius met behulp van 3D modellen
Walenkamp MM, Dobbe JG, Streekstra G, Strackee SD, Schep NW.
Nederlands Tijdschrift voor Handtherapie, 2012 nov

PHD PORTFOLIO

1. PhD training	Year	Workload (Hours/ECTS)
General courses		
Basic course legislation and organisation for clinical researchers	2012	0.9
Specific courses		
Advanced Analysis of Prognosis Studies (NIHES)	2013	0.9
Healthcare Purchasing & Supply Management (Master Health Care Management, Rotterdam School of Management, Erasmus University Rotterdam)	2015	5
Optimising Health Service Networks (Master Health Care Management, Institute of Health Policy & Management Erasmus University Rotterdam)	2015	5
Seminars, workshops and master classes		
Weekly department seminars	2012-2015	3
Presentations		
The Minimal Clinically Important Difference of the PRWE Annual Meeting of American Society for Surgery of the Hand (ASSH), Seattle, Washington, United States of America	2015	0.5
Predictors of Instability in Distal Radius Fractures, a systematic review and meta-analysis Annual Meeting of the Federation of European Societies for Surgery of the Hand (FESSH), Milan, Italy	2015	0.5
The Minimal Clinically Important Difference of the PRWE Spring meeting of the Dutch Society for Surgery of the Hand, Amsterdam, The Netherlands	2015	0.5
The Minimal Clinically Important Difference of the PRWE 16th European Federation of National Associations of Orthopaedics and Traumatology annual congress, Prague, Czech Republic	2015	0.5
Outcomes scores in distal radius fracture research (invited lecture) 16th European Congress for Trauma and Emergency Surgery, Amsterdam, The Netherlands	2015	0.5
The Minimal Clinically Important Difference of the PRWE Spring Scientific meeting of the British Society for Surgery of the Hand, Bath, England	2015	0.5
The Amsterdam Wrist Rules, A Clinical Decision Rule Instructional Course of the American Society for Surgery of the Hand (ASSH), Maui, Hawaii, United States of America	2015	0.5
The Amsterdam Wrist Rules, A Clinical Decision Rule Annual Meeting of the American Association for Hand Surgery, Paradise Island, Bahamas	2015	0.5
Een multicenter cross-sectionele studie om te evalueren of artsen op basis van het lichamelijk onderzoek in staat zijn een distale radiusfractuur te voorspellen Najaarsdag van de Nederlandse Vereniging voor Heelkunde, Utrecht, Nederland	2014	0.5
De definitie van een instabiele distale radius fractuur Najaarsdag van de Nederlandse Vereniging voor Heelkunde, Utrecht, Nederland	2014	0.5
De Amsterdam Wrist Rules, een klinische beslisregel Traumadagen, Amsterdam, Nederland	2014	0.5
The definition of an unstable distal radius fracture Fall meeting of the Dutch Society for Surgery of the Hand, St Michelsgestel, The Netherlands	2014	0.5
The definition of an unstable distal radius fracture Osteosynthese International 2014, Annual Meeting of the Küntscher Society, Krems, Austria	2014	0.5
The Amsterdam Wrist Rules, A Clinical Decision Rule Annual Meeting of the Federation of European Societies for Surgery of the Hand (FESSH), Paris, France	2014	0.5
De Amsterdam Wrist Rules, een klinische beslisregel Voorjaarsbijeenkomst Nederladse Vereniging voor Handchirurgie, Rotterdam, Nederland	2014	0.5
Corrective Osteotomies of Malunions of the Radius using 3D Models 32. Jahrestagung der Sektion Kindertraumatologie, Frankfurt, Germany	2013	0.5
De Amsterdam Wrist Rules, een klinische beslisregel bij polstrauma Chirurgendagen, Veldhoven, Nederland	2013	0.5
Functionele uitkomst na behandeling met volaire hoekstabiele plaat versus fixateur externe bij patiënten met een instabiele distale radiusfactuur Assistentensymposium Traumachirurgie, Soesterberg, Nederland	2013	0.5
3D modellen voor preoperatieve planning van correctie osteotomiën Assistentensymposium Traumachirurgie, Soesterberg, Nederland	2012	0.5
(Inter)national conferences		
Annual Meeting of American Society for Surgery of the Hand (ASSH), Seattle, Washington, United States of America	2015	1
Annual Meeting of the Federation of European Societies for Surgery of the Hand (FESSH), Milan, Italy	2015	0.75
Spring meeting of the Dutch Society for Surgery of the Hand, Amsterdam, The Netherlands	2015	0.25
16th European Federation of National Associations of Orthopaedics and Traumatology annual congress, Prague, Czech Republic	2015	0.75
16th European Congress for Trauma and Emergency Surgery, Amsterdam, The Netherlands	2015	0.75
Spring Scientific meeting of the British Society for Surgery of the Hand, Bath, England	2015	0.5
Instructional Course American Society for Surgery of the Hand, Maui, Hawaii, United States of America	2015	0.75
Annual Meeting of the American Association for Hand Surgery, Paradise Island, Bahamas	2015	1
Najaarsdag van de Nederlandse Vereniging voor Heelkunde, Utrecht, Nederland	2014	0.25

Najaarsdag van de Nederlandse Vereniging voor Heelkunde, Utrecht, Nederland	2014	0.25
Traumadagen, Amsterdam, Nederland	2014	0.5
Fall meeting of the Dutch Society for Surgery of the Hand, St Michelsgestel, The Netherlands	2014	0.25
Osteosynthese International 2014, Annual Meeting of the Küntscher Society, Krems, Austria	2014	0.75
Annual Meeting of the Federation of European Societies for Surgery of the Hand (FESSH), Paris, France	2014	0.75
15th European Congress for Trauma and Emergency Surgery, Amsterdam, The Netherlands	2015	0.75
Voorjaarsbijeenkomst Nederlandse Vereniging voor Handchirurgie, Rotterdam, Nederland	2014	0.25
Assistentensymposium Traumachirurgie, Soesterberg, Nederland	2014	0.25
Traumadagen, Amsterdam, Nederland	2013	0.5
32. Jahrestagung der Sektion Kindertraumatologie, Frankfurt, Germany	2013	0.5
Chirurgendagen, Veldhoven, Nederland	2013	0.5
Assistentensymposium Traumachirurgie, Soesterberg, Nederland	2013	0.25
Traumadagen, Amsterdam, Nederland	2012	0.5
Assistentensymposium Traumachirurgie, Soesterberg, Nederland	2012	0.25

2. Teaching	Year	Workload (Hours/ECTS)
Supervising		
Dorien Salentijn, Radiological criteria for acceptable reduction in intra-articular distal radius fractures and their relation to patient-reported functional outcome, Trauma Training Center, Columbia University Medical Center, New York	2016	2
Anna Heijne, the correlation of clinically utilized outcome instruments and the DASH score in distal radius fractures, Trauma Training Center, Columbia University Medical Center, New York	2015	2
Kasper Roth, Functional Outcome after Corrective Osteotomy for Malunited Forearm Fractures in Children: a Systematic Review and Meta-Analysis of Individual Participant Data, Department of Orthopedic Surgery, Erasmus University Medical Centre, Rotterdam	2015	2
Iris Westra, Carpal alignment in distal radius fractures, Trauma Training Center, Columbia University Medical Center, New York	2015	1
Madelief Marsman, Clinical relevance of scapholunate dissocation in patients with conservatively treated distal radius fracture, Trauma Training Center, Columbia University Medical Center, New York	2015	2
Bente Dubois, External validation of a clinical decision model to predict the presence of a wrist fracture in children	2015	2
Niels Hakkens, Costs of distal radius fracture treatment, Trauma Unit, AMC	2015	1
Sema Aydin, Predictors of instability in distal radius fractures, Trauma Unit, AMC	2014	2
Lara Vos, The Minimal Clinically Important Difference of the PRWE, Trauma Unit, AMC	2014	1
Jony van Hilst, External validation of clinical prediction model for instability in distal radius fractures	2014	1
Other Initiation and coordination of a hand surgery research fellowship program at the Trauma Training Center in Columbia University Medical Center, New York	2015	

3. Parameters of Esteem	Year
Grants	
Hoofdaanvrager ZonMW Doelmatigheidsonderzoeksubsidie	2013
AMC Graduate School Scholarship	2011
Awards and Prizes	
Best poster award in upper extremity at the 16th European Federation of National Associations of Orthopaedics and Traumatology annual congress, Prague, Czech Republic	2015
Top 15 best posters of the Instructional Course American Society for Surgery of the Hand, Maui, Hawaii, United States of America	2014

DANKWOORD

DANKWOORD

Velen hebben direct of indirect bijgedragen aan de totstandkoming van dit proefschrift. Hierbij wil ik iedereen dan ook graag hartelijk danken en een aantal in het bijzonder:

Prof. dr. Goslings, beste Carel, hartelijk dank voor je kritische blik en je geduld. Jouw perfectionisme vormde een welkome aanvulling op mijn overhaaste slordigheidjes. Je liet mij vrij om mijn promotietijd zelf in te vullen en dat heeft naast een proefschrift geresulteerd in een geweldige ervaring. Veel dank hiervoor.

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Dr. Strackee, beste Simon, jij bent zo slim dat bijna niemand je praatjes op congressen begrijpt. Toch vertel je alles met zo'n enthousiasme en overtuiging dat iedereen luistert. Veel dank voor je ideeën, hulp en begeleiding.

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Lieve Stefan, hartelijk dank voor je steun de afgelopen jaren.

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ABOUT THE AUTHOR

ABOUT THE AUTHOR

Monique Margaretha Jozefa Walenkamp was born in Leiderdorp on January 31st 1986. She grew up in Oegstgeest where she graduated from bilingual Gymnasium at the Rijnlands Lyceum. She initially wanted to become an engineer and went to the Technical University of Delft to study Life Science & Technology. However, after completing her first year she decided to switch to medicine at the Erasmus University of Rotterdam.

Monique combined her 4th and 5th year of medical school with a research master Clinical Epidemiology at the University of Utrecht. Her research project led her to the Academic Medical Centre (AMC) in Amsterdam, where she helped design and initiate the Amsterdam Wrist Rules study and the VIPER-trial. Her efforts were rewarded with a PhD scholarship for which she paused her clinical rotations in Rotterdam. After starting the VIPER-trial in multiple hospitals, Monique resumed her rotations and combined this with her PhD research. She did her final rotation at the Trauma Unit in the AMC and graduated in February 2014 as a Medical Doctor.

In 2013, she managed to secure a large government grant (ZonMW Doelmatigheidssubsidie) for the implementation study of the Amsterdam Wrist Rules. This allowed a new PhD researcher who is currently running this study to be appointed.

Monique loves travelling. During medical school, she did a six months trauma research fellowship in Cape Town followed by a two month journey through Southern Africa. She also did a three months research fellowship at Columbia University Medical Centre in New York (supervisor Dr. Melvin Rosenwasser) in 2015. During this period, she initiated a research fellowship program for Dutch students and young doctors who want to do research in hand surgery at Columbia University Medical Centre.

Monique is currently working as a surgical resident (ANIOS) at the Department of Surgery in Maasstad Hospital Rotterdam (supervisor Dr. R.A. Klaassen).

Monique M.J. Walenkamp