Surgical- and imaging techniques to optimize volar plating in distal radius fractures

How can we do better?

Bergsma, M.

SURGICAL- AND IMAGING TECHNIQUES TO OPTIMIZE VOLAR PLATING IN DISTAL RADIUS FRACTURES

MINKE BERGSMA

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Colophon

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SURGICAL- AND IMAGING TECHNIQUES TO OPTIMIZE
VOLAR PLATING IN DISTAL RADIUS FRACTURES

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SURGICAL- AND IMAGING TECHNIQUES TO OPTIMIZE VOLAR PLATING IN DISTAL RADIUS FRACTURES

By

Minke Bergsma

Thesis
Submitted to Flinders University
for the degree of

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SHORT SUMMARY & GENERAL INTRODUCTION

SHORT SUMMARY

The aim of this thesis was to improve volar plating for distal radius fractures by reducing tendon related peri-operative iatrogenic complication rate, both on the volar and dorsal side of the wrist with the use of (new) imaging techniques. We have specifically focused on preventing plate- and screw mal-positioning leading up to these complications.

On the dorsal side, the protruding screws can cause extensor tendon attrition and rupture. On this side of the wrist, there is no room for error as the closest tendons are on average only half a millimeter away from the dorsal bony cortex (**chapter 3**). Without the use of views *additional* to the standard lateral and antero-posterior views, in 40% of patients at least one screw was found to be protruding the dorsal cortex 0.5 mm or more (**chapter 1**). The Dorsal Tangential View, in South Australian popularized as the Lleyton Hewitt View –after the famous 'Come On' cry of the Adelaide tennis player- has been advocated in recent literature to detect protruding screws intra-operatively based on pre-clinical and small clinical studies (**chapter 5)**. We found out the efficacy of this view is high; in 31% of the distal radius fracture surgeries, intra-operative management was changed based on this view (**chapter 6**). However, when using post-operative tri-planar CT-reconstructions to identify remaining protruding screws in patients that where checked intra-operatively with the DTV, the sensitivity of this view appeared to be only 52% (**chapter 7**). We explored three-dimensional fluoroscopy (3DF) for detection of dorsal screw penetration and could not conclude that 3DF outperforms DTVs for this purpose. We postulated that the accuracy of DTV might improve after training. And indeed, inter-observer reliability, sensitivity, specificity and accuracy of this view improved after training (**chapter 9**).

On the volar side, mal-positioning of the volar plate with respect to the watershed line can lead to plate prominence and interference with the volar flexor tendons. In literature we found eight different interpretations of the definition the 'watershed line' (**chapter 4**). With the use of Q3DCT-imaging we identified the true watershed line. We postulated that the ulnar radial prominence, situated on the watershed line on the ulnar side of the radius, is the best reference marker for this line as it is easy to palpate for the surgeon (**chapter 10**). When using the most volar point of the volar distal radius on a lateral x-ray as watershed line, we found that plate design directs plate (mal) positioning with respect to this watershed line; the use of the DVR plate resulted in a safer plate positioning compared to the VA-LCP plate. (**chapter 2**). In

some individuals, the tendons are much closer so the surgeon should keep in mind the danger of hardware to the flexor tendons even when staying well proximal from the watershed line (**chapter 3**).

GENERAL INTRODUCTION

COMPLICATIONS ASSOCIATED WITH VOLAR PLATE FIXATION OF DISTAL RADIUS FRACTURES: HOW CAN WE DO BETTER?

Epidemiology of Distal Radius Fractures

The human wrist consists out of two rows of in total eight carpal bones and the distal part of the ulna and the radius. Though, when spoken about a 'broken wrist', the bone that is usually affected is the distal radius. The incidence of distal radius fractures is 27 per 10.000 per year and these fractures account for 2.5% of all emergency department visits. Distal radius fractures are therefore one of the most common injuries[1]. The lifetime risk of sustaining a distal radius fracture is 15% for women and 2% for men[2]. A distal radius fracture is most commonly caused by a fall on an outstretched hand (FOOSH), and occurs in two main groups: in the elderly after relatively low energy trauma and in young adults after high energy trauma. In the Netherlands, the majority of distal radius fractures occur in older women after low energy trauma[3]. The variation in peak incidence in the Netherlands, is influenced by the severity of the winter and the possibility of skating on natural ice[4]. An Australian study also reported the existence of seasonal variation in a milder winter climate, with fewer fractures occurring in autumn, thus factors beyond slippery weather must be partly responsible for seasonality[5].

Burden to Society

For reasons not fully understood, and likely multi-factorial, the incidence of this fracture appears to be on the rise[6]. In the US a 17% increase in incidence of distal radius fractures was shown in a 40 year time span[7]. The future burden of distal radius fractures in the United States is expected to be $240 million in primary/direct expenses per year[8]. Many of the societal effects of these fractures extend beyond the significant medical costs, including decreased school attendance, lost work hours, loss of independence and lasting disability.

In the past years, a global trend has led to more invasive treatment of distal radius fractures: there has been a shift from both non-operative to operative treatment and from closed reduction and external fixation to open reduction and internal fixation (ORIF)[9-12]. Currently, in the Netherlands the rate of all distal radius fractures in adults which are treated surgically varies between 0%-23% with an average of 9.6% [13]. Whereas in Australia there is an even more surgically oriented treatment for distal radius fractures. A survey held in Australia showed 47% of surgeons would opt for a surgical fixation in a typical distal radius fracture case[14].

Operative Strategies

While electing surgical treatment, a surgeon is currently facing two main choices; K-wire fixation or internal fixation with plating. Stable internal fixation with plate fixation is believed to permit early motion and optimizes rehabilitation[15]. Classically, when opted for internal fixation, a plate on the dorsal side of the wrist was the preferred choice for fixation. Most distal radius fractures are dorsally displaced, and the dorsum of the distal radius is subcutaneous and easy to access. However, the concomitant rising incidence of extensor tendon complications due to direct contact between these structures and the dorsal plate could not be neglected[15]. For this reason, a volar approach gained popularity over the past decades and is now the most common used ORIF technique for distal radius fractures. On the volar side of the distal radius, more physical space is available to allow for plate positioning. The concave surface of this part of the radius (i.e. the pronator fossa) protects flexor tendon from irritation. In addition, blood supply to fracture fragments can be maintained with a volar approach. In the fracture configuration, the volar cortex is usually less comminuted and volar scars are better tolerated[16].

Volar plating was originally reserved for volarly displaced fractures, it now has become the standard approach for most dorsally displaced fractures in clinical practice[16,17]. Volar plates may be used as a template for fracture reduction[18]. Plates are designed to improve and maintain anatomic alignment, even in patients with poor metaphyseal bone quality[15]. Most volar plates have a volar cortical angle of ± 25 degrees. The volar locking plate's screw system act as a single unit for fracture fixation, where the conventional non-locking plates required compression between the implant and the bone for stabilization. In current clinical practice, surgeons mostly opt for volar plates over K-wires.

Current Clinical Problem

However, despite many scientific attempts, neither of the two options has proven to be superior[19-23]. Most studies indicate that there are clinical advantages in the early post-operative period, but at later stages there is no clinically significant difference[24]. One could argue that the comparison between K-wires and volar plating seems to be coloured significantly by the relative high incidence of complications after volar plating for distal radius fractures. A recent systematic review reports an overall complication rate of up to 27%[25]. Even with volar plates (as traditionally seen with dorsal plating), tendon irritation or rupture represent a significant proportion of the complication rate: up to 57% of the total number of complications[25] and a total tendon related complication rate of 6.8%[26] has been reported.

With these percentages, and considering the high overall incidence of distal radius fractures that continues to rise, combined with the growing trend of operative treatment for these distal radius fractures: the absolute number of -iatrogenic-complications associated with treatment of distal radius fractures becomes a substantial burden to society. For example, the mean additional cost of a complication after ORIF is $1853, compared to $1362 after closed reduction[27], while the operative fixation rate for distal radius fractures in the Medicare population continues to rise, with a significant trend toward open fixation[12]. If the incidence of these complications is reduced, volar plate fixation may become more favourable for our patients as the preferred surgical treatment in distal radius fractures. If not, we may see the pendulum in favour of operative treatment swing back to towards non-operative treatment.

How Can We Do Better?

The growing body of evidence on iatrogenic complications associated with volar plate fixation, is arguably preventable when considering few key anatomical concepts. Anecdotally, opinion leaders in our field argue that the majority of these complications are due to inadequate operation techniques (i.e. plate and screw mal-positioning) and we consider these avoidable using appropriate imaging techniques and anatomical concepts: Professor Jorge Orbay, the upper limb surgeon who introduced volar plating for distal radius fractures, stressed at the most recent Asia-Pacific Wrist Association Annual Meeting that inadequate techniques that go unrecognized intra-operatively, will results in :, 1) penetration of the extensor compartments by too long screws putting the extensor tendons at risk dorsally; 2) interference of a very distal volar plate with the flexor tendon system and 3) distal screws cutting through the subchondral bone and penetrating the radiocarpal joint[25]

Therefore, the overall aim of this thesis is to reduce the peri-operative iatrogenic complication rate associated with volar plating for distal radius in order to decrease the physical- and financial burden of post-operative sequelae for patients- and society respectively. The overall study question is: how can we do better to avoid plate- and screw mal-positioning leading up these complications? The focus to achieve this goal is on improving hardware placement by 1) optimizing and standardizing the detection of protruding hardware during the operation with (new) radiological techniques; and 2) refining surgical technique.

Part I of this thesis comprises two chapters outlining of the problem of protruding hardware in clinical practice, one on the dorsal side where the extensor tendons are situated and one on the volar side where the flexor tendons are situated.

Part II examines the involved (patho-) anatomy on both the dorsal and the volar side in two chapters.

Part III aims to tackle the problem on the dorsal side by improving imaging techniques to detect protruding hardware in four chapters.

Part IV entails one chapter that aims to tackle the problems on the volar side by improving the surgical technique to prevent protruding hardware.

PART I – CURRENT CLINICAL PROBLEMS

Dorsal

Chapter 1: Incidence of Dorsal Screw Penetration – published in Chapter 8 as: Diagnosis of Dorsal Screw Penetration after Volar Plating of the Distal Radius: Intra-Operative Dorsal Tangential Views versus Three-Dimensional Fluoroscopy

Volar plates are known to reduce the incidence of post-operative iatrogenic –extensor– tendon injuries as compared to tendon ruptures in the extensor compartments that were traditionally seen with dorsal plating[28,29]. However, the potential complication of a dorsally protruding screw that is obscured by Lister's tubercle on plain lateral radiographs remains a pitfall [25,30,31]. **Chapter 1** will analyse the incidence of dorsal screw penetration when only anteroposterior and lateral views are used as final per-operative check.

Volar

Chapter 2: Distal Radius Volar Plate Design and Volar Prominence to The Watershed Line in Clinical Practice: Comparison of Soong Grading of Two Common Plates in 400 Patients

Iatrogenic flexor tendon rupture following volar plate malpositioning in distal radius fracture fixation is a recognized complication; when the plate is positioned too volar with respect to the watershed line -the most volar aspect of the volar margin of the radius-[32-35]. The clinical importance of prominent hardware volar to the watershed line was established in a landmark study by Soong et al. demonstrating that plates prominent at the watershed line increased the risk of tendon injury[36]. Plate design may direct plate positioning in clinical practice, and thus increase the chance of tendon rupture based on design factors rather than surgeon factors. In **chapter 2** the influence of plate design on placement of the volar plate will be analysed.

PART II: ANATOMICAL BASIS FOR IMPROVEMENT – PATHO-ANATOMY

Dorsal and Volar

Chapter 3: MRI Study on the Distance between the Distal Radius and the Flexor- and Extensor Tendons: Is There Any Room for Error/Hardware?

Prominent hardware in contact with tendons is thought to lead to pressure necrosis and attritional or direct rupture. Dorsally protruding screws are easily missed on conventional anteroposterior and lateral fluoroscopic views. The flexor tendons are at closest proximity to the volar distal radius at the watershed line[16]. Distal plate placement brings hardware in closer contact with flexor tendons and can therefor result in flexor tendon pathology[37]. The exact distance between the cortex of the distal radius and the tendons will provide the surgeon with an accurate idea on the safe margin to prevent tendon complications, and will allow for identification of patients at risk in the postoperative period. In **chapter 3** we will identify the in vivo distance between the dorsal volar cortex of the distal radius and respectively the extensor tendons and flexor tendons, on the level where hardware is placed in closest relation to the tendons based on MRI scans.

Volar

Chapter 4: Interpretations of The Term "Watershed Line" Used As Reference For Volar Plating

The term 'watershed line' was introduced by Nelson and Orbay who defined this line "a theoretical line marking the most volar aspect of the volar margin of the radius", and proposed to have it serve as the distal margin for volar plating to minimize these tendon injuries. However, there is some confusion, with other authors having their own interpretation of the watershed line. **Chapter 4** aims to give an overview of all used definitions of the watershed line in current literature.

PART III: TACKLING THE DORSAL PROBLEM: IMPROVING IMAGING TECHNIQUE

Chapter 5: Volar Plating: Imaging Modalities for the Detection of Screw Penetration

Chapter 6: Volar Plating in Distal Radius Fractures: A Prospective Clinical Study on Efficacy of Dorsal Tangential Views to Avoid Screw Penetration.

Chapter 7: Accuracy of Dorsal Tangential Views to Avoid Screw Penetration with Volar Plating of Distal Radius Fractures

Chapter 8: Diagnosis of Dorsal Screw Penetration after Volar Plating of the Distal Radius: Intra-Operative Dorsal Tangential Views versus Three-Dimensional Fluoroscopy

Chapter 9: Optimizing and Standardizing the Lleyton Hewitt View: An Anatomical and Imaging Study on the Influence of Training on Diagnostic Accuracy

The lateral or elevated lateral view is often used as a final check in volar plating for distal radius fractures. The potential complication of a dorsally protruding screw that is obscured by Lister's tubercle on these elevated lateral radiographs is a preventable iatrogenic pitfall[8-10]. In **chapter 5**, we will define what the best intra-operatively available diagnostic imaging technique is for the detection of dorsal and intra-articular screw penetration. In 2015, Hill and colleagues recommended the intraoperative use of dorsal tangential view (DTV) to detect dorsal screw penetration after volar plating based on a cadaveric study[11]. Several pre-clinical studies agree that the use of DTV increases accuracy in detecting dorsal screw penetration in cadavers after volar plating of the radius[11-15]. In **chapter 6** we will define the efficacy of this additional view in clinical setting. **In chapter 7** we will analyse its accuracy in the clinical setting. In **chapter 8** we will explore if the diagnostic performance of 3-dimensional fluoroscopy is better than DTV. In **chapter 9** we will analyse if diagnostic performance of DTV can be improved with training.

PART IV: TACKLING THE VOLAR PROBLEM – IMPROVING SURGICAL APPROACH

Chapter 10: The Watershed Line of The Distal Radius: Cadaveric and Imaging Study of Anatomical Landmarks

The watershed line, defined as the most volar part of the distal radius, is impossible to define during surgery, when one can only rely on the bare eye and lateral fluoroscopic views. **Chapter 9** will define the exact location of the watershed line and relate this line to anatomical landmarks that are useful to the surgeon during surgery.

PART V: SUMMARY/SAMENVATTING, DISCUSSION AND CONCLUSIONS

REFERENCES

1. Larsen CF, Lauritsen J. Epidemiology of acute wrist trauma. *International journal of epidemiology*. 1993;22(5):911-916.

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

3. Kleinlugtenbelt YV. *Research methodology in distal radius fracture care: 1 step backward, 2 steps forward*, AMC-UvA; 2017.

4. van Lieshout AP, van Manen CJ, du Pre KJ, et al. Peak incidence of distal radius fractures due to ice skating on natural ice in The Netherlands. *Strategies in trauma and limb reconstruction (Online)*. 2010;5(2):65-69.

5. Sanders KM, Seeman E, Ugoni AM, et al. Age- and gender-specific rate of fractures in Australia: a population-based study. *Osteoporos Int*. 1999;10(3):240-247.

6. Nellans KW, Kowalski E, Chung KC. The epidemiology of distal radius fractures. *Hand Clin*. 2012;28(2):113-125.

7. Melton LJ, 3rd, Amadio PC, Crowson CS, O'Fallon WM. Long-term trends in the incidence of distal forearm fractures. *Osteoporos Int*. 1998;8(4):341-348.

8. 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;36(8):1282-1287.

9. Mellstrand-Navarro C, Pettersson HJ, Tornqvist H, Ponzer S. The operative treatment of fractures of the distal radius is increasing: results from a nationwide Swedish study. *Bone Joint J*. 2014;96-b(7):963-969.

10. Mattila VM, Huttunen TT, Sillanpaa P, Niemi S, Pihlajamaki H, Kannus P. Significant change in the surgical treatment of distal radius fractures: a nationwide study between 1998 and 2008 in Finland. *J Trauma*. 2011;71(4):939-942; discussion 942-933.

11. Wilcke MK, Hammarberg H, Adolphson PY. Epidemiology and changed surgical treatment methods for fractures of the distal radius: a registry analysis of 42,583 patients in Stockholm County, Sweden, 2004-2010. *Acta Orthop*. 2013;84(3):292-296.

12. Farner S, Malkani A, Lau E, Day J, Ochoa J, Ong K. Outcomes and cost of care for patients with distal radius fractures. *Orthopedics*. 2014;37(10):e866-878.

13. Walenkamp MMJ, Mulders MAM, Selles CA, Goslings JC, Westert GP, Schep NWL. [Analysis of variation in the surgical treatment of distal radius fracture]. *Ned Tijdschr Geneeskd*. 2017;161(0):D1042.

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

15. Orbay JL, Fernandez DL. Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report. *J Hand Surg Am*. 2002;27(2):205-215.

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

17. Kamano M, Honda Y, Kazuki K, Yasuda M. Palmar plating for dorsally displaced fractures of the distal radius. *Clin Orthop Relat Res*. 2002(397):403-408.

18. Buzzell JE, Weikert DR, Watson JT, Lee DH. Precontoured fixed-angle volar distal radius plates: a comparison of anatomic fit. *J Hand Surg Am*. 2008;33(7):1144-1152.

19. Brennan SA, Kiernan C, Beecher S, et al. Volar plate versus k-wire fixation of distal radius fractures. *Injury*. 2016;47(2):372-376.

20. Franceschi F, Franceschetti E, Paciotti M, Cancilleri F, Maffulli N, Denaro V. Volar locking plates versus K-wire/pin fixation for the treatment of distal radial fractures: a systematic review and quantitative synthesis. *Br Med Bull*. 2015;115(1):91-110.

21. Costa ML, Achten J, Parsons NR, et al. Percutaneous fixation with Kirschner wires versus volar locking plate fixation in adults with dorsally displaced fracture of distal radius: randomised controlled trial. *BMJ*. 2014;349:g4807.

22. Chaudhry H, Kleinlugtenbelt YV, Mundi R, Ristevski B, Goslings JC, Bhandari M. Are Volar Locking Plates Superior to Percutaneous K-wires for Distal Radius Fractures? A Meta-analysis. *Clin Orthop Relat Res*. 2015;473(9):3017-3027.

23. Mellstrand Navarro C, Ahrengart L, Tornqvist H, Ponzer S. Volar Locking Plate or External Fixation With Optional Addition of K-Wires for Dorsally Displaced Distal Radius Fractures: A Randomized Controlled Study. *Journal of orthopaedic trauma*. 2016;30(4):217-224.

24. Zong SL, Kan SL, Su LX, Wang B. Meta-analysis for dorsally displaced distal radius fracture fixation: volar locking plate versus percutaneous Kirschner wires. *J Orthop Surg Res*. 2015;10:108.

25. 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. *Journal of orthopaedic trauma*. 2007;21(5):316-322.

26. Azzi AJ, Aldekhayel S, Boehm KS, Zadeh T. Tendon Rupture and Tenosynovitis following Internal Fixation of Distal Radius Fractures: A Systematic Review. *Plast Reconstr Surg*. 2017;139(3):717e-724e.

27. Pang EQ, Truntzer J, Baker L, Harris AHS, Gardner MJ, Kamal RN. Cost minimization analysis of the treatment of distal radial fractures in the elderly. *Bone Joint J*. 2018;100-B(2):205-211.

28. Lutsky K, Boyer M, Goldfarb C. Dorsal locked plate fixation of distal radius fractures. *J Hand Surg Am*. 2013;38(7):1414-1422.

29. Tavakolian JD, Jupiter JB. Dorsal plating for distal radius fractures. *Hand Clin*. 2005;21(3):341-346.

30. 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;91(8):1837-1846.

31. Tarallo L, Mugnai R, Zambianchi F, Adani R, Catani F. Volar plate fixation for the treatment of distal radius fractures: analysis of adverse events. *Journal of orthopaedic trauma*. 2013;27(12):740-745.

32. Soong M, van Leerdam R, Guitton TG, Got C, Katarincic J, Ring D. Fracture of the distal radius: risk factors for complications after locked volar plate fixation. *J Hand Surg Am*. 2011;36(1):3-9.

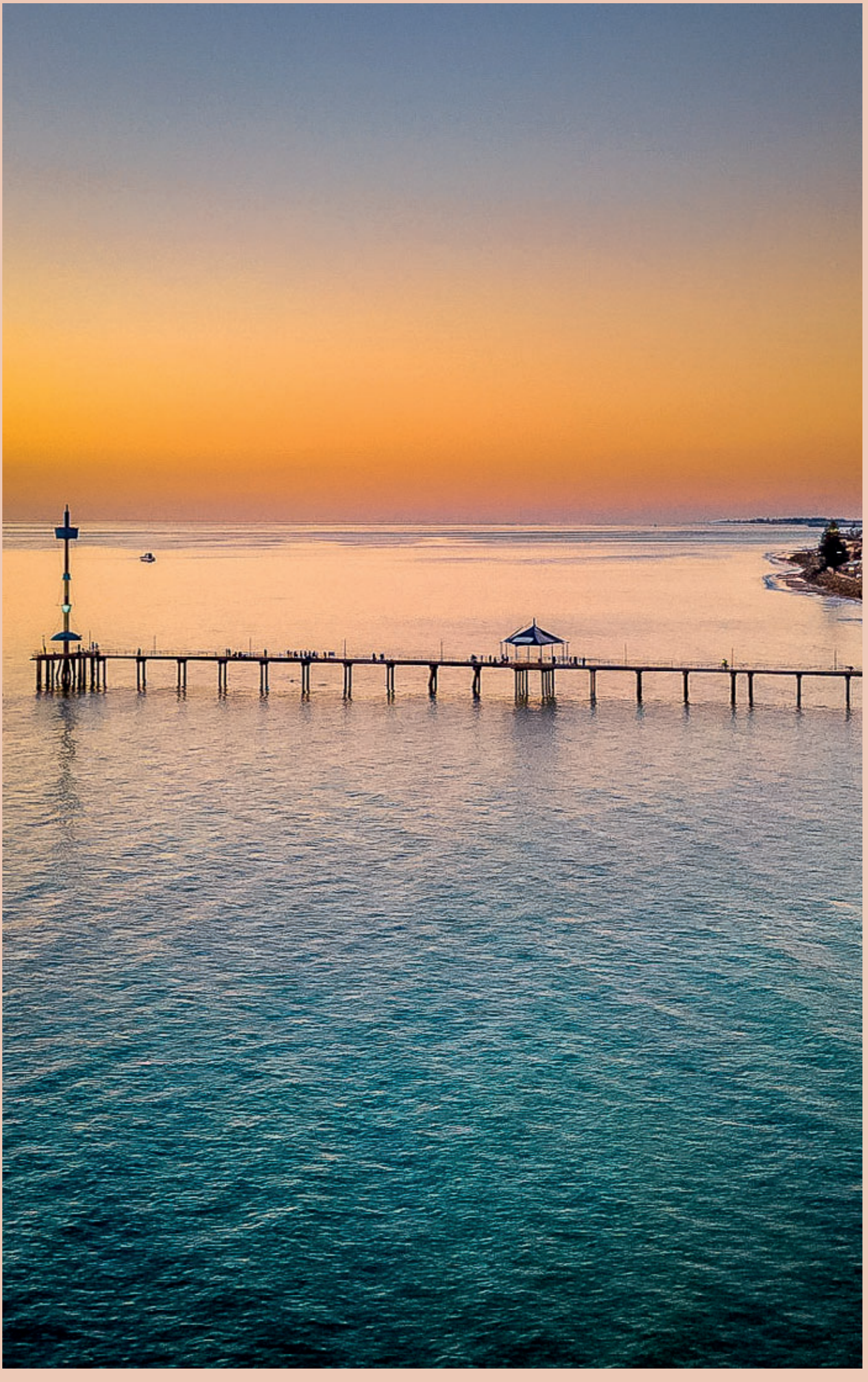
33. Selvan DR, Perry D, Machin DG, Brown DJ. The role of post-operative radiographs in predicting risk of flexor pollicis longus tendon rupture after volar plate fixation of distal radius fractures - a case control study. *Injury*. 2014;45(12):1885-1888.

34. Berglund LM, Messer TM. Complications of volar plate fixation for managing distal radius fractures. *J Am Acad Orthop Surg*. 2009;17(6):369-377.

35. Lee DS, Weikert DR. Complications of Distal Radius Fixation. *The Orthopedic clinics of North America*. 2016;47(2):415-424.

36. Soong M, Earp BE, Bishop G, Leung A, Blazar P. Volar locking plate implant prominence and flexor tendon rupture. *J Bone Joint Surg Am*. 2011;93(4):328-335.

37. Agnew SP, Ljungquist KL, Huang JI. Danger zones for flexor tendons in volar plating of distal radius fractures. *J Hand Surg Am.* 2015;40(6):1102-1105.



PART I

CURRENT CLINICAL PROBLEMS

1

INCIDENCE OF DORSAL SCREW PENETRATION

Part of:

DIAGNOSIS OF DORSAL SCREW PENETRATION AFTER VOLAR PLATING OF THE DISTAL RADIUS: INTRA-OPERATIVE DORSAL TANGENTIAL VIEWS VERSUS THREE-DIMENSIONAL FLUOROSCOPY

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(Published in Chapter 8)

STUDY DESIGN – PROSPECTIVE MATCHED COHORT STUDY

Patients with distal radius fractures undergoing ORIF were included in a prospective multicentre randomized clinical trial (i.e. EF3X-trial) investigating the effectiveness of the intra-operative use of advanced 3DF *versus* 2DF.[17] The main outcome of the index study was to evaluate the quality of fracture reduction and fixation on intra-operative 3DF, and the subsequent need for immediate revision in both respective groups. Post-operative CTs served as the reference standard.

FIRST INDEX STUDY: 2DF AND 3DF PATIENT COHORTS

Out of a total 206 patients with an intra-articular distal radius fracture who were included in the index EF3X-trial, 103 patients were allocated to 2DF and 103 patients to 3DF. For the purpose of this study, we excluded 91 patients: 21 patients without a volar plate; 29 patients with additional dorsal and/or lateral plates that obscured dorsal screw penetration on post-op CT; 29 patients with a post-op CT-scan of insufficient quality to serve as the reference standard; and 12 patients without a postoperative reference CT-scan.

We included the 115 patients who underwent volar plating for an intra-articular distal radius fracture: 55 patients were randomized to intra-operative 2DF, whereas 60 patients to 3DF. All patients were treated by- or under supervision of a senior orthopaedic or trauma consultant at one of the participating hospitals between October 2009 and July 2014. A volar approach through the FCR-bed was used in all patients to expose the volar radius (i.e. modified Henry approach).[19] Volar locking plates were inserted in all distal radius fractures (LCP 2.4 mm[20] and VA-LCP 2.4 mm[21]; Synthes, Oberdorf, Switzerland). In the 2DF patient cohort, AP and elevated lateral views were used intra-operatively throughout the procedure at surgeons' discretion. DTVs were not part of hospital protocols, and not used in surgeons' respective practice. Therefore, the 2DF group served as the baseline reference.

2DF PATIENT COHORT: BASELINE INCIDENCE OF POST-OP SCREW PENETRATION

Without the routine use of intra-operative DTV or 3DF, 40% of patients (22 out of 55 patients) had –at least– one dorsal screw penetrating (≥ 0.5 mm) on post-operative CT imaging, whereas in 13% (7 out of 55 patients) two screws were penetrating. In total, 29 out of 225 screws (13%) were found to be penetrating with a penetration distance on average of 1.1 mm (range 0.6 – 4.9 mm) and a median length of 20 mm (interquartile range [IQR] 18 – 22 mm, range 16 – 26 mm).

The screw positions at risk for dorsal screw penetration were distributed as follows; 16 screws (55%) in the most radial position (i.e. 2nd compartment), 5 screws (17%) in the second most radial position (2nd compartment), 7 screws (17%) in the most ulnar position (4th compartment), 1 screw (3%) in the second most ulnar position (3rd compartment), and none in the central screw position (i.e. Lister's Tubercle, in plates with 5 holes).

2

DISTAL RADIUS VOLAR PLATE DESIGN AND VOLAR PROMINENCE TO THE WATERSHED LINE IN CLINICAL PRACTICE: COMPARISON OF SOONG GRADING OF TWO COMMON PLATES IN 400 PATIENTS

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ABSTRACT

Purpose

To compare plate positioning in clinical practice of two commonly used volar locking plate designs with respect to the watershed line as classified by the Soong grading system.

Methods

For this retrospective study, we included a total of 400 patients who underwent open reduction and internal fixation between May 2013 and February 2018. Cohort 1 was defined as patients treated with DVR plates (ZimmerBiomet, Belrose, Australia) during this period. Cohort 2 comprised 200 patients who had volar plate fixation with Variable Angle LCP plates (DePuy Synthes, North Ryde, Australia) during the same period. Standardized lateral wrist radiographs were categorized into Soong Grade 0,1 or 2.

Results

In Cohort 1, 87 plates (43.5%) were not prominent volar to the watershed line - Grade 0 -, 95 plates (47.5%) demonstrated Grade 1 prominence and 18 plates (9.0%) demonstrated Grade 2 prominence. In Cohort 2, 63 plates (31.5%) were Grade 0, 103 plates (51.5%) were Grade 1 and 34 plates (17%) had Grade 2 prominence on, and volar to, the watershed line. These radiographic results show a greater incidence of volar plate prominence with respect to the watershed line, as defined as Soong Grading, in cohort 2.

Conclusion

This study shows that the use of the Variable Angle LCP plate results in more prominent volar positioning with respect to the watershed line, as compared to the DVR plate.

INTRODUCTION

Nowadays, volar plates are the most commonly used technique to fixate distal radius fractures.[1-4] However, flexor tendon rupture following volar plate prominence is a recognized complication when the plate is positioned distal with respect to the watershed line.[3,5-8]

Nelson and Orbay coined the term *watershed line* as "a theoretical line marking the most volar aspect of the volar margin of the radius" to serve as the distal margin for volar plating to minimize tendon injuries.[9-11] Subsequently, Soong and colleagues defined the watershed line as "the most prominent part of the volar surface of the distal part of the radius, where the flexor tendons lie closest to the plate and bone" (Figure 1).[5] The clinical importance of prominent implants volar to the watershed line was established in their landmark cohort study using the Soong grading system, demonstrating that plates prominent at the watershed line increased the risk of tendon injury, while plates that were not more distal to the watershed line had no ruptures (Figure 2).[5]

These results suggest that plate positioning in relation to the watershed line is an important technical detail of the surgery, although the actual plate application during surgery is directed by the fracture characteristics, patient anatomy as well as fitting of the plate to the volar radius contours. Plate design may direct positioning in relation to the watershed line during surgery.

Limthongthang and colleagues reported a significant difference between several volar locking distal radius plate designs (VLP) with respect to volar prominence to the watershed line in their cadaveric study.[12] The authors found that despite optimal plate placement in non-fractured cadaveric distal radii in a controlled study setting, many VLP designs have concerning prominent profiles volar to the watershed line to varying extents.[12] Additionally, one may argue that in clinical practice, the volar plate is positioned primarily in relation to the fracture characteristics rather than the watershed line. This means that plate positioning may therefore potentially violate the recommendations based on the Soong Grading system.[5]

Therefore, the purpose of this clinical imaging study was to compare plate positioning of two commonly used volar locking plate designs with respect to the watershed line on plain lateral radiographs as classified by the Soong grading system. Secondary outcomes included the association of the plate type and the Soong grading on plate removal and the plate type on plate lift-off. We defined "lift-off" as a plate that is not fixed flush to the volar cortex, but lifted volarly even though it is proximal to the watershed line. Our primary null hypothesis is that there is no difference in Soong Grading (Grade 0, 1 and 2) on plain lateral radiographs between the two plate designs compared in this study in clinical practice.

MATERIALS AND METHODS

This study was approved by our local Human Research Ethics Committee. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed for this retrospective comparative cohort study.[13]

We included two large consecutive cohorts of patients with intra- and extra-articular distal radius fractures surgically treated by a large number of different orthopaedic trauma surgeons in a Level 1 trauma center, with two of the most common contemporary plate designs. We identified all patients treated with volar plating for a distal radius fracture based on operating room list coding for billing purposes. A total of 400 patients who underwent open reduction and internal fixation between May 2013 and February 2018 were included. Images were obtained by a picture archiving communication system (PACS). Only skeletally mature patients (age^{3}18) were included in this study. Patients whose intra- or post-operative lateral view X-rays were not of acceptable quality (n=16) and patients whose post-operative X-rays showed loss of fracture reduction at 2 or 6 weeks follow up (n=3) or had a corrective osteotomy included in their surgical planning (n=3) were excluded from this study cohort. A lateral view was considered acceptable when the projection of the volar cortex of the pisiform was located between the volar cortices of the capitate and the scaphoid, and the view projected a lateral view of the plate. The best available postoperative lateral view based on the narrowest projected profile of the plate was selected.[5] There were 67 different respective primary listed surgeons.

Cohort 1 was defined as 200 patients treated with DVR plates (ZimmerBiomet, Belrose, Australia) between May 2013 and February 2018. Cohort 2 comprised 200 patients who had volar plate fixation with Variable Angle LCP plates (DePuy Synthes, North Ryde, Australia) in this timeframe. Due to hospital standards, there was a change in preferred plate from DVR to Variable Angle LCP late 2015. This resulted in the DVR plate being used in the first two years of the study –in which the Variable Angle LCP plate was not available- while the Variable Angle LCP plate was the first choice of volar distal radius plate, when the DVR was not used anymore. Fractures were graded according to the AO/OTA classification by one observer blinded for study outcomes (i.e. X-rays including placed plates and Soong grading). Baseline characteristics can be found in Table 1.

There seemed to be no difference between age, affected side, sex and fracture type between the two cohorts (Table 1).

While the Soong grading system has been proven to be reliable[14], two independent observers categorized the lateral wrist radiographs into Soong Gradings of 0,1 or 2 as described by Soong et al.[5] Disagreement was solved by consensus after discussion between the two observers. If disagreement remained, a third observer was consulted. Initially, a line was drawn parallel to the volar cortical bone of the radial shaft. A parallel line was drawn to this and moved to be tangential to the most volar extent of the volar cortex of the distal radius. Plates that were placed entirely dorsal to this line, were graded as Soong Grade 0. Plates at or volar to this line but proximal to the most volar part of the distal radius (so that the recess of the pronator fossa could be seen) were recorded as Soong Grade 1. Plates at or volar to this line and directly on or beyond the most volar part of the distal radius were recorded as Soong Grade 2 (Figure 2 and 3). When plate lift-off was noted by one of the observers, this was recorded as well (Figure 4).

The patient information system was used to identify all patients that underwent early plate removal (within three months) or revision as this was the shortest follow up available for all patients. Plate removal is usually not planned with either of the plates. As the surgical interventions on the patients included in the study at any different public hospital within the state would be captured on our state-wide clinical information database, any subsequent relevant surgeries were available to us for record, although if any of the patient sought revision surgery or implant removal surgery outside of the state health services or through private healthcare sector, that information was not actively sought by us.

Statistics

General descriptive statistics on patient sex, injured side, fracture type and age at baseline were gathered and presented as percentages for categorical variables and mean and standard deviation for continuous data (Table 1). Due to the ordinal character of the Soong grading system, differences between the two plates were performed by use of a Mann Whitney U-test.

Univariable logistic regression analysis was applied to assess the association between reoperation and plate design or Soong grading, after using the multivariable testing to make sure there were no potential confounders (age, sex, fracture type). Soong grading categories 0 and 1 were merged, as Grade 2 defines true plate prominence at the watershed line. Odds ratios (OR) for reoperation with 95%CI are presented and statistical significance was considered in case $p<0.05$.

A post hoc power analysis was performed to determine the observed power of the study. The analysis of 200 patients in Cohort 1 (all consecutive patients treated with DVR plates) and 200 patients in Cohort 2 (all consecutive patients treated with Variable Angle Plate LCP plates) revealed a power of 85.6%, based on a Wilcoxon (Mann-Whitney) rank sum test to detect the observed differences in Soong grading between both cohorts ($\alpha = 0.05$).

RESULTS

Based on final consensus, in Cohort 1, 182 plates (91%) were classified as Grade 0 or 1 (87 plates [43.5%] Grade 0 and 95 plates [47.5%] Grade 1) and 18 plates (9.0%) as Grade 2 (Figure 2 and Table 2). In Cohort 2, 166 plates (83%) were classified as Grade 0 or 1 (63 plates [31.5%] Grade 0 and 103 plates [51.5%] Grade 1) and 34 plates (17%) as Grade 2 (Figure 3 and Table 2). Comparison of Soong Grading between the two plates showed a significant difference between the two cohorts ($p<0.05$). The proportion with volar plate prominence defined as Grade 2 was lower in the cohort of patients treated with the DVR plate compared to the cohort of patients treated with the Variable Angle LCP plate.

In each cohort, 9 patients underwent re-operation. Five of these 18 patients had the volar plate graded as Soong Grade 0, 3 as Soong Grade 1 and 10 as Soong Grade 2. Association between plate design and re-operation was not observed (OR1.00: 95% CI 0.39; 2.57). Analysis showed an OR of 10 (95% CI 3.76; 27.05) for Soong Grade 2 compared to the merged Soong Grade 0 and 1 category.

In Cohort 1, plate lift-off (Figure 4) was observed in 9 (4.5%) cases, which was significantly less than in Cohort 2, where plate lift-off was registered in 23 (11.5%) cases ($p<0.05$).

DISCUSSION

The results of this study showed that the proportion with volar plate prominence defined as Grade 2 was lower in the cohort of patients treated with the DVR plate compared to the cohort of patients treated with the Variable Angle LCP plate. This implies that the use of DVR plates resulted in less prominent plate positioning with respect to the watershed line as compared to the use of Variable Angle LCP plates in terms of Soong grading. We have however not found an increased need for early plate removal in the cohort treated with the Variable Angle LCP plate. Analysis was performed in a large cohort of patients treated by a large group of orthopaedic trauma surgeons. The fact that a total of 400 patients are treated by almost 70 primary surgeons might indicate that on average the surgeons perform only six to seven volar plating for distal radius fracture surgeries in this timeframe. However, this number indicates only the first -out of two or three- listed surgeons per surgery, and most primary surgeons were fellows that only performed this surgery in our hospital for maximal a year. The DVR plate and the Variable Angle LCP plate have been used, as these are commonly used volar distal radius plates, well recognized and established designs with comparable clinical efficacy reported.[15-19]. Our study focused purely on the prominence of both the plates and not on the clinical complications that might be a result of this prominence, as established by Soong and colleagues.[5]

There are no reports of increased incidences of clinical adverse events or tendon ruptures with the Variable Angle LCP plate in current literature and neither have we experienced any notable rise in this issue in our clinical practice. This could imply that there are other plate design attributes, like bevelling, polishing and distal contouring that are important to protect the flexor tendons in addition to the relationship to the watershed line. Additionally, based on the results of this study it is our opinion Soong Grading may be predetermined by the plate design, independent of the fracture type or surgical technique.

Soong et al. found a correlation between flexor tendon ruptures and plate prominence with respect to the watershed line. In our study, a considerable odds ratio for re-operation was found for Soong Grade 2 compared to grade 0 and 1. With 18 cases of reoperations in this cohort of 400 patients, we could not stratify the risk of reoperation according to plate type. This is in line with the results of Selles et al, who found a statically significant correlation between plate removal and Soong grading, but a negative correlation between plate removal and plate type.[20] Lutsky et al. found that patients who had implants removed had a greater plate prominence volarly defined as higher Soong grading.[21]

Both the Variable Angle LCP and the DVR plate have been subject in an in-vitro study analysing prominence of plate profiles volar to the watershed line.[12] With optimal plate placement in non-fractured cadaveric distal radii studied in a controlled setting, the Variable Angle LCP plate resulted in a larger area and thickness profile compared to the DVR plate when both were placed in an optimal position. Another cadaveric study showed the DVR to have a low distal profile.[22] These factors might have contributed to the difference in Soong grading in our cohorts, apart from placement of the plate.

The results of this study should be interpreted in the light of its strengths and weaknesses. Major strengths of this study are the large cohort of patients and the representation of daily clinical practice, with surgeries performed by almost 70 different surgeons. In this setting, fracture characteristics and surgical considerations may dictate plate positioning apart from plate design. Although the cohorts have been included retrospectively, this is an imaging analysis of actual clinical cases, which makes it a stronger representative sample of actual clinical application. We excluded patients who had a corrective osteotomy included in the surgical planning and patients whose post-operative X-rays showed loss of fracture reduction as these findings might change anatomy and therefore influence Soong grading. When re-operation occurred after loss of reduction, the final implanted volar plate was included.

The retrospective design is a limitation of the study. Another major limitation is the limited relation to clinical follow up. Except for early plate removal performed in our hospital, we have not actively studied the association between plate positioning and adverse outcomes in this study. We were limited by three months follow up as this was the longest follow up available for the later cohort treated with Variable Angle LCP plates. However, due to clinical practice and governance the standard follow up of volar plating for distal radius fractures is three months. The decision of plate removal based on plate prominence being problematic would have been made by this point in our clinical practice. Patients presenting later than the three month follow up mark will be the patients that actually experience symptoms, which we may have lost.

We found some limitations to the use of the Soong grading system. A difficulty we faced in this study was the variability in quality of lateral view x-rays of the wrist. A lateral X-ray with the forearm in even slight malrotation would result in the plate not being observed in its true profile and hence assessing its position in relation to the most volar prominence on radius- the radiological marker of watershed line- becomes difficult. For this reason, we had to exclude 7 cases. We believe that by recognizing this limitation and removing cases in which this would clearly cause issues, we minimized its effect on our results. However, because this study used images from existing clinical imaging, and due to geometric nature of the plates where the distal flare of the plate has a slight in-plane rotation from the shaft of the plate, slight obliquity in the images cannot be entirely avoided. Soong et al. recommend the use of the most volar projection of the volar distal radius as the reference point. However, the authors feel that despite a good lateral projection, in some cases either the radial prominence or the ulnar prominence projects more volarly. As the radial (lateral) prominence of the radius projects more distal compared to the ulnar (medial) prominence of the distal radius, the use of this reference point can result in a lower Soong grade. Also, the grading system does not take plate lift-off into consideration. Plate lift-off might cause interference with flexor tendons without the plate being classified as Soong Grade 2. In literature, plate lift-off or inappropriate placed plates have been described as potential causes of flexor tendon pathologies.[23,24] Plate lift-off was significantly more common in the cohort of patients treated with the Variable Angle LCP plate. The clinical relevance of plate lift-off could be subject of a subsequent study.

In addition to the Soong grading System, Kitay et al have described quantitative measurements of plate position as they concluded that Soong grading alone was not predictive for the need for plate removal.[25] In their study, patients with increased (>2 mm) plate to critical line distance had an increased need for implant removal. They also found that distance between the plate and the volar rim did not correlate with the need for implant removal. This would compare to the difference between Soong grade 1 and 2. A cadaveric study confirming increased contact pressure between the FPL volar plates placed distal from the watershed line, additionally suggested that fixed dorsally tilted fracture fragments may increase risk for rupture due to increased volar rim prominence and possible dorsal displacement of the FPL.[26]

In conclusion, this study shows that in clinical practice, the Variable Angle LCP plate is associated with a higher rate of prominent volar plate positioning with respect to the watershed line as compared to the use of DVR plates. Because both plates have been associated with similar outcomes in literature, there might be other design attributes that are important to protect the flexor tendons in clinical application.

Results of this study showed that the use of DVR plates in clinical practice is associated with less prominent plate positioning with respect to the watershed line as compared to the use of Variable Angle LCP plates in terms of Soong Grading.

FIGURE AND TABLE LEGENDS

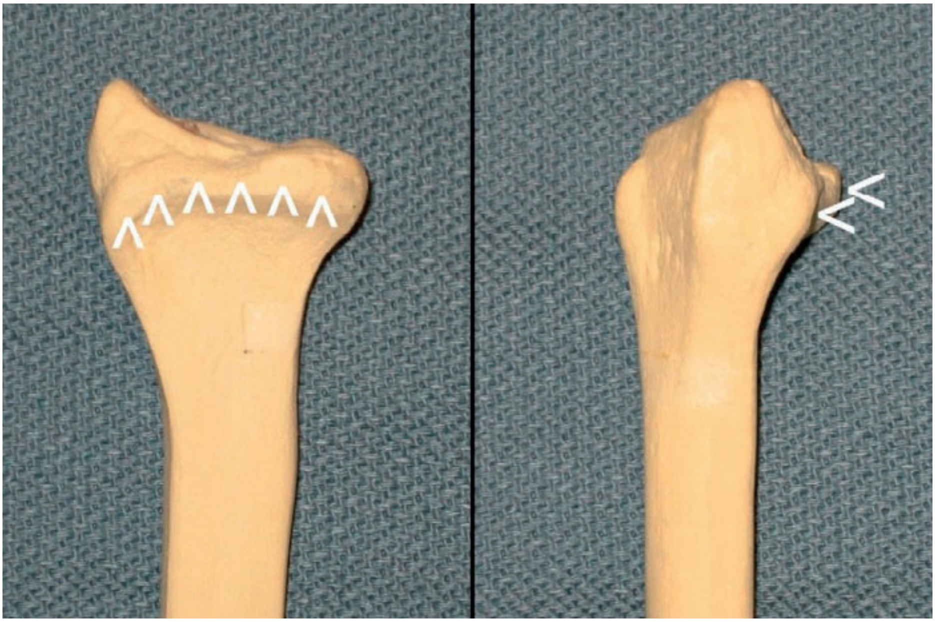

Figure 1: Soong and colleagues defined the watershed line as "the most prominent part of the volar surface of the distal part of the radius, where the flexor tendons lie closest to the plate and bone".

Radiograph illustrating the determination of implant prominence with use of a line (the critical line) through the most volar extent of the volar rim (red line), drawn parallel to the volar cortical bone of the radial shaft (green line). (With kind permission from Soong and colleagues.)

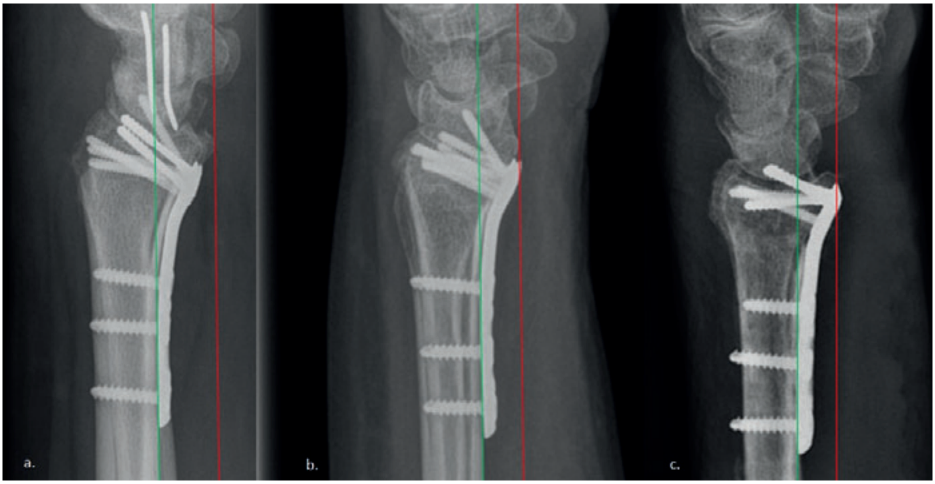

Figure 2: Lateral radiographs of a distal radial fracture treated with a DVR plate demonstrating (a.) Soong Grade 0 prominence (plate dorsal to critical line), (b.) Soong Grade 1 (plate volar to critical line, proximal to volar rim) prominence and (c.) Soong Grade 2 prominence (volar to critical line, at volar rim). Cohort 1 87 plates (43,5%) were Grade 0, 95 plates (47,5%) were Grade 1 and 18 plates (9,0%) were Grade 2.

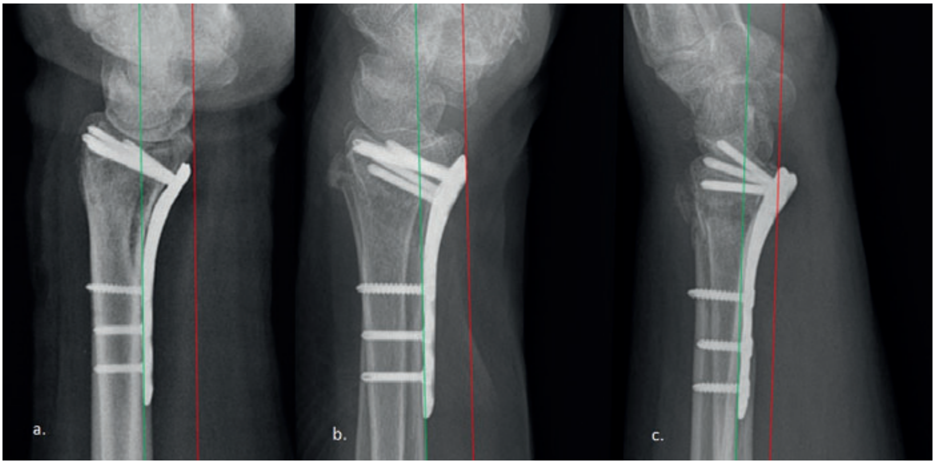

Figure 3: Variable Angle LCP Plate with Soong Grade 0 (a.), Soong Grade 1 (b.) and Soong Grade 2 (c.) In Cohort 2 63 plates (31,5%) were Grade 0, 103 plates (51,5%) were Grade 1 and 34 plates (17%) were Grade 2

Figure 4: Plate lift-off. We defined a lift-off plate as a plate that is not fixed flush to the volar cortex, but lifted volarly even though it is proximal to the watershed line. Plate lift-off could therefore cause interference with flexor tendons without the plate being classified as Soong Grade 2.

Table 1. Patient Demographics

	Cohort 1: DVR Plate (n=200)		Cohort 2: VA LCP Plate (n=200)	
	N	%	N	%
Sex				
Male	52	26%	51	25.5%
Female	148	74%	149	74.5%
Injured Side				
Right	76	38%	92	46%
Left	124	62%	108	54%
Age, year	55 (18)		56(19)	
Fracture Type				
A	**46**	**23%**	**35**	**17.5%**
A2	14		11	
A3	32		24	
B	**70**	**35%**	**78**	**39%**
B1	8		2	
B2	25		37	
B3	37		39	
C	**84**	**42%**	**87**	**43.5%**
C1	5		4	
C2	43		44	
C3	36		39	

Normal variables are presented as means (standard deviations).
Categorical variables are presented as percentage
** Unpaired t-test

Table 2. Soong Grade per Cohort

	Cohort 1: DVR Plate (n=200)		Cohort 2: VA LCP Plate (n=200)		
	N	%	N	%	*P-value*
Soong Grading					*<0.05*
Grade 0	87	43.5%	63	31.5%	
Grade 1	95	47.5%	103	51.5%	
Grade 2	18	9.0%	34	17.0%	

REFERENCES

1. Lutsky K, Boyer M, Goldfarb C. Dorsal locked plate fixation of distal radius fractures. *J Hand Surg Am*. 2013;38(7):1414-1422.

2. Tavakolian JD, Jupiter JB. Dorsal plating for distal radius fractures. *Hand Clin*. 2005;21(3):341-346.

3. Berglund LM, Messer TM. Complications of volar plate fixation for managing distal radius fractures. *The Journal of the American Academy of Orthopaedic Surgeons*. 2009;17(6):369-377.

4. Nana AD, Joshi A, Lichtman DM. Plating of the distal radius. *J Am Acad Orthop Surg*. 2005;13(3):159-171.

5. Soong M, Earp BE, Bishop G, Leung A, Blazar P. Volar locking plate implant prominence and flexor tendon rupture. *J Bone Joint Surg Am*.. 2011;93(4):328-335.

6. Soong M, van Leerdam R, Guitton TG, Got C, Katarincic J, Ring D. Fracture of the distal radius: risk factors for complications after locked volar plate fixation. *J Hand Surg Am*. 2011;36(1):3-9.

7. Selvan DR, Perry D, Machin DG, Brown DJ. The role of post-operative radiographs in predicting risk of flexor pollicis longus tendon rupture after volar plate fixation of distal radius fractures - a case control study. *Injury*. 2014;45(12):1885-1888.

8. Lee DS, Weikert DR. Complications of Distal Radius Fixation. *Orthop Clin North Am*. 2016;47(2):415-424.

9. Orbay JL, Touhami A. Current concepts in volar fixed-angle fixation of unstable distal radius fractures. *Clin Orthop Relat Res*.. 2006;445:58-67.

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

11. Nelson DL, Orbay J, Bindra R. Anatomy of the Volar Distal Radius. 2008, date of reference May 2018; http://eradius.com/AnatomyOfDistalRadius.htm.

12. Limthongthang R, Bachoura A, Jacoby SM, Osterman AL. Distal radius volar locking plate design and associated vulnerability of the flexor pollicis longus. *J Hand Surg Am*. 2014;39(5):852-860.

13. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol*.. 2008;61(4):344-349.

14. Lutsky K, Jimenez M, Rivlin M, Matzon JL, Maltenfort M, Beredjiklian PK. Reliability of the Soong Classification for Volar Plate Position. *J Hand Surg Am* 2016, Vol.41(7): 199-e202

15. Matschke S, Marent-Huber M, Audige L, Wentzensen A. The surgical treatment of unstable distal radius fractures by angle stable implants: a multicenter prospective study. *J Orthop Trauma*. 2011;25(5):312-317.

16. 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;21(5):316-322.

17. Wilson J, Viner JJ, Johal KS, Woodruff MJ. Volar Locking Plate Fixations for Displaced Distal Radius Fractures: An Evaluation of Complications and Radiographic Outcomes. *Hand (N Y)*. 2017:1558944717717505.

18. MacFarlane RJ, Miller D, Wilson L, et al. Functional Outcome and Complications at 2.5 Years Following Volar Locking Plate Fixation of Distal Radius Fractures. *J Hand Microsurg.* 2015;7(1):18-24.

19. 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;91(8):1837-1846.

20. Selles CA, Reerds STH, Roukema G, van der Vlies KH, Cleffken BI, Schep NWL. Relationship between plate removal and Soong grading following surgery for fractured distal radius. *J Hand Surg Eur Vol.* 2018;43(2):137-141.

21. Lutsky KF, Beredjiklian PK, Hioe S, Bilello J, Kim N, Matzon JL. Incidence of Hardware Removal Following Volar Plate Fixation of Distal Radius Fracture. *J Hand Surg Am.* 2015;40(12):2410-2415.

22. Buzzell JE, Weikert DR, Watson JT, Lee DH. Precontoured fixed-angle volar distal radius plates: a comparison of anatomic fit. *The Journal of hand surgery.* 2008;33(7):1144-1152.

23. Casaletto JA, Machin D, Leung R, Brown DJ. Flexor pollicis longus tendon ruptures after palmar plate fixation of fractures of the distal radius. *J Hand Surg Eur Vol.* 2009;34(4):471-474.

24. Selvan DR, Machin DG, Perry D, Simpson C, Thorpe P, Brown DJ. The role of fracture reduction and plate position in the aetiology of flexor pollicis longus tendon rupture after volar plate fixation of distal radius fractures. *Hand (N Y).* 2015;10(3):497-502.

25. Kitay A, Swanstrom M, Schreiber JJ, et al. Volar plate position and flexor tendon rupture following distal radius fracture fixation. *J Hand Surg Am.* 2013;38(6):1091-1096.

26. Wurtzel CNW, Burns GT, Zhu AF, Ozer K. Effects of Volar Tilt, Wrist Extension, and Plate Position on Contact Between Flexor Pollicis Longus Tendon and Volar Plate. *J Hand Surg Am.* 2017;42(12):996-1001

PART II

ANATOMICAL BASIS FOR IMPROVEMENT – PATHO-ANATOMY

3

MRI STUDY ON THE DISTANCE BETWEEN THE DISTAL RADIUS AND THE FLEXOR- AND EXTENSOR TENDONS: IS THERE ANY ROOM FOR ERROR/HARDWARE?

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ABSTRACT

Purpose

To quantify the distances between the cortex of the distal radius and flexor- and extensor tendons.

Methods

We analyzed 50 magnetic resonance images (MRI) of intact wrist without pathology. The distances between the volar cortex and the flexor pollicis longs (FPL), index flexor digitorum profunduns (FDPi), flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) were measured at the level of the watershed line and 3 and 6 mm proximal to this level.

The distances between the dorsal cortex and the extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB), extensor pollicis longus (EPL), extensor indicis proprius (EIP) and the extensor digitorum communis (EDC) were measured at the level of Lister's tubercle and 5 mm distal to this level. Analysis was descriptive.

Results

At the watershed line, the FPL, FDPi, FDP and FDS were located at an average of 3.1 mm, 2.4 mm, 3.6 mm and 5.1 mm respectively volar to the volar cortex. The distances of the FDP and FDSP increased at 3 mm proximal to the watershed line, and increased for all four tendons at 6 mm proximal to the watershed line.

Dorsally, at Listers' tubercle the ECRL, ECRB, EPL, EIP and EDC were identified at an average of respectively 0.7 mm, 0.5 mm, 0.5 mm, 2.6 mm and 3.2 mm dorsal to the dorsal cortex of the distal radius. At 5 mm more distal, these tendons were located on average respectively 1.2 mm, 1.0 mm, 0.7 mm, 1.9 mm and 1.8 mm dorsal to the dorsal cortex.

Conclusion

On the volar side, on average there is enough room for a volar plate when staying proximal to the watershed line. On the dorsal side, there is virtually no room for protruding screws as physical anatomical space is limited to a maximum of 0.7 mm from cortex to tendon, with screw increments being 2 mm.

INTRODUCTION

Despite the change from preferencing volar plating over dorsal plating, the number of complications associated with the use of volar plates cannot be overlooked. Overall complication rates of up to 27% have been reported[1], including tendon irritation, tendon rupture, tenosynovitis, carpal tunnel syndrome, complex regional pain syndrome and nerve palsy[2]. This evidence implies that damage to the soft tissues weakens the success of volar plating. In literature, these complications are largely attributed to interference of prominent hardware with soft tissue, mainly tendons. On the volar side of the wrist prominent plate positioning with respect to the watershed line could cause attrition of the flexor tendons on the volar side, while protruding screws on the dorsal side of the wrist interfere with the extensor tendons. While precautions with hardware such as contouring and beveling of the volar plate, uni-cortical fixation and the insertion of pegs are used, it is not known how much space for error –i.e. Hardware- there is between the cortex of the distal radius and the flexor and extensor tendons respectively. Additionally, a more detailed appreciation of these distances, could guide a surgeon in safe hardware positioning.

3

The reported incidence of tendon related adverse events after volar plating for distal radius fractures is as high as 12%.[1,3-7]. On the volar side of the distal radius, the flexor tendons are at closest proximity to the volar distal radius at an anatomical landmark called the watershed line[8]. Plate prominence caused by distal placement of the plate with respect to the watershed line brings hardware in closer contact with flexor tendons and can result in tendon rupture. Soong et al. Have described the relation between prominent hardware at the watershed line and flexor tendon ruptures.[6] both ruptures of the flexor pollicis longus (FPL) and index finger flexor digitorum profundus (FDPi) tendon have been described in several studies[4,6,9]. The few anatomical studies that have attempted to describe the relation between the volar anatomical structures relevant to volar plating for distal radius fractures did so in cadavers, in which the anatomy is distorted by desiccation and dissection.[8,10,11]

On the dorsal side of the distal radius, protruding screws are easily missed on conventional antero-posterior (AP) and lateral fluoroscopic views as they get obscured by lister's tubercle. The extensor pollices and the extensor digitorum communis on the dorsal side of the distal radius are identified to be at the highest risk after volar plating.[12] no study has measured the actual tendon –cortex distance.

Magnetic resonance imaging (MRI) has been used to enhance our understanding of the surgical anatomy of a number of body regions.[13-16] Agnew et al. have attempted to identify danger zones for flexor tendons in volar plating for distal radius fractures with the use of MRI on two levels of the distal radius.[17] McCann et al. identified the relation between relevant structures on the volar side of the distal radius on MRI scans, however they only described the relation of these structures to the flexor carpi radialis and not to the cortex or in relation with implants.[16]

The purpose if this study is to identify the in vivo distance between the volar cortex of the distal radius and the flexor tendons, and the dorsal cortex of the distal radius and the extensor tendons, at anatomical locations where potential hardware would be in closest proximity to the tendons.

METHODS

After ethical approval from our institutional research committee (protocol #64.18), we used the hospital picture archiving and communication system (PACS) to identify and evaluate all patients that underwent a wrist MRI scan between December 2011 and March 2018. Patients younger than 17 years old were excluded as their growth plate is not fused and because fixed angle volar plating is not relevant to the paediatric population.[16] we only included patients with at least a high quality T1-weighted axial wrist MRI that included all levels of the distal radius needed for the measurements included in this study. Patients with reported pathology to or a condition that could affect the anatomy of the distal radius, flexor and extensor tendons and soft tissue surrounding the distal radius were excluded. All excluded pathology can be found in Table 1. Technically unsatisfactory MRIs that did not permit for accurate measurements were excluded as well. Out of 743 patients, fifty patients met the strict inclusion criteria and were included in this study. At the time of the MRI, the mean age of the patients was 40 (range 17-73). There were 24 (48%) men and 26 (52%) women included. Twenty-one (42%) of the MRI scans were of the left wrist and 29 (58%) of the MRI scans were of the right wrist. Most MRIs had been ordered to investigate ulnar sided wrist pain. As is protocol in our institution, al MRIs were made with the wrist in neutral position in a wrist coil.

The dual-screen viewing technology of PACS software allowed for simultaneous assessment of multidirectional cuts. This allowed us to create a reproducible axial plane in each patient at each of the levels of the distal radius in which measurements were performed. The reconstructed axial plane was parallel to the articular surface of the distal radius: the radial inclination in the coronal axes and the volar tilt in the sagittal axes was used to determine the definitive axial axis (Figure 1). On the volar side of the distal radius, the shortest distances between the volar cortex of the distal radius and the FPL, FDPi, closest FDP and FDS were measured at the level of the watershed line (defined as location were the volar cortex of the distal radius was most prominent on the reconstructed axial slice) and 3 and 6 mm proximal to this level.[16] (Figure 2) on the dorsal side of the distal radius, the shortest distances between the cortex and the ECRL, ECRB, EPL, EIP and the EDC situated closest to the distal radius were measured on the level where Lister's tubercle protruded most on the reconstructed axial slice and 5 mm distal to this level, as this is the location where protruding screws often occur. (Figure 3) To identify the danger zones[17] of the tendons that are reported to be at highest risk, on the volar side of the wrist, the radial to ulnar positions of the FPL and the FDPi were measured in percentages of the total radial to ulnar width of the distal radius at the respective levels by drawing a line parallel to the two most ulnar points of the distal radius, and a line parallel to this line at most radial point of the distal radius and the level of the respective tendon and the volar cortex. (Figure 4) On the dorsal side of the wrist, the radial to ulnar positions of the EPL and the EIP were measured in percentages of the total radial to ulnar width of the distal radius at the respective levels. The circumference of the wrist was measured in the reconstructed axial slice at the level of the watershed line. Measurements were taken in millimeters and rounded to the nearest 0.1 mm.

To determine the inter-observer reliability of this measuring method, two observers independently performed all measurements on 10 MRIs prior to this study. The two observers were radiology and orthopaedic residents, both with over two years of experience in the field of (orthopaedic) surgery. During their learning curve, but before measurements to establish inter observer reliability were performed, they were supervised by a fellow hand surgery. After an excellent inter-observer reliability (icc 0.88 and 0.97 for respectively volar and dorsal tendon-bone distance measurements and icc 0.99 and 0.98 for respectively volar and dorsal width measurements) was established, one observer (orthopaedic surgery resident) performed all measurements on the MRIs of the 50 patients included in this study.

General descriptive statistics on patient gender, injured side, fracture type and age at baseline were gathered and presented as percentages for categorical variables and mean and standard deviation for normal data. Outcome data on distances between the respective tendons and the cortex of the distal radius in mm were presented as mean, standard deviations and range. Ulnar to radial positions of the respective tendons from the sigmoid notch were given in percentages, standard deviations and ranges. Inter-observer agreement was assessed with the intra-class correlation coefficient. Differences between the male and female were analyzed using the unpaired t-test.

Pearson correlation coefficient was used to analyze the relation between measured distance between tendons and cortex on both sides of the wrist, and age of the patient at time of the MRI and circumference of the wrist.

RESULTS

At the watershed line, the FPL, FDPi, FDP and FDS were located at an average of respectively 3.1 mm, 2.4 mm, 3.6 mm and 5.1 mm volar to the volar cortex of the distal radius. At 3 mm proximal to the watershed line, the FPL, FDPi, FDP and FDS were located at an average of 3.0 mm, 3.7 mm, 5.9 mm and 6.0 mm volar to the volar cortex of the distal radius. This distance increased to 4.0 mm, 5.8 mm, 8,5 mm and 7.8 mm at 6 mm proximal to the watershed line.(Figure 2, Table 2) The FPL and FDPi were located at 43% and 64% of the total width of the distal radius from the sigmoid notch at the watershed line, and at 45% and 68% at 3 mm proximal and at 48% and 73% at 6 mm proximal from the watershed line.(Figure 2)

At the level where Lister's tubercle protruded most, the ECRL, ECRB, EPL, EIP and EDC were located at an average of respectively 0.7 mm, 0.5 mm, 0.5 mm, 2.6 mm and 3.2 mm dorsal to the dorsal cortex of the distal radius. At 5 mm distal to Lister's tubercle, these tendons were on average respectively 1.2 mm, 1.0 mm, 0.7 mm, 1.9 mm and 1.8 mm dorsal to the cortex of the distal radius. (figure 3, able 3) the EPL and EIP were located at an average of respectively 59% and 79% of the total width of the distal radius from the sigmoid notch at the level of lister's tubercle. Five mm distal from lister's this was respectively 52% and 75%. (Figure 4).

There was no significant difference in distances of tendons and cortex on both the volar and dorsal aspect of the wrist in men and women (p=0.46 95% ci -0.46 - 1.02). There was also no statistically significant correlation between volar bone-tendon distances and wrist circumference (r=0.10 p=0.49 df=48), age (r=0.23 p=0.12 df=48) or radial to ulnar width of the distal radius at the level of the watershed line (r=0.09 p=0.56 df=48). No statistical significance was detected between the dorsal tendon – bone distances and the wrist circumference (r=0.02 p=0.88 df=48), age (r=0.05 p=0.73 df=48) or radial to ulnar width of the distal radius at the level of the watershed line (r=0.19 p=0.18 df=48).

DISCUSSION

Classically when opting for internal fixation for a distal radius fracture, a plate on the dorsal side of the wrist was the preferred choice for fixation. However, the concomitant rising incidence of extensor tendon complications due to direct contact between these structures and the dorsal plate could not be neglected18. For this reason, a volar approach gained popularity over the past decades and is now the most common used open reduction and internal fixation technique for distal radius fractures. It is believed that on the volar side of the distal radius, more physical space is available to allow for plate positioning. The concave surface of this part of the radius (i.e. The pronator fossa) protects flexor tendon from irritation. Our results show there is approximately three times as much space between the cortex of the distal radius and the tendons on the volar side compared to the dorsal side, which could be an argument in favor of the historical decision to change from dorsal to volar plating.

We have examined a large cohort of patients in order to provide objective, anatomic relationships between the flexor and extensor tendons of the wrist and the bony cortex of the distal radius to quantify how much space the wrist allows for placement of hardware in case of volar plating for distal radius fractures.

The results of this study should be interpreted in the light of its strengths and weaknesses. A major limitation of this study is that the measurements have been performed on static MRIs. The position of the wrist in these MRIs is protocolled in our institution. However, the contact pressure between the FPL and volar plate has been shown to be influenced by the position of the wrist, with an increased contact pressure with increased extension of the wrist[19,20]. These results might indicate a changing distance between all tendons and cortex depending on wrist movement. Further studies, including 4D-MRI could extrapolate on our results by identifying tendon-bone distances in different positions of the wrist. Strengths of this study include its large number of patients, and an analysis of undisturbed anatomy in patients with their wrist positioned in a coil on MRI– rather than cadaveric specimens. Subsequent studies may focus on the relations between the cortex of the distal radius and the tendons in the altered anatomy of patients after volar plating for distal radius fractures, including plate-to-tendon contact as one can imagine that scar formation over the plate would affect the interference with the tendons.

This study shows that on the volar side of the distal radius, the FPL and FDPi are closest to the volar margin of the distal radius and situated within 40% and 70% of the distal radial width. The distance between the tendons and the volar margin of the distal radius, especially of the FPL, does not increase until 6 mm proximal from the watershed line. These results show a slight discrepancy with a previous study describing the location of the FPL and the FDPi in MRIs of 40 patients.[17] our study demonstrates both tendons to be slightly further away (3.0 mm and 3.7 in our study vs 2.6 mm and 2.2

mm found by McCann et al.[17]) from the bone 3 mm proximal from the watershed line. The results were more similar 6 mm proximal to the watershed line. This difference might be attributed to the different axial plane chosen, where we feel our methods of reconstructing an axial plane is better standardized between patients. We do concur with Agnew et al., that there is a high risk area on the volar side of the distal radius located from the watershed line to at least 3 mm proximal from the watershed line and within central 40% to 70% of the distal radial width.

In previous literature, the watershed line has been used as a reference point for safe placement of volar plates. It is argued that plate placement proximal to this line decreases the contact pressure between a volar plate and the FPL[19,20] and allows for safer plate positioning. However, in this study we found the distance between the FPL and the volar cortex decreased slightly from the watershed line and 3 mm proximal to the watershed line, and only increases 6 mm proximal to the watershed line. Hence plate placement just proximal to the watershed line would not be safer than placement at or prominent of the watershed line. Staying 6 mm or more proximal to the watershed line maximizes the distance between the flexor tendons and the plate. Unfortunately, in clinical practice the surgeon is guided by fracture characteristics, which might urge more distal placement of the volar plate. The average thickness of recent generation volar plates ranges around 2.0-2.5 mm[21], which is smaller than the average tendon-bone distance we measured for the tendons on all locations on the volar aspect of the wrist – but the range of distances between the cortex and the tendons for especially the FPL and FDPi started well below 2 mm at the watershed line and 3 mm proximal to the watershed line. So, while the average thickness of recent generation volar plates is thin enough for the average patients, in some cases these plates may interfere with flexor tendons even when placed proximal to the watershed line. When moving the wrist, the tendons might move even closer to the bone.

Additionally, the watershed line is not a straight transverse line, and might be situated more proximal at the level of the FPL sulcus when compared to the ulnar prominence. Hence, if the ulnar prominence is used as reference point for safe plate positioning the FPL might still be in danger. Scope for further work in this area would involve cadaveric analysis of the exact course of the watershed line, its relation to the volar tendons and its relation to safe plate placement.

Limgthongthang et al., have described that even despite optimal plate placement in relation to the watershed line, various volar locking plate designs placed at their perfect position have prominent profiles volar to the watershed line.[10] A combination of these results and the results we found in this study could add to the evaluation of safety of volar plates. Comparable to our in vivo results, the previously mentioned in vitro study[15] described the FPL and the volar edge of the watershed line to be in direct contact. Especially when the volar tilt of the radius is not corrected, a volar plate might still be prominent even when placed in the perfect position. We found the tendons closest to the volar cortex of the distal radius are located in the central area of the volar distal radius, and it seems logical that the profile of a safe plate should take this into account.

On the dorsal side of the wrist, tendons of all compartments are close to the dorsal cortex of the distal radius. Five mm distal from Lister's –the level where screws are located in volar plating for distal radius fractures- all tendons are on average within 2 mm from the dorsal cortex. On average, the EPL is even as close as 0.7 mm. This implies that even screw protrusion of less than 1 mm could cause tendon attrition. The only studies describing the relationship between dorsal screw penetration and tendon related complications, found a clinical correlation between screws protruding 1.5 mm and problems in third and fourth extensor compartments[22,23]. In literature, the use of unicortical screws has been advocated. It has also been suggested to subtract 2 mm from the estimated screw length to protect the extensor tendons. Based on our results we concur with the latter trend, especially given the characteristics of the fixed angle screws used in volar plating for distal radius fractures.

In conclusion, while on average there is enough space for a recent generation volar plate on the volar side of the wrist, one should keep in mind the distance between the volar cortex and the FPL does not increase until 6 mm proximal to the watershed line. Due to the limited space available on the dorsal side – with the EPL as close as 0.7 mm- and the sharp edges of screws now located on this side of the wrist, there is no room for error here.

FIGURE AND TABLE LEGENDS

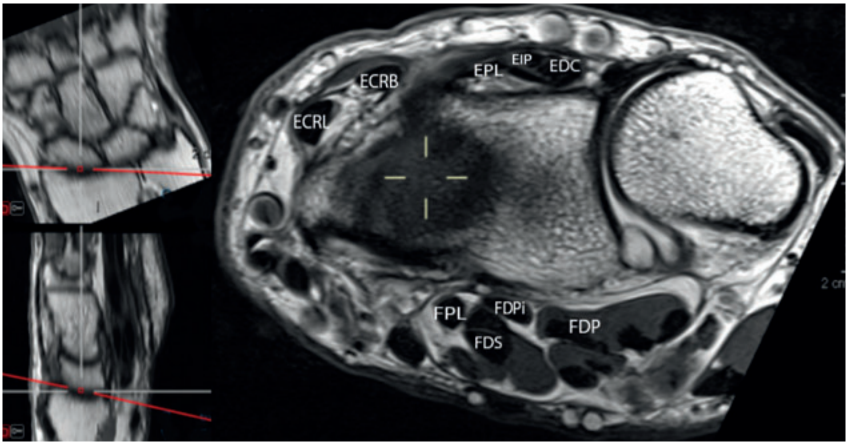

Figure 1. The reconstructed axial plane was parallel to the articular surface of the distal radius: the radial inclination in the coronal axes (left top) and the volar tilt in the sagittal axes (left bottom) was used to determine the definitive axial axis (right).

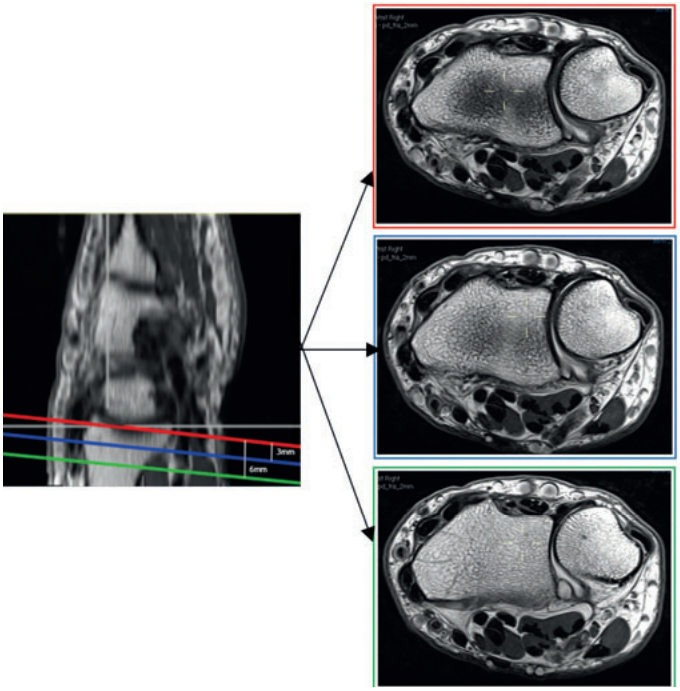

Figure 2. Volar measurements at the level of the watershed line and 3 and 6 mm proximal to the watershed line.

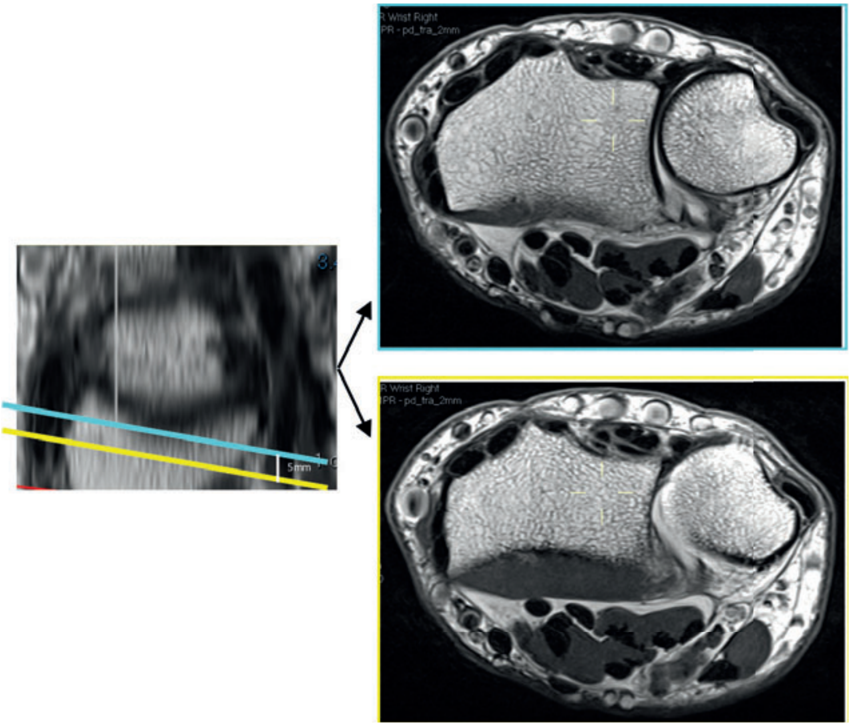

Figure 3. Dorsal measurements at Lister's tubercle (yellow) and 5 mm distal to Lister's tubercle (light blue).

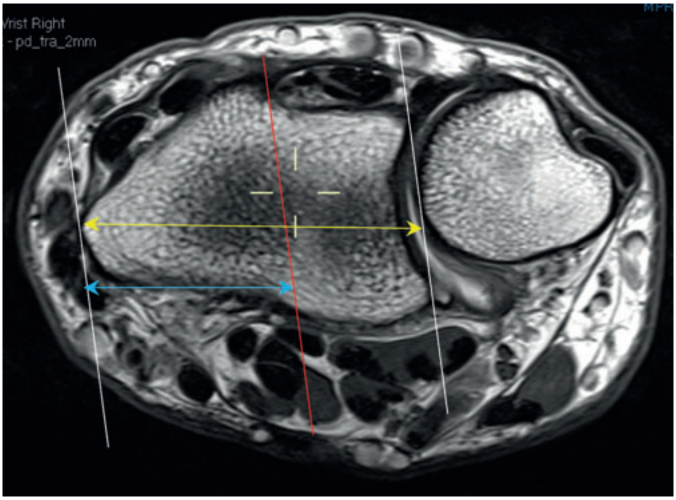

Figure 4. The radial to ulnar positions of the FPL, FDPi, EPL and EIP were measured in percentages of the total radial to ulnar width of the distal radius at the respective levels. The yellow line is the width of the distal radius and the blue line in this case represents the radial to ulnar position of the FDPi.

Table 1. Patients with reported pathology to or a condition that could affect the anatomy of the distal radius, flexor and extensor tendons and soft tissue surrounding the distal radius were excluded. Excluded pathology and conditions included but were not limited to the conditions listed in this table.

Tenosynovitis
Recent trauma
Soft tissue swelling
Both recent and healed distal radius fractures
Malignancy in the wrist
Acute fracture of the carpals or ulna
Active period of rheumatoid arthritis at time of the MRI
Tendon rupture
Cyst/ganglion in structures involved in the study

Table 2.1, 2.2 and 2.3. Volar measurements at the watershed line (1.1, red), 3 mm proximal to the watershed line (1.2, blue) and 6 mm proximal to the watershed line (1.3, green). Colors corresponding to Figure 2.

2.1 Watershedline (in mm)	Mean	SD	Range
FPL	3,1	0,9	0,9-5,2
FPPi	2,4	0,9	1,2-4,8
FDP	3,6	1,4	1,5-7,5
FDS	5,1	1,4	2,9-8,8

2.2 3 mm proximal (in mm)	Mean	SD	Range
FPL	3,0	1,0	1,3-5,1
FPPi	3,7	1,6	1,3-7,6
FDP	5,9	2,3	2,6-11,9
FDS	6,0	1,6	3,4-9,8

2.2 3 6 mm proximal (in mm)	Mean	SD	Range
FPL	4,0	1,3	1,8-6,6
FPPi	5,8	1,9	2,8-10,1
FDP	8,5	2,3	1.0-15,3
FDS	7,8	2,0	4,1-12,4

Table 3.1 and 3.2. Dorsal measurements at Lister's tubercle (2.2, yellow) and 5 mm distal to Lister's tubercle (2.1, light blue). Colors corresponding to figure 3.

3.1 5 mm distal	mean	SD	Range
ECRL	0,7	0,4	0,1-1,9
ECRB	0,5	0,3	0,0-1,2
EPL	0,5	0,4	0,12,8
EIP	2,6	1,3	0,5-8,6
Closest EDC	3,2	1,7	0,7-10,4

3.2 Lister's	mean	SD	Range
ECRL	1,2	0,5	0,3-2,4
ECRB	1,0	0,4	0,0-2,1
EPL	0,7	1,0	0,0-5,3
EIP	1,9	1,0	0,4-6,3
Closest EDC	1,8	1,2	0,1-7,0

REFERENCES

1. 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;21(5):316-322
2. Lattmann T, Dietrich M, Meier C, Kilgus M, Platz A. Comparison of 2 surgical approaches for volar locking plate osteosynthesis of the distal radius. J Hand Surg Am. 2008;33(7):1135-1143
3. Johnson NA, Cutler L, Dias JJ, Ullah AS, Wildin CJ, Bhowal B. Complications after volar locking plate fixation of distal radius fractures. Injury. 2014;45(3):528-533.
4. Drobetz H, Kutscha-Lissberg E. Osteosynthesis of distal radial fractures with a volar locking screw plate system. Int Orthop. 2003;27(1):1-6
5. White BD, Nydick JA, Karsky D, Williams BD, Hess AV, Stone JD. Incidence and clinical outcomes of tendon rupture following distal radius fracture. J Hand Surg Am. 2012;37(10):2035-2040
6. Soong M, Earp BE, Bishop G, Leung A, Blazar P. Volar locking plate implant prominence and flexor tendon rupture. J Bone Joint Surg Am. 2011;93(4):328-335
7. Nunley JA, Rowan PR. Delayed rupture of the flexor pollicis longus tendon after inappropriate placement of the pi plate on the volar surface of the distal radius. J Hand Surg Am. 1999;24(6):1279-1280
8. Orbay J. Volar plate fixation of distal radius fractures. Hand Clin. 2005;21(3):347-354
9. Fuller DJ. The Ellis plate operation for Smith's fracture. J Bone Joint Surg Br. 1973;55(1):173-178
10. Limthongthang R, Bachoura A, Jacoby SM, Osterman AL. Distal radius volar locking plate design and associated vulnerability of the flexor pollicis longus. J Hand Surg Am. 2014;39(5):852-860
11. Imatani J, Akita K, Yamaguchi K, Shimizu H, Kondou H, Ozaki T. An anatomical study of the watershed line on the volar, distal aspect of the radius: implications for plate placement and avoidance of tendon ruptures. J Hand Surg Am. 2012;37(8):1550-1554
12. Azzi AJ, Aldekhayel S, Boehm KS, Zadeh T. Tendon Rupture and Tenosynovitis following Internal Fixation of Distal Radius Fractures: A Systematic Review. Plast Reconstr Surg. 2017;139(3):717e-724e
13. Fucentese SF, von Roll A, Koch PP, Epari DR, Fuchs B, Schottle PB. The patella morphology in trochlear dysplasia--a comparative MRI study. Knee. 2006;13(2):145-150
14. Inan M, Senaran H, Mackenzie WG. Center of the femoral head: A magnetic resonance imaging study. J Pediatr Orthoped. 2006;26(4):471-473
15. Keser S, Savranlar A, Bayar A, Ulukent SC, Özer T, Tuncay Ib. Anatomic localization of the popliteal artery at the level of the knee joint: a magnetic resonance imaging study. Arthroscopy. 2006;22(6):656-659
16. McCann PA, Amirfeyz R, Wakeley C, Bhatia R. The volar anatomy of the distal radius--an MRI study of the FCR approach. Injury. 2010;41(10):1012-1014
17. Agnew SP, Ljungquist KL, Huang JI. Danger zones for flexor tendons in volar plating of distal radius fractures. J Hand Surg Am. 2015;40(6):1102-1105

18. Orbay JL, Fernandez DL. Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report. J Hand Surg Am. 2002;27(2):205-215

19. Wurtzel CNW, Burns GT, Zhu AF, Ozer K. Effects of Volar Tilt, Wrist Extension, and Plate Position on Contact Between Flexor Pollicis Longus Tendon and Volar Plate. J Hand Surg Am. 2017;42(12):996-1001

20. Matityahu AM, Lapalme SN, Seth A, Marmor MT, Buckley JM, Lattanza LL. How placement affects force and contact pressure between a volar plate of the distal radius and the flexor pollicus longus tendon: a biomechanical investigation. J Hand Surg Eur Vol. 2013;38(2):144-150

21. Martineau D, Shorez J, Beran C, Dass AG, Atkinson P. Biomechanical performance of variable and fixed angle locked volar plates for the dorsally comminuted distal radius. Iowa Orthop J. 2014;34:123-128

22. Sugun TS, Karabay N, Gurbuz Y, Ozaksar K, Toros T, Kayalar M. Screw prominences related to palmar locking plating of distal radius. J Hand Surg Eur Vol. 2011;36(4):320-324

23. Bianchi S, van Aaken J, Glauser T, Martinoli C, Beaulieu JY, Della Santa D. Screw impingement on the extensor tendons in distal radius fractures treated by volar plating: sonographic appearance. AJR Am J Roentgenol. 2008;191(5):W199-203.

4

INTERPRETATIONS OF THE TERM "WATERSHED LINE" USED AS REFERENCE FOR VOLAR PLATING

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ABSTRACT

Purpose

The objective of this systematic review is to provide an overview of all interpretations of the definition of the watershed line used in literature.

Methods

The PRISMA G uidelines were followed for this review. A comprehensive search was performed for definitions of the watershed line given in literature. A total of 32 studies giving an explicit interpretation of the definition of the watershed line or anatomical reference for plate positioning in writing and/or imaging were included.

Results

In 32 studies, we found eight different landmarks used to refer to the watershed line or correct plate positioning. Five studies used two different soft tissue landmarks. Six different bony landmarks were described in 24 studies. These could further be subdivided into three anatomical interpretations, described in seven studies: interpretations in which the term watershed line is explained as a distinguishable anatomical line and two surgical interpretations described in 15 studies: interpretations which are purely reflecting the optimal location of the volar plate. One interpretation of the watershed line described in two studies combined both anatomical and surgical landmarks.

Conclusion

The (mis)interpretation of the definition of the term 'watershed line' as described by Orbay is subject to the type of landmarks and purpose used; soft tissue or bony landmarks and anatomical or a surgical purpose. A clear distinction can be made between interpretations using bony landmarks –as the true watershed line is defined- and definitions using soft tissue landmarks –which might represent the reference points surgeons use in clinical practice.

INTRODUCTION

Since their introduction by Orbay in 2000[1], the popularity of volar plates for distal radius fractures has continued to rise[2-8]. Volar plates are less likely to violate soft tissue structures – especially tendons- compared to the traditionally used dorsal plates[7-10] as there is more physical space between the volar side of the distal radius and the flexor tendons. However, potential iatrogenic –flexor– tendon rupture after volar plating is an infrequent but avoidable complication due to malpositioning of the plate[7,11-14]. Retrospective studies report flexor tendon ruptures in up to 12% of patients after volar plating of the distal radius [13-18]. This significant percentage of flexor tendon injuries, combined with the ongoing popularity of volar plating, will result in a marked increase in incidence of flexor tendon problems after volar plating of distal radius fractures.

Orbay proposed the term 'watershed line'-defined as "the transverse ridge that limits the concave surface of the volar radius"- as a reference point for safe plate placement to avoid iatrogenic flexor tendon tenosynovitis and rupture[19]. Later, Nelson and Orbay coined the watershed line as "a theoretical line marking the most volar aspect of the volar margin of the radius.[20] (Figure 1) Subsequently, several articles describe the watershed line as '…closest to the flexor tendons'[21-25].

In 2011, Soong et al. showed that Orbay's definition is indeed clinically relevant, as he found that plates prominent at the watershed line increase the risk of tendon injury. In the control group with plates with more proximal positioning, no ruptures were seen[14]. Soong et al. recommended that surgeons avoid implant prominence at the watershed line [14]. Soong defined the watershed line as "the most prominent part of the volar surface of the distal radius" (Figure 1)[11]. Cadaveric studies show it remains a challenge to place the plate correctly in relation to the watershed line, as the watershed line may not be an easy identifiable distinct line intra-operatively [26,27]. Moreover, as both the Orbay and Soong definitions already illustrate, the interpretation of the term watershed line may vary.

Remarkably, both the initial definition and this subsequent interpretation of the watershed line refer to bony anatomical landmarks, while upon the volar approach –especially in fractured distal radii- these bony landmarks are hard or even impossible to identify. In clinical practice, surgeons may rely on the soft tissue anatomy to orientate themselves to correct placement of the plate – which might influence their interpretation of the watershed line.

This review aims to provide an overview of the interpretations of the definition of the watershed line of the distal radius as provided by Orbay and its anatomical landmarks made in current literature. This will help identify anatomical landmarks that may assist in proper placement of a volar plate when fixing a distal radius fracture in order to avoid flexor tendon injury We hypothesize the interpretation of the term watershed line is not consistent throughout the orthopaedic literature, and may be categorized into "soft tissue" and "bony referenced" references.

METHODS

Our systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines[28]. Keywords included, but were not limited to, 'distal radius fractures', 'volar plating', 'flexor tendon rupture', 'prominence' and 'watershed line'. The full search strategy is in Appendix 1. In collaboration with a clinical librarian, a search was performed in the electronic medical databases Pubmed, Medline, Scopus and Cochrane (inception to December 2018) to identify relevant studies. We supplemented the electronic search with manual searches. The references list of each selected article was checked to identify additional studies missed at the electronic search. EndNote X8 (Boston, USA) software was used to manage the search. All studies published in English with full text availability were included. There were no limitations for year of publication.

Study Selection

First, titles and abstracts were screened on relevance. We included all studies that described volar plating surgical techniques (as part of prospective- and retrospective case series), volar plate placement, anatomy of the volar distal radius and/or the relation between volar plating and flexor tendon pathologies for full text analysis. The full text of these studies was screened for a description or characterization of the watershed line and/or anatomical landmarks for placement, location or positioning of a volar plate. All studies giving an explicit definition of the watershed line or anatomical reference for plate positioning in imaging and/or writing were included. Studies depicting the watershed line in one or more of their figures were also included. Discrepancies were resolved by consensus after discussion between the senior authors.

Data Collection

We collected all interpretations and images of the watershed line or anatomical reference for plate positioning. These were categorized by consensus between all authors. Included studies are described in Table 1 and Figure 2.

RESULTS

Study Selection

The search yielded 343 unique citations. The manual search yielded 7 additional manuscripts, of which after full text review two were included in the study. A total of 32 studies were eventually included. All of these studies described or characterized the watershed line and 19 of these 32 studies depicted the watershed line in a figure as well.

Study Characteristics

Four publications were review articles; two analyzing (tendon) complications after volar plate fixation for distal radius fractures[7,15], and two studies reviewing the anatomy and morphology of the volar distal radius[27,29].

The following eight publications were cadaveric studies focusing on; the anatomy of the distal radius in two[26,30], two analyzing the fit of volar plates[23,31], and four studies evaluating the relation between volar plate and tendons[18,32-34].

Sixteen of the included publications were performed in a clinical setting. Four of these were case series describing tendon injury[21,35-37]. Five studies were imaging studies[22,38-41], four analyzing the anatomy of the distal radius and one the relation between the distal radius and plate fit. Two retrospective studies and one prospective study analyzed the outcome after volar plating for distal radius fractures[17,42,43]. Four clinical studies directly analyzed the relation between plates and flexor tendons[11,44,45].

Four publications were expert opinions on the anatomy of the distal radius or volar plating of distal radius fractures[19,20,24,46].

Outcomes: Interpretations of the Watershed line and references for plate positioning

Thirty-two articles were found describing the watershed line. Several of these interpretations of the term watershed line were identical or shared the same anatomical components. Based on consensus amongst the four senior authors experienced in volar plating for distal radius fractures, all characterizations were grouped according to the flowchart in Table 2.

In general, after comparing all descriptions, 'the watershed line' could be divided into interpretations that are based on 1) soft tissue landmarks[22,40,43,44,47], and 2) interpretations using bony landmarks as the main anatomic reference[11,17,19-21,23,24,26,27,29,31,34,36-38,42,46,48].

We found eight different interpretations of the term 'watershed line'. Two descriptions used soft tissue landmarks; 1) "the distal border of the pronator quadratus"[32,40,43,44] and 2) "the origin of the volar carpal ligaments" [22] as landmark. The descriptions using bony landmarks could further be subdivided into anatomical characterizations: descriptions in which the watershed line is interpreted as a distinguishable anatomical line[11,20,27,36-38,48] and surgical characterizations: descriptions which are purely reflecting the optimal location of the volar plate[17,19,21,23,24,31,34,42,46].

We found three different anatomical descriptions and two different surgical descriptions using bony landmarks. One characterization combined both the anatomical and the surgical description. The three anatomical descriptions using bony landmarks were: 3) "a theoretical line marking the most volar aspect of the distal radius"[11,20,36,37]; 4), "the distal radial physeal scar"[38,48]; and 5) "the most distal edge of the epiphysis"[27]. The two surgical descriptions using bony landmarks were 6) "the ridge that distally limits the concave profile of the pronator fossa"[17,19,21,23,24,34,42,46] and 7): "the ulnar prominence"[31]. The one characterization that combined both anatomical and surgical definitions was 8): "the distal margin of the pronator fossa on the radial side and a hypothetical line between the distal higher and proximal lower lines on the ulnar aspect"[26,29]. All characterizations are written out and depicted in Table 2 and Figure 1. Three descriptions did not fall under one of these subgroups, either because they were contradictive in itself, or failed to present any landmark[33,41,45] (Appendix 2). The most proximal interpretation of the 'watershed line' was "the distal border of the pronator quadratus"[32,40,43,44] and the most distal interpretation was "the most distal edge of the epiphysis"[27] (Figure 2).

Lastly, we found articles giving a very similar written description of the watershed line, but interestingly show great differences between their illustrated versions of these respective lines in their included figures. Additionally, several references[33,41,45] gave contradictive descriptions. For example, Komura et al. only described the distance Orbay proposed to be situated between the joint line and the watershed line, while missing the essential definition of the line itself.[45]

DISCUSSION

The aim of this systematic review was to provide an overview of the different interpretations of the term 'watershed line' as described by Orbay used in literature, in order to answer the clinically relevant question: "what are the anatomical landmarks of the distal radius used for proper placement of a volar plate when fixing a distal radius fracture in order to avoid flexor tendon injury?"

We found 32 articles giving a description of the watershed line, referring to both soft tissue- as well as bony landmarks, which could be further reduced to a total of eight different descriptions when grouping these 32 interpretations according to the used landmarks. Interpretations of the watershed line, and thus landmarks for correct placement of volar plates for distal radius fractures, are not consistent throughout the orthopaedic literature.

Orbay defined the term 'the watershed line' as an anatomical reference for placement of a volar plate for distal radius fractures[19]. As often occurs with new terms, over time alternations to the initial meaning can develop and might lead to incorrect use or understanding of the term[49]. In the index reference of the term 'watershed line', the first definition Orbay used was 'the transverse ridge that distally limits the concave surface of the volar radius" in 2005[19]. Later, on the website of the Eradius in 2008, Orbay in collaboration with Nelson, further defines the watershed line, but this time re-phrased as 'a theoretical line marking the most volar aspect of the volar margin of the radius'[20]. The first characterization is defined by a line that is only distinguishable on the bare bone and thus not visible upon surgery. The latter characterization (the end of the concavity) is a surgical definition: it defines the most distal limit where a volar plate can be placed to keep the volar flexor tendons safe. Also, as the design of most volar plates follows the concave profile, this surgical definition fits the use of the volar plate best.

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Most articles explaining the term watershed line, indeed refer to the definition of Orbay[7,11,17-19,21,22,34,35,37,38,40,41,44,45]. His surgical definition is most used, which may be explained by the fact that this reference is an actual article rather than a website[20], which is easier to find and cite. However, even when naming and referencing Orbay, a wide range of interpretations of the watershed line are given.

Even though the difference between the more anatomical characterization of Orbay and the more surgical characterization of Orbay&Nelson[19,20] is only a few millimeters, these millimeters may exactly be the difference between safe plate placement and plate placement in a prominent position where it can interfere with the flexor tendons and cause iatrogenic tendon rupture.

According to Imatani et al., who performed an anatomical study on 20 cadaveric specimens, the watershed line may not be an easy identifiable distinct line intra-operatively, as it corresponds to the distal margin of the pronator fossa in the lateral half of the volar radius and to a hypothetical line between the distal and proximal lines in the medial ulnar half[26] (Figure 2 dark green line). By combining Orbay's anatomical and surgical characterizations in a cadaveric study, the authors do not give a clear answer as to where the watershed line is located. Although, the authors do argue to use the radial and ulnar bony prominence should be key structures for volar plate placement intra-operatively.

The previous description by Imatani et al.[26] was taken one step further by Opperman et al., who described the ulnar prominence " as a good landmark of the distal limit for safe plate positioning"[31]. The authors agree that this is the most volar part of the volar surface -and therefor located on the watershed line according to the index definition-, as it protrudes more than the radial prominence and is palpable upon surgery, might therefore be the most useful landmark for volar plate placement. Future research should point out how safe placement is clinically when related to this prominence.

Several other articles referred to soft tissue landmarks, mostly the distal border of the pronator quadratus, as a reference of plate position. Not only is the pronator quadratus situated well below both the end of the concave surface of the pronator fossa and the most volar surface of the distal radius, soft tissue structures –especially the pronator quadratus- or often either disrupted by the fracture itself, or dissected upon the volar surgical approach when the plate is placed, or both. It may therefore not be the most reliable landmark to guide a surgeon to safe plate placement.

The fact that we found several articles giving a very similar written descriptions of the watershed line but showing great differences in their illustrated interpretations of the term watershed line, and articles giving contradictive descriptions further adds to our impression that the term watershed line is subject to a great intra- and inter-observer variability and is not easily uniformly defined.

CONCLUSION

The results of this review have demonstrated that the definition of the watershed line provided by Orbay; "a theoretical line marking the most volar aspect of the volar margin of the radius", has been misinterpreted consistently in current literature. This resulted in descriptions of this definition, characterized by soft tissue or bony landmarks that are related to the initial finding. Soong et al. validated the concepts of the watershed line, and defined its consequences in volar plating for distal radius fractures. Opperman et al. highlighted the ulnar most volar bony prominence "as a good landmark of the distal limit for safe plate positioning"[31], which is indeed located on the true watershed line.

FIGURE AND TABLE LEGENDS

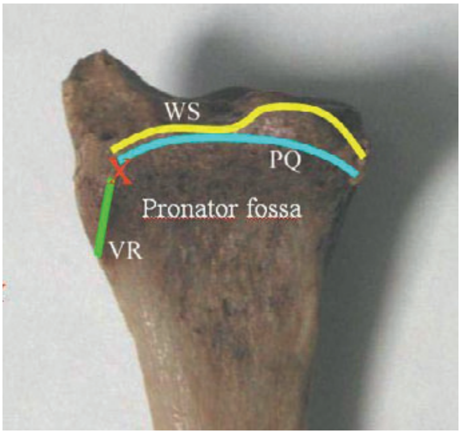

Figure 1: Nelson and Orbay coined the term *watershed line* (WS) as "a theoretical line marking the most volar aspect of the volar margin of the radius", to serve as the distal margin for volar plating to minimize these tendon injuries[19,20,46]. PQ = Pronator Quadratus Line, or PQ Line; WS = Watershed Line; X = Volar Radial Tuberosity; VR = Volar Radial Ridge (with kind permission from http://eradius.com/AnatomyOfDistalRadius.htm[20])

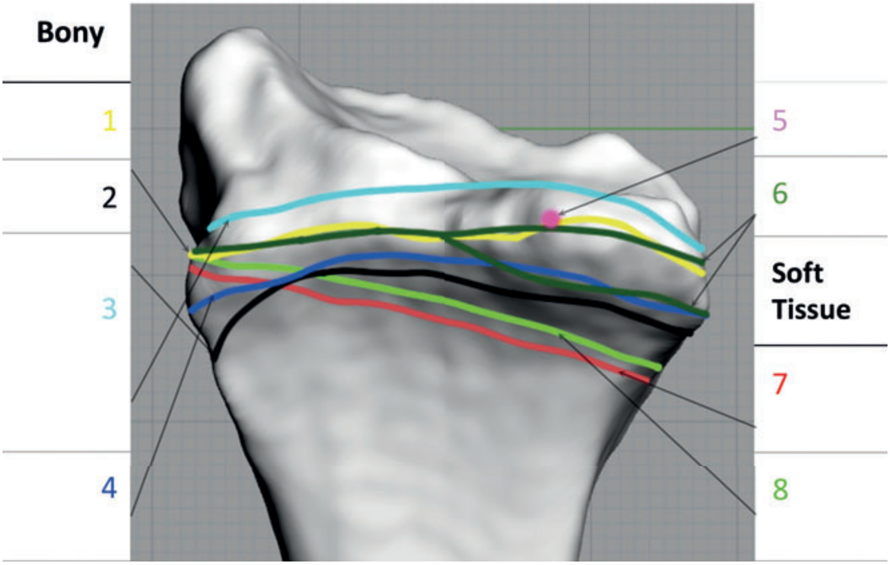

Figure 2: Definitions of line. Colors correspond to characterizations in Table 1. The most proximal landmark used to characterize the watershed line was "the distal border of the pronator quadratus"[32,40,43,44] (red line) and the most distal was "the most distal edge of the epiphysis"[27] (light blue line)

Table 1: Characterizations of the watershed line. Colors correspond to Figure 2.

Number	Description	References
1	A theoretical line marking the most volar aspect of the distal radius	11,20,36,37
2	The distal radial physeal scar	30,47
3	The most distal edge of the epiphysis	27
4	The ridge that limits the concave profile of the pronator fossa OR transverse ridge	17,19,21,23,24,34,42,46
5	The ulnar prominence	31
6	Distal margin of the pronator fossa on the radial side and a hypothetical line between the distal higher rand the proximal lower lines in the ulnar aspect	26,29
7	The distal border of the pronator quadratus muscle	32,40,43,44
8	The origin of the volar carpal ligaments	22

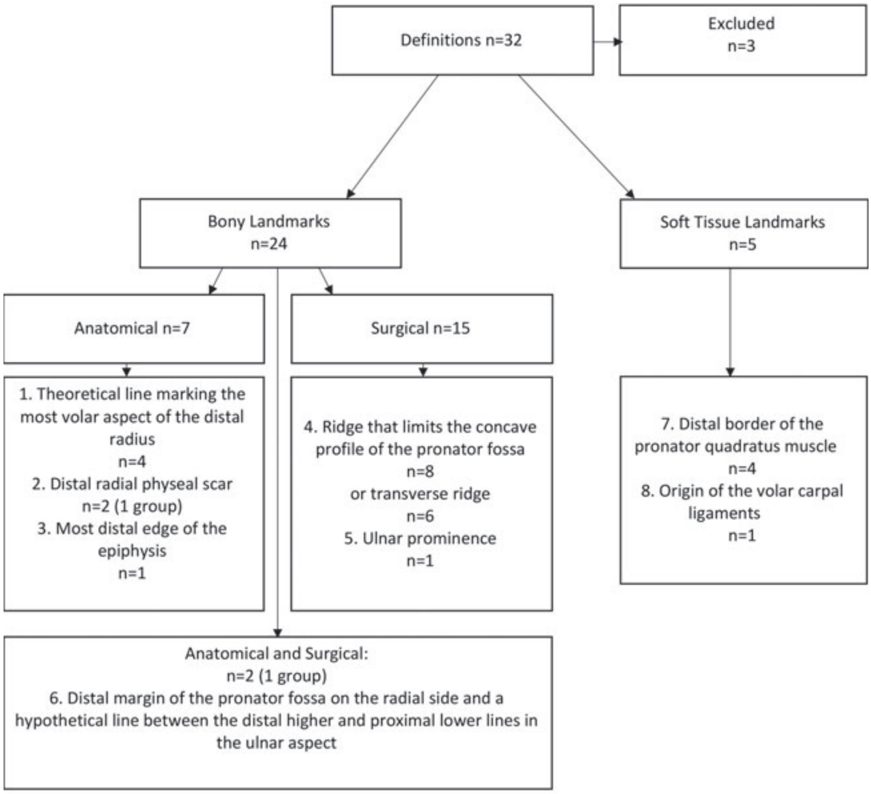

Table 2: Flowchart of eight different definitions of the watershed line / plate position. They are separated based on their soft tissue or bony landmarks, anatomical or surgical relevance. *Excluded due to no clear or contradictory definition.

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REFERENCES

1. Orbay JL. The treatment of unstable distal radius fractures with volar fixation. *Hand surgery : an international journal devoted to hand and upper limb surgery and related research : journal of the Asia-Pacific Federation of Societies for Surgery of the Hand*. 2000;5(2):103-112.
2. Koval KJ, Harrast JJ, Anglen JO, Weinstein JN. Fractures of the distal part of the radius. The evolution of practice over time. Where's the evidence? *The Journal of bone and joint surgery American volume*. 2008;90(9):1855-1861.
3. Kakar S. Clinical Faceoff: Controversies in the Management of Distal Radius Fractures. *Clinical orthopaedics and related research*. 2015;473(10):3098-3104.
4. Koval K, Haidukewych GJ, Service B, Zirgibel BJ. Controversies in the management of distal radius fractures. *J Am Acad Orthop Surg*. 2014;22(9):566-575.
5. Members of the Writing R, Voting Panels of the AUCotToDRF, Watters WC, Sanders JO, Murray J, Patel N. The American Academy of Orthopaedic Surgeons Appropriate Use Criteria on the treatment of distal radius fractures. *The Journal of bone and joint surgery American volume*. 2014;96(2):160-161.
6. Murray J, Gross L. Treatment of distal radius fractures. *J Am Acad Orthop Surg*. 2013;21(8):502-505.
7. Berglund LM, Messer TM. Complications of volar plate fixation for managing distal radius fractures. *The Journal of the American Academy of Orthopaedic Surgeons*. 2009;17(6):369-377.
8. Nana AD, Joshi A, Lichtman DM. Plating of the distal radius. *J Am Acad Orthop Surg*. 2005;13(3):159-171.
9. Lutsky K, Boyer M, Goldfarb C. Dorsal locked plate fixation of distal radius fractures. *J Hand Surg Am*. 2013;38(7):1414-1422.
10. Tavakolian JD, Jupiter JB. Dorsal plating for distal radius fractures. *Hand Clin*. 2005;21(3):341-346.
11. Soong M, Earp BE, Bishop G, Leung A, Blazar P. Volar locking plate implant prominence and flexor tendon rupture. *The Journal of bone and joint surgery American volume*. 2011;93(4):328-335.
12. Selvan DR, Perry D, Machin DG, Brown DJ. The role of post-operative radiographs in predicting risk of flexor pollicis longus tendon rupture after volar plate fixation of distal radius fractures - a case control study. *Injury*. 2014;45(12):1885-1888.
13. Lee DS, Weikert DR. Complications of Distal Radius Fixation. *The Orthopedic clinics of North America*. 2016;47(2):415-424.
14. Soong M, van Leerdam R, Guitton TG, Got C, Katarincic J, Ring D. Fracture of the distal radius: risk factors for complications after locked volar plate fixation. *The Journal of hand surgery*. 2011;36(1):3-9.
15. Asadollahi S, Keith PP. Flexor tendon injuries following plate fixation of distal radius fractures: a systematic review of the literature. *Journal of orthopaedics and traumatology : official journal of the Italian Society of Orthopaedics and Traumatology*. 2013;14(4):227-234.
16. Bentohami A, de Burlet K, de Korte N, van den Bekerom MP, Goslings JC, Schep NW. Complications following volar locking plate fixation for distal radial fractures: a systematic review. *The Journal of hand surgery, European volume*. 2014;39(7):745-754.

17. 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. *Journal of orthopaedic trauma*. 2007;21(5):316-322.

18. Limthongthang R, Bachoura A, Jacoby SM, Osterman AL. Distal radius volar locking plate design and associated vulnerability of the flexor pollicis longus. *The Journal of hand surgery*. 2014;39(5):852-860.

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

20. Nelson DL, Orbay J, Bindra R. Anatomy of the Volar Distal Radius. 2008; http://eradius.com/AnatomyOfDistalRadius.htm.

21. Adham MN, Porembski M, Adham C. Flexor tendon problems after volar plate fixation of distal radius fractures. *Hand (New York, NY)*. 2009;4(4):406-409.

22. Agnew SP, Ljungquist KL, Huang JI. Danger zones for flexor tendons in volar plating of distal radius fractures. *The Journal of hand surgery*. 2015;40(6):1102-1105.

23. Buzzell JE, Weikert DR, Watson JT, Lee DH. Precontoured fixed-angle volar distal radius plates: a comparison of anatomic fit. *The Journal of hand surgery*. 2008;33(7):1144-1152.

24. Im JH, Lee JY. Pearls and Pitfalls of the Volar Locking Plating for Distal Radius Fractures. *The journal of hand surgery Asian-Pacific volume*. 2016;21(2):125-132.

25. Kitay A, Swanstrom M, Schreiber JJ, et al. Volar plate position and flexor tendon rupture following distal radius fracture fixation. *The Journal of hand surgery*. 2013;38(6):1091-1096.

26. Imatani J, Akita K, Yamaguchi K, Shimizu H, Kondou H, Ozaki T. An anatomical study of the watershed line on the volar, distal aspect of the radius: implications for plate placement and avoidance of tendon ruptures. *The Journal of hand surgery*. 2012;37(8):1550-1554.

27. Obert L, Loisel F, Gasse N, Lepage D. Distal radius anatomy applied to the treatment of wrist fractures by plate: a review of recent literature. *Sicot-j*. 2015;1:14.

28. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*. 2009;62(10):1006-1012.

29. Imatani J, Akita K. Volar Distal Radius Anatomy Applied to the Treatment of Distal Radius Fracture. *Journal of wrist surgery*. 2017;6(3):174-177.

30. McCann PA, Amirfeyz R, Wakeley C, Bhatia R. The volar anatomy of the distal radius - An MRI Study of the FCR approach. *Injury*. 2010;41(10):1012-1014.

31. Oppermann J, Wacker M, Stein G, et al. Anatomical fit of seven different palmar distal radius plates. *Archives of orthopaedic and trauma surgery*. 2014;134(10):1483-1489.

32. Goorens CK, Van Royen K, Grijseels S, et al. Ultrasonographic evaluation of the distance between the flexor pollicis longus tendon and volar prominence of the plate as a function of volar plate positioning and pronator quadratus repair - A cadaver study. *Hand surgery & rehabilitation*. 2018.

33. Matityahu AM, Lapalme SN, Seth A, Marmor MT, Buckley JM, Lattanza LL. How placement affects force and contact pressure between a volar plate of the distal radius and the flexor pollicus longus tendon: a biomechanical investigation. *The Journal of hand surgery, European volume*. 2013;38(2):144-150.

34. Tanaka Y, Aoki M, Izumi T, Fujimiya M, Yamashita T, Imai T. Effect of distal radius volar plate position on contact pressure between the flexor pollicis longus tendon and the distal plate edge. *The Journal of hand surgery*. 2011;36(11):1790-1797.

35. Cross AW, Schmidt CC. Flexor tendon injuries following locked volar plating of distal radius fractures. *The Journal of hand surgery*. 2008;33(2):164-167.

36. Rajeev AS, Sreverthana S, Harrison J. Rupture of Flexor Pollicis Longus Tendon: A Complication of Volar Locking Plating of the Distal Radius. *European journal of trauma and emergency surgery : official publication of the European Trauma Society*. 2010;36(4):385-387.

37. Valbuena SE, Cogswell LK, Baraziol R, Valenti P. Rupture of flexor tendon following volar plate of distal radius fracture. Report of five cases. *Chirurgie de la main*. 2010;29(2):109-113.

38. McCann PA, Amirfeyz R, Wakeley C, Bhatia R. The volar anatomy of the distal radius--an MRI study of the FCR approach. *Injury*. 2010;41(10):1012-1014.

39. Oura K, Oka K, Kawanishi Y, Sugamoto K, Yoshikawa H, Murase T. Volar morphology of the distal radius in axial planes: a quantitative analysis. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*. 2015;33(4):496-503.

40. Pall Singh TS, Sadagatullah AN, Yusof AH. Morphology of distal radius curvatures: A CT-based study on the Malaysian Malay population. *Singapore medical journal*. 2015;56(10):562-566.

41. Yoneda H, Iwatsuki K, Hara T, Kurimoto S, Yamamoto M, Hirata H. Interindividual anatomical variations affect the plate-to-bone fit during osteosynthesis of distal radius fractures. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*. 2016;34(6):953-960.

42. Wilson J, Viner JJ, Johal KS, Woodruff MJ. Volar Locking Plate Fixations for Displaced Distal Radius Fractures: An Evaluation of Complications and Radiographic Outcomes. *Hand (New York, NY)*. 2017:1558944717717505.

43. Ahsan ZS, Yao J. The importance of pronator quadratus repair in the treatment of distal radius fractures with volar plating. *Hand (New York, NY)*. 2012;7(3):276-280.

44. Kara A, Celik H, Bankaoglu M, Oc Y, Bulbul M, Sugun TS. Ultrasonic Evaluation of the Flexor Pollicis Longus Tendon Following Volar Plate Fixation for Distal Radius Fractures. *The Journal of hand surgery*. 2016;41(3):374-380.

45. Komura S, Tanahashi H, Yamada Y, Yokoi T, Nonomura H, Suzuki Y. Distal plate placement for distal radius fractures limits wrist motion. *European Journal of Orthopaedic Surgery and Traumatology*. 2012;22(1):29-34.

46. Orbay JL, Touhami A. Current concepts in volar fixed-angle fixation of unstable distal radius fractures. *Clinical orthopaedics and related research*. 2006;445:58-67.

47. Goorens CK, Van Royen K, Grijseels S, et al. Ultrasonographic evaluation of the distance between the flexor pollicis longus tendon and volar prominence of the plate as a function of volar plate positioning and pronator quadratus repair — A cadaver study. *Hand Surgery and Rehabilitation*. 2018.

48. McCann PA, Clarke D, Amirfeyz R, Bhatia R. The cadaveric anatomy of the distal radius: implications for the use of volar plates. *Annals of the Royal College of Surgeons of England*. 2012;94(2):116-120.

49. Somford MP, Nieuwe Weme RA, van Dijk CN, FF IJ, Eygendaal D. Are eponyms used correctly or not? A literature review with a focus on shoulder and elbow surgery. *Evidence-based medicine*. 2016;21(5):163-171.

4

PART III

TACKLING THE DORSAL PROBLEM - IMPROVING IMAGING TECHNIQUE

5

VOLAR PLATING: IMAGING MODALITIES FOR THE DETECTION OF SCREW PENETRATION

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ABSTRACT

Background

Volar plating for distal radius fractures exposes the risk of extensor tendon rupture, mechanical problems and osteoarthritis due to protruding screws.

Purposes

The purpose of this review was to identify the best intra-operative diagnostic imaging modality to identify dorsal and intra-articular protruding screws in volar plating for distal radius fractures.

Methods

The PRISMA guidelines were followed for this review. In vitro and in vivo studies that analysed the reliability, efficacy and/or accuracy of intra-operatively available imaging modalities for the detection of dorsal or intra-articular screw protrusion after volar plating for distal radius fractures were included.

Results

Described additional imaging modalities are additional fluoroscopic views (Pronated Views, Dorsal Tangential View, Radial Groove View, Carpal Shoot Through View), 3D and rotational fluoroscopy and ultrasound. For detection of dorsal screw penetration, additional fluoroscopic views show better results than conventional views. Based on small (pilot) studies, ultrasound seems to be promising. For intra-articular screw placement, 3D or 360 degrees fluoroscopy shows better result than conventional views.

Conclusions

Based on this systematic review the authors recommend the use of at least one of the following additional imaging modalities to prevent dorsal protruding screws; Carpal Shoot Through View, Dorsal Tangential View or Radial Groove View. Tilt views are recommended for intra-articular assessment. Of all additional fluoroscopic views, the Dorsal Tangential View is most studied and proves to be practical and time efficient, with higher efficacy, accuracy and reliability compared to conventional views.

INTRODUCTION

Volar plating for distal radius fractures have demonstrated to reduce the incidence of postoperative iatrogenic extensor tendon injuries compared to dorsal plating[1]. However, with this technique the average reported incidence of postoperative complications is still as high as 16.5%[2,]. The overall reported complication rate of extensor tendon rupture is as high as 6% [3]. Based on findings during surgical re-exploration for tendon transfer, prominent screws are thought to be a cause of extensor tendon ruptures[4]. One study found that screws protruding as much as 6.5 mm may be hidden by Lister's tubercle on standard lateral views[5]. Also, distal screws in comminuted fracture patterns can cut through the subchondral bone and penetrate the radiocarpal joint[3]. The articular surface of the distal radius is biconcave and tilted in 2 planes[6], which makes it difficult to show screws to be intra- or extra-articular on radiographic views. Depth gauge measurement in distal radius fractures is difficult, especially with dorsal multi-fragmentation[7,8] . The use of depth gauge for initial measurement of screw length results in the screws penetrating the cortex in approximately 9.1-9.4% of locking screws placed in volar plates[8,9].

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Intraoperative detection of dorsal protruding or intra-articular placed screws gives the surgeon the opportunity to change the screw and thereby prevent the risk of postoperative iatrogenic complications and prevent the risk of reinterventions. The objective of this study is therefor to perform a systematic review of studies on intraoperative diagnostic imaging strategies with respect to the detection of both dorsal and intra-articular screw penetration in volar plating for distal radius fractures. The specific goal of this review was to determine what fluoroscopic view or imaging modality has the highest observer reliability, diagnostic efficacy and/or accuracy based on both in vitro and in vivo studies for detection of dorsal protruding screws and of intra-articular protruding screws.

METHODS

Our systematic review was conducted and reported in the accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines[10]

Search Strategy

Keywords included: 'radius fractures', 'volar plating', and 'screw penetration'. The full search including all keywords can be found in Appendix 3. There were no limitations for year of publication. With help of a medical librarian we performed a comprehensive search of five electronic medical databases: MEDLINE, Pubmed, SCOPUS, Web of Science and Cochrane in June 2018 to identify relevant studies.

To ensure comprehensive searches, search strategies were individualised to each electronic database. The electronic search was supplemented with manual searches. The references list of each selected article was checked to identify additional studies missed at the electronic search. We did not include grey literature. EndNote X8 software was used to manage the search and remove duplicates. We included all retrospective- and prospective in vitro- and in vivo studies analysing imaging strategies to detect protruding screws in distal radius fractures treated with volar plating in models, cadavers and/or adult patients that reported diagnostic performance characteristics (i.e. intra- and inter-observer-reliability, efficacy and/or sensitivity, specificity, and/or accuracy) of respective fluoroscopic views, additional imaging modalities or a combination of these. We included in vitro studies with and without fractured distal radii and in vivo studies of extra- and intra articular fractures. All studies published in English with full text available were included.

Study Selection

Titles and abstracts were screened on relevance by two independent researchers. Discrepancies were resolved by consensus after discussion between the two reviewers and a third researcher. Both authors examined the full-text papers for eligibility, and cases of doubt were sorted out by discussion with the co-authors.

Quality Assessment

We assessed the quality of each included study in duplicate by having two reviewing authors using the 'User's Guide to the Surgical Literature, how to use an Article about a Diagnostic Test', by Bhandari et al[11]. This evaluation assesses six aspects of methodological quality. Primary guides include (1) whether the clinicians faced diagnostic uncertainty and (2) whether there was an independent, blind comparison with a reference study. The secondary guidelines focus on (3) whether the results of the test being evaluated influence the decision to perform the reference standard and (4) whether the methods for performing the tests were described in sufficient detail to permit replication. Regarding the results, it evaluates if (5) the likelihood ratios are being calculated or the data necessary for this calculation are provided. It also evaluates if (6) the results aid in caring for patients in the clinical setting.

Results of the quality assessment can be found in Table 1.

Data Collection

We collected information pertaining to study characteristics, including general study descriptives, description of the imaging modality, information regarding the reference standard and reported outcomes. This data is represented in a pre-defined database. The database is enclosed in Appendix 4 (for dorsal screw penetration) and 5 (for intra-articular screw penetration). Especially for studies reporting on dorsal screw penetration, different outcomes to report on accuracy were presented. As it is relatively easy to change a screw peri-operatively –even if it is falsely showing to protrude– we opted to present the sensitivity of additional modalities to compare their accuracy in these cases.

Statistical analysis and data synthesis

To find the best intraoperative modality to detect protruding screws in volar plating for distal radius fractures, we aimed to analyse the intra- and inter-observer-reliability, efficacy and/or sensitivity, specificity, and accuracy of available modalities. Where applicable, data was pooled and a meta-analysis for sensitivity and efficacy was performed. Since there was substantial heterogeneity in the outcomes of the studies, we refrained from performing a formal meta-analysis that directly tests for differences in outcomes among the various treatment options. We elected to merely summarize the outcomes per imaging modality. Summary outcomes per imaging modality are reported in Tables 2, 3, 4 and 5.

The search yielded 163 citations, of which we included 47 studies after title and abstract screening. Thirteen studies were excluded based on full text review (Appendix 6). Thirty-four articles met criteria after full text review and were included in our systematic review. The characteristics of individual studies can be found in Appendix 4 and 5.

Quality assessment

The studies included in this review were diverse. The methodological quality of the included studies is presented in Table 1.

RESULTS

Imaging Modalities

All studies comparing AP and lateral views- to additional views (Oblique, DTV, CST, RGV) or additional imaging modalities (360 degrees- or 3D fluoroscopy and US) found additional views and imaging modalities obtain better results compared to only conventional fluoroscopic views. Additional imaging modalities included additional fluoroscopic views in twenty-seven studies, 360 degrees fluoroscopy in one study, rotational fluoroscopy in one study and US in seven studies. We interpreted the 'Hoya view', the 'Skyline view' and the 'Dorsal Horizon View' to be the same as the 'Dorsal Tangential View' (DTV), which was studied in a total of 19 studies.

DORSAL SCREW PENETRATION

A total of 27 studies analysed imaging modalities detecting dorsal screw penetration. One of these studies analysed dorsal and intra –articular screw penetration simultaneously. Thirteen were in vitro (cadaveric-) studies, and 13 were in vivo (clinical-) studies. Additionally, one study had an in vitro and an in vivo component. Study characteristics of all studies reporting on the detection of dorsal screw penetration can be found in Appendix 4.

In Vitro – Cadaveric

Fourteen studies reported on imaging modalities for detection of dorsal screw penetration in a cadaveric setting[7-9,12-22].

Reliability

Four studies analysed the reliability of additional views or imaging modalities [7,13,14,17]. The lowest inter-observer reliability was found for oblique pronated views[7] and AP views[7,13]. One study analysing the inter-observer reliability of US found an agreement between observers that could be attributed to chance for US (ICC=-0.0129) when comparing the results of three observers using DTV and US to detect DSP in ten cadaveric wrists[17]. The inter-observer reliability of DTV ranged from K=0.44 to K=0.91[7,13,17]. One study found an inter-observer reliability for CST of 0.66 when analysing the results of 10 observers interpreting the views made of one model.[7] All studies analysing intra- and inter-observer reliability of conventional and additional views used premade views, made by the researchers, rather than including the positioning of the wrist by the observers in their analysis.

Reliability per imaging modality can be found in Table 2.

Efficacy

No cadaveric studies have analysed the efficacy of imaging modalities for detection for dorsal screw penetration.

Accuracy

Fourteen studies have reported on the accuracy of imaging modalities in a cadaveric setting[7-9,12-22]. Two of these studies did not describe their used reference standard[14,17], all other studies used direct observation of screw penetration as reference standard.

The lowest ranges of sensitivity were described for AP[7] (12%, one study involving ten screws), and oblique pronation[7,13,14] (range, 12%-65%, three studies involving a total of 302 screws). A wide range of sensitivity was found for both lateral[7,9,13,15,18] (16%-96%, five studies involving a total of 436 screws) and oblique pronation[7,13,14] (range, 0%-88%, 3 studies involving a total of 302 screws). The reported sensitivity of RGV was 63%[20] (one study involving 32 screws), of CST 78%-86%[7,8] (2 studies involving a total of 136 screws). A sensitivity of up to 100% was found for both DTV[7-9,13-15,17-21] (range 51%-100%, a total of 11 studies involving a total of 739 screws) and US[12,16,17,19] (range 43,3%-100%, 4 studies involving a total of 129 screws).

Sensitivity per imaging modality can be found in Table 4.

Meta-analysis

Data of nine studies could be included in a meta-analysis analysing the sensitivity of additional fluoroscopic views. In this meta-analysis, the DTV showed a sensitivity of 91% for the detection of dorsal screw penetration[6,9,15,17,18,21,23-25]. Sensitivity for the detection of dorsal screw penetration of lateral fluoroscopic views was 81%[9,15,18]. Combined results of two studies showed a sensitivity of 54%, specificity of 100% and accuracy of 63% for US[12,17].

In vivo – Clinical

Thirteen studies analysed imaging modalities detecting dorsal screw penetration in a clinical setting[6,16,23-33].

Reliability

Brunner et al. performed the only clinical study in this review that reported on reliability[25]. They analysed the inter- and intra- observer reliability of three blinded observers on the screw tip cortex distance measurements of fluoroscopic DTV images and CT reconstructions of 22 patients. This study showed an inter observer reliability of ICC=0.72 and intra observer reliability of ICC=0.77 for measurements on DTV.

Reliability per imaging modality can be found in table 2.

Efficacy

Eleven clinical studies reported numbers that indicate efficacy of imaging modalities detecting dorsal screw penetration in a clinical setting [6,16,23,25,27-33]. DTV is reported to lead to a change in intraoperative management in up to 27% of patients [23,25,27,29,32]. Pooled data for the efficacy defined as cases with changed management due to DTV is 20.7%, in a total of 163 patients [6,27,29,33]. One study analysing the efficacy of US found 25.7% of all screws to be protruding in 46 patients[30].

The CTS showed an efficacy of 17%in a prospective study of 42 patients[28]. The RGV detected DSP in 14% of the patients in one study involving 91 patients[31].

Efficacy per imaging modality can be found in Table 3.

Accuracy

Five clinical studies analysed the accuracy of additional imaging techniques for dorsal screw penetration in a clinical setting[23,24,26,31,34]. The lowest reported sensitivity is 16.2% for pronated oblique views and 42% for lateral views in a study comparing lateral views, pronated views, supinated views and DTV in 47 patients using ultrasound as reference standard[34]. The highest reported sensitivities were found for the RGV and US. A reported sensitivity of RGV of 95% was found in one study analysing 93 patients with CT-scan as reference standard[31]. Again, a reported sensitivity of 100% was found for US, however this was only in one study that analysed 9 patients with symptoms of tendon pathology, with surgery as reference standard[26]. Sensitivity of DTV ranged from 58.3%-70%[23,24,34]. Ganesh et al. performed a retrospective study of 22 non-consecutive patients with intraoperative DTV and postoperative CT as reference standard. They found a sensitivity of 67% for the DTV[23].

Sensitivity per imaging modality van be found in Table 4.

INTRA-ARTICULAR SCREW PENETRATION

Nine studies analysed imaging modalities detecting intra-articular screw penetration[7,12,35-41]. Six studies were in vitro (cadaveric-) studies, and three were in vivo (clinical-) studies. Study characteristics of all studies reporting on the detection of intra-articular screw penetration can be found in Appendix 5.

In Vitro – Cadaveric

Six studies analysed imaging modalities for detection of intra-articular screw penetration in a cadaveric setting[7,12,35,36,38,40].

Reliability

The only cadaveric study including intra-articular screw detection in its analysis is the study of Poole et al[7], which pooled numbers for dorsal and intra articular screw detection. For results see Cadaveric-Reliability for dorsal screw penetration.

Efficacy

No cadaveric studies have analysed the efficacy of imaging modalities for detection for intra-articular screw penetration.

Accuracy

Six studies analysed the accuracy of imaging modalities for intra-articular screw penetration in a cadaveric setting[7,12,35,36,38,40]. Tweet et al. reported on the sensitivity of lateral and AP views when using direct visualisation as reference standard, which were respectively 61% and 93%[35]. For both views a low specificity was found in another study when using the same reference standard, respectively 10% and 30%[38]. Both studies found good results of additional 11 degrees AP views: a sensitivity of 91%[35] and a specificity of 100%[38]. Tweet et al. also found a sensitivity of 93% for 360 degrees fluoroscopy[35]. Surprisingly, they found a sensitivity for elevated lateral views of only 63%, however they did not label the views they showed the observers as elevated which might have influenced the outcomes. 3D fluoroscopy was analysed in one study using CT-scan as reference standard[40]. In this study, a sensitivity of 68% for 3D fluoroscopy was found. By adding Digital Volume Tomography, the sensitivity increased to 88%.

5

Sensitivity, specificity and/or accuracy per imaging modality can be found in table 5.

In Vivo – Clinical

Three studies analysed imaging modalities for detection of intra-articular screw penetration in a clinical setting[37,39,41].

Reliability/ Efficacy

No clinical studies have analysed the reliability or efficacy of imaging modalities for detection of intra-articular screw penetration.

Accuracy

The accuracy for the detection of intra-articular screw penetration is reported in three clinical studies[37,39,41]. Kumar et al. reported only tilted lateral and AP views correctly showed no screws to penetrate the joint in 10 patients, which would result in a specificity of 100%[37]. No reference standard was described in this study. Pace and Cresswell retrospectively analysed 186 patients and found that in half of these patients' screws appeared to be intra-articular in standard AP and lateral views, while tilted views of only 8 patients showed screws to appear intra-articular[39]. They assumed only these 8 to have true intra-articular screw penetration, however do not describe reference standard.

Patel et al. performed a survey of conventional and tilt views of 34 patients among 65 physicians[41]. They found that adding a 30 degree tilt lateral view to lateral and AP views increases the accuracy by 19%[41].

Sensitivity, specificity and/or accuracy per imaging modality can be found in Table 5.

DISCUSSION

The purpose of this review was to identify the best Evidence-Based intraoperative diagnostic imaging strategy, based on reliability, efficacy and accuracy to identify dorsally protruding screws and intra-articular placed screws in volar plating for distal radius fractures based on in vitro cadaveric- and on in vivo clinical studies.

The results of this study should be interpreted in the light of its limitations. As there was a large heterogeneity between all the included studies, a direct comparison is hard to make. This review also reports on separate additional modalities, while clinical practice might require a combination of additional modalities. Most studies included only a small number of patients or cadavers, and a majority of the clinical studies had a retrospective design, lacked a reference standard or seemed to be biased. If a reference standard was used, this was often CT-scan, which in itself is a questionable golden standard especially for intra-articular placed screws given the cartilage layer situated in the joint.

Conventional fluoroscopic AP and lateral views are still commonly used as final check of hardware placement. However, several authors have stated the limitations of these conventional views[14,21,27,32]. The results of this systematic review show AP and lateral views to be inferior in all studies where they were compared to another modality. For intra-articular screw placement, these views are insufficient as well, often projecting screws to be intra-articular while they are not [37,38].

Oblique views in 45 degrees supination or pronation align the X-ray beam with the natural tilt of the dorsal cortex, which could allow for better detection of DSP. The 45 degrees supination view has been described to best detect DSP in the 1st and 2nd dorsal compartment[5,7,14,25]. The 45 degrees pronation view has been described to be accurate in the 4th compartment, but only slightly better than the DTV[32]. However, these views are sensitive only for isolated screw positions, and do not image the third extensor compartment[14].

In the past years, several additional views have been described to detect dorsal screw penetration. We found the Dorsal Horizon View, Tangential View, Skyline View and Hoya View to be the same as the Dorsal Tangential View (DTV). Several authors have described this view to be the most reliable view to detect dorsal screw penetration in the 3rd and in some studies also the 4th compartment[14,23,32]. In contrast, Giugale et al described an increased accuracy of the DTV in evaluation to more radial screws[18]. Another study found supinated oblique views to be reliable for the radial region of the distal radius, RGV for the central region and DTV for the ulnar region while DSP in the ulnar region was difficult to identify with oblique view[20]. A third study found DTV to be most sensitive in the central region, compared to the ulnar and radial region[15].

However, the disagreement between accuracy of the DTV in the ulnar and radial region could be independent of the benefit of the DTV. It has been suggested that the central screws are more likely to include the EPL in their trajectory[42]. Protrusion as small as 1.5 mm has been described to be associated with tendon pathology, particularly in those screws that threaten the 3rd or 4th dorsal compartments[9,30]. Based in this evidence, the improved sensitivity of the DTV in a cadaveric setting in the identification of a small amount of dorsal cortex perforation through the central holes highlights its true benefit[18]. However, small, non-consecutive or retrospective clinical series reported a lower sensitivity of DTV[23,24]. This could indicate the DTV is a better "rule out" indicator than a "rule in" indicator[18].

Limitations of the DTV include the fact that it cannot (always) be a perfect dorsal tangential view due to the volume of the forearm soft tissues[43]. Also, the variability of the angle in which the screws are positioned limits the visualisation of the same transversal plane. Additionally, the accuracy of the DTV decreases as inclination of the forearm deviates from 15 degrees relative to the axis of the X-ray beam[18,21]. There is also a potential for overexposure of the image, as the image intensifier has difficulty regulating radiation dose based on perceived density[8,28]. This would result in the need to obtain more images and therefore more exposure to radiation. Stoops et al found less images needed to obtain an accurate CST view[8].

The CST view is also reported to be efficacious and reliable in detecting dorsal screw penetration in the 1st, 3rd and 4th compartment[7]. A recent cadaveric study comparing the CST to the DTV, found the CST to me more sensitive[8]. However, the accuracy nor the reliability of this view has been evaluated in a clinical setting. The Radial Groove View has also proven to have a high sensitivity in one cadaveric study[44], and might be most useful in the proximal halve of the EPL groove[20].

Overall, even though additional views improve the detection of dorsal screw penetration compared to lateral views alone, none of these views has proved to be perfect. Furthermore, according to Vaiss et al. additional views add to radiation exposure and surgical time[29]. It has been suggested US might be a better modality to analyse dorsal screw penetration, as it is safe and easily available in operating rooms. Gurbuz et al. found US to be equally accurate to the DTV for protrusion in the 2nd and 3rd compartment, and superior to the DTV in the 4th compartment[19]. One recent study did report a poor inter-observer agreement for US, which implies the use of US is highly user-dependant. Even though US does not expose to additional radiation, the authors of this review feel the set-up of US is more time consuming than additional fluoroscopy.

With regard to intra articular screw penetration, conventional views are mostly described to falsely show screws to be protruding intra articular on conventional views[37-39]. Described additional imaging modalities to detect intra articular screws are tilt views, wrist series, tangential AP and lateral views, 360 degrees fluoroscopy, 3D fluoroscopy and digital volume tomography[35-40]. Results of these studies show conventional AP and lateral views to be inferior to the other modalities, but only 360 degrees fluoroscopy to have a comparable accuracy to CT[35,36] but no combination of views seems to detect all intra-articular screws.

Due to the limitations of additional imaging modalities and US, several other methods to prevent screw penetration have been proposed. Several authors describe routinely downsizing the screw length to avoid screw prominence[45], even though this may reduce the biomechanical construct compared to bi-cortical screw fixation[46].

Benson et al suggested to intraoperatively make a dorsal incision ulnar to Listers tubercle to check on the 3rd compartment[45]. Ljungquist et al. recommended the use of the lunate depth measure on X-ray to estimate the length of the longest screw[47]. Magaraggia et al are currently working on an unified planning and guidance framework for guided drilling using a camera and reference points and preoperatively defined screw lengths[48]. In this review, we have found only one case in which arthroscopy has been used to check upon intra-articular screw placement[37]. As wrist arthroscopy is upcoming in the evaluation and reduction of fractures, this technique might also be used in the future to intraoperatively detect intra-articular placed screws. Early removal has also been suggested to prevent tendon ruptures for patients that develop problems[49].

CONCLUSION

Even though the heterogeneity of the studies is large and the overall quality of the included studies is moderate, we can conclude that conventionally used fluoroscopic views are not sufficient to detect screw penetration in volar plating for distal radius fractures. Therefore, additional intraoperative imaging modalities are required. Several additional fluoroscopic views have been described, of which the DTV is most studied and shows good results for the detection of dorsal screw penetration. The CST has been subject to a few studies and shows good results as well. US seems to be promising in pre-clinical and small cohort studies. No additional imaging technique has proven to be perfect. As it appears to be most practical in daily operative practice, we recommend the use of the DTV for the detection of DSP, especially for the 3rd compartment where the EPL is situated. Additional views adapted to the concave surface of the joint make interpreting fluoroscopic views on intra-articular screw penetration easier, however no accurate method has been described yet.

FIGURE AND TABLE LEGENDS

Table 1. Methodological quality of included studies according to Bhandari et al.

Study	Primary Guidelines		Secondary Guidelines		Results	Implications for patient care?
	Did clinicians face diagnostic uncertainty?	Independent blind comparison with a reference standard?	Did the results of the test influence the decision to perform the reference standard?	Were the methods described in sufficient detail to permit replication?	Are likelihood ratios of the test being evaluated or data necessary for their calculations provided?	Will the reproducibility of the test result and its interpretation be satisfactory in clinical setting?
Bianchi	No	Indeterminate	Yes	Yes	No	No
Borggrefe	No	Yes	No	Yes	Yes	No
Brunner	No	No	N/A	Yes	No	Yes
Cha	No	Yes	No	Yes	Yes	No
Dolce	No	Yes	No	Yes	Yes	Yes
Ganesh	No	Yes	Indeterminate	No	Yes	Yes
Giugale	No	Yes	No	No	Yes	Yes
Gurbuz	No	Yes	No	No	No	Yes
Haug	No	Yes	No	Yes	No	Yes
Hill	No	Yes	No	Yes	No	Yes
Joseph	No	No	N/A	Yes	Yes	No
Kiyak	No	No	Indeterminate	Yes	Yes	Yes
Kumar	Yes	Yes	No	Yes	Yes	Yes
Lee	No	Yes	No	Yes	Yes	Yes
Marsland	No	No	N/A	Yes	No	No
Oc	Yes	Yes	No	Yes	No	Yes
Ozer 2011	No	No	N/A	Yes	Yes	No

Table 1. Continued

Study	Primary Guidelines		Secondary Guidelines		Results	Implications for patient care?
	Did clinicians face diagnostic uncertainty?	Independent blind comparison with a reference standard?	Did the results of the test influence the decision to perform the reference standard?	Were the methods described in sufficient detail to permit replication?	Are likelihood ratios of the test being evaluated or data necessary for their calculations provided?	Will the reproducibility of the test result and its interpretation be satisfactory in clinical setting?
Ozer 2012	No	Yes	No	Yes	No	Yes
Pace	Yes	Yes	No	No	Yes	Yes
Patel	No	Yes	No	No	No	No
Poole	No	Yes	No	Yes	No	Yes
Rausch	No	No	N/A	Yes	Yes	No
Riddick	No	Yes	No	No	No	Yes
Soong	No	Yes	No	No	Yes	Yes
Stoops	No	Yes	No	Yes	No	Yes
Sugun	Yes	No	N/A	Yes	Yes	Yes
Takemato	No	Yes	No	Yes	No	Yes
Taylor	Yes	No	N/A	Yes	Yes	No
Thomas	No	Indeterminate	No	No	No	No
Tweet	No	Yes	No	No	Yes	Yes
Vaiss	No	No	No	Yes	Yes	No
Vernet	Indeterminate	Yes	No	No	No	No
Watchmaker	No	Yes	No	No	Yes	Yes
Williams	No	Yes	No	No	Yes	No

Indeterminate: unable to determine based on data provided in manuscript. N/A: not applicable, ie no reference standard used

Table 2. Characteristics of Excluded Study [ordered by first author]

Study	Reason for exclusion
Aldemir 2017	Focussed on the use of a improved design of the volar plate.
Balfour 2016	Description of technique and illustrative cases only.
Boyer 2003	Focussed on the use of a dorsal plate
Diong 2018	No data reporting on reliability, efficacy or accuracy.
Granville 2012	No full text available
Herisson 2017	No data reporting on reliability, efficacy or accuracy.
Klammer 2012	Not focussing on screw penetration, but on imaging the DRUJ itself.
Klein ?	No full text available
Ljunquist 2015	Measuring the lunate depth as predictor for screw length is not useful as intra-operative imaging strategy.
Maschke 2007	No data reporting on reliability, efficacy or accuracy.
Magaraggia 2017	Pilot study of a new device. No reported numbers on statistical reliability, efficacy or accuracy.
Matullo 2010	Use of the contralateral hand to obtain lateral tilt wrist radiographs not useful as intra-operative imgaging strategy.
Smith 2004	Focussed on evaluation of placement of the place, not screws

Table 3. Studies reporting on the sensitivity for detection of Dorsal Screw Penetration

	Study	N *Cadavers/ Patients*	*Screws*	Design	Reference*	Lateral	AP	Pronation	Suppi-nation	DTV*	CST	RGV	360 / 3D	Moun-ted camera	US
Cadaveric	Cha 2017**	4	32	Cadaveric	Direct visu-alisation			Depending on angle and position		88%		63%			
	Vernet 2017	10	40	Cadaveric Survey						97,0%					43,3%
	Stoops** 2017	7	126-231	Cadaveric Survey	Direct visu-alisation					75%	86%				
	Giugale 2017	2	32	Cadaveric Survey	Direct visu-alisation	96,4%				97,2%					
	Poole 2017	1	10	Cadaveric Survey		16%	12%	12%	40%	51%	78%				
	Williams 2017	4	16	Cadaveric	Direct visu-alisation										100%
	Gurbuz **,*** 2017	10	40	Cadaveric Survey	Direct visu-alisation					100%					100%
	Watch-maker 2016	5	3	Cadaveric + Prospective series	Direct visu-alisation	18,2%* incl oblique									63,3%
	Hill 2015	21	252	Cadaveric Survey	Direct visu-alisation	58.7%		54.4%	88.2%	66,5%					
	Dolce 2014	8	128	Cadaveric	Direct visu-alisation	24,5%				100%					
	Haug 2013	6	25	Cadaveric Survey	Direct visu-alisation/CT					96%					

Table 3. Continued

	Study	N		Design	Reference*	Lateral	AP	Pronation	Suppi-nation	DTV*	CST	RGV	360 / 3D	Moun-ted camera	US	
Cadaveric	Ozer**, *** 2012	10	40	Cadaveric Survey	Not described	80%* inc l oblique		65% *4th comp 93%	0% *2nd comp 92%	95%						
	Riddick 2011	1	14	Cadaveric Survey	Direct visu-alisation	66%		64%		83%						1mm protru-sion
	Thomas 2009 ***	?	4/cad	Cadaveric Survey	Direct visu-alisation								77%			
Clinical	Oc 2018	47	Indeter-minate	Retrospec-tive Cohort	US	41.67%		16.67%	50.00%	58.33						
	Kiyak 2017			Case Series						70%						
	Ganesh 2016	25	175	Retrospec-tive Cohort	CT					66,7%						
	Bianchi 2008	9 sympto ma-tic patients	Indeter-minate	Case Series	Surgery										100%	
	Lee 2013	93	?	Indetermi-nate	CT							95%				

N= number, AP: anteroposterior , DTV: Dorsal Tangential View, CST: Carpal Shoot Through view, RGV: Radial Groove View, 360/3D: 360 degrees or 3 dimensional fluoroscopy, US: Ultrasound

* We interpretated the Hoya view, Skyline view and Dorsal Horizon View to be the same as the Dorsal Tangential View

**In case sensitivity in studies was given per amount of DSP and could not be recalculated, 2 mm DSP was chosen (because less is irrelevent due to manufractured length interval of 2 mm). These studies are not included in the meta analysis unless they gave exact numbers with which overal sensitivity could be calculated.

*** in case sensitivity in sudies was given per compartment/region and overall sensitivity could not be calculated, the central region or 3rd compartment were chosen (because EPL rupture is most relevant complication described in literature). These studies are not included in the meta-analysis unless they gave exact numbers with which overal sensitivity could be calculated.

Table 4. Studies reporting on the reliability for detection of dorsal screw penetration

	Study	N: Images	N: Cadavers	N: Patients	N: Screws	N: Observers	Level Observers	Outcome	PA Inter	PA Intra	Lat Inter	Lat Intra	Pronation Inter	Pronation Intra	Suppination Inter	Suppination Intra	DTV Inter	DTV Intra	CST Inter	CST Intra	US Inter	CT Inter	CT Intra
Cadaveric	Vernet 2017	?	10		40	3	orthopaedic surgical residents	Concordance correlation coefficient (K)									0,91				-0,0129		
	Poole 2017	42	1		10	10	orthopaedic surgeons	Inter-/intra-observer reliability (K)	0,2	0,37	0,36	0,96	0,05	0,52	0,69	0,86	0,72	0,76	0,66	0,86			
	Hill 2015	84	21		84	63	'all levels'	Cumulative Interrater agreement (K)	0,31				0,19		0,72		0,44						
	Ozer ** 2012	40	10		40	2	consultants/ specialized registrars	Inter observer agreement (%)			100%				90%		100%						
Clinical	Brunner 2015			22	88-110	3	not described	Inter and intra observer reliability STCD measurement (ICC)									0,72	0,77				0,87	0,85

PA: posteroanterior, Lat: lateral, DTV: Dorsal Tangential View, CST:Carpal Shoot Through, US: Ultrasound, CT:CT-scan, K:Kappa, ICC: intraclass coefficient

Table 5. Studies reporting on the Efficacy for detection of Dorsal Screw Penetration

	Study	Design	N		Outcome		AP + lateral	DTV	CST	RGV	3D	US
			Patients	Screws	% Cases with penetrating srews detected	% penetrating screws detected						
Clinical Stud	Taylor 2017	Retrospe-ctive	25	?	x			8%				
	Brunner 2015	Prospec-tive	22	93		x		11.8%				
	Rausch 2015	Prospec-tive	48	232		x		5.17% additional after lat+ AP			4.31% additional after DTV (1 intra articular)	
	Marsland 2014	Prospec-tive	42	Indeter-minate	x	x			Cases: 14% Screws: 17% (1 screw intra articular)			
	Vaiss 2014	Retrospec-tive	75	300	x	x	0%	Cases: 14.7% Screws: 5%				
	Lee 2013	Prospec-tive	91	Indeter-minate	x		0%			14%		
	Sugun 2011	Indeter-minate	46	230		x						25.7%

Table 5. Continued

Study	Design	N		Outcome		AP + lateral	DTV	CST	RGV	3D	US
Joseph 2011	Retrospec-tive	15	Indeter-minate	x			26,70%				
Ozer 2011	Indeter-minate	27	125		x	6.4%	8.8%				

N=number, lat=lateral. DTV= Dorsal Tangential View, CST=Carpal Shoot Through, RGV= Radial Groove View, 3D: 3 Dimensional Fluoroscopy, US: ultrasound

Table 6. Studies reporting on the sensitivity, specificity and accuracy for detection of Intra-Articular Screw Penetration

	Study	N			Design	Reference*	Outcome	Lateral	AP	Oblique	Tilt	3D	360	DVT	CT
		cadavers	*patients*	*screws*											
Cadaveric	Borggrefe 2015	12		36-48	Cadaver Survey	3D CT reconstruction	Sensitivity	58%				68%		88%	
	Takemoto 2012	8		40	Cadaver Survey	Direct visualization	Sensitivity	84,50%							95,20%
	Tweet 2010	30		30	Cadaver Survey	Direct Visualization	Sensitivity	61%	93%		11° AP: 91% 22° Lat: 63%		93%		
	Soong 2008	1		20	Cadaveric	Direct visualization	Specificity	10%	30%		11° AP: 100% 15°, 23°, 30° lat: all 60%				
Clinical	Pace 2010		128	Indeter-minate	Retrospective Cohort	No revision surgery	Specificity	28%			63%				
	Patel 2013		34	Indeter-minate	Survey	rotational fluoroscopy	Accuracy	58.8%			AP + lat + 30° lat: 77.5%				
	Kumar 2001		10	indeter-minate	Indeter-minate	Indeter-minate	Specificity	0%			100%				

N= number, AP: anteroposterior , lat: lateral, Tilt: Anatomical tilt , 360: 360 degrees fluoroscopy, 3D: 3 dimensional fluoroscopy, DVT: digital volume tomography

REFERENCES

1. Chen CH, Zhou RK, Zhen HQ, Huang L, Jiao YJ. Efficacy of volar and dorsal plate fixation for unstable dorsal distal radius fractures. Int J Clin Exp Med. 2015;8(3):4375-4380
2. Bentohami A, de Burlet K, de Korte N, van den Bekerom MP, Goslings JC, Schep NW. Complications following volar locking plate fixation for distal radial fractures: a systematic review. J Hand Surg Eur Vol. 2014;39(7):745-754
3. 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;21(5):316-322
4. Tarallo L, Mugnai R, Zambianchi F, Adani R, Catani F. Volar plate fixation for the treatment of distal radius fractures: analysis of adverse events. J Orthop Trauma. 2013;27(12):740-745
5. Maschke SD, Evans PJ, Schub D, Drake R, Lawton JN. Radiographic evaluation of dorsal screw penetration after volar fixed-angle plating of the distal radius: a cadaveric study. Hand (N Y). 2007;2(3):144-150
6. Rausch S, Marintschev I, Graul I, et al. Tangential View and Intraoperative Three-Dimensional Fluoroscopy for the Detection of Screw-Misplacements in Volar Plating of Distal Radius Fractures. Arch Trauma Res. 2015;4(2):e24622
7. Poole WE, Marsland D, Durani P, Hobbs CM, Sauvé PS. Detecting dorsal screw penetration following volar plate fixation of the distal radius–A validation study in a saw bone model. Trauma. 2016:1460408616664550
8. Stoops TK, Santoni BG, Clark NM, Bauer AA, Shoji C, Schwartz-Fernandes F. Sensitivity and Specificity of Skyline and Carpal Shoot-Through Fluoroscopic Views of Volar Plate Fixation of the Distal Radius: A Cadaveric Investigation of Dorsal Cortex Screw Penetration. Hand (N Y). 2017;12(6):551-556
9. Dolce D, Goodwin D, Ludwig M, Edwards S. Intraoperative evaluation of dorsal screw prominence after polyaxial volar plate fixation of distal radius fractures utilizing the Hoya view: a cadaveric study. Hand (N Y). 2014;9(4):511-515
10. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. J Clin Epidemiol. 2009;62(10):1006-1012
11. Bhandari M, Montori VM, Swiontkowski MF, Guyatt GH. User's guide to the surgical literature: how to use an article about a diagnostic test. J Bone Joint Surg Am. 2003;85-A(6):1133-1140
12. Williams D, Singh J, Heidari N, Ahmad M, Noorani A, Di Mascio L. Assessment of penetration of dorsal screws after fixation of the distal radius using ultrasound: cadaveric study. Ann R Coll Surg Engl. 2016;98(2):138-142
13. Hill BW, Shakir I, Cannada LK. Dorsal Screw Penetration With the Use of Volar Plating of Distal Radius Fractures: How Can You Best Detect? J Orthop Trauma. 2015;29(10):e408-413
14. Ozer K, Wolf JM, Watkins B, Hak DJ. Comparison of 4 fluoroscopic views for dorsal cortex screw penetration after volar plating of the distal radius. J Hand Surg Am. 2012;37(5):963-967

15. Riddick AP, Hickey B, White SP. Accuracy of the skyline view for detecting dorsal cortical penetration during volar distal radius fixation. J Hand Surg Eur Vol. 2012;37(5):407-411

16. Watchmaker JD, Daley RA, Watchmaker GP, Grindel SI. Ultrasound Imaging Improves Identification of Prominent Hardware in the Surgical Treatment of Distal Radius Fractures: A Cadaveric and Prospective Clinical Study. J Wrist Surg. 2016;5(1):36-41

17. Vernet P, Durry A, Nicolau X, et al. Detection of penetration of the dorsal cortex by epiphyseal screws of distal radius volar plates: Anatomical study comparing ultrasound and fluoroscopy. Orthop Traumatol Surg Res. 2017;103(6):911-913

18. Giugale JM, Fourman MS, Bielicka DL, Fowler JR. Comparing Dorsal Tangential and Lateral Views of the Wrist for Detecting Dorsal Screw Penetration after Volar Plating of Distal Radius Fractures. Adv Orthop. 2017;2017:1402517

19. Gurbuz Y, Kucuk L, Gunay H, Ozaksar K, Sugun TS, Bilge O. Comparison of ultrasound and dorsal horizon radiographic view for the detection of dorsal screw penetration. Acta Orthop Traumatol Turc. 2017

20. Cha SM, Shin HD. Detections of Screw Penetration during Volar Plating for Distal Radius Fractures. J Wrist Surg. 2017;6(4):340-348

21. Haug LC, Glodny B, Deml C, Lutz M, Attal R. A new radiological method to detect dorsally penetrating screws when using volar locking plates in distal radial fractures. The dorsal horizon view. Bone Joint J. 2013;95-b(8):1101-1105

22. Thomas AD, Greenberg JA. Use of fluoroscopy in determining screw overshoot in the dorsal distal radius: a cadaveric study. J Hand Surg Am. 2009;34(2):258-261

23. Ganesh D, Service B, Zirgibel B, Koval K. The Detection of Prominent Hardware in Volar Locked Plating of Distal Radius Fractures: Intraoperative Fluoroscopy Versus Computed Tomography. J Orthop Trauma. 2016;30(11):618-621

24. Kiyak G. In vivo confirmation of the reliability of the dorsal tangential view of the wrist. Hand Surg Rehabil. 2018;37(1):56-59

25. Brunner A, Siebert C, Stieger C, Kastius A, Link BC, Babst R. The dorsal tangential X-ray view to determine dorsal screw penetration during volar plating of distal radius fractures. J Hand Surg Am. 2015;40(1):27-3

26. Bianchi S, van Aaken J, Glauser T, Martinoli C, Beaulieu JY, Della Santa D. Screw impingement on the extensor tendons in distal radius fractures treated by volar plating: sonographic appearance. AJR Am J Roentgenol. 2008;191(5):W199-203.

27. Joseph SJ, Harvey JN. The dorsal horizon view: detecting screw protrusion at the distal radius. J Hand Surg Am. 2011;36(10):1691-1693

28. Marsland D, Hobbs CM, Sauve PS. Volar locking plate fixation of distal radius fractures: use of an intra-operative 'carpal shoot through' view to identify dorsal compartment and distal radioulnar joint screw penetration. Hand (N Y). 2014;9(4):516-521

29. Vaiss L, Ichihara S, Hendriks S, Taleb C, Liverneaux P, Facca S. The utility of the fluoroscopic skyline view during volar locking plate fixation of distal radius fractures. J Wrist Surg. 2014;3(4):245-249

30. Sugun TS, Karabay N, Gurbuz Y, Ozaksar K, Toros T, Kayalar M. Screw prominences related to palmar locking plating of distal radius. J Hand Surg Eur Vol. 2011;36(4):320-324

31. Lee S, Bae K, Choy W. Use of the radial groove view intra-operatively to prevent damage to the extensor pollicis longus tendon by protruding screws during volar plating of a distal radial fracture. Bone Joint J. 2013;95(10):1372-1376

32. Ozer K, Toker S. Dorsal tangential view of the wrist to detect screw penetration to the dorsal cortex of the distal radius after volar fixed-angle plating. Hand (N Y). 2011;6(2):190-193

33. Taylor BC, Malarkey AR, Eschbaugh RL, Gentile J. Distal Radius Skyline View: How to Prevent Dorsal Cortical Penetration. J Surg Orthop Adv. 2017;26(3):183-186

34. Oc Y, Kilinc BE, Gulcu A, Varol A, Ertugrul R, Kara A. Ultrasonography or direct radiography? A comparison of two techniques to detect dorsal screw penetration after volar plate fixation. Orthop Surg Res. 2018;13(1):70

35. Tweet ML, Calfee RP, Stern PJ. Rotational fluoroscopy assists in detection of intra-articular screw penetration during volar plating of the distal radius. J Hand Surg Am. 2010;35(4):619-627

36. Takemoto RC, Gage M, Rybak L, Zimmerman I, Egol KA. Accuracy of detecting screw penetration of the radiocarpal joint following volar plating using plain radiographs versus computed tomography. Am J Orthop. 2012;41(8):358-361

37. Kumar D, Breakwell L, Deshmukh SC, Singh BK. Tangential views of the articular surface of the distal radius-aid to open reduction and internal fixation of fractures. Injury. 2001;32(10):783-786

38. Soong M, Got C, Katarincic J, Akelman E. Fluoroscopic evaluation of intra-articular screw placement during locked volar plating of the distal radius: a cadaveric study. J Hand Surg Am. 2008;33(10):1720-1723

39. Pace A, Cresswell T. Use of articular wrist views to assess intra-articular screw penetration in surgical fixation of distal radius fractures. J Hand Surg Am. 2010;35(6):1015-1018

40. Borggrefe J, Bolte H, Worms W, et al. Comparison of intraoperative flat panel imaging and postoperative plain radiography for the detection of intraarticular screw displacement in volar distal radius plate ostheosynthesis. Orthop Traumatol Surg Res. 2015;101(8):913-917

41. Patel A, Culbertson MD, Lahey P, Semenovski M, Choueka J. Improving accuracy and confidence in distal radius volar plate screw placement through supplemental radiography: examining specialty, education, and experience levels. Hand (N Y). 2013;8(3):308-314

42. Perry DC, Machin DM, Casaletto JA, Brown DJ. Minimising the risk of extensor pollicis longus rupture following volar plate fixation of distal radius fractures: a cadaveric study. Ann R Coll Surg Engl. 2011;93(1):57-60

43. Herisson O, Delaroche C, Maillot-Roy S, Sautet A, Doursounian L, Cambon-Binder A. Comparison of lateral and skyline fluoroscopic views for detection of prominent screws in distal radius fractures plating: results of an ultrasonographic study. Arch Orthop Trauma Surg. 2017;137(10):1357-1362

44. Lee SK, Bae KW, Choy WS. Use of the radial groove view intra-operatively to prevent damage to the extensor pollicis longus tendon by protruding screws during volar plating of a distal radial fracture. Bone Joint J. 2013;95-b(10):1372-1376.

45. Benson EC, DeCarvalho A, Mikola EA, Veitch JM, Moneim MS. Two potential causes of EPL rupture after distal radius volar plate fixation. Clin Orthop Relat Res. 2006;451:218-222

46. Wall LB, Brodt MD, Silva MJ, Boyer MI, Calfee RP. The effects of screw length on stability of simulated osteoporotic distal radius fractures fixed with volar locking plates. J Hand Surg Am. 2012;37(3):446-453

47. Ljungquist KL, Agnew SP, Huang JI. Predicting a safe screw length for volar plate fixation of distal radius fractures: lunate depth as a marker for distal radius depth. J Hand Surg Am. 2015;40(5):940-944

48. Magaraggia J, Wei W, Weiten M, et al. Design and evaluation of a portable intra-operative unified-planning-and-guidance framework applied to distal radius fracture surgery. Int J Comput Assist Radiol Surg. 2017;12(1):77-90

49. Asadollahi S, Keith PP. Flexor tendon injuries following plate fixation of distal radius fractures: a systematic review of the literature. J Orthop Traumatol. 2013;14(4):227-234

Appendices can be found online.

5

6

VOLAR PLATING IN DISTAL RADIUS FRACTURES: EFFICACY OF ADDITIONAL DORSAL TANGENTIAL VIEWS TO AVOID DORSAL CORTICAL SCREW PENETRATION IN 100 PATIENTS

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ABSTRACT

Purpose

The purpose of this prospective cohort study of patients treated with volar plating for distal radius fractures is to evaluate the efficacy (defined as detection rate, or the ability to detect dorsally protruding screws) of additional dorsal tangential views (DTV) after obtaining standard anteroposterior (AP) and elevated lateral views by evaluating the change in intraoperative strategy in 100 patients.

Materials and Methods

100 patients aged 18 years and older undergoing volar plating for acute extra- or intra- articular distal radius fractures were prospectively enrolled. Intraoperative fluoroscopy views, including AP, elevated lateral and DTV were obtained. Intraoperative –screw– revision frequency for dorsal screw protrusion, screw position relative to volar plate and to dorsal compartment, and screw lengths were evaluated.

Results

Additional DTV led to a change of intraoperative management in 31 of 100 (31%) of patients. A total of 35 out of 504 screws (6.9%) were changed. Screws in the radial styloid had highest risk of being too long; 16 (46%) were revised. Nine (26%) screws in the 2nd from radial and five (14%) screws in both the 2nd from ulnar and most ulnar screw holes were revised after DTV. No screws were revised in the central hole. The median length of revised protruding screws was 22 mm (range, 12 to 26 mm), and these were changed to 20 mm (range, 10 to 22 mm).

Conclusion

In this prospective series of 100 patients, obtaining additional DTV is found to be efficient as it led to change in intraoperative strategy in one-third of patients. We concur with previous pilot studies that DTV, after obtaining conventional AP and elevated lateral views, is advised to avoid dorsally protruding screws, which could minimize the potential for iatrogenic extensor tendon rupture after volar plating for distal radius fractures. Diagnostic accuracy of DTV is subject of a subsequent prospective cohort study with post-operative CT to serve as the reference standard. Dorsal Tangential View is most studied and proves to be practical and time efficient, with higher efficacy, accuracy and reliability compared to conventional views.

INTRODUCTION

Volar plates for distal radius fractures are increasingly popular[1-5] and have demonstrated to reduce the incidence of post-operative iatrogenic –extensor– tendon injuries as compared to tendon ruptures in the extensor compartments that were traditionally seen with dorsal plating[6,7]. However, some tendon related complications remain. The -in our hospital standardly used- 20-degree elevated lateral view (a view equivalent to the radial inclination to optimally visualize the radio-carpal joint) is often used as a final check in volar plating for distal radius fractures. The potential complication of a dorsally protruding screw that is obscured by Lister's tubercle on these elevated lateral radiographs is a preventable iatrogenic pitfall[8-10].

In 2015, Hill and colleagues recommended the intraoperative use of dorsal tangential view (DTV) to best detect dorsal screw penetration after volar plating based on a cadaveric study[11]. In prior work, Ozer and colleagues also compared lateral-, supination-, pronation-, and DTV fluoroscopy views in cadavers to avoid protruding screws in extensor compartments, and subsequent possible extensor tendon rupture, as standard lateral views failed to detect all screw penetrations[12]. All these pre-clinical studies agree that the use of DTV increases accuracy in detecting dorsal screw penetration in cadavers after volar plating of the radius[11-15]. Oblique views do show increased accuracy as well. However, they are only sensitive for isolated screw positions, do not image the third extensor compartment[16] and have a low overall sensitivity[12]. Therefore, they are not standardly used in our hospital. Interestingly, the accuracy of DTV in clinical practice has been recently debated in a retrospective review of 26 non-consecutive patients with both DTV and post-operative computed tomography (CT) available as the reference standard[17].

In our Level-I Trauma Centre DTV fluoroscopy is routinely obtained as per hospital protocol (Figure 1). In our hospital, this method is affectionately known as the Lleyton Hewitt view, after the "Come On" cry of the former number 1 tennis player from Adelaide (Figure 2). Due to his well-known pose, this radiological position has been commonly used in our hospital for many years. Clinical pilot studies found DTV to be clinically efficient for detection of dorsal screw protrusion in a small series of patients[17-22]. To the best of our knowledge, the clinical efficacy of DTV has not been evaluated to date in a large prospective cohort study[2,3]. Therefore, the purpose of this prospective cohort study is to evaluate the efficacy, measured as changes in intraoperative strategy (cases in which one or more screws were changed) based on the additional DTVs that are part of daily practice in our institution.

Based on our clinical experience and previous literature[17,18,20], we hypothesize that in one-third of patients undergoing volar plating for distal radius fractures dorsally protruding screws are identified and changed intraoperatively based on additional DTV after standardized AP and elevated lateral views did not identify incorrect screw lengths.

MATERIALS AND METHODS

This project was approved by the local Human Research Ethics Committee, in accordance to the Declaration of Helsinki.

At our Level-I Trauma Centre, we prospectively included 100 patients undergoing volar plating for extra- or intra-articular distal radius fractures, between September 2016 and May 2017.

Inclusion Criteria

Patients were included in the study if they were aged 18 years or older, sustained an acute displaced fracture of the distal radius and had a complete radiographic assessment, including anteroposterior and lateral radiographs and/or CT scan displaying the complete fracture, and where open reduction and internal fixation (ORIF) with a volar approach and volar locking plate (VA-LCP, Synthes, North Ryde, NSW, Australia) was indicated. The indication for surgery was radiological evidence of distal radius fracture instability[23]; such as dorsal comminution, palmar metaphyseal comminution, dorsal tilt >20 degrees, fragment translation >1cm, radial shortening >5 mm, intra-articular disruption, associated ulna fracture or severe osteoporosis. Additionally, inclusion criteria included radiocarpal subluxation or dislocation, displaced fracture of the radial styloid, rotated fracture of the volar lunate faced, and displaced intra-articular fractures.

Exclusion Criteria

Exclusion criteria were in accordance with the recent study by Brunner and colleagues[18]: prior injuries or surgeries that could have affected the anatomy of the distal radius, and fractures that needed intraoperative augmentation. Patients who had a dorsal approach or additional dorsal fixation were excluded. In our study period, two patients were excluded because no DTV were recorded on the Picture Archiving and Communication System (PACS).

Patients

A total of 100 patients with 100 distal radius fractures underwent surgery and met these inclusion criteria. Of these patients, the mean age was 57 years (range, 18-89). There were 30 (30%) men and 70 (70%) women. Distal radius fracture occurred in 50 right (50%) and 50 left (50%) wrists. According to the AO/Orthopaedic Trauma Association classification[24] 39 fractures were type A (A1:0, A2:17, A3:22), 39 were type B (B1:6, B2:14, B3: 19) and 22 were type C (C1: 9, C2:7, C3:6).

Surgical Treatment

All fractures were surgically treated by or under the supervision of an attending trauma consultant at the Department of Orthopaedic Surgery. A volar approach **through** the FCR-bed was used to expose the volar radius. Variable locking compression plates (VA-LCP, Synthes, North Ryde, NSW, Australia) were used. The plate was used according to the recommendations of the manufacturer. Even though smooth pegs -that might reduce the risk on tendon pathology- are available for this design, the smooth peg configuration in this design might reduce the stability as well[25]. Therefore, our department has decided not to use smooth pegs with this plate design. In 68 cases 4 distal holes were used and in 32 cases 5 distal holes were used. Depth gauge was used to determine the screw length. It is common practice in our hospital to subtract 2 mm from the measured gauge length to define the screw length. Screw lengths of initial and revised screws were recorded by direct observations of the researchers or based on surgeons' report.

Imaging Technique – Dorsal Tangential View

Prior to the index procedure, surgeons were instructed to save all their DTV views– including fluoroscopy views that revealed protruding screws– to our Digital Archiving System. Pre-operatively, surgeons did not receive additional specified instructions on performance or standardization of DTV fluoroscopy (Siemens, OEC 9900 Elite) as it has been common practice in our Level I Trauma Centre.

Obtaining DTV as standardized in our trauma protocol is according to pre-clinical work by Haug[14] and Hill[11], as well the clinical recommendation by Brunner and colleagues[18] based on their pilot study: the forearm placed in 75° degrees inclination to the horizontal arm table, and the wrist held in maximum flexion. The dorsal cortex of the distal radius was thereby positioned with 15° of inclination to the vertical X-ray beam of the fluoroscope. As Brunner and colleagues concluded based on their pilot work, we also accounted for the variation in anatomy by performing a continuous view while changing angle between 5 and 20 degrees, rather than using a sterile goniometer for precise adjustment of forearm inclination[18]. During the defined study period, there was no protocolled post-operative CT assessment in place to evaluate the accuracy of DTV.

Statistical Analysis

Patient characteristics (age, gender, affected side and fracture type) were summarized with frequencies and percentages for categorical variables and with mean and standard deviation for continuous variables. SPSS 21.0 (IBM Corp, Armonk, New York) was used for statistical analyses.

Power analysis revealed that with an estimated 35% of patients[17,18,20] undergoing volar plating for distal radius fractures dorsally protruding screws are identified and changed intraoperatively based on additional DTV after standardized AP and elevated lateral views, 21 patients were needed in the AP & Lateral-group *versus* 21 patients in the additional DTV-group to detect this difference with 80 % power ($\alpha = 0.05$, $\beta = 0.2$).

Post-hoc power analysis reveals 99 % power ($\alpha = 0.05$) with a total of 100 patients.

RESULTS

Efficacy of Dorsal Tangential Views (DTV)

A total of 35 out of 504 screws (6,9%) were changed after obtaining additional DTVs. This led to change of intraoperative strategy based on additional DTVs after standardized AP and elevated lateral views in 31 of 100 (31%) prospectively included patients.

DTVs revealed dorsal cortex protrusion in 26 of 100 included fractures (26%) –the remainder 5 cases (5%) had screws changed to longer screws– with a median screw length of 22 mm (range, 12 to 26 mm) changed to 20 mm (range, 10 to 22 mm). All screws that were 24 or 26mm length were exchanged for shorter screws. Following changes to shorter screws, none continued to protrude on subsequent DTVs.

Treating surgeons decided to change to longer screws in 5 cases (5%) with **median** lengths from 16 mm (range, 14 to 20 mm) to 20 mm (range 16 to 24 mm).

The exchange of screws was distributed equally among fracture types and was not found to be more prevalent in more complex cases: in Type A 13 cases out of 39 (33%), Type B 12 cases out of 39 (31%), Type C 6 cases out of 22 (27%) had one or more screws exchanged.

Screws in the radial styloid had highest risk of being too long; 16 (46%) were changed. No screws after DTV were changed in the central –Lister's Tubercle– hole in plates with 5 holes. Nine (26%) in the 2nd from radial- and five (14%) in both 2nd from ulnar and ulnar positions were changed (Figure 3). There were no screws found to protrude the distal radio-ulnar joint (DRUJ).

During the study period, one patient had an extensor pollicis longus (EPL) rupture, which may have been caused by either the protruding screw that was not identified on DTV, or fracture fragment spica obscuring the obtained view as identified on computed tomography (Figure 4).

DISCUSSION

The purpose of this prospective cohort study of patients treated with volar plating for distal radius fractures is to evaluate the efficacy (defined as detection rate, or the ability to detect dorsally protruding screws) of additional DTV after obtaining standard AP and elevated lateral views by evaluating the change in intraoperative strategy in 100 patients. To the best of our knowledge, to date there are no large prospective clinical trials to evaluate the efficacy of DTV in daily practice.

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In our prospective cohort of 100 included distal radius fractures in 100 patients we found that DTV identified protruding screws in 26 cases (26%) and led to change of intraoperative management in 31 cases (31%) - after standardized AP and elevated lateral views were deemed satisfactorily.

Delayed ruptures of extensor tendons secondary to the use of volar locking compression plates for distal radial fractures is in some cases an avoidable iatrogenic complication[26,27] of the increasingly popular open reduction and volar plating techniques for fractures of the distal radius[28]. Multiple pre-clinical studies evaluated specific fluoroscopy views in cadaveric specimens to identify the optimal per-operative view to identify dorsal screw penetration in the extensor compartments [11-14,29,30]. These studies highlighted that standardized anteroposterior and lateral view are insufficient to appreciate screw penetration due to complex bony anatomy of the distal radius, especially with regards to Lister's tubercle and the EPL groove on the dorsal side. Subsequently, three clinical pilot studies found DTV to be clinically reliable for assessment of the distance between the screw tip and the dorsal cortex in a small series of patients[18-20]. The authors also stated that choosing locking screw length 2-4 mm shorter than measured, aids to prevent protruding screws[17]. Also, the availability new generation of low-profile dorsal plates that are associated with less tendon rupture[31] might reduce tendon ruptures in the future.

In 2015, Brunner and colleagues evaluated the reliability of DTV clinically in a preliminary study of 22 patients. The authors found DTV to be reliable in terms of in vivo visualisation of the –fractured– dorsal radial cortex and reliable assessment of the distance between the screw tip and the dorsal cortex. In line with pre-clinical studies[11,14,29,32,33], the authors also conclude that DTV may allow for detection of dorsal screw perforation during volar plating of distal radius fractures.

In contrast in 2016, the accuracy of DTV was debated in a review of 26 –non-consecutive– patients with both DTV and post-operative computed tomography (CT) available as the reference standard[17]. This is illustrated by one case in our series where the DVT was found to be negative for dorsal screw penetration, but this patient did have an EPL tendon rupture either caused by a protruding screw or a fracture fragment. To date, there has not been a larger subsequent prospective cohort study to evaluate efficacy, nor accuracy.

In a recent review article Balfour advocated the use of ultrasound (US) to identify excessively long screws or screw penetration into joints[34]. Similar to the above listed pre-clinical cadaveric and small clinical work using image intensifier (ii), various studies evaluated the reliability and accuracy of US for the detection of dorsal screw penetration, and found US to be useful for accurate measurement of structures around the wrist in cases where intra-articular and/or comminuted fractures require engagement of screws in the dorsal cortex.[35,36]. A recent study compared ultrasound and the dorsal horizon view in a cadaveric setting, and found ultrasound to be a slightly more reliable and effective procedure for detection of dorsal screw penetrations[37]. Although promising, US may not be as readily available as fluoroscopy and, in addition, accuracy may be user dependent.

This study should be interpreted in the light of strengths and weakness. This study is limited by the purpose and design –a prospective cohort study– rather than a randomized controlled trial comparing traditional AP and elevated lateral views in group 1, and an additional DTV in group 2. We considered a RCT to be unethical as the latter has been common practice in our institution with a pre-study estimate of 35% of change in intraoperative practice (i.e. change of screws)[17,18,20] as a result of these protocolled additional fluoroscopy views. Another weakness by design is the lack of reference standard: screw penetration is not objectified by direct dorsal visualisation (as done in vitro studies) [11,14,29,32,33] nor by postoperative CT scanning[17,18], and therefore accuracy of DVT is beyond the scope of this study. The latter is subject of our subsequent future prospective accuracy study. As the quality of DTV is subject to the positioning of the patient[14,] which is challenged by the available space in the mini c-arm, the quality might be influenced by the experience of the surgeon. We will therefor study the influence of training on the DTV in a future inter-observer reliability study.

We conclude that obtaining additional DTV is found to be efficient as it led to change in per-operative strategy in one-third of patients. We concur with previous pilot studies that DTV –the Lleyton Hewitt view in South Australia– after obtaining conventional AP and elevated lateral views is advised to avoid dorsally protruding screws, which could further minimise the potential for iatrogenic extensor tendon rupture caused by protruding screws after volar plating for distal radius fractures. Despite using this technique, the surgeon needs to be mindful that there is still a 1% chance of EPL tendon rupture[37]. Finally, we recommend further prospective studies to determine the accuracy of DTV using CT as the reference standard, and long-term follow-up studies to evaluate the clinical significance of this potential problem.

FIGURE LEGENDS:

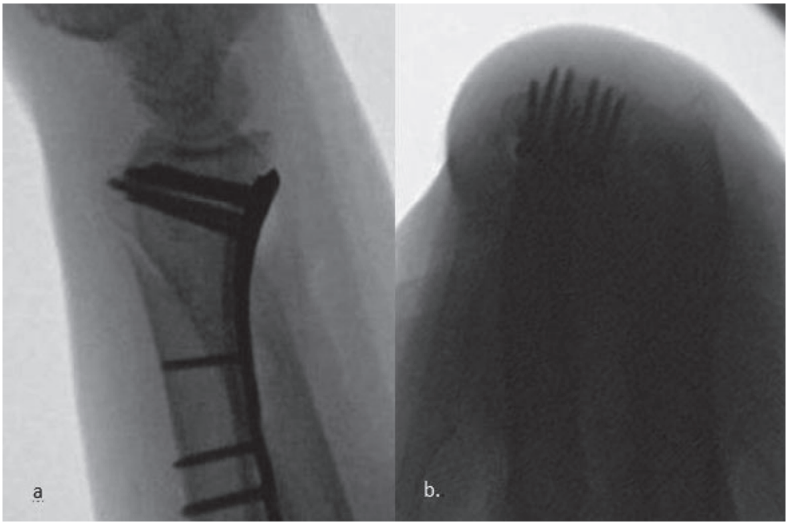

Figure 1: The purpose of this prospective cohort study is to evaluate the efficacy, measured as changes in intraoperative strategy after standardized anteroposterior (AP) and 20-degree elevated lateral view, **(a)** based on additional DTVs **(b)**.

Figure 2: Obtaining DTV as standardized in our trauma protocol is according to pre-clinical work by Haug[14] and Hill[11], as well the clinical recommendation by Brunner and colleagues[18] based on their pilot study: the forearm placed in 75 degrees inclination to the horizontal arm table, and the wrist held in maximum flexion. In our Level-I Trauma Centre DTV fluoroscopy is routinely obtained as per hospital protocol, perhaps because it is popularised throughout South Australia as the Lleyton Hewitt View (Doornberg JN. Volar Plating in Distal Radius Fractures: a Prospective Clinical Study on Efficacy of Dorsal Tangential Views (aka Lleyton Hewitt View) to Avoid Dorsal Screw Penetration. Podium Presentation presented at Annual Meeting of the Australian Orthopaedic Association, South Australian Branch; 2017; Lyell McEwin Hospital, Adelaide). The use of the eponym Lleyton Hewitt View has been approved by Mr. Hewitt.

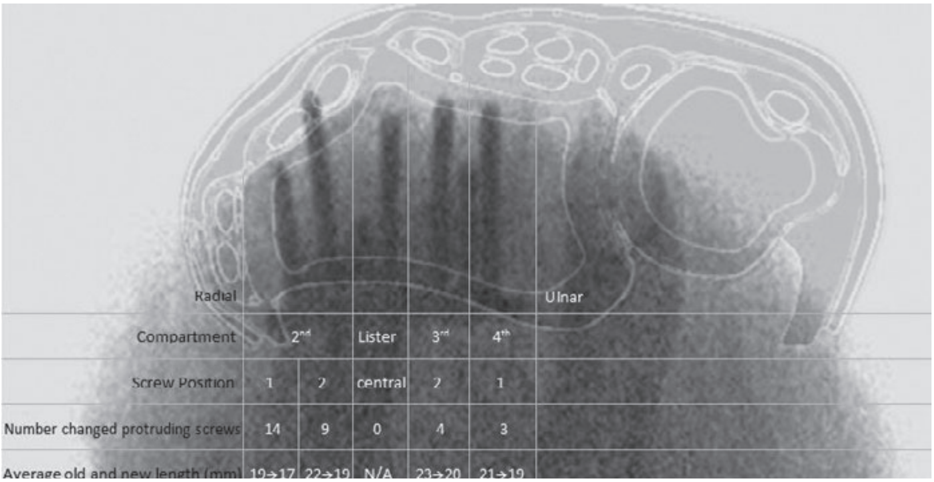

Figure 3: Screws in the radial styloid had highest risk of misplacement; 16 (46%) were changed. No screws after DTV were changed in the central –Lister's Tubercle– hole in plates with 5 holes. Nine (26%) in the 2nd from radial- and 5 (14%) in both 2nd from ulnar and ulnar positions were changed.

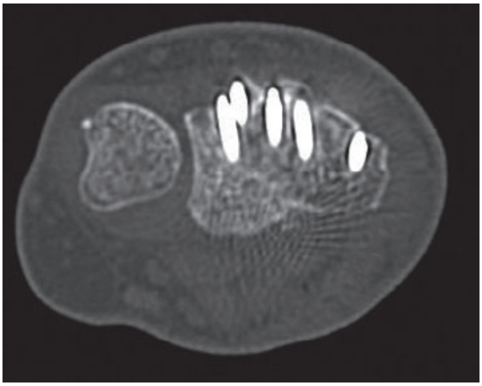

Figure 4: During the study period, one patient had an extensor pollicis longus (EPL) rupture, which may have been caused by either a protruding screw that was not identified on DTV, or fracture fragment spice obscuring the obtained view as identified on computed tomography.

REFERENCES

1. Koval KJ, Harrast JJ, Anglen JO, Weinstein JN. Fractures of the distal part of the radius. The evolution of practice over time. Where's the evidence? *J Bone Joint Surg Am*. 2008;90(9):1855-1861.
2. Kakar S. Clinical Faceoff: Controversies in the Management of Distal Radius Fractures. *Clin Orthop Relat Res*. 2015;473(10):3098-3104.
3. Koval K, Haidukewych GJ, Service B, Zirgibel BJ. Controversies in the management of distal radius fractures. *J Am Acad Orthop Surg*. 2014;22(9):566-575.
4. Members of the Writing Review, and Voting Panels of the AUC on the Treatment of Distal Radius Fractures, Watters WC, Sanders JO, Murray J, Patel N. The American Academy of Orthopaedic Surgeons Appropriate Use Criteria on the treatment of distal radius fractures. *J Bone Joint Surg Am*. 2014;96(2):160-161.
5. Murray J, Gross L. Treatment of distal radius fractures. *J Am Acad Orthop Surg*. 2013;21(8):502-505.
6. Lutsky K, Boyer M, Goldfarb C. Dorsal locked plate fixation of distal radius fractures. *J Hand Surg Am*. 2013;38(7):1414-1422.
7. Tavakolian JD, Jupiter JB. Dorsal plating for distal radius fractures. *Hand Clin*. 2005;21(3):341-346.
8. 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;21(5):316-322.
9. 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;91(8):1837-1846.
10. Tarallo L, Mugnai R, Zambianchi F, Adani R, Catani F. Volar plate fixation for the treatment of distal radius fractures: analysis of adverse events. *J Orthop Trauma*. 2013;27(12):740-745.
11. Hill BW, Shakir I, Cannada LK. Dorsal Screw Penetration With the Use of Volar Plating of Distal Radius Fractures: How Can You Best Detect? *J Orthop Trauma*. 2015;29(10):e408-413.
12. Ozer K, Wolf JM, Watkins B, Hak DJ. Comparison of 4 fluoroscopic views for dorsal cortex screw penetration after volar plating of the distal radius. *J Hand Surg Am*. 2012;37(5):963-967.
13. Maschke SD, Evans PJ, Schub D, Drake R, Lawton JN. Radiographic evaluation of dorsal screw penetration after volar fixed-angle plating of the distal radius: a cadaveric study. *Hand (N Y)*. 2007;2(3):144-150.
14. Haug LC, Glodny B, Deml C, Lutz M, Attal R. A new radiological method to detect dorsally penetrating screws when using volar locking plates in distal radial fractures. The dorsal horizon view. *Bone Joint J*. 2013;95-b(8):1101-1105.
15. Giugale JM, Fourman MS, Bielicka DL, Fowler JR. Comparing Dorsal Tangential and Lateral Views of the Wrist for Detecting Dorsal Screw Penetration after Volar Plating of Distal Radius Fractures. *Adv Orthop*. 2017;2017:1402517.

16. Della Croce P, Poole GC, Luikart G. Detecting and quantifying introgression in hybridized populations: simplifying assumptions yield overconfidence and uncertainty. *Mol Ecol Resour*. 2016;16(6):1287-1302.

17. Ganesh D, Service B, Zirgibel B, Koval K. The Detection of Prominent Hardware in Volar Locked Plating of Distal Radius Fractures: Intraoperative Fluoroscopy Versus Computed Tomography. *J Orthop Trauma*. 2016;30(11):618-621.

18. Brunner A, Siebert C, Stieger C, Kastius A, Link BC, Babst R. The dorsal tangential X-ray view to determine dorsal screw penetration during volar plating of distal radius fractures. *J Hand Surg Am*. 2015;40(1):27-33.

19. Ozer K, Toker S. Dorsal tangential view of the wrist to detect screw penetration to the dorsal cortex of the distal radius after volar fixed-angle plating. *Hand (N Y)*. 2011;6(2):190-193.

20. Joseph SJ, Harvey JN. The dorsal horizon view: detecting screw protrusion at the distal radius. *J Hand Surg Am*. 2011;36(10):1691-1693.

21. Rausch S, Marintschev I, Graul I, Wilharm A, Klos K, Hofmann GO et al. Tangential View and Intraoperative Three-Dimensional Fluoroscopy for the Detection of Screw-Misplacements in Volar Plating of Distal Radius Fractures. *Arch Trauma Res*. 2015;4(2):e24622.

22. Taylor BC, Malarkey AR, Eschbaugh RL, Gentile J. Distal Radius Skyline View: How to Prevent Dorsal Cortical Penetration. *J Surg Orthop Adv*. 2017;26(3):183-186.

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

24. Boretto JG, Pacher N, Giunta D, Galucci GL, Alfie V, De Carli P. Comparative clinica; study of locking screws versus smooth locking pegs in volar plating of distal radius fractures. *J Hand Surg Eur Vol*. 2013;39(7):755-60.

25. Marsh J, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA et al. Fracture and dislocation classification compendium-2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma*. 2007;21(10 Suppl):S1-133.

26. Hattori Y, Doi K, Sakamoto S, Yukata K. Delayed rupture of extensor digitorum communis tendon following volar plating of distal radius fracture. *Hand Surg*. 2008;13(3):183-185.

27. Al-Rashid M, Theivendran K, Craigen M. Delayed ruptures of the extensor tendon secondary to the use of volar locking compression plates for distal radial fractures. *J Bone Joint Surg Br*. 2006;88(12):1610-1612.

28. Berglund LM, Messer TM. Complications of volar plate fixation for managing distal radius fractures. *J Am Acad Orthop Surg*. 2009;17(6):369-377.

29. Dolce D, Goodwin D, Ludwig M, Edwards S. Intraoperative evaluation of dorsal screw prominence after polyaxial volar plate fixation of distal radius fractures utilizing the Hoya view: a cadaveric study. *Hand (N Y)*. 2014;9(4):511-515.

30. Haug LC, Deml C, Blauth M, Arora R. Dorsal screw penetration following implant removal after volar locked plating of distal radius fracture. *Arch Orthop Trauma Surg*. 2011;131(9):1279-1282.

31. Yu YR, Makhni MC, Tabrizi S, Rozental TD, Mundanthanam G, Day CS. Complications of low-profile dorsal versus volar locking plates in the distal radius: a comparative study. *J Hand Surg Am*. 2011;36(7):1135-41.

32. Poole WE, Marsland D, Durani P, Hobbs CM, Sauvé PS. Detecting dorsal screw penetration following volar plate fixation of the distal radius–A validation study in a saw bone model. *Trauma.* 2016:1460408616664550.

33. Riddick AP, Hickey B, White SP. Accuracy of the skyline view for detecting dorsal cortical penetration during volar distal radius fixation. *J Hand Surg Eur Vol.* 2012;37(5):407-411.

34. Balfour GW. Using Ultrasound to Prevent Screw Penetration. *J Hand Surg Am.* 2016;41(3):453-456.

35. Sügün TS, Özaksar K, Gürbüz Y. Screw prominence of locking plating in distal radius fractures. *J Hand Surg Am.* 2012;37(12):2646-2647.

36. Bianchi S, van Aaken J, Glauser T, Martinoli C, Beaulieu JY, Della Santa D. Screw impingement on the extensor tendons in distal radius fractures treated by volar plating: sonographic appearance. *AJR Am J Roentgenol.* 2008;191(5):199-203.

37. Gürbüz Y, Kucuk L, Gunay H, Özaksar K, Sügün TS, Bilge O. Comparison of ultrasound and dorsal horizon radiographic view for the detection of dorsal screw penetration. *Acta Orthop Traumatol Turc.* 2017;51(6):448-450.

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ACCURACY OF DORSAL TANGENTIAL VIEWS TO AVOID SCREW PENETRATION WITH VOLAR PLATING OF DISTAL RADIUS FRACTURES

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ABSTRACT

Background

Intra-operative Dorsal Tangential Views (DTVs) have shown accurate in pre-clinical studies and efficacious in clinical pilot series. The aim of this prospective study was to assess diagnostic performance of DTVs to detect dorsal screw protrusion in clinical practice.

Methods

We prospectively included 50 consecutive patients undergoing volar plating for 50 distal radius fractures. Fluoroscopic DTVs were routinely obtained and screw revision was documented. Multi-planar reconstructions of postoperative CTs allowed for detection and quantification of dorsal screw penetration using reproducible measuring techniques.

Results

Intra-operatively, in 16 of 50 patients (32%) screws were revised based on DTV, with 13 of 218 screws (6.0%) being revised due to dorsal prominence. One screw was changed because DTV showed it was in the distal radio-ulnar joint. Post-operatively, in 10 patients (20%) the CT revealed 12 additional screws penetrating ≥ 1 mm with an average of 1.8 mm (range 1.0-4.5 mm). DTV had a sensitivity of 52% (i.e. the probability of DTV to correctly detect protruding screws), a negative predictive value of 95% and accuracy of 95%. No ≥ 1 mm protruding screw remained in the 3rd compartment.

Conclusions

In one-third of our patients, the incidence of protruding screws that can cause iatrogenic extensor tendon rupture was reduced by obtaining additional DTVs.

While DTV reduces the incidence of dorsal screw penetration considerably, this study reveals limited sensitivity. Therefore, one should keep in mind that dorsal screw penetration may go unnoticed on DTVs and proper surgical technique remains paramount.

INTRODUCTION

Dorsally protruding screws are an important cause of post-operative tendon injuries[1], which is a complication in up to 10% of patients after volar plating for distal radius fractures[2]. Several authors recommend DTV to detect dorsal screw penetration[3-5]. Small clinical pilot studies without reference standard found a high efficacy for the detection of protruding screws,[5,6,7]. In a previous prospective cohort of 100 patients we found an efficacy of DTV of 31%8. In cadaveric work, the DTV has shown a promising accuracy of dorsal screw penetration detection of up to 100%[6-12]. In contrast, small retrospective clinical studies of non-consecutive patients report a sensitivity from only 58% to 70% [13-15]. Given these contradicting results, a larger prospective cohort of consecutive patients is needed to study the accuracy of DTV in clinical practice.

The purpose of this subsequent clinical prospective cohort study was to analyze the diagnostic performance of the DTV in a large cohort of patients undergoing volar plating to detect dorsal screw penetration using post-op CT as reference standard.

MATERIALS AND METHODS

This study was approved by our Institutional Review Board.

Patients

We prospectively included 50 consecutive patients that underwent volar plating between May 2017-August 2018. Patients that 1) were ≥ 18 years, 2) had an intra-articular distal radius fracture with indication for volar plating, 3) had preoperative radiographic assessment were included. Exclusion criteria were: prior injuries and/or surgeries of the distal radius and fractures that required intraoperative augmentation[9]. 34(68%) of the patients were women. Mean age was 57 years (range, 18-87). 30(60%) distal radius fractures were right-sided. According to the AO/OTA classification[16,17], 16(32%) fractures were type B and 34(68%) type C.

Surgical Treatment

All fractures were treated by 17 primary surgeons, representing daily practice in our Level 1 trauma-center. VA-LCP plates (Synthes, North Ryde, NSW, Australia) with four distal holes in 26 cases (52%), and five distal holes in 24 cases (48%) were used. To define final screw length, in our institution 2 mm is subtracted from the measured depth gauge length. This was ultimately up to surgeons' discretion, as was the decision to exchange screws. There were no smooth pegs used. Initial and final screw lengths of screws revised after DVT were recorded.

DTV - Imaging Technique I

Surgeons were instructed to save all DTVs (OEC 9900 Elite, Siemens, Erlangen, Germany). In our institution, obtaining DTV was standardized for several years according to pre-clinical work[3,12]: the forearm placed in 75° inclination to the horizontal arm table, the wrist held in maximum flexion8. Surgeons accounted for variation in anatomy by performing a live view while changing angle between 5- and 20°[6]. As our aim was to study DTV in clinical practice, surgeons didn't receive additional training on DTV.

Postoperative CT as Reference Standard – Imaging Technique II

As reference standard postoperative CT was used: Axial images of 1mm slices were obtained, allowing for multi-planar reconstructions according to Brunner's study design6. All CTs were loaded into Osirix DICOM Viewer (Pixmeo SARL, Switzerland). We created multi-planar reconstructions with the axial and sagittal planes parallel to the center of each of the distal screw. Measurements were performed in this plane (Figure 1). Both qualitative properties of the DTV (dorsal screw penetration) and quantitative (length of /protrusion) were determined. Measurements were obtained by independent, blinded observers. In a separate study, inter-observer reliability of this technique was almost perfect[18].

Dorsal Screw Penetration Categorized and Quantified

In 2016, Ganesh defined dorsal screw penetration as cortex protrusion of ≥1 mm on postoperative CT14.

In 2011, Sugun defined dorsal screw penetration differently: cortex protrusion of ≥ 0.5 mm using ultrasound as reference standard19. One could argue in clinical practice, the 0.5 mm threshold may correspond to bicortical fixation rather than true protruding screws. We concur with both groups that it is unknown what length of screw prominence will result in tenosynovitis/rupture: the "room for error" in the dorsal compartments is unknown. Therefore, cut-offs were evaluated sequentially in this study.

Statistical Analysis

Mean and range were used for continuous variables and frequencies and percentages were used for categorical variables. Patient characteristics were described using frequencies and percentages for categorical variables and mean and range for continuous variables. Further statistical analysis of diagnostic performance characteristics was according to standardized formulas, and in accordance to methods described by Ganesh14. In the accuracy analysis, only screws that were identified to dorsally protruding were included. An independent t-test was performed to analyze the difference in incidence of screw penetration between the groups of patients with and without screw changes.

RESULTS

Intra-Operative Dorsal Screw Protrusion and Revision (Figure 2)

Additional DTV led to revision of screws in 16 of 50 patients (32%). Eighteen of 218 screws (8.3%) were revised. Seven of these changed screws were located in the most radial position; none in both the second-from-radial- and central-(plates with five distal holes) position, five in the second from ulnar position and six in the most ulnar position (Table 1).

This translates to six screws changed in the 2nd compartment, 5 screws changed in the 3rd compartment and six screws changed in the 4th compartment, one screw in the 5th compartment.

Thirteen of the 18 changed screws were changed for shorter screws (Table 1) with a median initial length of 22 mm (range; 18-26 mm) and median final length 18 mm (range; 14-24 mm). Four screws were changed for longer screws (range initial length; 16-18 mm, range final length; 20-24 mm), for example in one case because the surgeon felt the screw did not capture the dorsal fragment.

One screw was changed because it was recognized to be in the distal radio-ulnar joint (DRUJ) on the DTV. All revised screws were located in the most distal row of the volar plate. None of the changed screws continued to protrude on further DTV radiographs according to the treating surgeon.

Postoperative Dorsal Screw Protrusion (≥ 1.0 mm) – Distal Row

In 10 of 50 patients (20%), qualitative multi-planar CT analysis revealed remaining dorsally protruding screws that were not identified on the DTV intra-operatively: 12 screws out of 218 screws (5.5%) of the distal row still protruded the dorsal cortex with ≥ 1.0 mm.18

Of these 12 screws unrecognized on DTV: nine (75%) were situated in the most radial screw hole, one in the second from radial hole (8%) and two (17%) in the most ulnar hole. These screws had a median length of 20 mm (range; 16-26 mm) and protruded on average 1.8 mm (range; 1.0-4.5 mm). No screws protruded in the central -in plates with five distal screw positions- or in the second from radial position. Meaning all protruding screws in the 3rd compartment (extensor pollicis longus groove) were identified with DTV.

In two patients (4%), two screws (0.9%) were found to be placed intra-articular on the tri-planar CT-reconstructions, one in the radio-carpal joint and one in the DRUJ (Figure 3). Both patients underwent revision surgery.

Four (25%) of the 16 patients that had intra-operative screw revision after obtaining DTV a total of four screws were (still) found to be protruding on CT reconstructions (Figure 4). Two of these screws –both in the most radial position- were initially changed based on DTV but proved to be still protruding on CT.

In six (18 %). of the 34 patients that had no intra-operative screw revision after DTV, eight protruding screws were found on CT.

The difference in incidence of dorsal screw penetration ≥ 1.0 mm on postoperative CT scan between the group of patients that had screws exchanged during surgery and the group that had not, was not significant (p=0.26, 95% CI -0.32-0.17) with the numbers available.

Post-Operative Dorsal Screw Protrusion – Proximal-Distal Row

Additionally, four screws out of the total 63 used screws (6.5%) in the second from distal row (6.3%) were found to protrude in the proximal-distal row by ≥ 1.0 mm. The range of the lengths was 18-24 mm and the average protrusion 1.3 mm (range; 1.0-1.7 mm). Three additional screws in the proximal distal row were found to breach the dorsal cortex by on average 0.9 mm (range; 0.8-0.9 mm).

Diagnostic Performance Characteristics of DTV (Table 1)

The sensitivity of DTV -the probability to correctly detect dorsally protruding screws-in the distal row was 52%. The negative predictive value was 95%. The accuracy was 95%. When including proximal distal row, the sensitivity of DTV for detecting dorsally protruding ≥1 mm reduced to respectively 45%, 91% and 94%.

Post-Operative Dorsal Screw Protrusion (≥ 0.5 mm) – Distal Row

In 16 out of 50 patients (32%), the post-operative CT revealed 20 (9,2%) remaining screws of the distal row still protruding the dorsal cortex with ≥ 0.5 mm17 (Figure 5).

Of these 20 screws unrecognized on DTV: 11 (55%) were situated in the most radial screw hole, five in the second from radial hole (25%), none in the central screw hole in plates with five distal screw positions, one (5%) in the second from ulnar screw hole (directed at the 3rd compartment) and three (15%) in the most ulnar hole. These screws had a median length of 21 mm (range; 16-26 mm) and protruded on average 1.5 mm (range; 0.5-4.5 mm).

In 5 (31%) of the 16 patients that had intra-operative screw revision after DTV, a total of six screws were protruding on CT reconstructions. In 11(32%) of the 34 patients that had no screw revision after DTV during surgery, 14 protruding screws were protruding.

The difference in incidence of dorsal screw penetration on postoperative CT scan between these two groups was not significant (p=0.89, 95% CI -0.28-0.30) with the number available.

When defining protruding screws as ≥ 0.5 mm cortex protrusion, the sensitivity of DTV for detection of dorsally protruding screws in the distal row was 39%, the negative predictive value 91% and the accuracy 91%. Considering a worst-case scenario, when including the proximal row and using a threshold for protrusion of ≥ 0.5 mm, sensitivity of DTV further decreased to 32.5%.

DISCUSSION

In this prospective cohort of 50 patients treated with volar plating, in 13 patients (26%) screws were found to be protruding intra-operatively using DTV. Though post-operatively, we identified screws that were protruding ≥ 1mm in an additional 10 of 50 patients (20%) using post-operative CT scans as reference standard. However, all protruding screws in the EPL groove were successfully identified with intra-operative DTV. Thus, apart from detecting 13 of 218 screws (6.0%) for revision due to dorsal prominence intra-operatively; surgeons failed to detect a total of twelve screws remaining prominent post-operatively (5.5%). Therefore, DTV reduces the proportion of screw prominence of ≥ 1mm from 11.5 % to 5.5%, however limited sensitivity may raise concern. We calculated an accuracy (i.e. the percentage of screws in which the DTV correctly identified a screw to either be protruding or placed correctly) of 95% of the per-operative DTV, a sensitivity (i.e. the probability of DTV to correctly detect protruding screws) of 52% and a negative predictive value (the probability of a screw to be of a correct length when not detected to be protruding by DTV) of 95%.

This study is designed as the first prospective cohort study on accuracy of the DTV, using post-op CT as reference standard following previously reported pre-clinical cadaveric studies and pilot trials [4-7,9,10,12]. Advanced imaging software utilizing reproducible multi-planar post-operative CT reconstructions to detect dorsal screw protrusion was used. A limitation of the current study is its deliberate design as a prospective cohort instead of a RCT. However, we deemed an RCT unethical as DTV leads to screw revision in one-third of patients8. Second, an inherent methodological statistical flaw on any study on this subject is that all intra-operatively revised screws are regarded as protruding, and therefore true positives of the DTV; consequently, there were no screws regarded as false positives. Additionally, the accuracy may be higher when DTV is used in less complex non-intra-articular fractures. Finally, as this study was designed to reflect clinical practice, surgeons were not additionally trained in obtaining and interpreting DTV. Given the results of this study, this will subject to a subsequent study.

In cadaveric studies reporting excellent accuracy of DTVs, pre-made DTVs were shown to observers [6,8,20-24]. The discrepancy between the high accuracy found in these cadaveric studies and subsequent clinical studies could indicate that 1) the accuracy of DTV depends both on moderate inter-observer reliability when interpreting the DTV images; and 2) reflects the technical challenges of obtaining the ‘perfect’ DTV in the first place, which might be influenced by surgeon experience or training. Remarkably, when retrospectively reviewing the prospectively obtained intra-operative DTVs in our study, we identified additional screws to be protruding in cases where surgeons did not decide to revise any screws; thus, reflecting the former: limited inter-observer reliability of interpretation of the DTVs on the screen. While this study does represent clinical practice, it may be of added value to specifically train surgeons in obtaining and interpreting DTVs.

The sensitivity found in this study (52%) is slightly lower than expected based on clinical series reporting a sensitivity ranging from 58-70%[13-15]. This may be caused by a more reliable advanced imaging method (Figure 1). Additionally, previous clinical series may be limited by their retrospective design with non-routine post-op CT scans and/or non-consecutive patients11,14,15. The sensitivity of DTV for detection of dorsal screw penetration decreased further to 45% when the second from distal row of screws were included. We therefore conclude DTV is less useful for detection of dorsal screw penetration in this location.

Finally, an MRI imaging study on (patho-)anatomy from our group reveals the extensor tendons can be as close to the dorsal cortex as 0.7 mm, with the closest tendon-cortex distance in the 3rd compartment. Therefore, we also defined screw protrusion as cortex protrusion of ≥ 0.5 mm as described by Sugun[19]. Using this definition, the sensitivity of DTV for the distal row decreased from 52% to 38%. Additionally, one screw was defined as protruding the EPL groove with 0.8 mm. It is unknown what length of screw protrusion and duration of subsequent synovitis will result in tendon rupture. Lee and colleagues found a sensitivity of 92.8% for their "radial groove view" (RGV) to detect screw protrusion specifically in the groove of the EPL using ≥ 1mm on post-operative CT scans[25].

In our series, one screw violating the DRUJ was changed based on the DTV (Figure 3B). One remaining screw that was not changed during the index procedure proved to violate the DRUJ on the post-op CT, but -in hindsight- should have been identified on the DTV fluoroscopy images intra-operatively (Figure 3A). This indicates DTV may also be useful for intra-articular screws in the DRUJ. Recent studies claim the reversed-skyline view to accurately and efficiently assess the DRUJ[26]. This was not the subject of this study, but it emphasizes the need for adequate understanding of intra-operative imaging details, and DTV is not an exclusive way to identify protruding screws dorsally or in the DRUJ.

Some advice to use unicortical screws as this would attain comparable stability[27,28], or suggest the use of smooth pegs, because threaded screws have self-tapping flutes at the tips which are sharp by design. However, few surgeons choose not to adopt these techniques as they argue whether unicortical fixation results in the same biomechanical stability of volar plating for respective distal radius[24], although recent biomechanical studies do support the use of unicortical pegs or screws in fixed angle plates, which extend to 75% of the anteroposterior diameter achieving comparable stability[27]. As one could argue that our prospective series with 17 surgeons may represent daily clinical practice in a large teaching hospital, the detection of screw penetration intraoperatively remains important to allow for screw exchange prior to closure.

In conclusion, this prospective accuracy data with CT reference standard builds on previously published pre-clinical and retrospective clinical work: DTV -in addition to AP and lateral intra-operative fluoroscopy views- are accurate to detect dorsal screw protrusion in an attempt to prevent iatrogenic extensor tendon rupture after volar plate fixation. Acquiring a DTV is economical and efficacious, but is arguably challenging to obtain and read. While DTV reduces the incidence of dorsal screw penetration considerably, its sensitivity is limited raising the concern that the DTV may not be as useful as prior studies suggested. Therefore, one should keep in mind that dorsal screw penetration may go unnoticed on DTVs and surgical technique and adequate understanding of intra-operative imaging details remains paramount.

FIGURE AND TABLE LEGENDS

Table 1. Number of revised screws for shorter screws and number of screws protruding on postoperative CT reconstructions in both the distal and the proximal row.

Screw Hole	**Changed intra-operatively after DT**	**Protruding ≥ 1.0 mm on post-operative CT reconstructions**	**Protruding ≥ 0.5 mm on post-operative CT reconstructions**
Most ulnar	3	2	3
2nd from ulnar	3	0	1
Central (in plates with 5 distal holes)	0	0	0
2nd from radial	0	1	5
Most radial	7	9	11
Subtotal Distal Row	13	12	20
Proximal Row Ulnar	0	1	1
Proximal Row Radial	0	3	6
Total	13	16	27

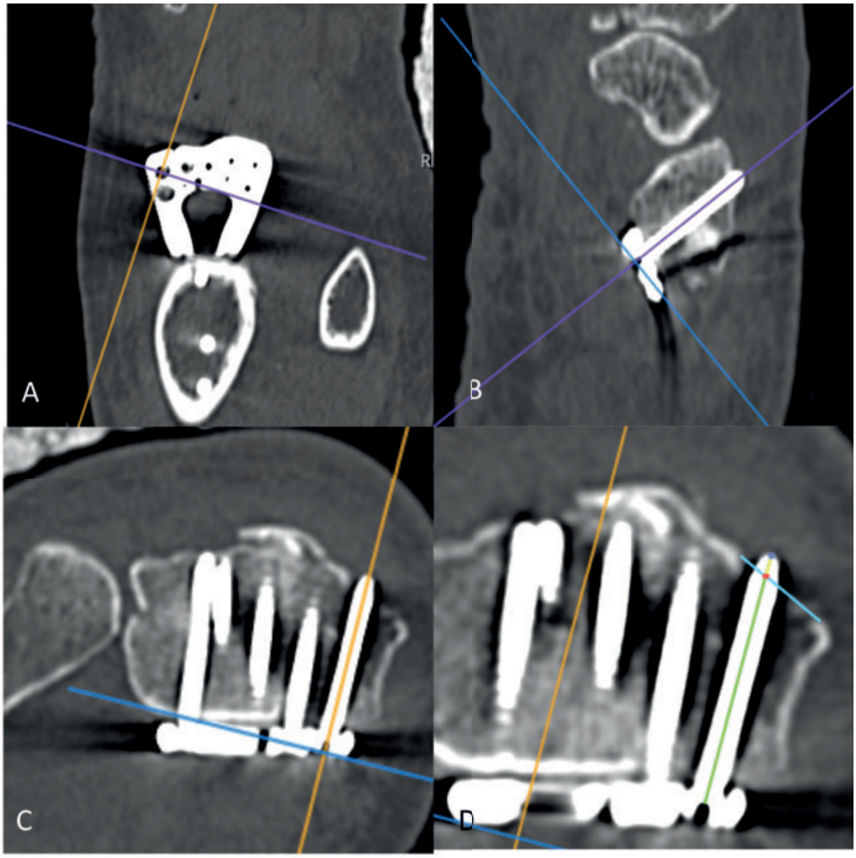

Figure 1. Multi-planar reconstructions at the center of each of the distal angular-stable screws of the VA-LCP (A) with the sagittal (B) and axial (C) planes parallel to the screw. Measurements were performed in the reconstructed axial plane (D).

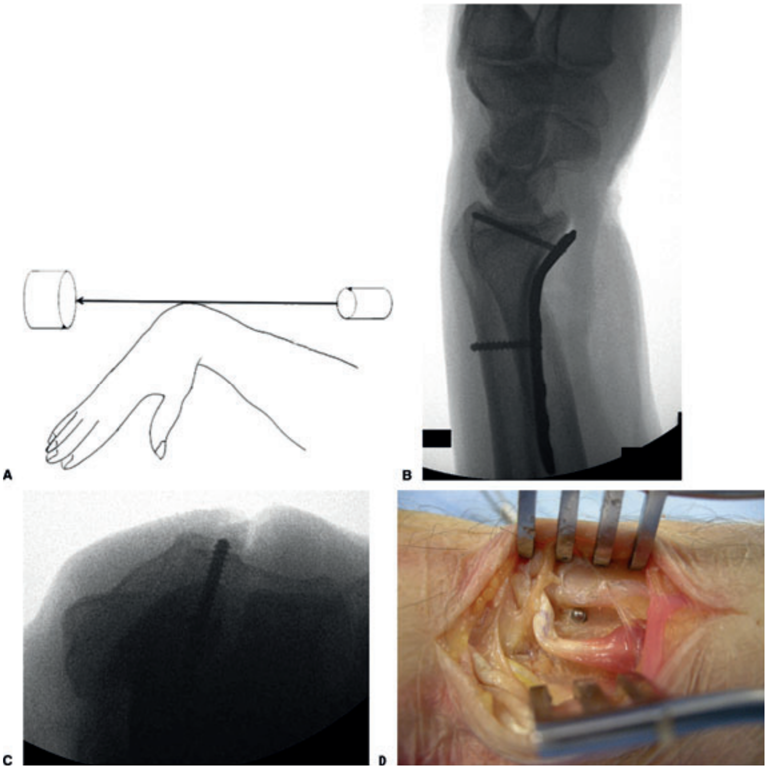

Figure 2. Dorsal tangential view revealing the dorsally protruding screw that is obscured by Lister's tubercle on plain lateral radiographs. Reproduced from Ozer and colleagues[6].

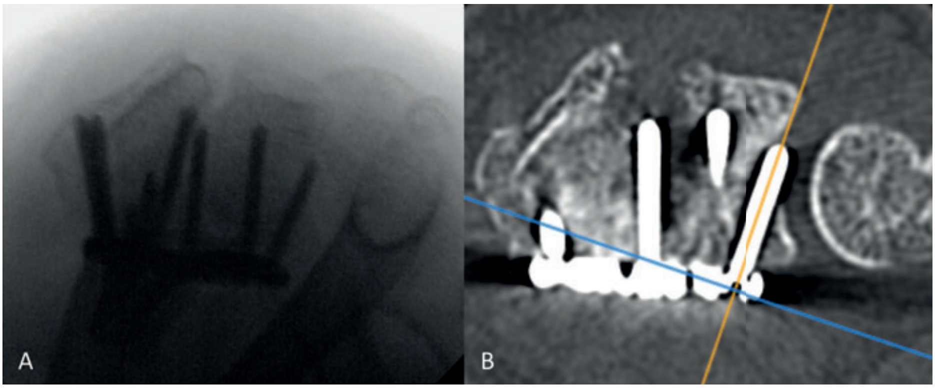

Figure 3. One remaining screw that was not changed during the index procedure but -in hindsight- should have been identified on the DTV images intra-operatively (A) as it proved to violate the DRUJ on the post-op CT reference standard (B).

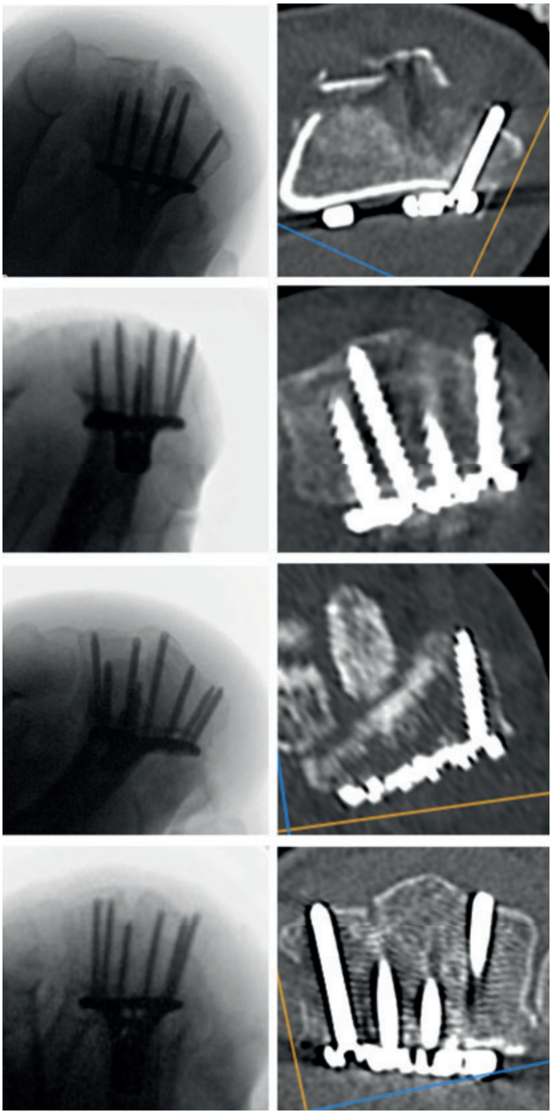

Figure 4. Out of the 16 patients that had intra-operative screw revision after obtaining DTV, in four of these patients (25%), a total of four other screws were still found to be protruding on postoperative multiplanar CT reconstructions. On the left side the final DTV (after screw revision) with on the right sight the matching post-operative multiplanar CT reconstructions.

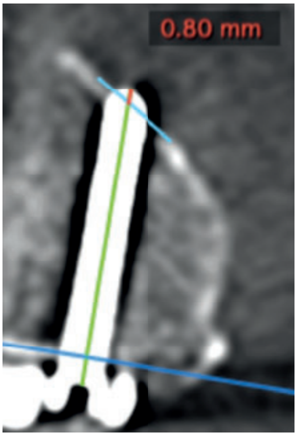

Figure 5. We defined screws breaching the dorsal cortex, as cortex protrusion of either less than 1 mm[12] or less than 0.5 mm [17].

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REFERENCES

1. Tarallo L, Mugnai R, Zambianchi F, Adani R, Catani F. Volar plate fixation for the treatment of distal radius fractures: analysis of adverse events. J Orthop Trauma. 2013;27(12):740-745.
2. Al-Rashid M, Theivendran K, Craigen M. Delayed ruptures of the extensor tendon secondary to the use of volar locking compression plates for distal radial fractures. J Bone Joint Surg Br. 2006;88(12):1610-1612.
3. Hill BW, Shakir I, Cannada LK. Dorsal Screw Penetration With the Use of Volar Plating of Distal Radius Fractures: How Can You Best Detect? J Orthop Trauma. 2015;29(10):e408-413.
4. Ozer K, Toker S. Dorsal tangential view of the wrist to detect screw penetration to the dorsal cortex of the distal radius after volar fixed-angle plating. Hand (N Y). 2011;6(2):190-193.
5. Joseph SJ, Harvey JN. The dorsal horizon view: detecting screw protrusion at the distal radius. J Hand Surg Am. 2011;36(10):1691-1693.
6. Brunner A, Siebert C, Stieger C, Kastius A, Link BC, Babst R. The dorsal tangential X-ray view to determine dorsal screw penetration during volar plating of distal radius fractures. J Hand Surg Am. 2015;40(1):27-33.
7. Marsland D, Hobbs CM, Sauve PS. Volar locking plate fixation of distal radius fractures: use of an intra-operative 'carpal shoot through' view to identify dorsal compartment and distal radioulnar joint screw penetration. Hand (N Y). 2014;9(4):516-521.
8. Bergsma M, Doornberg JN, Duit R, et al. Volar plating in distal radius fractures: A prospective clinical study on efficacy of dorsal tangential views to avoid screw penetration. Injury. 2018.
9. Bergsma, M, Denk, Doornberg JN, Van den Bekerom M, Kerkhoffs GMMJ, Jaarsma, RL Obdeijn MC. Volar Plating: Imaging Modalities for the Detection of Screw Penetration. Journal of Wrist Surgery, 2019. 10.1055/s-0039-1681026.
10. Ozer K, Wolf JM, Watkins B, Hak DJ. Comparison of 4 fluoroscopic views for dorsal cortex screw penetration after volar plating of the distal radius. J Hand Surg Am. 2012;37(5):963-967.
11. Maschke SD, Evans PJ, Schub D, Drake R, Lawton JN. Radiographic evaluation of dorsal screw penetration after volar fixed-angle plating of the distal radius: a cadaveric study. Hand (N Y). 2007;2(3):144-150.
12. Haug LC, Glodny B, Deml C, Lutz M, Attal R. A new radiological method to detect dorsally penetrating screws when using volar locking plates in distal radial fractures. The dorsal horizon view. Bone Joint J. 2013;95-b(8):1101-1105.
13. Oc Y, Kilinc BE, Gulcu A, Varol A, Ertugrul R, Kara A. Ultrasonography or direct radiography? A comparison of two techniques to detect dorsal screw penetration after volar plate fixation. J Orthop Surg Res. 2018;13(1):70.
14. Ganesh D, Service B, Zirgibel B, Koval K. The Detection of Prominent Hardware in Volar Locked Plating of Distal Radius Fractures: Intraoperative Fluoroscopy Versus Computed Tomography. J Orthop Trauma. 2016;30(11):618-621.

15. Kiyak G. In vivo confirmation of the reliability of the dorsal tangential view of the wrist. Hans Surg Rehabil. 2018;37(1):56-59.

16. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma. 2007;21(10 Suppl):S1-133.

17. Muller ME, Nazarian S, Koch P, Schatzker J. The comprehensive classification of fractures of long bones. Berlin: Springer-Verlag; 1990.

18. Diagnosis of Dorsal Screw Penetration after Volar Plating of the Distal Radius: Intra-Operative Dorsal Tangential Views versus Three-Dimensional Fluoroscopy Traumaplatform Website http://www.traumaplatform.org/currentprojects. Accessed April 15, 2019.

19. Sugun TS, Karabay N, Gurbuz Y, Ozaksar K, Toros T, Kayalar M. Screw prominences related to palmar locking plating of distal radius. J Hand Surg Eur Vol. 2011;36(4):320-324.

20. Gurbuz Y, Kucuk L, Gunay H, Ozaksar K, Sugun TS, Bilge O. Comparison of ultrasound and dorsal horizon radiographic view for the detection of dorsal screw penetration. Acta Orthop Traumatol Turc. 2017;51(6):448-450.

21. Riddick AP, Hickey B, White SP. Accuracy of the skyline view for detecting dorsal cortical penetration during volar distal radius fixation. J Hand Surg Eur Vol. 2012;37(5):407-411.

22. Dolce D, Goodwin D, Ludwig M, Edwards S. Intraoperative evaluation of dorsal screw prominence after polyaxial volar plate fixation of distal radius fractures utilizing the Hoya view: a cadaveric study. Hand (N Y). 2014;9(4):511-515.

23. Vernet P, Durry A, Nicolau X, et al. Detection of penetration of the dorsal cortex by epiphyseal screws of distal radius volar plates: Anatomical study comparing ultrasound and fluoroscopy. Orthop Traumatol Surg Res. 2017;103(6):911-913.

24. Giugale JM, Fourman MS, Bielicka DL, Fowler JR. Comparing Dorsal Tangential and Lateral Views of the Wrist for Detecting Dorsal Screw Penetration after Volar Plating of Distal Radius Fractures. Adv Orthop. 2017;2017:1402517.

25. Lee SK, Bae KW, Choy WS. Use of the radial groove view intra-operatively to prevent damage to the extensor pollicis longus tendon by protruding screws during volar plating of a distal radial fracture. Bone Joint J. 2013;95-b(10):1372-1376.

26. El Amiri L, Igeta Y, Pizza C, Facca S, Hidalgo Diaz JJ, Philippe L. Distal radius fluoroscopic skyline view: extension-supination versus flexion-supination. Eur J Orthop Surg Traumatol. 2018.

27. Wall LB, Brodt MD, Silva MJ, Boyer MI, Calfee RP. The effects of screw length on stability of simulated osteoporotic distal radius fractures fixed with volar locking plates. J Hand Surg Am. 2012;37(3):446-453.

28. Dardas AZ, Goldfarb CA, Boyer MI, Osei DA, Dy CJ, Calfee RP. A Prospective Observational Assessment of Unicortical Distal Screw Placement During Volar Plate Fixation of Distal Radius Fractures. J Hand Surg Am. 2018;43(5):448-454

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DIAGNOSIS OF DORSAL SCREW PENETRATION AFTER VOLAR PLATING OF THE DISTAL RADIUS: INTRA-OPERATIVE DORSAL TANGENTIAL VIEWS VERSUS THREE-DIMENSIONAL FLUOROSCOPY

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ABSTRACT

Background

Dorsal tangential views (DTV) are efficacious to detect dorsal cortex screw penetration after volar plating for distal radius fractures to prevent iatrogenic extensor tendon complications. Three-dimensional fluoroscopic (3DF) imaging has been introduced as an advanced intra-operative imaging technique to increase diagnostic accuracy.

The primary aim was to investigate whether intra-operative 3DF imaging outperforms DTVs to detect dorsal cortex screw penetration after volar plating for an intra-articular distal radius fracture in terms of diagnostic performance characteristics.

Methods

One-hundred sixty-five prospectively enrolled patients who underwent volar plating for an intra-articular distal radius fracture were retrospectively evaluated to study three intra-operative imaging protocols: 1) standard two-dimensional fluoroscopic (2DF) imaging with antero-posterior (AP) and elevated lateral images (n=55); 2) 2DF with AP, lateral, and DTV images (n=50); and 3) 3DF (n=60). Multi-planar reconstructions of post-operative computed tomography (CT) scans served as the reference standard.

Results

To detect dorsal screw penetration, sensitivity of DTVs was 39% with a negative predictive value of 91% and an accuracy of 91%; *versus* a sensitivity of 25% for 3DF with a negative predictive value of 93% and an accuracy of 93% (P = 0.26). On the CT reference standard post-operatively, we found penetrating screws in 1) 40% of patients in the 2DF reference cohort; 2) in 32% of patients in the 2DF cohort with AP, lateral and DTV images; and 3) in 25% of patients in the 3DF cohort (P = 0.08). In all three groups, the 2nd compartment was prone for penetration; and, the post-operative incidence decreased when more advanced imaging was used. No protruding screws remained in situ with 3DF in the third compartment (extensor pollicis longus [EPL] groove), and 1 in the DTV-group.

Conclusions

Advanced intra-operative imaging aids in identifying protruding screws in the dorsal wrist compartments. However, based on diagnostic performance characteristics, one cannot conclude that 3DF outperforms DTVs for this purpose. DTVs are sufficiently accurate to detect dorsal screw penetration, and arguably more efficacious than 3DF.

INTRODUCTION

Open reduction and internal fixation (ORIF) of a distal radius fracture with a volar plate is increasingly popular.[1-5] One potential technical error is protrusion of the dorsal compartments with penetrating screws that are obscured on lateral fluoroscopic imaging by Lister's tubercle, with the risk of extensor tendon irritation and rupture.[6] Intra-operative Dorsal Tangential Views (DTV) (forearm is per-operatively placed in 75 degrees inclination with the wrist in flexion) has been shown a promising imaging technique to avoid dorsal cortex screw penetration.[7-9] Several cadaveric and pre-clinical studies have shown accurate detection of dorsal cortex screw penetration with DTV.[10,11] Subsequently, Ganesh and colleagues were the first to report on the incidence of dorsal cortex penetrating screws using post-operative computed tomography (CT) scans as the reference standard addressing the accuracy of DTV: in their pilot study, the incidence of penetrating screws on post-op CT reference was 17% (5 out of 30 patients).[12]

In orthopaedic trauma, previous studies reported on increased revision rates of fixation using advanced 3DF imaging, thereby reducing rates of subsequent revision surgery as compared to conventional two-dimensional fluoroscopy (2DF).[13-15] Mehling et al. reported on revision of misplaced screws after volar plating for distal radius fractures.[16] In one-third of cases, screws were found to be too long, too radial or intra-articularly placed on 3DF intra-operatively; however, these screws were not detected with conventional 2DF. For the purpose of detecting dorsal compartment violation, it is of interest to investigate whether 3DF is of additional value *versus* DTV to decrease the number of dorsal cortex penetrating screws post-operatively.

Therefore, the aim of this retrospective study of three prospective cohorts of 165 patients treated with volar plating for distal radius fractures is to determine whether intra-operative 3DF is preferred over DTV to detect dorsal screw penetration with post-operative CT imaging as the reference standard. Specifically, we compared 1) diagnostic performance characteristics of DTV *versus* 3DF; 2) incidence of post-op dorsal cortex screw penetration in these respective prospective cohorts of a) conventional 2DF; b) 2DF with DTV; and c) 3DF groups; and 3) specific compartments at risk using the varying imaging modalities.

MATERIALS AND METHODS

In accordance to the Declaration of Helsinki, we retrospectively reviewed prospectively collected post-operative CT-scans of two prospective trials of adult patients with an intra-articular distal radius fracture that were approved by our Institutional Review

Boards (IRB).[17,18] This study was designed as a multicentre prospective matched cohort study, with retrospective image analysis of post-op CT reference standard.

Study design – Prospective Matched Cohort Study

In the first index study, patients with distal radius fractures undergoing ORIF were included in a prospective multicentre randomized clinical trial (i.e. EF3X-trial) investigating the effectiveness of the intra-operative use of advanced 3DF *versus* 2DF.[17] The main outcome of the index study was to evaluate the quality of fracture reduction and fixation on intra-operative 3DF, and the subsequent need for immediate revision in both respective groups. Post-operative CTs served as the reference standard.

In the second index study, patients with intra-articular distal radius fractures were prospectively included in a single Level-1 Centre cohort study to evaluate the diagnostic performance characteristics of DTV to detect dorsal screw penetration after volar plating, with post-op CT as the reference standard.[18]

For the purpose of the current imaging study, three prospective cohorts of patients with distal radius fractures undergoing ORIF from both prospective trials were combined in order to evaluate three different intra-operative imaging strategies: 1) standard 2DF with AP and elevated lateral images (n=55); 2) 2DF with AP, elevated lateral, and DTV images (n=50); and 3) 3DF (n=60) (Table I).

First Index Study: 2DF and 3DF Patient Cohorts

Out of a total 206 patients with an intra-articular distal radius fracture who were included in the index EF3X-trial, 103 patients were allocated to 2DF and 103 patients to 3DF. For the purpose of this study, we excluded 91 patients: 21 patients without a volar plate; 29 patients with additional dorsal and/or lateral plates that obscured dorsal screw penetration on post-op CT; 29 patients with a post-op CT-scan of insufficient quality to serve as the reference standard; and 12 patients without a postoperative reference CT-scan.

We included the 115 patients who underwent volar plating for an intra-articular distal radius fracture: 55 patients were randomized to intra-operative 2DF, whereas 60 patients to 3DF. All patients were treated by- or under supervision of a senior orthopaedic or trauma consultant at one of the participating hospitals between October 2009 and July 2014. A volar approach through the FCR-bed was used in all patients to expose the volar radius (i.e. modified Henry approach).[19] Volar locking plates were inserted in all distal radius fractures (LCP 2.4 mm[20] and VA-LCP 2.4 mm[21];

Synthes, Oberdorf, Switzerland). In the 2DF patient cohort, AP and elevated lateral views were used intra-operatively throughout the procedure at surgeons' discretion. DTVs were not part of hospital protocols, and not used in surgeons' respective practice. Therefore, the 2DF group served as the baseline reference.

2DF Patient Cohort: Baseline Incidence of Post-op Screw Penetration

Without the routine use of intra-operative DTV or 3DF, 40% of patients (22 out of 55 patients) had –at least– one dorsal screw penetrating (≥ 0.5 mm) on post-operative CT imaging, whereas in 13% (7 out of 55 patients) two screws were penetrating. In total, 29 out of 225 screws (13%) were found to be penetrating with a penetration distance on average of 1.1 mm (range 0.6 – 4.9 mm) and a median length of 20 mm (interquartile range [IQR] 18 – 22 mm, range 16 – 26 mm).

The screw positions at risk for dorsal screw penetration were distributed as follows; 16 screws (55%) in the most radial position (i.e. 2nd compartment), 5 screws (17%) in the second most radial position (2nd compartment), 7 screws (17%) in the most ulnar position (4th compartment), 1 screw (3%) in the second most ulnar position (3rd compartment), and none in the central screw position (i.e. Lister's Tubercle, in plates with 5 holes) (Figure 2).

Second Index Study: DTV Patients Cohort

We included 50 prospectively enrolled patients who were surgically treated with a variable angle locking compression plate (VA-LCP, Synthes, North Ryde, NSW, Australia) for an intra-articular distal radius fracture at our Level-1 Trauma Centre between May 2017 and August 2018 for retrospective use of this prospective data.

CT Reference Standard: Assessment of Dorsal Cortex Screw Penetration on Triplanar Reconstructions

We defined dorsal cortex screw penetration as screws penetrating ≥ 0.5 mm.[22] All patients were followed-up with a post-operative wrist CT-scan within 1 week with a slice thickness of <1mm (Somatom Definition AS+, Siemens, Erlangen, Germany). CT-scans were obtained in an axial plane and saved as Digital Imaging and Communications in Medicine (DICOM) files. We created triplanar reconstruction in OsiriX lite version 9 (open-source software; https://www.osirix-viewer.com[23]) with an adjusted axial plane parallel to the screw. We only evaluated the most distal row of the volar locking plate as we consider the physical anatomical space for the extensor tendons as most limited. Two observers (BLINDED INITIALS), which had not been involved in patients' care, independently evaluated each screw for (1) penetration of the dorsal cortex, (2) the total length of the screw, (3) the amount of dorsal cortex screw penetration in millimetre (mm), and (4) the violated dorsal compartment.

Measurements were obtained by following these steps (Figure 1): 1) The axial, sagittal and coronal planes were adjusted parallel to the distal angular stable screw. 2) On the axial plane, we measured the total length of the dorsal penetrating screw from screw head to screw tip. 3) We constructed a line at each side of the penetrating screw. 4) By measuring the distance from the screw tip to the constructed line, we determined the penetration distance from the screw tip to the dorsal cortex *(www.traumaplatform.org/currentprojects)*.

Statistical Analysis

Two independent observers not involved in patient care (BLINDED INITIALS) conducted initial measurements in a set of 20 randomly selected cases in order to assess the inter-observer reliability of the above described new CT-measurement technique. We used Kappa, a quantitative measure accounting for agreement by chance among observers, to assess the inter-observer agreement for penetration of the screw and the linear-weighted Kappa for the total length of a screw (as this is a categorical variable). Confidence intervals were calculated by using the standard error. According to Landis and Koch,[24] the Kappa for dorsal screw penetration and the linear-weighted Kappa for the total length of a screw was almost perfect: 0.84 (95% CI, 0.74 – 0.94) and 0.82 (95% CI, 0.70 – 0.95). A Kappa above 0.81 indicates almost perfect agreement. Inter-observer agreement of dorsal screw penetration was calculated by an intra-class correlation coefficient (ICC) through a two-way random-effects model with absolute agreement to assess how much each measurement differs from the other observer. The ICC for the amount of dorsal cortex screw penetration distance was excellent: 0.96 (95% CI, 0.95 – 0.97).[25]

Patient characteristics were summarized with frequencies and percentages for categorical variables and with mean and range for continuous variables. Diagnostic performance characteristics were calculated according to standard formulas, which were previously used by Ganesh et al. for their assessment of DTV intra-operatively.[12] We calculated differences in sensitivity between DTV and 3DF and the incidence of screw penetration among the 2DF, DTV and 3DF group by a Pearson's Chi-squared test. A two-tailed *P*-value less than 0.05 was considered significant. All statistical analyses were performed using Stata 15 (StataCorp LP, College Station, TX, USA).

RESULTS

DTV Patient Cohort

The sensitivity of intra-operative DTV to detect dorsally penetrating screws was 39% with a negative predictive value of 91% and an accuracy of 91%.

With the routine use of intra-operative DTV, 32% of patients (16 out of 50 patients) had –at least– one dorsal screw penetrating on post-operative CT imaging, whereas in 4% of patients (2 out of 50 patients) two screws were penetrating, and in 4% of patients (2 out of 50 patients) three screws were penetrating. In total, 20 out of 218 screws (9%) were found to be penetrating with a penetration distance of 1.5 mm (range 0.5 – 4.5 mm) and a median length of 21 mm (IQR 18 – 24 mm, range 16 – 26 mm).

Of the penetrating screws; 11 screws (55%) were situated in the most radial position (i.e. 2nd compartment), followed by 5 screws (25%) in the second most radial position (i.e. 2nd compartment), 3 screws (15%) in the most ulnar position (i.e. 4th compartment), 1 screw (5%) in the second most ulnar screw position (i.e. 3rd compartment), whereas none were found in the central –Lister's Tubercle– screw position (in plates with 5 holes). Additionally, two out of 218 screws (1%) were found to be placed intra-articular (one in the radio-carpal joint and one in the distal radial ulnar joint [DRUJ]).

3DF Patient Cohort

The sensitivity of intra-operative 3DF was 25% with a negative predictive value of 93% and an accuracy of 93%.

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With the use of intra-operative 3D fluoroscopy, 25% of patients (15 out of 60 patients) had –at least– one dorsal screw penetrating on post-operative CT-imaging, whereas in 5% (3 out of 60 patients) two screws were found to be penetrating. In total, 18 out of 248 screws (7%) were found to be penetrating with a penetration distance of 1.6 mm (range 0.7 – 4.0 mm) and a median length of 20 mm (IQR 18 – 20 mm, range 16 – 26 mm).

Advanced imaging with intra-operative fluoroscopy showed penetration in the following positions: 8 screws (44%) in the most radial position (i.e. 2nd compartment), 6 screws (33%) in the second most radial position (i.e. 2nd compartment), 3 screws (17%) in the most ulnar position (4th compartment), and 1 screw (5%) in the central position. No screws were found to be penetrating the second most ulnar position (i.e. 3rd compartment).

DISCUSSION

ORIF with a volar approach is becoming the mainstay of treatment for patients with a distal radius fracture.[1-5] We aimed to answer the question if advanced intra-operative 3DF is preferable over DTV in clinical practice to avoid dorsal cortex screw penetration as one of the potential iatrogenic complications of volar plating causing extensor tendon irritation and subsequent rupture.[26] Based on diagnostic performance characteristics and post-op incidence of screw penetration in the dorsal compartments, one can conclude that 3DF is not superior over DTVs. Moreover, DTVs are arguably more efficacious than advanced 3DF when taken into account use of resources for intra-operative 3D imaging.

This study should be interpreted in the light of strengths and weaknesses. A strength by design is the use of a new reliable CT-measurement technique to evaluate and measure dorsal cortex screw penetration as the reference standard to evaluate the diagnostic performance characteristics of 3DF *versus* DTV. Limitations include: 1) the study was designed as an imaging study, therefore lacking clinical follow-up data on the incidence of extensor tendon related complications (e.g. tenosynovitis and tendon rupture); and 2) designed as a case control study of prospective cohorts rather, than a prospective RCT comparing the intra-operative use of DTV *versus 3DF*.

Sensitivity was slightly better for DTV as compared to 3DF, although there was no statistical difference (DTV: 39% *versus* 3DF: 25%, P = 0.26), while the accuracy was high and similar between both groups (DTV: 91% *versus* 3DF: 93%). We postulate the difference in sensitivity between both cohorts may be caused by the following: surgeons were familiar with DTV as this was part of our hospital protocol, while the intra-operative use of advanced 3DF was not routine for most surgeons. When compared to existing literature, previous pre-clinical studies on DTV reported sensitivities ranging from 58-70%, while –to the best of our knowledge– no studies exist reporting on the sensitivity for 3DF for dorsal screw penetration.[7,27,28]

The incidence of post-op dorsal screw penetration was 25% for 3DF *versus* 32% in the DTV group (P = 0.08), and compared to a mere baseline incidence of 40% in the conventional 2DF-group. The latter is comparable to one other study: one prospective clinical trial evaluated the incidence of unrecognized dorsal cortex screw penetration on post-operative CT-imaging after intra-operative use of 2DF - without DTV or 3DF.[29] The authors found penetrating screws in 37% of patients. In contrast to studies using advanced imaging: Ganesh et al. found prominent screw tips in 17% of patients on post-operative CT-imaging with the use of DTV intra-operatively.[12] Although in our study results are promising to reduce screw penetration, and the incidence was lowest in the most advanced imaging group (i.e. 3DF), still 1 out of 4 patients left the operating room with prominent dorsal screw tips in the extensor compartment. Moreover, one could argue that obtaining 3DF intra-operatively is time-consuming and expensive as compared to obtaining a 'simple' DTV, and requires a trained team to obtain the 3D images intra-operatively.

The 2nd compartment was at highest risk for dorsal cortex screw penetration; however, while using more advanced imaging the number of penetrating screws decreased. Additionally, no protruding screws remained in situ in the third compartment (extensor pollicis longus [EPL] groove) with 3DF, whereas we found 1 screw in the DTV-group (2%). This is in line with prior studies, in which the 2nd compartment has been violated as the most common site, followed by the third and fourth compartment.[22,29] Despite the high number of penetrating screws in the radial compartment, the slope on the dorsal aspect provides some room for error as reports on tendon ruptures in this compartment are scarce.[26] In contrast, the EPL in the 3rd compartment might easily be injured due to the small anatomical space and the narrow tendon sheath.[30] To put things into context, extensor tendon related complications due to dorsal penetrating screws vary between 0 and 30%, perhaps leaving a majority of dorsal penetrating screws asymptomatic.[22,29,31,32] However, as dorsal penetration can be avoided by a combination of meticulous surgical technique (subtracting 2 mm of measured depth) and the use of correct imaging strategies (DTV), one should always aim to avoid significant morbidity of extensor tendinitis- and subsequent surgical intervention for (late) rupture.

In conclusion, the current study supports to obtain 'simple' DTVs to minimize dorsal penetrating screws after volar plating. One could argue that 3DF is not required to be part of a surgeon's armamentarium to avoid dorsal screw penetration, as it did not improve the diagnostic performance, while implementing this technique in the daily routine may be labour intensive and expensive.

TABLE AND FIGURE LEGENDS

Table 1: Patient Characteristics of Three Imaging Groups

Characteristic	Cohort 1: 2DF	Cohort 2: 2DF + DTV	Cohort 3: 3DF
No. of patients	55	50	60
Age*	56 (24 - 76)	57 (18 - 87)	56 (22 - 79)
Sex†			
Male	18 (33)	16 (32)	24 (40)
Female	37 (67)	34 (68	36 (60)
Side of fracture†			
Left	31 (56)	20 (40)	39 (65)
Right	24 (44)	30 (60)	21 (35)
AO / OTA-type 23†			
A	8 (15)	.	4 (7)
B	10 (18)	16 (32)	9 (15)
C	37 (67)	34 (68)	47 (78)

*Mean with range. † Number with percentage.

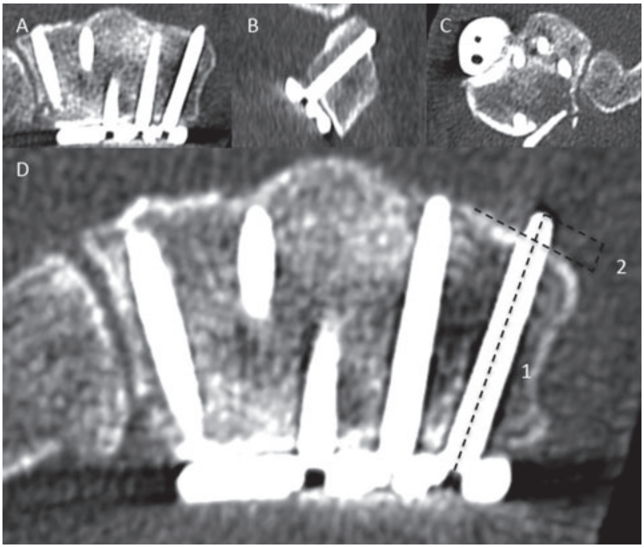
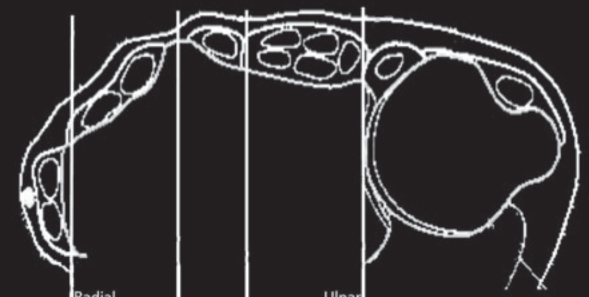


Figure 1: Triplanar reconstructions with the axial (A), sagittal (B), and coronal planes (C). Measurements were performed in the adjusted axial plane parallel to the dorsal cortex penetrating screw in the most radial position (i.e. 2nd compartment). Number 1 is the line on which the total length of the penetrating screw was measured. Line number 2 represents the dorsal cortex penetrating screw distance *(www.traumaplatform.org/currentprojects)*.



Compartment	2nd		Lister's Tubercle	3rd	4th
Screw position	1	2	central	2	1
Number penetrating screws	16	5	.	1	7
Median penetrating distance (mm)	1.2	1.7	.	0.9	1.1
Median length penetrating screws (mm)	18	20	.	24	22
Number non penetrating screws	36	46	22	49	43
Median length non-penetrating screws (mm)	16	18	20	20	18
Total screws placed	52	51	22	50	50

Figure 2: Courtesy to the Lleyton Hewitt Study group for using this figure.[33] Screws in the 2nd compartment were at highest risk of being too long, followed by the 4th compartment, the 3rd compartment, and the central –Lister's Tubercle– compartment.

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REFERENCES

1. Kakar S. Clinical Faceoff: Controversies in the Management of Distal Radius Fractures. *Clinical orthopaedics and related research*. 2015;473(10):3098-3104.
2. Koval K, Haidukewych GJ, Service B, Zirgibel BJ. Controversies in the management of distal radius fractures. *The Journal of the American Academy of Orthopaedic Surgeons*. 2014;22(9):566-575.
3. Koval KJ, Harrast JJ, Anglen JO, Weinstein JN. Fractures of the distal part of the radius. The evolution of practice over time. Where's the evidence? *The Journal of bone and joint surgery American volume*. 2008;90(9):1855-1861.
4. Murray J, Gross L. Treatment of distal radius fractures. *The Journal of the American Academy of Orthopaedic Surgeons*. 2013;21(8):502-505.
5. Members of the Writing R, Voting Panels of the AUCotToDRF, Watters WC, Sanders JO, Murray J, Patel N. The American Academy of Orthopaedic Surgeons Appropriate Use Criteria on the treatment of distal radius fractures. *J Bone Joint Surg Am*. 2014;96(2):160-161.
6. Al-Rashid M, Theivendran K, Craigen MA. Delayed ruptures of the extensor tendon secondary to the use of volar locking compression plates for distal radial fractures. *The Journal of bone and joint surgery British volume*. 2006;88(12):1610-1612.
7. Brunner A, Siebert C, Stieger C, Kastius A, Link BC, Babst R. The dorsal tangential X-ray view to determine dorsal screw penetration during volar plating of distal radius fractures. *The Journal of hand surgery*. 2015;40(1):27-33.
8. Haug LC, Glodny B, Deml C, Lutz M, Attal R. A new radiological method to detect dorsally penetrating screws when using volar locking plates in distal radial fractures. The dorsal horizon view. *The bone & joint journal*. 2013;95-b(8):1101-1105.
9. Hill BW, Shakir I, Cannada LK. Dorsal Screw Penetration With the Use of Volar Plating of Distal Radius Fractures: How Can You Best Detect? *Journal of orthopaedic trauma*. 2015;29(10):e408-413.
10. Ozer K, Wolf JM, Watkins B, Hak DJ. Comparison of 4 fluoroscopic views for dorsal cortex screw penetration after volar plating of the distal radius. *The Journal of hand surgery*. 2012;37(5):963-967.
11. Joseph SJ, Harvey JN. The dorsal horizon view: detecting screw protrusion at the distal radius. *The Journal of hand surgery*. 2011;36(10):1691-1693.
12. Ganesh D, Service B, Zirgibel B, Koval K. The Detection of Prominent Hardware in Volar Locked Plating of Distal Radius Fractures: Intraoperative Fluoroscopy Versus Computed Tomography. *Journal of orthopaedic trauma*. 2016;30(11):618-621.
13. Hufner T, Stubig T, Gosling T, Kendoff D, Geerling J, Krettek C. [Cost-benefit analysis of intraoperative 3D imaging]. *Der Unfallchirurg*. 2007;110(1):14-21.
14. Richter M, Geerling J, Zech S, Goesling T, Krettek C. Intraoperative three-dimensional imaging with a motorized mobile C-arm (SIREMOBIL ISO-C-3D) in foot and ankle trauma care: a preliminary report. *Journal of orthopaedic trauma*. 2005;19(4):259-266.
15. Wich M, Spranger N, Ekkernkamp A. [Intraoperative imaging with the ISO C(3D)]. *Der Chirurg; Zeitschrift fur alle Gebiete der operativen Medizen*. 2004;75(10):982-987.

16. Mehling I, Rittstieg P, Mehling AP, Kuchle R, Muller LP, Rommens PM. Intraoperative C-arm CT imaging in angular stable plate osteosynthesis of distal radius fractures. *J Hand Surg Eur Vol*. 2013;38(7):751-757.

17. Beerekamp MS, Ubbink DT, Maas M, et al. Fracture surgery of the extremities with the intra-operative use of 3D-RX: a randomized multicenter trial (EF3X-trial). *BMC musculoskeletal disorders*. 2011;12:151.

18. Bergsma M, Bulstra AE, Morris D, Janssen MM, Jaarsma RL, Doornberg JN. Accuracy of dorsal tangential views to avoid screw penetration with volar plating of distal radius fractures. *Paper presented at: AAOS Annual Meeting*. 2019 (March 12 - 16):Las Vegas, USA.

19. Henry MH, Griggs SM, Levaro F, Clifton J, Masson MV. Volar approach to dorsal displaced fractures of the distal radius. *Techniques in hand & upper extremity surgery*. 2001;5(1):31-41.

20. Synthes. LCP Distal Radius System 2.4. A comprehensive plating system to address a variety of fracture patterns. 2009;http://synthes.vo.llnwd.net/o16/Mobile/Synthes North America/Product Support Materials/Technique Guides/SUSA/SUTG2.4DRPltJ4569F.pdf.

21. Synthes. Variable Angle LCP Two-Column Volar Distal Radius Plate 2.4. For fragment-specific fracture fixation with variable angle locking technology. 2015;http://synthes.vo.llnwd.net/o16/LLNWMB8/INT Mobile/Synthes International/Product Support Material/legacy_Synthes_PDF/DSEM-TRM-0815-0464_LR.pdf.

22. Sugun TS, Karabay N, Gurbuz Y, Ozaksar K, Toros T, Kayalar M. Screw prominences related to palmar locking plating of distal radius. *J Hand Surg Eur Vol*. 2011;36(4):320-324.

23. Rosset A, Spadola L, Ratib O. OsiriX: an open-source software for navigating in multidimensional DICOM images. *Journal of digital imaging*. 2004;17(3):205-216.

24. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.

25. Cicchetti D. Guidelines, criteria and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychol Assess*. 1994;6:284-290.

26. Azzi AJ, Aldekhayel S, Boehm KS, Zadeh T. Tendon Rupture and Tenosynovitis following Internal Fixation of Distal Radius Fractures: A Systematic Review. *Plast Reconstr Surg*. 2017;139(3):717e-724e.

27. Kiyak G. In vivo confirmation of the reliability of the dorsal tangential view of the wrist. *Hand Surg Rehabil*. 2018;37(1):56-59.

28. Oc Y, Kilinc BE, Gulcu A, Varol A, Ertugrul R, Kara A. Ultrasonography or direct radiography? A comparison of two techniques to detect dorsal screw penetration after volar plate fixation. *Journal of orthopaedic surgery and research*. 2018;13(1):70.

29. Diong TW, Haflah NHM, Kassim AYM, Habshi S, Shukur MH. Use of Computed Tomography in Determining the Occurrence of Dorsal and Intra-articular Screw Penetration in Volar Locking Plate Osteosynthesis of Distal Radius Fracture. *The journal of hand surgery Asian-Pacific volume*. 2018;23(1):26-32.

30. Bianchi S, van Aaken J, Glauser T, Martinoli C, Beaulieu JY, Della Santa D. Screw impingement on the extensor tendons in distal radius fractures treated by volar plating: sonographic appearance. *AJR American journal of roentgenology*. 2008;191(5):W199-203.

31. 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. *Journal of orthopaedic trauma*. 2007;21(5):316-322.

32. McKay SD, MacDermid JC, Roth JH, Richards RS. Assessment of complications of distal radius fractures and development of a complication checklist. *The Journal of hand surgery*. 2001;26(5):916-922.

33. Bergsma M, Doornberg JN, Duit R, et al. Volar plating in distal radius fractures: A prospective clinical study on efficacy of dorsal tangential views to avoid screw penetration. *Injury*. 2018.

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STANDARDIZING AND OPTIMIZING THE DORSAL TANGENTIAL VIEW TO PREVENT SCREWS PROTRUDING IN THE DORSAL COMPARTMENTS: AN EXPERIMENTAL IMAGING STUDY ON THE INFLUENCE OF TRAINING ON DIAGNOSTIC ACCURACY AND RELIABILITY

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ABSTRACT

Purpose

To determine inter-observer agreement and diagnostic accuracy of the dorsal tangential view (DTV) of the wrist in a large group of observers who both obtain and interpret their own DTV views and to determine the influence of training.

Methods

Volar locking plates (DePuy Synthes, Belmont WA, Australia) were placed with randomly assigned protruding screws on the intact distal radius of ten fresh frozen cadaveric arms. Thirteen observers obtained and interpreted DTVs of these specimens for dorsal screw penetration without prior instruction. All observers were shown a training video on DTV and then repeated obtaining and interpreting DTVs of all specimens.

Results

Inter-observer agreement for decision of screw exchange improved significantly after training. Sensitivity of DTV was 0.88 (95% CI: 0.64 to 0.97) before training, and 0.92 (95%CI: 0.69 to 0.99) after training. The accuracy was 0.86 (95%CI: 0.77 to 0.95) before training and 0.90 (95%CI: 0.82 to 0.98) after training. This equated to a 36% less protruding screws remaining after training. The number of required ii-shots required decreased significantly.

Conclusion

Accuracy and inter observer agreement for DTV is lower than expected when surgeons both: 1) obtain- and 2) interpret the view themselves, but improves after training. While having some experience in DTV, surgeons performing distal radius fracture surgery in daily practice improve from adequate specialized training.

Clinical Relevance:

There is a discrepancy between preclinical and clinical results on diagnostic performance characteristics of DTV.

Specific training significantly improves reliability of DTV- and surgeons' confidence for decision making to change dorsally protruding screws in volar plating of the distal radius.

INTRODUCTION

Although volar plating for distal radius fractures is considered 'routine' for many surgeons, dorsal screw penetration after volar plating can interfere with the dorsal extensor tendon compartments causing postoperative complications such as tendon irritation and potentially tendon rupture.[1,2] Prevention with proper surgical strategies, as well as detection of dorsally protruding screws intra-operatively is therefore essential.[3]

Several intra-operative fluoroscopic imaging strategies have been described to improve recognition of penetrating screws in the dorsal compartments: carpal shoot through,[4,5] oblique view,[5-8] radial groove view[6,9] and rotational fluoroscopy.[10] Authors of pre-clinical studies and small clinical series have advocated the use of the Dorsal Tangential View (DTV) to improve the detection of dorsal screw penetration during volar plating of the distal radius.[5-8,11-18]

In pre-clinical cadaveric work, the DTV has shown a promising accuracy of dorsal screw penetration detection of up to 100%.[7,8,11,19-22] However, in small (retrospective) clinical series, a lower sensitivity ranging from 58% to 70% was reported.[15-17] Two of the previously mentioned pre-clinical studies also reported a (nearly) perfect inter-observer agreement for DTV.[7,22] A significant limitation of these pre-clinical studies on inter-observer agreement of the DTV, is that "premade" fluoroscopy images were presented to observers.[7,14,18,22,23] rather than views obtained by the observers themselves. This may explain the discrepancy between the promising accuracy of the former pre-clinical studies[12,18,24,25] *versus* the disappointing diagnostic performance of the latter small clinical series[15-17] with up to 26 non-consecutive patients[17]. One could argue that it is not the interpretation of the actual fluoroscopic images, but obtaining the correct view, that is the most challenging part of visualizing posterior protruding screws. Obtaining the correct view could therefore strongly influence the diagnostic performance characteristics of the DTV. Previous imaging studies in other areas found that training resulted in marked improvement in inter-observer agreement.[26-31]

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To the best of our knowledge, there are no reports on the inter-observer agreement and diagnostic accuracy of the DTV in a pre-clinical setting that actually reflects daily clinical practice: i.e. observers both obtaining- as well as interpreting the DTV themselves. The purpose of this cadaveric study is therefore to:

1) determine observer agreement and diagnostic accuracy of the DTV of cadaveric specimens that include wrist, elbow and humerus in observers that both obtain- as

well as interpret their own DTV views, in two rounds using Computed Tomography (CT) imaging as the reference standard: a) before- and b) after training; and

2) analyze the influence of training on the inter-observer agreement and diagnostic accuracy for obtaining and interpreting the DTVs to detect dorsal protruding screws in volar plating of the distal radius.

METHODS

The study protocol was approved by the Human Research Ethical Commission at our Institution under number 224.17. No funding was provided for this study.

Cadaveric Specimens

For this study, we used ten fresh frozen cadaveric arms without anatomical or radiographic signs of previous surgery or trauma to the distal radius or carpus. Via a modified volar Henry approach, AO variable Angle LCP Two-Column distal radius plates 2.4 mm with 5 distal holes in 9 cases and 4 distal holes in one to fit the width of the cadaveric radius were applied (Synthes, Belmont WA, Australia). All specimens were placed in room temperature 24 hours before start of any part of this study and placed in the freezer at a temperature of -20 degrees °C between different stages of this study. All volar plates were placed by the senior orthopaedic trauma surgeon using the modified Henry approach. The correct position of the plate was checked with fluoroscopy images obtained with a C-arm (Siemens, Bayswater, Australia). The proximal part of the plate was fixed with three 2.4 mm cortical screws. The holes of the most distal row were drilled by using a variable angle locking drill sleeve, the length of each hole was measured with a depth gauge and variable angle locking screws were placed in all holes.

Protruding Screws

In order to place a non-protruding screw 2 to 3 mm were subtracted of the measured length, while 2 to 3mm were added to the length to place a screw that would be dorsally protruding. The number and location of dorsally protruding screws were randomly assigned before commencement of the study. In an earlier efficacy study in a prospective clinical cohort, we found protruding screws on a DTV in 26% of the cases.[32] To increase the power of this study, one or more screws were protruding in 7 out of the 10 cadavers. The observers were blinded to the permutations of the screw length.

Distribution as randomly allocated by the computer (SPSS, St Leonards NSW, Australia) was as follows: Forty-nine distal screws were placed in ten cadaveric wrists. Seventeen of 49 (35%) screws protruded dorsally. CT reference imaging identified: 1 screw protruding 1 mm from tip to dorsal cortex, 3 screws 2 mm, 10 screws 3 mm, 1 screw 4 mm, and 2 screws 5mm.

Observers

Thirteen observers with varying levels of experience (five registrars, six orthopaedic trauma fellows, one upper limb fellow, one orthopaedic consultant) who perform volar plating for distal radius fractures in their day-to-day clinical practice and use DTV intra-operatively, were invited independently to our cadaver laboratory without prior instruction or explanation regarding the topic or purpose of the study. All observers were familiar with DTV, as it is protocolled in our institution. The observers were asked to obtain a DTV, using fluoroscopy with a C-arm (Figure 1), of each cadaveric specimen to detect potential dorsal protruding screws. No instructions or training was given about the execution of the view.

The observers were asked: 1) to identify any dorsally protruding screws, and the exact location of these protruding screw(s). 2) if they would opt to change any of these screws in clinical practice, and 3) if opted to change, to estimate how many millimeters (with increments of 2mm) they would subtract from the respective screw lengths. Finally, observers were asked how confident they were about their overall evaluation of the respective cadaveric wrist; on an oral analogue scale from 0 to 5 with a higher score indicating more confidence. The observer could make as many fluoroscopy images as required. The number of shots needed to satisfy the observer and answer the above questions was also recorded.

Standardized Training

After this initial assessment, the observers were asked to watch a training video of the DTV, given by a senior expert upper limb trauma surgeon. (www.traumaplatform.org/currentprojects) This included a discussion on the anatomy of the distal radius, the limitations of conventional anteroposterior/lateral views and the purpose, execution and interpretation of the DTV.

The observers then repeated the radiological assessment of the ten specimens which were randomly reassigned.

Reference Standard

Following completion of the radiological study by the 13 observers, a dorsal open approach was made to the cadaveric specimens and the length of the protruding screws measured. (Figure 2A)

Furthermore, a CT-scan was performed of all cadaveric wrists to determine the exact length of dorsal screw penetration. (Figure 2B) Osirix software (open-source software; https://www.osirix-viewer.com[33]**)** was used to create tri-planar reconstructions of the sagittal and coronal planes parallel to the center of each screw to measure the screw length and amount of screw protrusion in millimeters by a blinded observer as depicted in the video on: www.traumaplatform.org/currentprojects.

There was no discrepancy between dorsal screw penetration (yes/no) with dorsal open approach and on CT.

Statistics

Outcome measures were screw penetration (yes/no), screw exchange (yes/no), screw protrusion (in millimeters), confidence level (range from 0-5) and number of fluoroscopic images.

Descriptive statistics were described as absolute number with frequencies, and mean with standard deviation for the amount and degree of screw penetration to the 10 volar distal radius plates.

Inter-observer agreement was assessed for the categorical variables (screw penetration, screw exchange) among observers.[34-36] The guidelines proposed by Landis and Koch were used to interpret the kappa values[35]: slight agreement for values 0.01-0.20, fair agreement 0.21-0.40, moderate agreement 0.41-0.60, substantial agreement 0.61-0.80 and almost perfect agreement > 0.80. The agreement among the observers before training was compared with the results among the observers after training. Bootstrapping (number of resamples: 1000) was used to calculate the standard error, z-statistic, 95% CIs, and p values for the kappa values to compare groups.

Intra-class correlation was used to assess the inter-observer agreement of continuous variables (screw protrusion in millimeters) among observers using a two-way mixed-effects model with absolute agreement. Absolute agreement in an ICC assesses how much each measurement performed per observer differs from the other observers.

A score of 1 indicates perfect agreement, whereas 0 reflects no agreement. Fisher's Z transformation was used to calculate p values comparing individual groups.

Standard formulas with 95% confidence intervals were used to calculate the sensitivity and specificity on average (among the 13 participants) of the results before and after training.

A one-sample T-test was used to compare the estimated amount of protrusion by the observers to the exact measured screw protrusion in millimeters as measured on reconstructed CT-scans. Paired T-tests were used to compare the number of fluoroscopic images used before and after training.

RESULTS

Inter-observer agreement before- and after training

Kappa values representing the inter-observer agreement for diagnosis of dorsal screw penetration improved from moderate (k_{bt} = 0.52) before training-, to substantial (k_{at} = 0.66) after training. However, the improvement in categorical rating was not statistically significant with the number of observers (n = 13) and screws (n = 49) (p=0.073).

The kappa values representing inter-observer agreement for decision of screw exchange did improve significantly from moderate (k_{bt} = 0.51) before training, to substantial (k_{at} = 0.67) after training (p=0.043).

The intra-class correlation coefficient representing inter-observer agreement for number of millimeters needed to be subtracted from the protruding screws was moderate (ICC = 0.49) before training and improved to substantial (ICC = 0.69) after training, but was not statistically significant (p=0.146).

Diagnostic performance before and after training

The average sensitivity of detection of dorsal screw penetration on DTV was 0.88 (95% CI: 0.64 to 0.97) before training, and improved to 0.92 (95%CI: 0.69 to 0.99) after training. The specificity of detection of dorsal screw penetration on DTV was 0.84 (95%CI: 0.68 to 0.93) before training, and 0.87 (95%CI: 0.71 to 0.95) after training. The accuracy of detection of dorsal screw penetration on DTV was 0.86 (95%CI: 0.77 to 0.95) before training, and 0.90 (95%CI: 0.82 to 0.98) after training. Overlap of 95% confidence intervals indicate no significant increase in diagnostic performance measures.

The positive predictive values were 0.78 before training and 0.84 after training. The negative predictive values were 0.93 before training and 0.96 after training

Confidence Levels with execution and interpretation of DTV and Total Number of Fluoroscopy Shots before and after training

The average confidence level (0-5) increased significantly from 3.5(SD 1.1, range 1-4) on a scale from 0 to 5, with 5 representing most confidence to 4.0 (SD: 0.81, range 1-5) ($p<0.001$). The number of required ii-shots required decreased significantly from 1.8 (range: 1 - 6, SD: 0.96) to 1.5 (1 - 10, SD: 0.80) ($p=0.008$). In 44 % of cases a single radiological image was obtained before training, and this increased to 52% after training.

Difference in amount of screw penetration of undetected screws before and after training

Before training, a total of 25 screws with a mean amount of protrusion of 2.8 mm (SD 0.59, range 1.4-3.6) were missed. After training, a total of 16 screws with a mean amount of protrusion of 2.9 mm (SD 0.49, range 1.4-3.6) were missed. While there was no significant difference between the average amount of protrusion missed before and after training ($p= 0.55$), 36% of the screws that were missed are correctly defined after training.

Number if ii-shots before and after training

The number of required ii-shots required decreased significantly from 1.8 (range: 1 - 6, SD: 0.96) to 1.5 (1 - 10, SD: 0.80) ($p=0.008$). After training, in 52% of the cases the surgeon-observers only used 1 shot compared to 43% of the cases before training.

DISCUSSION

In this study we found that: 1) accuracy and inter observer agreement for DTV is lower when surgeons both obtain and interpret the view themselves, as compared to 'perfect premade' views in previous studies[7,8,11,14,18-23]; and 2) specific training significantly improves reliability of DTV from moderate- to substantial agreement, and surgeons' confidence for decision making to change dorsally protruding screws in volar plating of the distal radius.

The results of this study should be interpreted in the light of its strengths and weaknesses. A major strength is that the set-up of the study is that the observer-surgeons both obtained- and interpreted the DTV themselves, rather than interpret pre-made views. These observer-surgeons perform distal radius fracture surgery and use DTV in daily clinical practice. This is also a limitation; in contrast to previous studies, the views were not standardized with a goniometer. This may result in slightly different views, but one could argue that this represents daily clinical practice.[18] Second, both CT-scans and direct visualization by means of dorsal incisions were used to verify dorsally protruding screws. Advanced imaging software was used to measure the screw by means of tri-planar reconstructions. Third, we used a relatively large number of observers compared to prior studies.[7,22]

Limitations include: this study does not account for the learning curve experienced in the first session. Even though this may have influenced the results of the second session in addition to the training, and one could argue that experience may be just as important factor as training. Additionally, to represent clinical practice our observers did have experience in DTV as this is part of our institutions' protocol for distal radius fracture surgery. Future studies might focus on the influence of training apart from building up experience, and analyze larger subgroups of observers with different levels of experience. Another limitation results from the fact that the incidence of screw penetration in our specimens was higher than we found in an earlier study and prior literature. This does however increase the power of our study.

We found moderate inter-observer agreement of the DTV for dorsal screw penetration before training ($k_{bt} = 0.52$), with a diagnostic accuracy of 0.86 and sensitivity of 0.88. This is in contrast with the much more favorable results of previous pre-clinical studies from Ozer et al and Vernet et al. The authors found a nearly perfect inter-observer agreement for the DTV for the detection of dorsally protruding screws with respectively sensitivity of 0.95 and 0.97.[7,22] This can be explained by the fact that the DTV was 'perfectly premade' in these studies, often using a goniometer to establish the perfect position as described by Brunner et al.,[18] and with the observers only analyzing the images. In a small, non-consecutive clinical study a lower sensitivity of 0.67 for DTV was found as well, representing the difficulty to accurately both obtain and interpret the DTV in clinical practice.

The inter-observer agreement for screw exchange significantly improved after training, from moderate- to substantial agreement (P=0.043). This is most relevant in clinical practice, while previous pre-clinical studies only looked at whether screws were determined to be protruding by the observers in preclinical studies.[7,8,11,19-22]

The inter-observer variation of the DTV might be based on multiple components, including experience, execution of the DTV and quality of the image (depending on the materials and amount of swelling of the arm) and interpretation (observer bias/error). Based on our results of this study we believe that training can improve the execution and interpretation of the DTV. As suggested in previous literature, the moderate inter-observer agreement we found before training suggests surgeons untrained in DTV might experience a benefit from avoiding bi-cortical fixation by subtracting 2-4 mm from the gauche measured screw length.[17,37] Also the fact that both the observers' confidence as the average number of ii-shots needed before a satisfying DTV was made improved implies the importance of attention to training.

The improvement in sensitivity was not significant. This might be because our observers already had experience with DTV. Additionally, the observers were asked to focus on DTV and screw lengths only in cadaveric wrists rather than making this a part of a full distal radius fracture surgery with many (complex) steps and a need for the fixation to hold long-term, which might result in a lower threshold of defining screws as too long and change them. This lower threshold also explains the slightly lower accuracy 0.86 in this study compared to 0.95 in our cohort of 50 patients[38]. One should keep in mind accuracy does depend on the incidence of screw penetration, which was not similar in both studies.

After training, a total of 16 screws with a mean amount of protrusion were missed, which equated to a 36% less protruding screws after training. When reviewing these screws, surgeon-observers missed the same screw in eight (50%) cases (Figure 3A and 3B) in the 4th compartment. This may be due to relative proximal protrusion with the dorsal ridge obscuring protrusion more proximally (Figure 3C), possibly indicating that the DTV is less sensitive for screws located more proximal than the true "skyline" of the distal radius. The cases in which the surgeon-observers only needed 1 ii-shot to get an acceptable view increased by 19% after training. This represents a reduction in the total radiation dose to the patient, doctor and theatre staff.

In conclusion, accuracy and inter observer agreement in DTV is lower when surgeons both obtain and interpret the view themselves, as compared to 'perfect premade' views in previous studies. Specific training significantly improves reliability of DTV and surgeons' confidence for decision making to change dorsally protruding screws in volar plating of the distal radius. While having some experience in DTV, surgeons performing distal radius fracture surgery in daily clinical practice do seem to improve from adequate specialized training.

FIGURE AND TABLE LEGENDS

Figure 1: The observers were asked to obtain a DTV of cadaveric specimens that include wrist, elbow and humerus, using fluoroscopy with a C-arm.

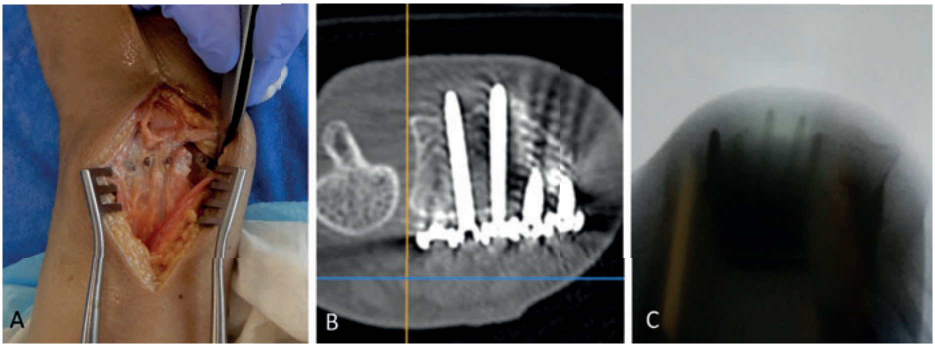


Figure 2: Following completion of the radiological study, a dorsal open approach was made to the cadaveric specimens (A). In this cadaveric specimen protrusion three protruding screws can be seen. (B) shows the tri-planar CT reconstruction of the same specimen showing two of the three protruding screws. (C) shows the DTV of the same specimen, showing the three protruding screws in the second and third from ulnar position, and the most radial position.

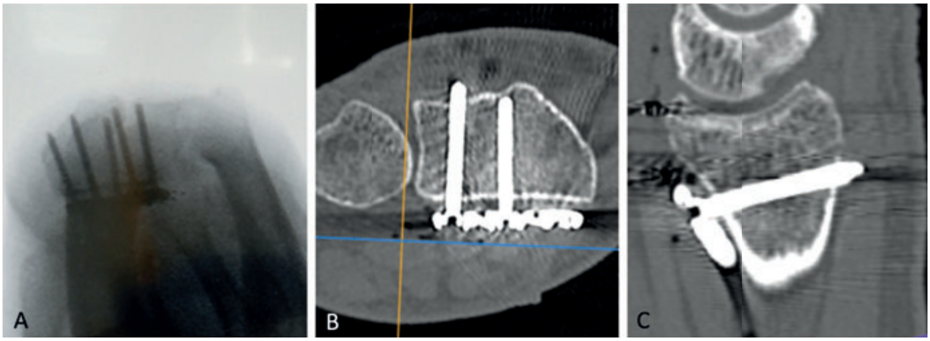


Figure 3: Out of the 16 times the surgeon-observers missed a screw after training, in eight times it concerned the same ulnar screw protruding in the 4th compartment, of which the DTV is depicted in A and, the axial CT-reconstruction in B and the sagittal CT-scan in C: revealing relative proximal plate positioning and therefore the screw protrusion obscured by the dorsal ridge

Table 1. Results.

	Before Training	After Training	Significance
Diagnostic Performance			
Sensitivity (95% CI)	0.88 (0.64 – 0.97)	0.92 (0.69 – 0.99)	*
Specificity (95% CI)	0.84 (0.68 – 0.93)	0.89 (0.74 – 0.96)	*
Accuracy (95% CI)	0.86 (0.77 – 0.95)	0.90 (0.82 – 0.98)	*
Positive Predictive Value (95% CI)	0.78 (0.54 – 0.91)	0.84 (0.61 – 0.94)	*
Negative Predictive Value (95% CI)	0.93 (0.78 – 0.99)	0.96 (0.81 – 0.99)	*
Inter-observer Agreement			
- for diagnosis of dorsal screw penetration (kappa)	moderate ($k_{bt} = 0.52$)	substantial ($k_{at} = 0.66$)	p=0.073
- for decision of screw exchange (kappa)	moderate ($k_{bt} = 0.51$)	substantial ($k_{at} = 0.67$)	p<0.05
- for number of mm needed to be subtracted from protruding screws (ICC)	moderate (ICC = 0.49)	substantial (ICC = 0.69)	p=0.146
Confidence levels (SD, range)	3.5 (1.1, 1-4)	4.0 (0.81, 1-5)	p<0.05
Number of ii-shots needed (SD, range)	1.8 (0.96, 1-6)	1.5 (0.80, 1-10)	P<0.05
Number of missed protruding screws (mean amount of protrusion, SD, range in mm)	25 (2.8, 0.59, 1.4-3.6)	16 (2.9, 0.49, 1.4-3.6)**	p=0.55

CI: Confidence Interval. ICC: intra-class coefficient, SD: Standard Deviation, ii: image intensifier (fluoroscopic shots).
* overlap of 95% confidence intervals indicate no significant difference.
** Observers missed the same screw in eight (50%) cases in the 4th compartment. This may be due to relative proximal plate positioning in this case (Figure 3).

REFERENCES

1. 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;21(5):316-322.
2. Azzi AJ, Aldekhayel S, Boehm KS, Zadeh T. Tendon Rupture and Tenosynovitis following Internal Fixation of Distal Radius Fractures: A Systematic Review. *Plast Reconstr Surg*. 2017;139(3):717e-724e.
3. Maschke SD, Evans PJ, Schub D, Drake R, Lawton JN. Radiographic evaluation of dorsal screw penetration after volar fixed-angle plating of the distal radius: a cadaveric study. *Hand (N Y)*. 2007;2(3):144-150.
4. Stoops TK, Santoni BG, Clark NM, Bauer AA, Shoji C, Schwartz-Fernandes F. Sensitivity and Specificity of Skyline and Carpal Shoot-Through Fluoroscopic Views of Volar Plate Fixation of the Distal Radius: A Cadaveric Investigation of Dorsal Cortex Screw Penetration. *Hand (N Y)*. 2017;12(6):551-556.
5. Poole WE, Marsland D, Durani P, Hobbs CM, Sauvé PS. Detecting dorsal screw penetration following volar plate fixation of the distal radius – A validation study in a saw bone model. *Trauma*. 2017;19(1):46-53.
6. Cha SM, Shin HD. Detections of Screw Penetration during Volar Plating for Distal Radius Fractures. *J Wrist Surg*. 2017;6(4):340-348.
7. Ozer K, Wolf JM, Watkins B, Hak DJ. Comparison of 4 fluoroscopic views for dorsal cortex screw penetration after volar plating of the distal radius. *J Hand Surg Am*. 2012;37(5):963-967.
8. Riddick AP, Hickey B, White SP. Accuracy of the skyline view for detecting dorsal cortical penetration during volar distal radius fixation. *J Hand Surg Eur Vol*. 2012;37(5):407-411.
9. Lee S, Bae K, Choy W. Use of the radial groove view intra-operatively to prevent damage to the extensor pollicis longus tendon by protruding screws during volar plating of a distal radial fracture. *Bone Joint J*. 2013;95(10):1372-1376.
10. Thomas AD, Greenberg JA. Use of fluoroscopy in determining screw overshoot in the dorsal distal radius: a cadaveric study. *J Hand Surg Am*. 2009;34(2):258-261.
11. Giugale JM, Fourman MS, Bielicka DL, Fowler JR. Comparing Dorsal Tangential and Lateral Views of the Wrist for Detecting Dorsal Screw Penetration after Volar Plating of Distal Radius Fractures. *Adv Orthop*. 2017;2017:1402517.
12. Ozer K, Toker S. Dorsal tangential view of the wrist to detect screw penetration to the dorsal cortex of the distal radius after volar fixed-angle plating. *Hand (N Y)*. 2011;6(2):190-193.
13. Gurbuz Y, Kucuk L, Gunay H, Ozaksar K, Sugun TS, Bilge O. Comparison of ultrasound and dorsal horizon radiographic view for the detection of dorsal screw penetration. *Acta Orthop Traumatol Turc*. 2017.
14. Hill BW, Shakir I, Cannada LK. Dorsal Screw Penetration With the Use of Volar Plating of Distal Radius Fractures: How Can You Best Detect? *J Orthop Trauma*. 2015;29(10):e408-413.

15. Oc Y, Kilinc BE, Gulcu A, Varol A, Ertugrul R, Kara A. Ultrasonography or direct radiography? A comparison of two techniques to detect dorsal screw penetration after volar plate fixation. *J Orthop Surg Res*. 2018;13(1):70.

16. Kiyak G. In vivo confirmation of the reliability of the dorsal tangential view of the wrist. *Hand Surg Rehabil*. 2018;37(1):56-59.

17. Ganesh D, Service B, Zirgibel B, Koval K. The Detection of Prominent Hardware in Volar Locked Plating of Distal Radius Fractures: Intraoperative Fluoroscopy Versus Computed Tomography. *J Orthop Trauma*. 2016;30(11):618-621.

18. Brunner A, Siebert C, Stieger C, Kastius A, Link BC, Babst R. The dorsal tangential X-ray view to determine dorsal screw penetration during volar plating of distal radius fractures. *J Hand Surg Am*. 2015;40(1):27-33.

19. Haug LC, Glodny B, Deml C, Lutz M, Attal R. A new radiological method to detect dorsally penetrating screws when using volar locking plates in distal radial fractures. The dorsal horizon view. *Bone Joint J*. 2013;95-b(8):1101-1105.

20. Dolce D, Goodwin D, Ludwig M, Edwards S. Intraoperative evaluation of dorsal screw prominence after polyaxial volar plate fixation of distal radius fractures utilizing the Hoya view: a cadaveric study. *Hand (N Y)*. 2014;9(4):511-515.

21. Gurbuz Y, Kucuk L, Gunay H, Ozaksar K, Sugun TS, Bilge O. Comparison of ultrasound and dorsal horizon radiographic view for the detection of dorsal screw penetration. *Acta Orthop Traumatol Turc*. 2017;51(6):448-450.

22. Vernet P, Durry A, Nicolau X, et al. Detection of penetration of the dorsal cortex by epiphyseal screws of distal radius volar plates: Anatomical study comparing ultrasound and fluoroscopy. *Orthop Traumatol Surg Res*. 2017;103(6):911-913.

23. Kennedy OJ, Roderick P, Poole R, Parkes J. Coffee and kidney disease. *Int J Clin Pract*. 2017;71(8).

24. Marsland D, Hobbs CM, Sauve PS. Volar locking plate fixation of distal radius fractures: use of an intra-operative 'carpal shoot through' view to identify dorsal compartment and distal radioulnar joint screw penetration. *Hand (N Y)*. 2014;9(4):516-521.

25. Joseph SJ, Harvey JN. The dorsal horizon view: detecting screw protrusion at the distal radius. *J Hand Surg Am*. 2011;36(10):1691-1693.

26. Bankier AA, Fleischmann D, De Maertelaer V, et al. Subjective differentiation of normal and pathological bronchi on thin-section CT: impact of observer training. *Eur Respir J*. 1999;13(4):781-786.

27. Berg WA, D'Orsi CJ, Jackson VP, et al. Does training in the Breast Imaging Reporting and Data System (BI-RADS) improve biopsy recommendations or feature analysis agreement with experienced breast imagers at mammography? *Radiology*. 2002;224(3):871-880.

28. Brorson S, Bagger J, Sylvest A, Hrobjartsson A. Improved interobserver variation after training of doctors in the Neer system. A randomised trial. *J Bone Joint Surg Br*. 2002;84(7):950-954.

29. Lujan ME, Chizen DR, Peppin AK, et al. Improving inter-observer variability in the evaluation of ultrasonographic features of polycystic ovaries. *Reprod Biol Endocrinol*. 2008;6:30.

30. Magnan MA, Maklebust J. The effect of Web-based Braden Scale training on the reliability of Braden subscale ratings. *J Wound Ostomy Continence Nurs.* 2009;36(1):51-59.

31. Patel AB, Amin A, Sortey SZ, Athawale A, Kulkarni H. Impact of training on observer variation in chest radiographs of children with severe pneumonia. *Indian Pediatr.* 2007;44(9):675-681.

32. Bergsma M, Doornberg JN, Duit R, et al. Volar plating in distal radius fractures: A prospective clinical study on efficacy of dorsal tangential views to avoid screw penetration. *Injury.* 2018.

33. Rosset A, Spadola L, Ratib O. OsiriX: an open-source software for navigating in multidimensional DICOM images. *J Digit Imaging.* 2004;17(3):205-216.

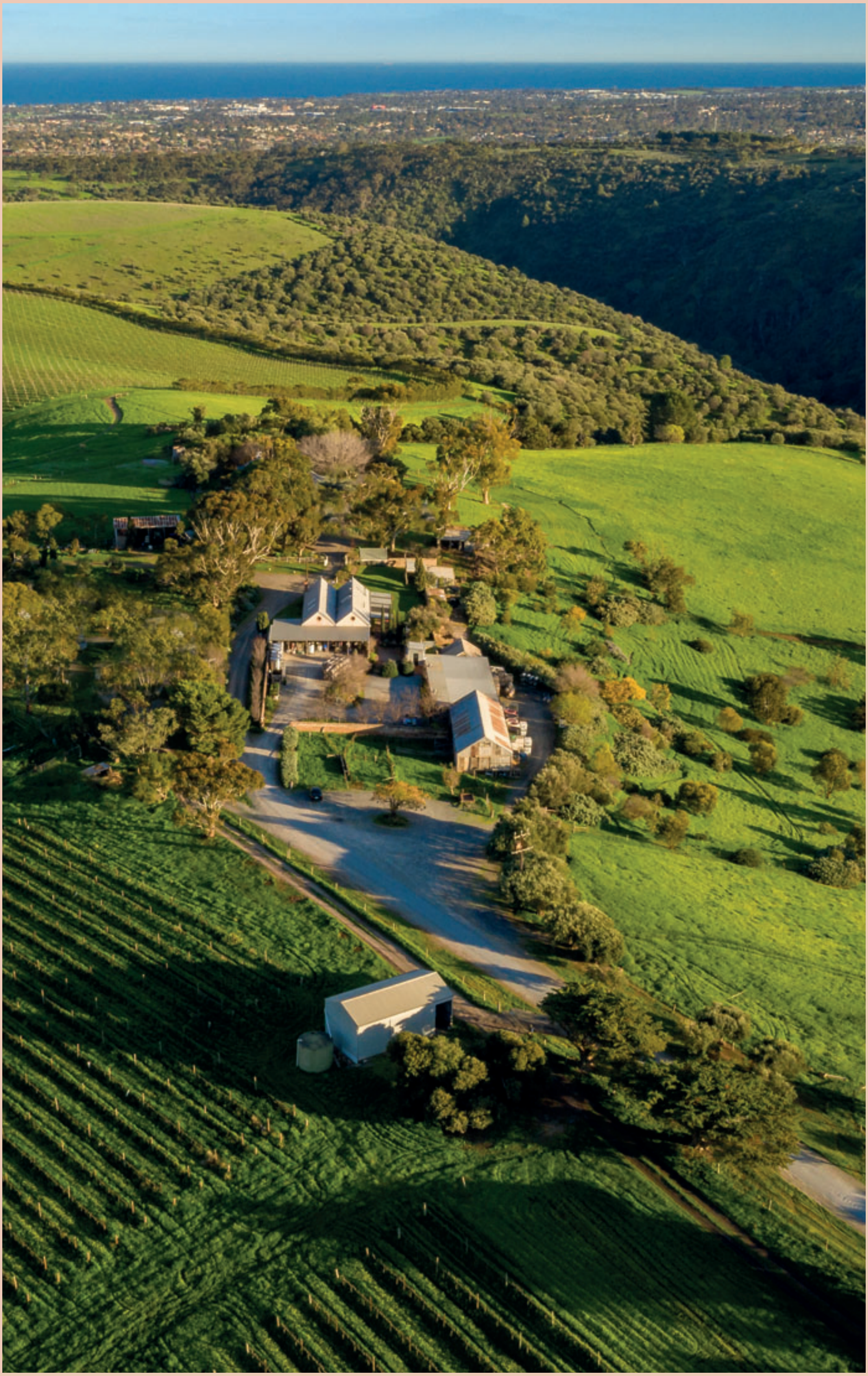
34. Cohen J. A coefficient of agreement for nominal scales. *Educ Psychol Meas.* 1960;20(1):37-46.

35. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977:159-174.

36. Posner KL, Sampson PD, Caplan RA, Ward RJ, Cheney FW. Measuring interrater reliability among multiple raters: an example of methods for nominal data. *Stat Med.* 1990;9(9):1103-1115.

37. Wall LB, Brodt MD, Silva MJ, Boyer MI, Calfee RP. The effects of screw length on stability of simulated osteoporotic distal radius fractures fixed with volar locking plates. *J Hand Surg Am.* 2012;37(3):446-453.

38. Bergsma M, Doornberg J.N., Jaarsma R. L. Volar Plating in Distal Radius Fractures: A Prospective Clinical Study on Efficacy of Dorsal Tangential Views to Avoid Screw Penetration. Paper presented at: AAOS Annual Meeting; March 12-16, 2019; Las Vegas, Nevada.



PART IV

TACKLING THE VOLAR PROBLEM - IMPROVING SURGIAL APPROACH

10

THE WATERSHED LINE OF THE DISTAL RADIUS: CADAVERIC AND IMAGING STUDY OF ANATOMICAL LANDMARKS

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ABSTRACT

Background

Placement of volar plates remains a challenge as the watershed line may not be an easy-identifia ble distinct line intra-operatively

Purposes

To define h ow anatomical landmarks identifiable upon the volar surgical approach to the distal radius relate to the watershed line.

Methods:

We identified anatomical landmarks macroscopically upon standard volar approach to the distal radius in ten cadaveric forearms, and marked these with Radio Stereometric Analysis beads in cadaveric wrists. The RSA beads were then referenced against the volar osseous structures using Quantification of Three-Dimensional Computed Tomography and advanced imaging software.

Results

The mean measurements were; the radial and ulnar prominences 11.1 mm and 2.1 mm proximal to the joint line of the distal radius respectively. The interfossa sulcus was 0.3 mm proximal and 3 mm dorsal to the ulnar prominence. The watershed line was between 3.5 (minimal) - 7.6 (maximal) mm distal to the distal line of insertion of the pronator quadratus.

Conclusion

The watershed line is situated distal to the pronator quadratus, but with a wide variability making it an impractical landmark for plate position. The osseous ulnar prominence is a good anatomical reference for safe plate positioning, as it is located on the watershed line and easily palpated at surgery. One should keep in mind the sulcus –the point on the watershed line where the flexor pollicis longus runs- can be situated just proximal from the ulnar prominence.

Clinical Relevance

Landmarks that are easy to identify upon surgical approach without the direct need for intra-operative imaging

INTRODUCTION

The watershed line should serve as the distal margin for placement of a volar plate to minimize flexor tendon injuries. Orbay defined the watershed line as “a theoretical line marking the most volar aspect of the volar margin of the radius” (Figure 1)[1-3]. Flexor and extensor tendon irritation have been identified as the most frequent complication of internal fixation of unstable distal radius fracture with a volar locking-plate[4]. The majority of iatrogenic tendon complications include flexor tendons: ruptures of the flexor pollicis longus tendon and flexor tendon tenosynovitis[4]. The clinical importance of the watershed line has been by Soong and colleagues: plates prominent at the watershed line increase the risk of flexor tendon injury[5]. The authors advised surgeons to avoid implant prominence at the watershed line[5].

The latter remains a challenge as cadaveric studies show that the watershed line may not be easy-identifiable intra-operatively [6,7]. As Imatani refers to their anatomical study: it may correspond to the distal margin of the pronator fossa in the radial half of the volar radius, and to a hypothetical line between the line that corresponds to the distal edge of the pronator fossa and a more prominent distal line in the ulnar half [6]. The ulnar prominence (or medial prominence as described by Imatani and colleagues) on the volar radius is a recommended key structures for accurate plate placement to avoid flexor tendon injury [6,8]. However, many subsequent definitions have been published (see review “The Definition of The Watershed Line of the Distal Radius as Reference for Volar Plate Positioning” in this edition of Journal of Wrist Surgery). Moreover, macroscopically upon surgical approach, the appearance and identification of these advised osseous landmarks, as well as on fluoroscopy intra-operatively, may not be as well-defined [5] as suggested by cadaveric studies using wide non-surgical dissection or dried bones[6,7]

To the best of our knowledge no cadaveric studies have correlated the surgically identifiable key volar references to the watershed line using advanced imaging.

Therefore, the purpose of our study is 1) to identify these defined anatomical landfto marks macroscopically upon standard volar approach to the distal radius, and mark these with Radio Stereometric Analysis (RSA-) beads in cadaveric wrists, and then 2) to subsequently reference the RSA-marked anatomical landmarks with key volar osseous references of the watershed line as defined using Quantification of Three-Dimensional Computed Tomography (Q3DCT) using advanced imaging software[9-11] (Figure 2B and C). The clinical relevance is to provide surgeons with intra-operative macroscopic landmarks that assist in correct plate position.

METHODS

Our Local Human Research Ethics Committee approved this study, in accordance to the Declaration of Helsinki under protocol number 224.17.

Cadaveric Specimens

This study was conducted with 10 left forearms including the elbow joint from fresh frozen cadavers. These forearms were from 6 males and 4 females; mean age 65 (range 42-90 years). None of the specimens had clinical or radiographic signs of prior surgery or trauma to the wrist.

Soft Tissue Landmarks 8,12-15: Soft Tissue Dissection and RSA Marking (Figure 2)

The cadaveric wrist was positioned in supination position to simulate the wrist during surgery in clinical practice. The forearm was secured in a wooden frame. The ulnar shaft, radial shaft, second and fifth metacarpals were fixed with K-wires to the wooden frame to minimize movement during further study procedures. Onto a tripod, a camera was mounted (Canon, Coolpix, A900), and photographs were taken of the specimen throughout the study.

A volar flexor carpi radialis (FCR) approach[16] to the distal radius was performed, through the bed of the FCR sheath to the pronator quadratus (PQ) and the volar wrist capsule by the Orthopaedic Upper Limb and Trauma Fellow (JND). The flexor tendons were retracted –but not resected as in previous cadaveric studies to further mimic the volar approach to the radius in clinical practice[6]. The pronator quadratus muscle (PQ) and capsular ligaments were not violated.

21-gauge needles were placed in the distal radio-ulnar joint (DRUJ) and in the radiocarpal joint. Radio Stereometric Analysis (RSA) marker beads were placed on the distal border of the PQ (Figure 2A). The radial and ulnar osseus prominences on the volar aspect of the distal radius were palpated, and after consensus RSA beads were secured on fibrous tissue overlying the maximal prominences. Photographs were repeated.

No further procedure to the distal radius, and the PQ was not validated. The skin was sutured with Nylon (Ethicon, Ethilon, monofilament 3-0).

All specimens with their wooden frame underwent a Computed Tomography (CT) scan using a GE Optima CT scanner (140 Kv, 200 mA, slice thickness 0.625 mm, interval 0.3 mm).

Osseous Landmarks1-7,17-27: Watershed Line as Defined on Three-Dimensional Computed Tomography (Q3DCT) (Figure 3)

The Digital Imaging and Communication in Medicine (DICOM) CT scans were loaded in 3D slicer (3D Slicer, Boston, MA). In 3D Slicer, osseous structures, including the pronator fossa, radial and ulnar osseous prominences defining the watershed line[6] and the interfossa sulcus for the flexor pollicis longus (FPL) tendon, were defined in axial, sagittal and coronal planes. RSA beads marking 1) the distal border of the pronator quadratus, and 2) the palpated radial and ulnar prominences were also defined.

The watershed line was defined as the most volar aspects of the distal radius in each fifth sagittal image of 0.625 mm^3. Separate Surface Tessellation Language (STL) files of the distal radius, 2) RSA markers and 3) the Watershed Line were created (Figure 3).

The 3D polygon mesh reconstructions were subsequently imported into Rhinoceros (McNeel, Seattle, WA) to quantify: 1) the most prominent line of points of the volar aspect of the radius; 2) the radial- and ulnar osseous prominences; and 3) distances between RSA soft tissue landmarks[8,12-15] and Q3DCT-defined osseous landmarks[1-7,17-27] (Figure 3A). A coordinate system was created to standardize the axes and quantification of CT-imaging for all specimens. The x-axis represents proximal to distal, the y-axis radio-ulnar, and the z-axis dorsal-to-volar. The x-axis representing the longitudinal axis of the radius was defined by the line through five points placed in the centroid of the five circumferences along the longitudinal axis of the radial shaft [28,29]. The circumferences were 0.5 cm proximal from each other, starting 3 cm proximal from the articular surface (Figure 4A). The direction of the y axis was from the distal tip of the radial styloid and the most radial aspect of the ulnar notch [29,30] (Figure 4B). The z-axis resulted from these x- and y-axes. (Figure 4C).

Relation of RSA-marked Soft Tissue Landmarks[8,12-15] and Q3DCT-Defined Osseous Landmarks[1-7,17-27]

The following landmarks were quantified using Q3DCT techniques[10,31]. The ulnar- and radial prominences were the two most prominent points determined by turning the modal around its x-axis and define the highest points on the z-axis (Figure 5A). The interfossa sulcus[28] was defined as the most dorsal point between the ulnar and radial prominences (Figure 5B). Two points on the joint line directly distal to the respective radial and ulnar prominences were also marked (Figure 5C). The most ulnar point of the volar margin of the distal radius was also marked (Figure 5D). Both the identification of all points for the axis-system and all landmarks have been performed by two observers in two specimens, and a 100% agreement on the location for these points was reached.

All measurements were performed parallel to the plane resulted from the two respective axes using the analyse distance function in Rhinoceros and determining the intersection of the two respective points in the plane parallel to the respective axis. (Figure 3B). We measured in the proximal to distal direction; the maximum and minimum distances between the marked watershed line and the PQ, the distance between bony ulnar and radial prominences and the interfossa sulcus and the PQ (Figure 6A) and the distance between the joint line and the true ulnar and radial prominences and between the radial and ulnar prominence and the interfossa sulcus themselves (Figure 6B). The most radial coordinate of the PQ was used to determine the distance between the PQ and the radial prominence. The joint line was defined as the knuckle line of the distal volar radius using the 'vertex' function in 'shaded' mode in a view perpendicular to the x-axis. We also measured in the ulnar to radial direction, the distance between the ulnar prominence, interfossa sulcus, and the ulnar border of the distal radius (Figure 6C). We also measured in anterior-posterior direction, the distance between the ulnar prominence, radial prominence, and the interfossa sulcus (Figure 6D).

Mapping of the Watershed line and the Pronator Quadratus

According to the mapping technique as described by Cole et al[32,33] and modified by our group[9,11], in this study the pronator quadratus –rather than a fracture line distribution and location were determined using Q3DCT techniques. Images of the 3D polygon mesh were obtained and imported in Macromedia Fireworks MX (Marcomedia Inc, San Francisco, CA, USA) to create bitmap images. These bitmap images were superimposed onto a distal radius template to form a compilation of distribution of the watershed line and the pronator quadratus. Figure 7 demonstrates an example of the radius, and mapping of the watershed line and the PQ of all specimens.

Statistical Analysis

Specimen characteristics were summarized with frequencies and percentages for categorical variables and with mean and standard deviation for continuous variables.

RESULTS

Watershed Line in Reference to Osseous Anatomy[1-7,17-27]

In the volar-to dorsa direction, on the X-axis, the radial prominence was situated proximal to the joint line of the scaphoid facet of the distal radius in eight specimens. In two specimens, this measurement could not be performed as the radial prominence was not located directly proximal of the joint line, but more radial. The mean distance between the ulnar prominence and the joint line of the lunate facet was far less compared to the radial prominence and the proximal joint line of the scaphoid facet (mean 2.1 vs 11.1 mm) ((Table 1, Figure 6B).

The radial prominence is located proximal to the ulnar prominence. The interfossa sulcus was located proximal to the ulnar prominence in six specimens. In the other four specimens, the interfossa sulcus was situated distal to the ulnar prominence. The radial prominence was situated proximal to the interfossa sulcus (Figure 6B).

On the Y-axis, he interfossa sulcus was located between the ulnar and the radial prominence, on average slightly more towards the ulnar prominence. (Table 2, Figure 6C).

On average, in the volar-to-dorsal direction (Z-axis), the interfossa sulcus was located between the ulnar and the radial prominence. In all specimens, the interfossa sulcus was dorsal to the ulnar prominence. In eight specimens, the interfossa sulcus was volar to the radial prominence. In two specimens the interfossa sulcus was dorsal to the radial prominence (Table 3, Figure 6D).

Watershed Line Defined in Reference to Soft Tissue Anatomy[8,12-15]

The distances between the PQ and the watershed line varied widely. In two specimens the radial prominence was situated respectively 1.3 and 0.2 mm more proximal than the most radial point of the PQ, in all other specimens the entire PQ was situated proximal to the watershed line. The mean minimum distance in distal-to-proximal direction between the watershed line and the PQ was 3.5 mm and the mean maximal distance. In all specimens, the distance between the PQ and the watershed line was smaller on the radial side compared to the ulnar side. In all cadaveric specimens, the radial edge of the PQ was situated more ulnar to the level of the radial prominence (Table 1, Figure 6A).

Reference Standard - Three-Dimensional Computed Tomography (Q3DCT) and Mapping of Pronator Quadratus in Relation to the Watershed line

The distribution and location of the pronator quadratus and the watershed line is represented in Figure 7 for all 10 specimens.

DISCUSSION

The aim of this study was to identify (intra-operative) macroscopic anatomical landmarks that can be utilized by orthopaedic surgeons during volar plating for distal radius fractures and relate these to the osseous watershed line using quantification of three-dimensional compute tomography (Q3DCT) as a reference to optimize volar plate application.

The results of this study should be interpreted in the light of its strengths and weaknesses. A major strength of the study is its newly designed method of identifying anatomical landmarks that allows for relating these to the watershed line in intact cadaveric wrists following the FCR approach and combined with this "soft tissue" and osseous anatomy based on Q3DCT imaging techniques. Weaknesses include the study is performed on intact distal radii without being distorted by the fracture.

The results show that the watershed line, including the volar radial and especially ulnar osseous prominences are situated well distal to the insertion PQ. Additionally, the ranges of distances between the watershed line and soft tissue anatomy (i.e. PQ) were wide, indicating there is a large variability between individuals. In concordance to Orbay's description of the watershed line[1], this line is situated between 10 and 15 mm proximal to the joint line on the radial side and 2 mm proximal to the joint line on the ulnar side. The radial prominence is on average 11.1 mm and the ulnar prominence on average 2.1 mm proximal to the joint line. As the ulnar prominence is easy to identify by palpation with the overlying fibrous transition zone, we would recommend this osseous ulnar prominence as the most useful anatomical reference in clinical practice for correct volar plate positioning. Fluoroscopic images could easily further aid to identification of the ulnar prominence. Further research can be conducted on the relation of different volar plates to the watershed line and described anatomical landmarks.

The ulnar prominence –defined as 'most volar extend on the volar rim …of the distal radius' has also been used as reference point for safe plate positioning on radiological imaging[5], as suggested in a previous anatomical study of the volar surface of the distal radius[6]. In this study, we have described how this point is related to other anatomical references involved in distal radius fracture surgery. The ulnar prominence is located 7.2 mm distal to the distal border of the PQ and 8.3 mm radial from the ulnar notch. However, while placing the volar plate one should keep in mind the radial prominence, another relevant point situated on the watershed line, is located 2.0 mm more proximal than the ulnar prominence.

Another important point on the watershed line is the interfossa sulcus, where the FPL may glide over a plate and cause FPL rupture [28]. As the interfossa sulcus was on average situated only 0.3 mm proximal from the ulnar prominence, the ulnar prominence indeed seems to be a relevant reference point for the watershed line. The interfossa sulcus was located distal to the radial prominence in all cadaveric specimens analysed in this study, with a mean of 1.4 mm. In seven specimens the interfossa sulcus was located proximal from the ulnar prominence (mean 1.1 mm, range 0.1-3.2 mm) and in three specimens distal to the ulnar prominence (0.4, 1.7 and 1.7 mm). Some plates already keep this sulcus in mind in their design.

CONCLUSION

For safe placement of the plate for volar plating for distal radius fractures, the surgeon needs easily identifiable landmarks. The insertion of the pronator quadratus is situated well proximal from the watershed line. The osseous ulnar prominence is a good anatomical reference point for the watershed line, as it is located on the watershed line and easily palpated upon surgery. We argue that the ulnar prominence could be used as the “Watershed Point” to refer to the watershed line in clinical practice, as it easy identifiable upon palpation. While using this anatomical reference point, one should keep in mind the sulcus –which is arguably the most important point on the watershed line- can be situated just proximal from the ulnar prominence.

TABLE AND FIGURE LEGENDS

Table 1. Distal to proximal measurements

Distance between:	Mean (mm)	Range (mm)
Osseous Anatomy		
Joint line of scaphoid facet – Radial prominence*	11.1	6.6-13.5
Joint line of lunate face – Ulnar prominence	2.1	1.3-3.5
Ulnar prominence – radial prominence	2.0	0.5-4.7
Ulnar prominence- interfossa sulcus (in 6 specimens)	1.2	-0.1-3.2
Interfossa sulcus – ulnar prominence (in 4 specimens)	1.0	0.2-1.7
Interfossa sulcus – Radial prominence	1.4	0.1-3.7
Soft Tissue – Osseous Anatomy		
Minimum distance watershed line - PQ	3.5	1.2-7.2
Maximum distance watershed line - PQ	7.6	3.6-10.6
Ulnar prominence- PQ	7.2	2.3-10.0
Radial Prominence PQ	2.8	-1.3-.5**
Interfossa sulcus- PQ	4.8	1.7-7.4

Table 2. Ulnar-to-radial distances (Y-axis, Figure 6C)

Distance between:	Mean (mm)	Range (mm)
Ulnar notch – ulnar prominence	8.3	7.0-13.0
Ulnar prominence - interfossa sulcus	9.7	5.0-13.7
Ulnar notch – interfossa sulcus	18.2	12.1-21.9

Table 3. Volar-to-dorsal distances (Z-axis, Figure 6D)

Distance between:	Mean (mm)	Range (mm)
Ulnar prominence – interfossa sulcus	3	1.8-5.6
Interfossa sulcus -radial prominence (in 8 specimens)	1.2	0.3-2.1
Radial prominence- interfossa sulcus (in 2 specimens)	0.8	0.4-1.2

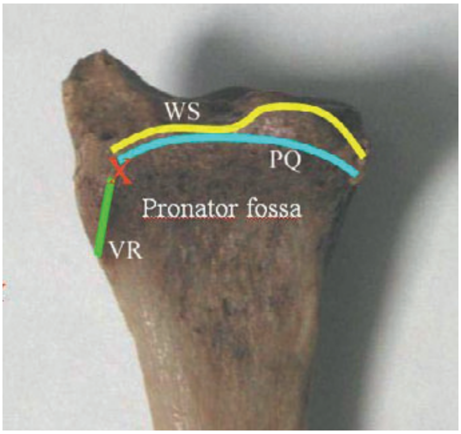

Figure 1. Nelson and Orbay coined the *watershed line* (WS) as "a theoretical line marking the most volar aspect of the volar margin of the radius", to serve as the distal margin for volar plating to minimize tendon injuries[1-3]. PQ = PronaToegevoegtor Quadratus Line, or PQ Line; WS = Watershed Line; X = Volar radial tuberosity; VR = Volar radial ridge (with permission from http://eradius.com/AnatomyOfDistalRadius.htm[3]).

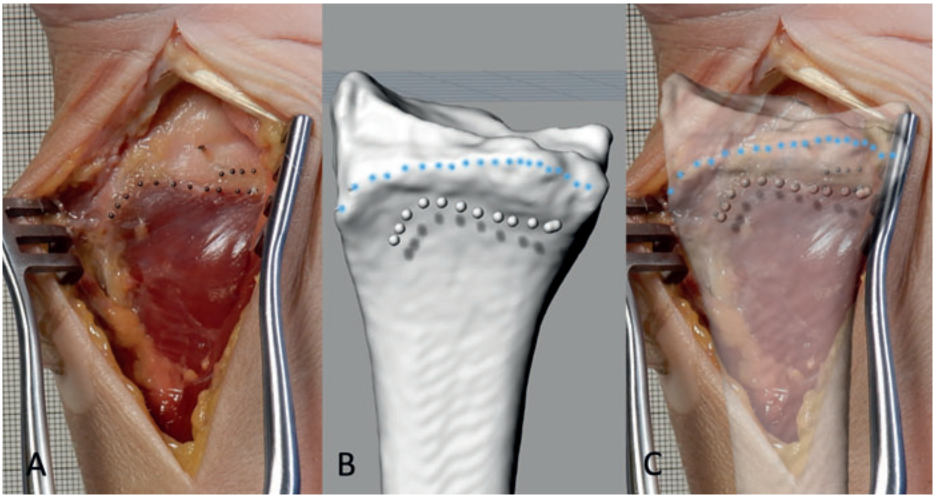

Figure 2. Anatomical landmarks of the volar cadaveric distal radius marked with RSA beads (A). Cadaveric specimen with subsequent RSA-marked anatomical landmarks were referenced using advanced imaging software(C)[9-11], (B) with the volar osseous references of the watershed line (light blue dots).

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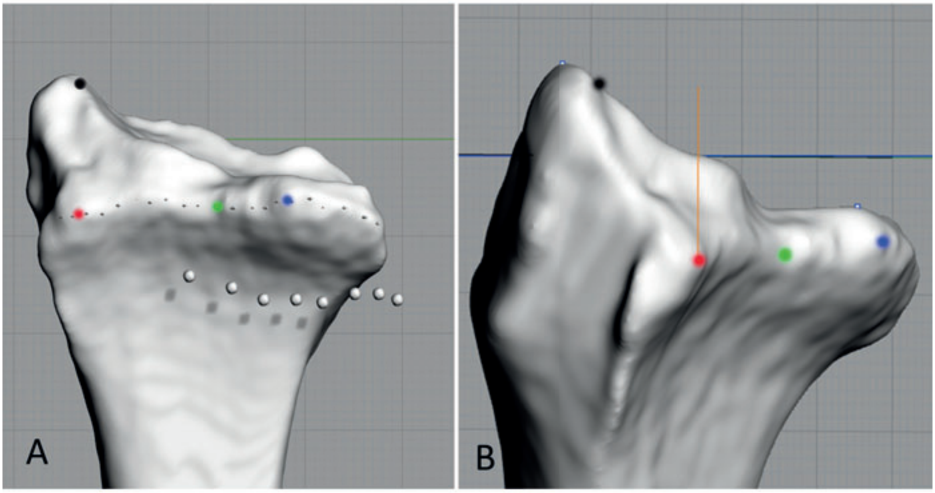

Figure 3. 3D polygon mesh reconstructions of the radius. (A) The most volar aspect of the radius (small dots) and the radial and ulnar osseous prominences (red and blue dots), and inter fossa sulcus (green dot) are marked. In (B) the orange line shows proximal-distal measurements performed parallel to the x-axis.

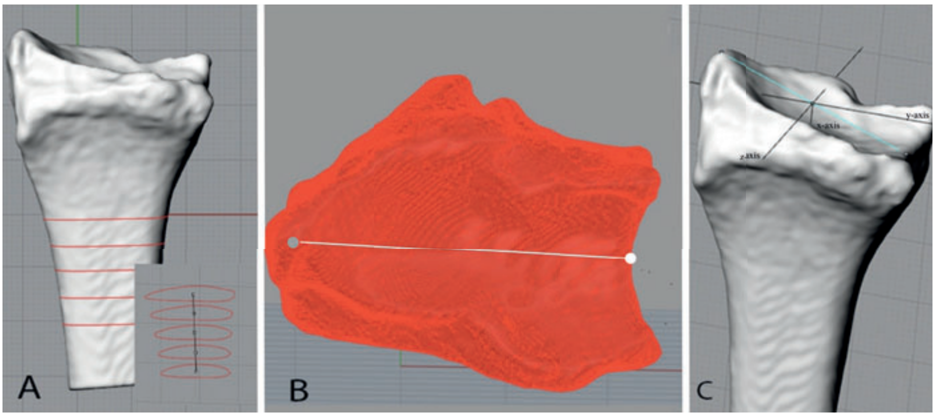

Figure 4. The x-axis represents proximal to distal, the y-axis radio-ulnar, and the z-axis dorsal-to-volar. The x-axis is aligned with the longitudinal axis of the radius as defined by the line through the centroid of the five circumferences along the longitudinal axis of the radial shaft [28,29] (A). The y axis was from the tip of the radial styloid (grey dot) and the most radial aspect of the ulnar notch (white dot) [29,30] (B). The z-axis resulted from these x- and y-axes. (C).

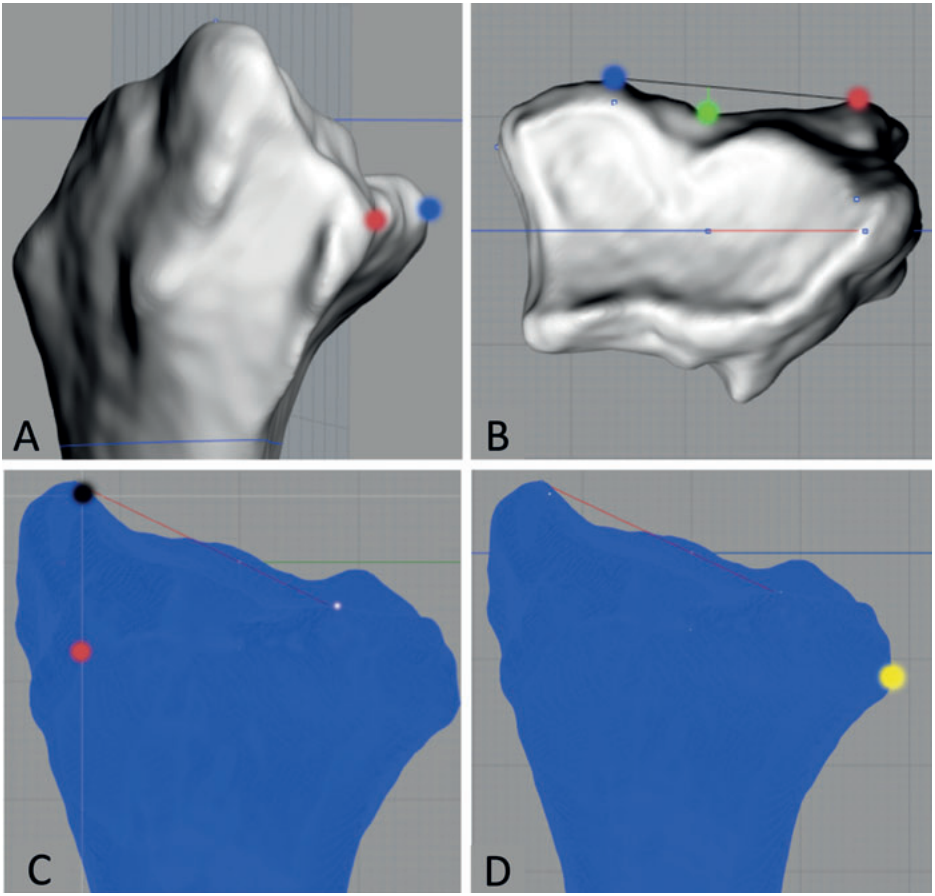

Figure 5. Distal radius landmarks[10,31]: (A) The ulnar and radial prominences are the two most prominent volar points. (B) The bone of the interfossa sulcus[28] was defined by drawing a line between the ulnar and radial prominence and determining the point of the volar margin of the distal radius that was furthest away from this line. (C) The point on the joint line directly distal to the radial prominence was defined using the vertex and intersection functions. (D) In antero-posterior view perpendicular to the x-axis, the most ulnar point of the volar margin of the distal radius was marked (yellow dot) (Figure 5D).

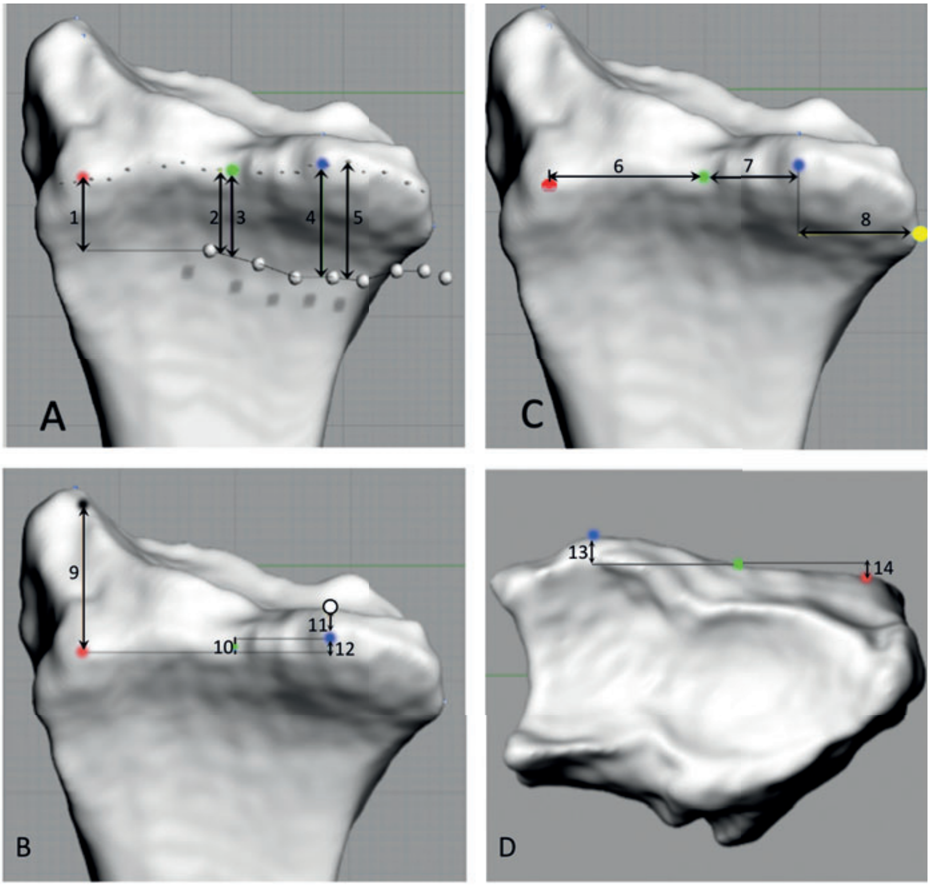

Figure 6. Proximal-distal distances soft tissue – osseous anatomy(A) and osseous anatomy(B). Ulnar - radial distances(C). Volar – dorsal distances (D).
1. Radial Prominence - PQ
2. Min. Watershed - PQ
3. Interfossa sulcus- PQ
4. Ulnar Prominence - PQ
5. Max. Watershed - PQ
6. Sulcus – Radial Prominence
7. Ulnar Prominence- Sulcus
8. Ulnar Notch – Ulnar Prominence
9. Joint line – Radial Prominence
10. Ulnar Prominence - Sulcus
11. Joint line – Ulnar Prominence
12. Ulnar Prominence – Radial Prominence
13. Ulnar Prominence - Sulcus
14. Sulcus – Radial Prominence

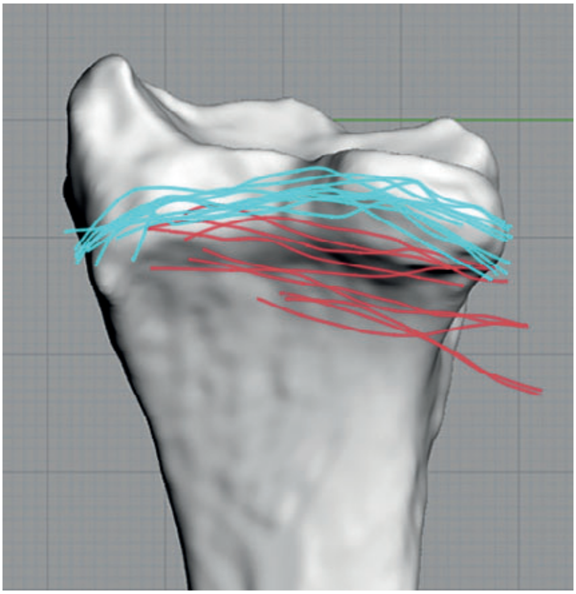

Figure 7. Distal radius with mapping of the watershed line (blue lines) and the PQ (red lines) of all ten specimens. Note the wide range, which makes the PQ position an unreliable surgical reference.

PART V

SUMMARY/SAMENVATTING, DISCUSSION AND CONCLUSIONS

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SUMMARY/SAMENVATTING

The aim of this thesis was to improve volar plating for distal radius fractures by reducing the associated tendon related peri-operative iatrogenic complication rate, both on the volar and dorsal side of the wrist with the use of (new) imaging techniques. We have specifically focused on preventing plate- and screw mal-positioning leading up to these complications.

On the dorsal side, the sharp protruding screws can cause extensor tendon attrition and rupture. On this side of the wrist, there is no room for error as the closest tendons are on average only half a millimeter away from the dorsal bony cortex (**chapter 3**). Without the use of views *additional* to the standard lateral and antero-posterior views, in 40% of patients at least one screw was found to be protruding the dorsal cortex 0.5 mm or more (**chapter 1**). The Dorsal Tangential View, or Dorsal Horizon View, in South Australian popularized as the Lleyton Hewitt View –after the famous ‘Come On’ cry of the Adelaide tennis player- has been advocated in recent literature to detect protruding screws intra-operatively based on pre-clinical and small clinical studies (**chapter 5)**. We found out the efficacy of this view is high; in 31% of the distal radius fracture surgeries, intra-operative management was changed based on this view (**chapter 6**). However, when using post-operative tri-planar CT-reconstructions to identify remaining protruding screws in patients that where checked intra-operatively with the DTV, the sensitivity of this view appeared to be only 52%. The negative predictive value of the view was 95% and the accuracy 95%, which might indicate this view is a better rule-in than a rule-out indicator (**chapter 7**). We explored a different technique -three-dimensional fluoroscopy (3DF)- for detection of dorsal screw penetration and could not conclude that 3DF outperforms DTVs for this purpose. Additionally, DTV outweighs the additional costs, radiation and time of 3DF. We postulated that the accuracy of any radiological view, but in this case specifically the DTV, might improve after training. And indeed, inter-observer reliability, sensitivity, specificity and accuracy of this view improved after training (**chapter 9**).

On the volar side, mal-positioning of the volar plate with respect to the watershed line can lead to plate prominence and interference with the volar flexor tendons. After keeping an eye out on volar plating in our practice, we quickly realized the term watershed line is subject to interpretation. And indeed, in literature we found eight different interpretations f the definition the ‘watershed line’ (**chapter 4**). With the use of Q3DCT-imaging we identified the true watershed line –defined as the most volar part of the distal radius and defined this line was situated 11,1 mm proximal from the articular surface on the radial side and 2,1 mm proximal from the articular surface on the ulnar side. We postulated that the ulnar radial prominence, situated

on the watershed line on the ulnar side of the radius, is the best reference marker for this line as it is easy to palpate for the surgeon. However, one should keep in mind that at the radial prominence, the watershed line is located on average 2.0 mm more proximal than on the ulnar prominence. Some recent generation volar plate designs already take this into account. We did identify the interfossa sulcus to be the most important point on the watershed line, as this is the location where the flexor pollicis longus tracks –the tendon that is most often identified to rupture after volar plating for distal radius fractures. As this sulcus lies within 0.3 mm proximal from the ulnar prominence, we again conclude this ulnar prominence is the best reference point for placement of the volar plate. (**chapter 10**).

Previously, Soong and his colleagues defined a grading system to be able to define whether a plate was placed in a 'safe' location (Grade 0), in an 'at risk' location (Grade 2) or in between (Grade 1). When using the most volar point of the volar distal radius on a lateral x-ray as watershed line, and Soong's grading system we found that plate design directs plate (mal) positioning with respect to this watershed line; the use of the DVR plate resulted in a lower grading compared to the VA-LCP plate in a large cohort of patients in the hands of generalizable group of surgeons. (**chapter 2**). We found that the hypothesis that plate prominence at the watershed line puts a patient at risk for flexor tendon rupture matches the closeness of the tendons to the volar cortex of the distal radius on MRI. At the watershed line, the tendons lie in closest relation to the bone, and only at 6 mm proximal from this watershed line there is on average enough space between the cortex and the tendons for the average thickness of a recent generation volar plate of 2-2.5 mm. In some individuals, the tendons are much closer so the surgeon should keep in mind the danger of hardware to the flexor tendons even when staying well proximal from the watershed line (**chapter 3**).

Het doel van dit proefschrift was het verbeteren van het opereren van distale radius fracturen middels volaire plaat door de incidentie van de bijbehorende peesgerelateerde peri-operatieve iatrogene complicaties -zowel aan de volaire als aan de dorsale zijde van de pols- te verlagen met behulp van (nieuwe) beeldvormingstechnieken. We hebben ons specifiek gericht op het voorkomen van het verkeerd positioneren van de plaat en schroeven, wat deze complicaties kan veroorzaken.

Aan de dorsale zijde kunnen de scherpe uitstekende schroeven irritatie en ruptuur van de extensorpees veroorzaken. Aan deze kant van de pols is er geen *room for error*, aangezien de dichtstbijzijnde pezen gemiddeld slechts een halve millimeter verwijderd zijn van de dorsale benige cortex (**hoofdstuk 3**). Zonder het gebruik van aanvullende fluoroscopie opnames -naast de standaard gebruikte laterale en antero-posterieure opname- bleek bij 40% van de patiënten ten minste één schroef de dorsale cortex te penetreren met minstens 0,5 mm (**hoofdstuk 1**). De Dorsal Tangential View, of Dorsal Horizon View, in Zuid-Australie gepopulariseerd als de Lleyton Hewitt View -naar de beroemde 'Come On'-uitroep van de uit Adelaide komende tennisser- wordt in de recente literatuur op basis van pre-klinische en kleine klinische studies geadviseerd om uitstekende schroeven intra-operatief te detecteren (**hoofdstuk 5**). We ontdekten dat de effectiviteit van deze opname hoog is; in 31% van de operaties veranderde het intra-operatieve beleid op basis van deze opname (**hoofdstuk 6**). Wanneer we driedimensionale CT-reconstructies gebruikten om resterende uitstekende schroeven te identificeren bij patiënten die intra-operatief werden gecheckt met de DTV, bleek de sensitiviteit van de DTV echter slechts 52% te zijn. De negatief voorspellende waarde was 95% en de nauwkeurigheid 95%. Dit kan betekenen dat dit een betere rule-in dan een rule-out indicator is (**hoofdstuk 7**). We bekeken ook een andere techniek -drie-dimensionale fluoroscopie (3DF)- voor de detectie van dorsale schroefpenetratie en konden niet concluderen dat 3DF hierin beter is dan de DTV (**hoofdstuk 8)**. Bovendien zijn de extra kosten, stralingsdosis en benodigde tijd hoger bij het gebruik van 3DF. We concludeerden dat de sensitiviteit van elke radiologische view, maar in dit geval specifiek de DTV, na training zou kunnen verbeteren. En inderdaad, de betrouwbaarheid, sensitiviteit, specificiteit en nauwkeurigheid van deze opname verbeterden na training (**hoofdstuk 9**).

Aan de volaire zijde kan mal-positionering van de volaire plaat ten opzichte van de *watershed line* leiden tot een uitstekende plaat die interfereert met de volaire flexorpezen. Na het observeren van de operaties met volaire platen in ons ziekenhuis, realiseerden we ons snel dat de term *watershed line* onderhevig is aan interpretatie.

En inderdaad, in de literatuur vonden we acht verschillende interpretaties van de definitie *'watershed line'* (**hoofdstuk 4**). Met het gebruik van Q3DCT-beeldvorming identificeerden we de ware *watershed line* - gedefinieerd als het meest volaire deel van de volaire distale radius- en vonden dat deze lijn zich 11,1 mm proximaal van het gewrichtsoppervlak aan de radiale zijde en 2,1 mm proximaal van het gewrichtsoppervlak aan de ulnaire zijde bevindt. We stelden vast dat de ulnaire prominentie van de radius, gelegen op de *watershed line* aan de ulnaire zijde, het beste referentiepunt is voor deze *watershed line*, omdat deze gemakkelijk te palperen is voor de chirurg. Men moet echter in gedachten houden dat bij de radiale prominentie, de *watershed line* gemiddeld 2,0 mm meer proximaal ligt dan op de ulnaire prominentie. Sommige recentere ontwerpen van de volaire plaat houden hier al rekening mee. We hebben de interfossa sulcus als een belangrijk punt op de *watershed line* geïdentificeerd, omdat dit de locatie is waar de flexor pollicis longus ligt - de pees die het vaakst scheurt na het plaatsen van een volaire plaat voor een distale radius fractuur. Aangezien deze sulcus binnen 0,3 mm proximaal van de ulnaire prominentie ligt, concluderen we opnieuw dat deze ulnaire prominentie het beste referentiepunt is voor plaatsing van de volaire plaat. (**hoofdstuk 10**). Eerder hebben Soong en zijn collega's een graderingssysteem gemaakt om te kunnen bepalen of een plaat 'veilig' (Grade 0) geplaatst is, *'at risk'* (Grade 2), of daar tussenin (Grade 1) is geplaatst. Bij gebruik van het meest volaire punt van de volaire distale radius op een laterale röntgenopname als *watershed line*, en het graderingssysteem van Soong, ontdekten we dat het design van de plaat de plaatsing van de plaat ten opzichte van de *watershed line* beïnvloedt. Het gebruik van de DVR-plaat resulteerde in een lagere Soong Gradering vergeleken met de VA-LCP-plaat in een groot cohort van patiënten in de handen van een generaliseerbare groep chirurgen. (**hoofdstuk 2**). We bevestigden de hypothese dat prominentie van de volaire plaat ter hoogte van de *watershed line* een risico op peesrupturen veroorzaakt, overeenkomt met de nabijheid van de pezen tot de volaire cortex van de distale radius op MRI. Bij de *watershed line* liggen de pezen het dichtst bij het bot, en pas 6 mm proximaal van deze *watershed line* is er gemiddeld voldoende ruimte tussen de cortex en de pezen voor de gemiddelde dikte van de recentere generatie volaire plaat van 2- 2.5 mm. Bij sommige mensen zijn de pezen veel dichterbij, dus de chirurg moet het gevaar van chirurgisch materiaal voor de flexor pezen in gedachten houden, zelfs als hij proximaal van de *watershed line* blijft (**hoofdstuk 3**).

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DISCUSSION AND CONCLUSIONS

The major strength of this thesis is the wide variety of study designs used to cover the analysis of prevention of iatrogenic tendon related complications after volar plating for distal radius fractures. The retrospective, and especially the prospective cohort studies are the first large cohorts of consecutive patients covering these topics. With the use of tri-planar CT reconstructions to measure screw length and a reproducible axis to perform anatomical measurements on MRI, we improved the reliability of radiological imaging studies. By designing new methods of Q3DCT analysis we have lied a foundation for research in the relation of soft and bony anatomy.

This thesis is also limited by its weaknesses. We were not able to perform a randomized controlled trial to define the efficacy of additional views to standard views in clinical practice, due to ethical considerations –as the DTV was already standardized in our institution. Due to the clinical character of our prospective cohort study to analyze the accuracy of the DTV, we had to assume all changed screws were true positives – while potentially an intra-operative CT could have provided more precise information. However, this set up was not viable and would have exposed both patient and surgical team to more radiation and surgical time. When analyzing the influence of training on the accuracy of the DTV, we could inherently not account for the test re-test effect. The anatomical studies were performed with the use of static MRIs and CT-scans of cadaveric specimens, which cannot account for true anatomy in living, moving human wrists. However, these studies are the closest to true anatomy in their field.

We can conclude that for safe placement of hardware during volar plating for distal radius fractures in order to prevent tendon related iatrogenic complications, on the dorsal side there is no room for error. Additional views as the DTV should be used by trained surgeons to prevent dorsal screw protrusion. Surgeons should keep in mind though that this view significantly reduces the number of dorsally protruding screws, but does not completely guarantee safe placement of screws. Therefore close follow-up of their patients and if indicated performing post-operative CT-scans remains paramount. On the volar side there is (some) room for the placement of volar plates, however –as long as fracture characteristics allow for it- surgeons should stay well below the watershed line, which they can identify by palpating the ulnar volar prominence and keep in mind the sulcus of the flexor polices longus is situated just proximal from this prominence.

While we have come a step closer in the prevention of iatrogenic tendon related complications after volar plating for distal radius fractures, there is still room for improvement. Analysis of images of moving wrists with volar plates in situ could provide information on the influence of volar plates, scarring and the (un)repaired pronator quadratus on the volar flexor tendons. The Q3DCT methods we designed can be used to identify the optimal placement of volar plates and create a guide for the surgeon to this placement. Long term follow-up of a large cohort of patients with different Soong Grading can provide the clinical relevance of different plate positioning. As we have only covered the influence of placed hardware on tendon related complications, future research should also focus on other causes of these complications – fracture characteristics and incidents during its treatment (like drilling).

ADDENDA

PORTFOLIO

	Year	Workload (Hours/ ECTS)
Courses		
Introduction to Statistics,	2017	0.5
Statistics	2018	0.7
Multivariate Statistics	2018	0.5
Scientific Writing in English,	2018	0.2
Creative Thinking & Innovation,	2018	0.2
License to operate ionising radiation apparatus (teacher and researcher)	2018	1.5
Workshops		
Critical Thinking & Problem Solving	2018	0.2
Conflict Resolution & Negotiation	2018	0.2
Master classes		
Entrepreneurial Thinking	2018	0.2
Leadership Specialization	2018	0.2
Online Classes		
Introduction to Emotional Intelligence	2018	0.2
Other		
Weekly Research Meetings Orthopaedic Department	2017-2019	8
Supervising		
Supervising Residents (2x) and students (2x) in research	2018-2019	4.0

Presentations and International Conferences

'Volar Plating in Distal Radius Fractures: a Prospective Clinical Study on Efficacy of Dorsal Tangential Views (aka Lleyton Hewitt View) to Avoid Dorsal Screw Penetration'		
1. Presentation: Australian Orthopaedic Association 77th Annual Scientific Meeting	2017	0.5
2. Presentation: Asia Pacific Wrist Association 3rd Annual Congress	2017	0.5
3. Poster: American Society of Surgery of the Hand, 73rd annual Meeting	2018	0.5
4. Presentation: Traumadagen	2018	0.5
5. Presentation: Australian Orthopaedic Trauma Association Annual General Meeting	2018	0.5
6. Presentation: American Academy of Orthopaedic Surgeons Annual Meeting	2019	0.5
'Volar Plating for Distal Radius Fractures: Systematic Review of Efficacy, Reliability and Accuracy of Diagnostic Imaging to Prevent Screw Protrusion'		
1. Presentation: Australian Orthopaedic Association SA/NT Branch Scientific Meeting	2017	0.5
2. Poster: American Society of Surgery of the Hand, 73rd annual Meeting	2018	0.5
'Distal Radius Volar Plate Design Predicts Volar Prominence to The Watershed Line on Lateral X-Rays: Comparison of Soong Grading of Two Common Low Profile Plates in 400 patients'		
1. Presentation: Orthopaedic Trauma Association 43th Annual	2018	0.5
Meeting	2018	
2. Poster: American Society of Surgery of the Hand, 73rd annual		0.5
Meeting	2018	
3. Presentation: Australian Orthopaedic Trauma Association		0.5
Annual General Meeting	2019	
4. Presentation: American Academy of Orthopaedic Surgeons		0.5
Annual Meeting		
Volar Plating in Distal Radius Fractures: A Prospective Clinical Study on Acuracy of Dorsal Tangential Views		
Presentation: Australian Orthopaedic Trauma Association Annual General Meeting	2018	0.5
Volar Plating for Distal Radius Fratures: Reliability, Efficacy and Accuracy of Intra-Operative Diagnostic Imaging Modalities for the Detection of Screw Penetration		
1. Presentation: Australian Orthopaedic Trauma Association Annual General Meeting	2018	0.5

(Inter)national Conferences

• Australian Orthopaedic Association SA/NT Branch Sientific Meeting	2017	0.25
• Asia Pacific Wrist Association Annual Congress	2017	0.25
• Traumadagen Amsterdam, The Netherlands	2018	0.25
• Australian Orthopaedic Association Annual Scientific Meeting	2018	1.0
• American Society of Surgery of The Hand Annual Meeting	2018	0.75
• Australian Orthopaedic Trauma Society Annual Scientific Meeting	2018	0.75
• Orthopaedic Trauma Association Annual Meeting	2018	1.0
• American Academy of Orthopaedic Surgeons Annual Meeting	2019	1.25

Parameters of Esteem

• Flinders University PhD Scholarship	2017
• Flinders High Potential PhD Grant	2017
• Prins Bernhard Cultuurfonds Cultuurfondsbeurs	2017
• Professor Rene Marti Keuning Eckhardt Foundation Research Scholarship	2017
• Stichting Jo Kolk Study Grant	2017
• Traumaplatform Seed Money/Travel Grant	2017
• Scholten-Cordes Fonds Study Grant	2017
• Stichting Anna Fonds Travel Grant	2017
• FUSA Development Grant	2018

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Jullie betekenen allebei de wereld voor me, en het betekent zoveel dat jullie ook nu naast me staan!
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Professor Jaarsma, beste Ruurd,
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Dear Josie, Beth, Grace, Jude and Anj, you all know from first-hand experience that having a social life is probably the single most important thing when you move to the other side of the world. Thanks to all of you, but especially Josie, for letting me into yours.

Dear Laura,
Thank you so much for being my best Aussie friend – my best Australian memories are definitely shared with you. You have such an amazing soul and with that have meant so much to me. It did hurt me to leave you at the airport, but I am sure we will meet again!

Floor,
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ABOUT THE AUTHOR

Minke Bergsma is the author behind this thesis. She's a resident Radiology at the Noordwest Ziekenhuisgroep Alkmaar, where she started her specialist training in January 2020.

Minke graduated from the gymnasium at the Christelijk College Nassau-Veluwe in Harderwijk, where she was an active member of the debate team in 2008 and started her medical studies at the Rijksuniversiteit Groningen in the same year. During her bachelor's degree she was an active member of a variety of academic and societal committees. She was coxswain and coach of the freshman's lightweight eight two years in a row, where she competed at national competitions. Before her master's she took some time off to travel Central America. During her master's degree, she completed internships in Groningen, Leeuwarden, Vlieland, Tanzania and at the Center of Tropical and Travel Medicine in Amsterdam. During her master's degree she also completed the Honours Leadership Program of the University of Groningen and the course United Nations and Multilateral Diplomacy at the Radboud University in Nijmegen. She joined the United Netherlands Delegation and won several awards for her participation in conferences at Oxford University and Harvard University. After her graduation she started working as surgical resident (not in training) at the Antonius hospital in Nieuwegein in 2015. In March 2017 she got offered a chance to start her PhD as first participant in the Cotutelle Program, a new collaboration between the University of Amsterdam and Flinders University, Adelaide, Australia. She completed her research overseas in October 2018. Afterwards, she returned to the Netherlands to finish her thesis.

Minke is driven and curious, she is now expanding her research experience into the field of clinical implementation of artificial intelligence in medical imaging. In her spare time Minke spends as much time as she can at the beach and on the water – preferably while traveling and combined with some good wine.