A new radiological method to detect dorsally penetrating screws when using volar locking plates in distal radial fractures

THE DORSAL HORIZON VIEW

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Penetration of the dorsal screw when treating distal radius fractures with volar locking plates is an avoidable complication that causes lesions of the extensor tendon in between 2% and 6% of patients. We examined axial fluoroscopic views of the distal end of the radius to observe small amounts of dorsal screw penetration, and determined the ideal angle of inclination of the x-ray beam to the forearm when making this radiological view.

Six volar locking plates were inserted at the wrists of cadavers. The actual screw length was measured under direct vision through a dorsal approach to the distal radius. Axial radiographs were performed for different angles of inclination of the forearm at the elbow.

Comparing axial radiological measurements and real screw length, a statistically significant correlation could be demonstrated at an angle of inclination between 5° and 20°. The ideal angle of inclination required to minimise the risk of implanting over-long screws in a dorsal horizon radiological view is 15°.

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Operative treatment of fractures of the distal radius with volar locking plates is increasingly being undertaken,[1,2] especially in unstable dorsally displaced fractures. Application of the plate on the palmar aspect of the radius reduces the risk of extensor tendon irritation, which is one of the major problems of dorsal plate fixation.[3,4] However, volar locking plates can cause irritation or rupture of the dorsal tendon in between 2% and 6% of patients.[5-7] This is mostly attributed to screw tips from the volar plates penetrating through the dorsal cortex of the distal radius. Selection of screws of the appropriate length is usually determined using a depth gauge. However, this can be difficult or impossible to perform when the far cortex is comminuted. Similarly it can be difficult to recognise penetrating screws on a two-dimensional image, as the shape of the distal radius is a complex three-dimensional (3D) structure.

Different methods of radiologically determining the length of the locking screws have been sought. Maschke et al[8] described an oblique lateral view in pronation and supination to detect dorsal screw penetration intra-operatively. These fluoroscopic images are demonstrably better in detecting inappropriate screw lengths compared with the standard lateral view.[8] However, it requires a minimal screw prominence of 2 mm to 4 mm for radiological detection. Recently the use of a dorsal tangential view of the distal end of the radius was reported by different authors.[9,10] However, neither study compared the radiological results with the screw penetration under direct vision.

Our aim was to examine whether an axial fluoroscopic view of the distal end of the radius can demonstrate minimal dorsal screw penetration during volar locked plating. Additionally we wanted to determine the ideal angle of inclination of the bone relative to the image intensifier to minimise the risk of over-projection. In order to compare the accuracy of the results, an additional CT scan was performed.

Materials and Methods

Volar locking plates (VA-LCP Two-Column Distal Radius Plate 2.4 mm; Synthes, Oberdorf, Switzerland) were inserted in six cadaveric distal radii (four female and two male, mean age 78.3 years (71 to 85)) using a standard volar approach. There was no evidence of previous injury in any of the cadaveric forearms. The correct position of the plate was controlled with an image intensifier. The plate was then secured through the gliding hole with the 2.4 mm cortex screw. Locking head screws were positioned using a variable angle drill sleeve. All screws used for this study had different lengths, matched to the thickness of each radius, determined under direct vision. The ideal screw length was when the tip of the locking head screw is just beneath and short of

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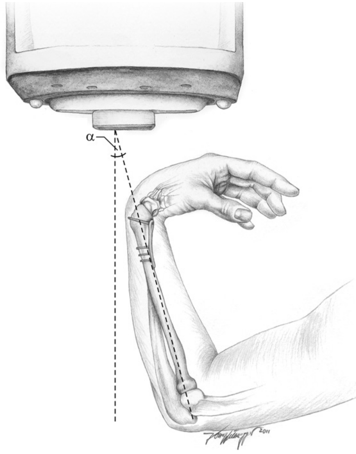

Fig. 1

Drawing of the experimental set-up: axial path of x-ray beams showing the forearm in a vertical position with maximal supination and flexion of the wrist (α, angle of inclination).

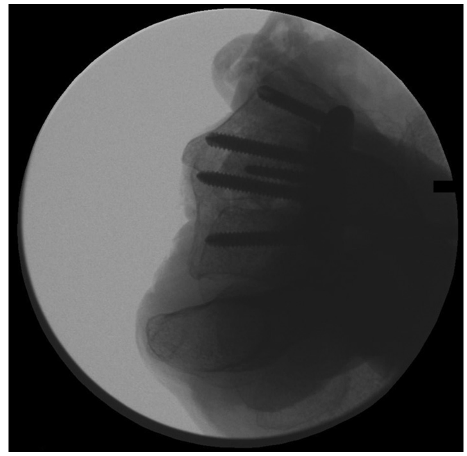

Fig. 2a

Fig. 2b

Axial radiological views of the distal radius with an angle of inclination of 15° showing a) screws placed after measurement under direct vision, with no screw penetrating the dorsal cortex, and b) with screws 2 mm longer than the directly measured screws, showing the tip of every locking screw clearly penetrating the dorsal cortex

penetrating the dorsal cortex. The screws were then sequentially numbered from 1 to 4 from the radial to ulnar side. Afterwards, the specimens were fixed in a vertical position with maximal supination and flexion of the wrist as shown in Figure 1.

Starting with a perpendicular position (angle of inclination (α) of 0°) the forearm was extended at the elbow in intervals of 5° to 45° using a digital goniometer (SmartTool Technologies, Oklahoma City, Oklahoma), and a fluoroscopic image was obtained at each angle. Each screw was then exchanged for another that was 2 mm longer, and the experiment was repeated. The actual length of the screw tip penetrating the dorsal cortex was measured using a digital calliper (Digi-Met; Preisser, Gammertingen, Germany) under direct vision. When the tip of a screw lay beneath the bone, the distance from the tip to the bony surface was indicated in negative values.

A CT-scan was performed for each specimen held in the same positions for both the shorter and the longer screws. In 3D reconstructions of the CT scans, we virtually arranged the same experimental set-up to measure the different angles of inclination of the images. The screw length penetrating through the dorsal cortex was measured by a resident hand surgeon (LH) and a radiologist (BG) who were blinded to the patient data. They assessed if the screw seemed to penetrate the dorsal cortex or if the screw appeared to be contained within the bone on each virtual image. The length of the screws penetrating the dorsal cortex was measured in mm using a Dicom viewer (Agfa IMPAX; Agfa HealthCare, Mortsel, Belgium; and OsiriX v.3.8.1; Osirix Foundation, Geneva, Switzerland) as a positive value, or as a negative value if the screw seemed too short (Fig. 2).

Statistical analysis. Mean values and standard deviations (SD) were calculated. The difference between real length of screw prominence under direct vision and measured values in the fluoroscopic image was investigated using Spearman's rank correlation coefficient. Correlation of each angle of inclination with real dorsal screw protrusion was analysed using intraclass correlation coefficients (ICC). Results were considered statistically significant if the p-value < 0.05. SPSS Statistics v20 software was used (IBM, Armonk, New York).

Results

In the six cadaver forearms a total of 25 locking head screws were evaluated in various angles of inclination of the forearm relative to the x-ray beam. In the first series using screws of reference length, measurement of dorsal

Table I. Mean difference between real length of screw prominence (as measured under direct vision) and measured length (in mm) in the radiograph and CT scan image

	Mean (SD) difference (mm)				
Angle of inclination	**Radiograph**	**CT scan**	**ρ***	**p-value†**	**Screws too long (n, %)**
Reference length 0					
5°	0.6 (0.9)	0.7 (0.8)	0.7	< 0.001	
10°	0.7 (0.7)	0.5 (0.7)	0.8	< 0.001	
15°	0.7 (0.6)	0.3 (0.6)	0.7	< 0.001	
20°	0.8 (0.7)	0.4 (0.7)	0.5	0.012	
25°	1.2 (1.1)	0.7 (0.9)	0.3	0.14	
30°	1.6 (1.3)	1.3 (1.1)	0.2	0.37	
35°	2.4 (1.7)	2.4 (1.3)	0.2	0.45	
40°	3.3 (2.1)	3.6 (1.5)	0.2	0.45	
45°	3.6 (2.2)	4.8 (1.7)	0.1	0.74	
Reference length +2 mm					
5°	0.7 (0.7)	0.9 (1.0)	0.7	< 0.001	20 (*80*)
10°	0.5 (0.6)	0.6 (0.8)	0.7	< 0.001	23 (*92*)
15°	0.2 (0.5)	0.5 (0.6)	0.6	0.001	24 (*96*)
20°	0.7 (0.8)	0.6 (0.7)	0.4	0.02	23 (*92*)
25°	1.1 (1.2)	1.0 (0.8)	0.2	0.31	18 (*72*)
30°	1.5 (1.6)	1.7 (1.1)	0.0	0.96	14 (*56*)
35°	2.4 (1.9)	2.7 (1.3)	-0.3	0.22	9 (*36*)
40°	3.2 (2.3)	3.8 (1.7)	-0.3	0.12	5 (*20*)
45°	4.4 (2.5)	5.2 (2.0)	-0.3	0.10	3 (*12*)

* Spearman's rho (comparing real length of screw prominence with measured length in the radiograph)
† corresponding to radiographs only

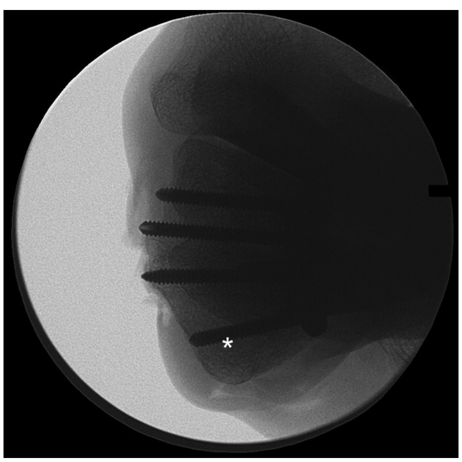

Fig. 3a

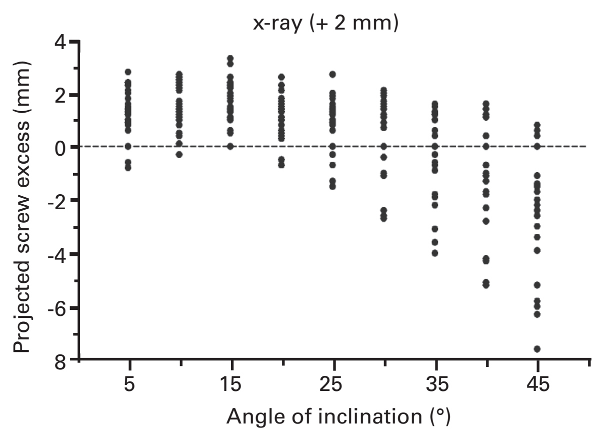

Fig. 3b

Figure 3a – axial radiological view (angle of inclination 15°) showing that although the screw R1 (*) has a real over-length of 0.5 mm, in this radiograph the tip of the screw does not seem to penetrate the dorsal cortex. Figure 3b – graph showing all measured values of screw projection for the screws of reference length + 2 mm. It is clear that the best significance is shown at an angle of inclination of 15° where 24 of 25 screws were clearly identified as too long.

surface screw penetration observed under direct vision had a mean value of -0.4 mm (-2 to 0.7). The series with the 2-mm-longer screws had a mean penetration of 1.9 mm (0.5 to 3.3) (Table I). The smallest difference between the measured length of screw prominence in the imaging and real length as measured under direct vision in the series with longer screws was seen at 15° of inclination of the forearm relative to the x-ray beam. The Spearman's rank correlation coefficient between the two measured values was $\rho = 0.6$ at 15° ($p = 0.01$). In the series with the longer screws, 24 out of 25 screws were detected as too long in the axial radiological view at 15°. The one screw that was not identified as too long appeared just flush with the dorsal cortex of the distal radius on the radiograph, whereas the actual excessive length was 0.5 mm. All measured values in the axial fluoroscopic view at different angles in the series with longer screws are shown in Figure 3.

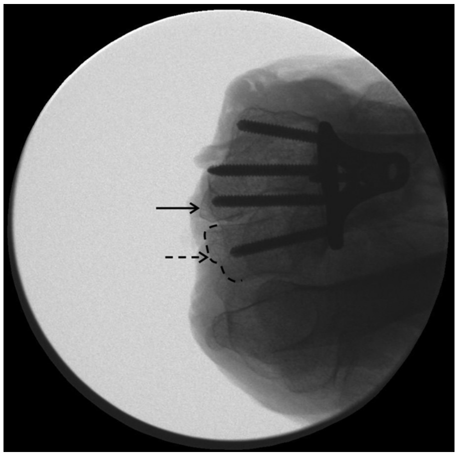

Fig. 4

Axial radiological view showing how over-projection can lead to misinterpretation of the screw length. The arrow shows the scaphoid bone and the dashed arrow shows the border of the lunate bone.

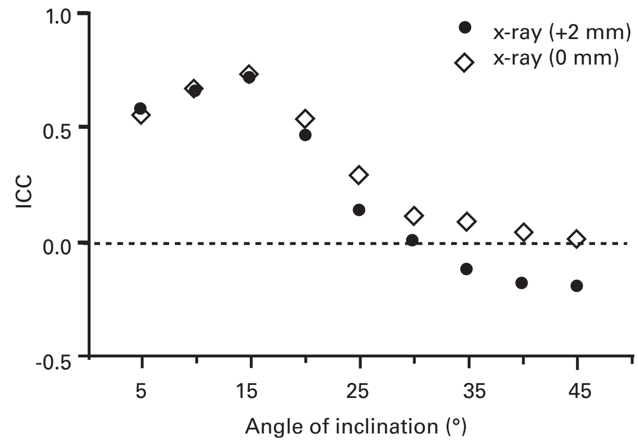

Fig. 5a

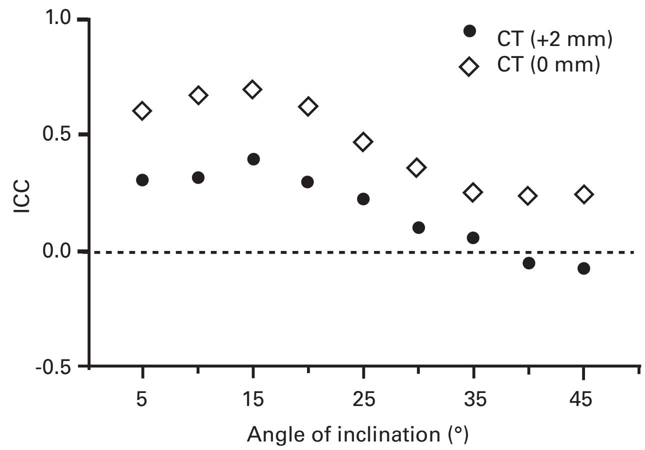

Fig. 5b

Scatter diagrams showing the correlation of the projected radiographs (short and long screws) with a) true excess and b) true screw prominence using intraclass correlation coefficient (ICC).

The greater the angle of inclination of the radius at the elbow exceeds 15°, the more the screw tips appear to be intra-osseus (negative values) although the real screw excess (as measured under direct vision) is positive. Both the dorsal edge of the distal radius and the proximal carpal row can explain any over-projection resulting in misinterpretation of the screw length (Fig. 4).

The correlation between the projected screw length in the radiographs and values measured under direct vision is shown in Figure 5. The correlation progressively improved from 5° to 15°, with the best correlation seen at 15° (ICC 0.74; $p < 0.001$), whereas the correlation deteriorated rapidly at angles of inclination > 20° (Fig. 5a). Comparing the measured screw length in the 3D reconstruction of the CT scan, with true excess in length of the screws, results in a similar curve for the series with shorter screws. The series with longer screws shows poor correlation with the measured excess length (at 15°, ICC 0.3; $p = 0.67$) (Fig. 5b).

Discussion

Our results demonstrate a statistically significant correlation between real dorsal screw penetration, as measured under direct vision, and measured screw length in the dorsal horizon radiograph. Statistical significance of the correlation is shown at angles of inclination of the radius at the elbow from 5° to 20° for screws that penetrate a known 2 mm through the far cortex. The highest correlation was found at 15° of inclination where we detected all but one screw as being too long.

If the arm is further extended with an angle of inclination > 20°, the risk of false interpretation is increased. At these higher angles the dorsal edge of the radius creates the impression of an intra-osseous screw position, and if the angle of inclination becomes even greater the scaphoid and the lunate bones seem to shift over the distal radius in the axial view.

We observed that screw protrusion seems to be slightly too long in CT scans compared with axial radiological views for the screws directly observed to be the correct length at virtual angles of inclination > 30°. In contrast screw protrusion is underestimated at virtual inclination angles between 10° and 30°. We conclude that correct screw length cannot be measured exactly with a CT scan. Indeed the standard deviation of values measured in 3D reconstruction CT are similar to those measured in conventional radiological images. Over-estimation of screw length in CT scans compared to fluoroscopic radiographs is described as a 'blooming effect' where structures with a higher density appear bigger in CT scans.[11,12] At greater angles of inclination the tip of the screw is projected away from hyperdense voxels of the cortical bone and appears next to hypodense voxels of the cancellous bone. By reason of the 'spillover effect'[11] these voxels are then misinterpreted as being part of the screw and making it look larger. As a consequence an exact measurement turns out to be impossible. Intra-operative 3D scans do not seem to be appropriate; as well as being expensive and impractical, the radiation dose is not justified.

We recommend using an image intensifier with a laser pointer for aiming accuracy. The forearm can then be maintained in position at an angle of 15° of extension relative to a perpendicular elbow. The image intensifier can then be centred to the radiocarpal joint. In order to receive a clear and sharp image in order to evaluate the dorsal cortex properly it is advantageous to use a digital image intensifier. In our experience, moving grids avoid over-exposure of the fluoroscopic image and are therefore recommended. This process does not take long and is worthwhile in avoiding complications or the need for further surgery. This dorsal horizon view could also be used at post-operative follow-up, as it is more accurate than a CT and would help decision making on the need to remove hardware or exchange of single screws.

A limitation of the study is the use of cadaver specimens and further clinical studies are needed to verify the benefit of this new radiological technique. It will be a challenge to determine a 15° angle of inclination consistently and accurately in clinical practice and so we recommend using a sterile goniometer. In order to minimise errors while positioning the arm at the correct angle intra-operatively, it would be helpful to use an x-ray permeable 15° wedge-shaped holding block. This can also reduce the exposure dose for the surgeon who would then not need to maintain the position of the anaesthetised arm during fluoroscopy.

In conclusion, a dorsal horizon fluoroscopic view of the distal end of the radius can facilitate the insertion of screws with minimal dorsal penetration during volar locking plating. The ideal angle of inclination of the radius at the elbow to minimise over-projection is 15°. It is a simple intra-operative radiological technique that helps to prevent the complication of extensor tendon irritation and its sequelae.

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No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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