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Radiographic Evaluation of Dorsal Screw Penetration After Volar Fixed-Angle Plating of the Distal Radius: A Cadaveric Study

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Abstract
Introduction Extensor tendon irritation and attritional tendon ruptures are potentially serious complications after open reduction and internal fixation of distal radius fractures. These complications are well recognized after dorsal plating of distal radii; and these are now being reported after errant screw placement during volar fixed-angle plating. Intraoperative detection of improper screw placement is critical, as corrective action can be taken before completion of the operative procedure. The purpose of this study was to define the extensor tendon compartments at risk secondary to dorsal screw penetration and to compare pronation and supination fluoroscopic images with standard lateral images in demonstrating dorsal screw prominence during volar locked plating.

Methods Eight fresh-frozen human cadaveric upper extremities underwent fixation with a volar, fixed-angle distal radius locked plate (Wright Medical Technology, Arlington, TN). Three fluoroscopic views (lateral, supinated, and pronated) followed by dorsal wrist dissections were compared to determine accuracy in detecting dorsal screw prominence and extensor tendon compartment violation. Subsequently, screws measuring 2, 4, 6, 8, and 10(mm longer than the measured depths were sequentially inserted into each distal locking screw, with each image deemed either “in” (completely inside the bone) or “out” (prominent screw tip dorsally-would typically be exchanged for a shorter screw intraoperatively).
Results The radial most distal locking screw (position 1) violated either the first (25%) or second (75%) extensor tendon compartments. The average screw prominence required for radiographic detection was: 6.5(mm for lateral views and 2(mm for supinated views. Pronated views did not identify prominent screws. Screws occupying plate position 2 consistently entered Lister’s tubercle, with 5/8 exiting the apex and 3/8 exiting the radial base. The average screw prominences for radiographic detection were: 2.75(mm-lateral views and 3.0(mm-supinated views. Although the screws entered the second dorsal compartment, they did not encroach upon either of the tendons. Screws occupying plate position 3 violated the third extensor tendon compartment in 7/8 specimens with 1/8 exiting the Ulan base of Lister’s tubercle. The average screw prominences for radiographic detection were: 3.5 (mm-lateral views and 2.5(mm-pronated views. Supinated views did not identify prominent hardware. Screws occupying plate position 4 all violated the IV dorsal extensor compartment-2/8 screws were noted to tent the posterior interosseous nerve. The average screw prominences required for radiographic detection were: 4.0(mm-lateral

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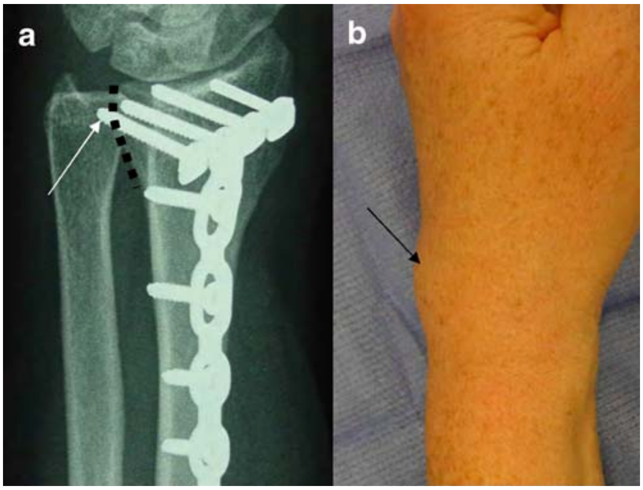

Figure 1 Sequelae of missed dorsal screw prominence: (a) 45° pronation view—long ulnar most distal locking screw (arrow): (b) clinical photo: extensor tenosynovitis (arrow)—required hardware removal and tenosynovectomy.

views and 2.5(mm-pronated views. The supinated views did not identify prominent screws.

Conclusions Volar fixed-angle plating has shown great promise in the advancement of distal radius fracture management. We have seen in our referral practices and in the literature an increase in the number of extensor tendon complications arising from unrecognized dorsally prominent screws, pegs, or tines. Standard PA and lateral radiographs cannot adequately visualize screw position and length secondary to the complex geometry of the dorsal cortex. We believe this study supports the routine application of intraoperative, oblique pronosupination fluoroscopic imaging for enhanced confirmation of distal locking screw position and length.

Keywords Distal radius fractures · Dorsal screw penetration · Volar fixed-angle plating

Introduction

Extensor tendon irritation and attritional tendon ruptures are serious complications after open reduction and internal fixation of distal radius fractures. These complications are well recognized after dorsal plating of distal radius fractures; they are now being reported with increasing frequency secondary to errant screw placement during volar fixed-angle plating [1, 5, 9, 12, 14, 16, 18]. Volar fixed-angle plating has gained popularity in the treatment of unstable fractures of the distal radius by providing stable fracture fixation while avoiding surgical exposure and violation of the dorsal soft-tissues. However, inserting screws of improper length and/or orientation, can lead to complications and poor clinical results despite satisfactory fracture reduction and fixation (Fig. 1) [11].

Intraoperative detection of improper screw placement is critical, as corrective action can be taken before completion of the procedure.

The anatomy of the distal forearm and wrist accounts for the high frequency of soft-tissue complications arising from the insertion of metallic implants. The volar surface of the distal radius is relatively flat and separated from the overlying flexor tendons by the interposed muscle belly of the pronator quadratus (PQ) (Fig. 2).

Re-approximating the muscle belly of the PQ over volarly inserted plates and screws maintains a low friction gliding surface for the flexor tendons. Additionally, instrumentation confined to the PQ fossa are remote from direct contact with the flexor tendons. Conversely, the dorsal surface of the distal radius has a complex geometry with tendon directly opposed to bone (Fig. 2). Dorsal hardware disrupts this intimate bone–tendon relationship, placing the extensor tendons at risk for irritation and attritional rupture.

The purpose of this study was to define the extensor tendon compartments at risk secondary to dorsal screw penetration and determine the accuracy of fluoroscopic evaluation in demonstrating dorsal screw prominence during volar locked plating.

Materials and Methods

Eight fresh frozen human cadaveric upper extremities were obtained from the Anatomic Gift Registry. Each extremity had a volar, fixed-angle distal radius locking plate

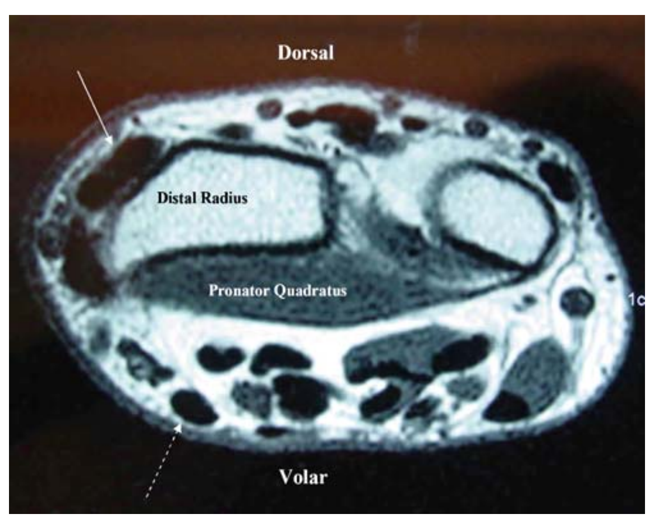

Figure 2 T1-weighted axial MRI of the wrist DRUJ: pronator quadratus interposed between the flexor tendons (dashed arrow) and the volar cortex of the distal radius; extensor tendons (solid arrow) coursing directly over the dorsal cortex of the distal radius. DRUJ= distal radioulnar joint.

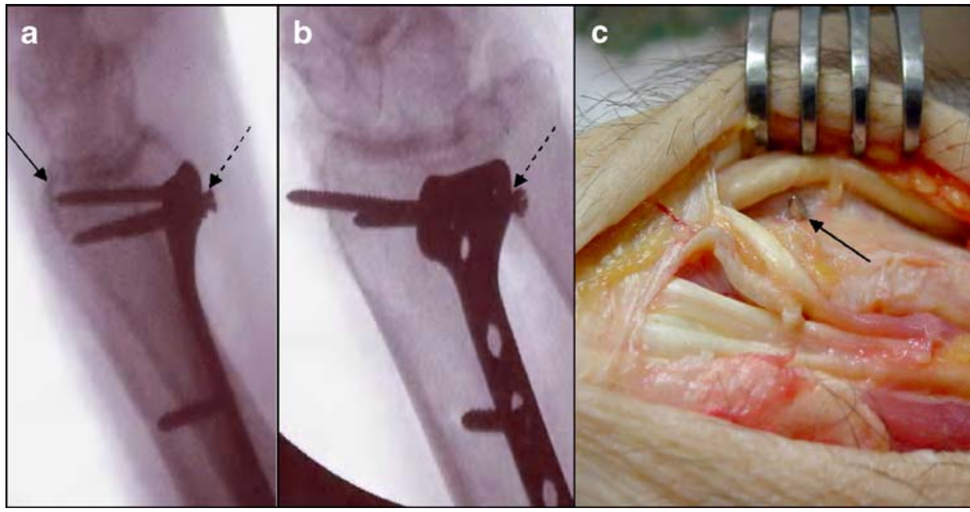

Figure 3 Screw Position 1 (screw is 6 mm proud): (a) neutral lateral—screw “in” (arrow); (b) 45° supination—screw “out”; (c) direct visualization—screw violation of extensor compartment II (arrow). Screws occupying the remaining distal locking holes have been backed out: isolating plate position 1 (dashed arrows).

(LOCON, Wright Medical Technology, Arlington, TN) inserted via a standard volar approach. All procedures were performed by two fellowship-trained hand surgeons. Coronal plane alignment was confirmed via fluoroscopic PA images; and the plates were secured to the radial shafts with 3.5-mm cortical screws. Next, all four of the distal locking screw holes were drilled utilizing the distal locking guide and sequentially numbered 1–4 (radial to ulnar). The bone was intentionally drilled in bicortical fashion, and the depths were measured and recorded using the standard depth gauge; 2.7-mm distal locking screws of the measured length were inserted into each (numbered) plate position. Violation of the dorsal cortex was evaluated fluoroscopically in three planes: (1) neutral lateral (utilizing scaphopisocapitate alignment), (2) supinated view, and (3) pronated view [19] (Figs. 3 and 4).

The angles of the pronation and supination fluoroscopic images were not standardized. This was intentionally done to further simulate the intra-operative environment and allow for “live time” imaging in these multiple planes. Four observers (two attending upper extremity surgeons, one orthopedic surgery resident, and one medical student) evaluated the images and came to a consensus whether each screw was deemed “in” (completely inside the bone) or “out” (prominent screw tip dorsally—would be typically exchanged for a shorter screw intra-operatively).

After hardware placement and fluoroscopic evaluation, the dorsal cortex of the distal radius and all extensor tendon compartments over the distal radius were exposed via a standard dorsal approach to the wrist. Screw prominence was evaluated under direct visualization and the extensor compartment violated by the drill hole was photographed and recorded for each distal-locking screw position.

Evaluation progressed from screw position 1 sequentially through position 4. To allow discrete evaluation of screw position 1, the remaining screws were backed out 5 mm; this was repeated for each successive position. After the depth-gauge-measured screws were visually evaluated, the screw occupying plate position 1 (radial most distal-locking screw) was removed and exchanged with a screw measuring 2 mm longer. Direct visualization confirmed screw tip violation of the dorsal cortex. The series of three fluoroscopic images

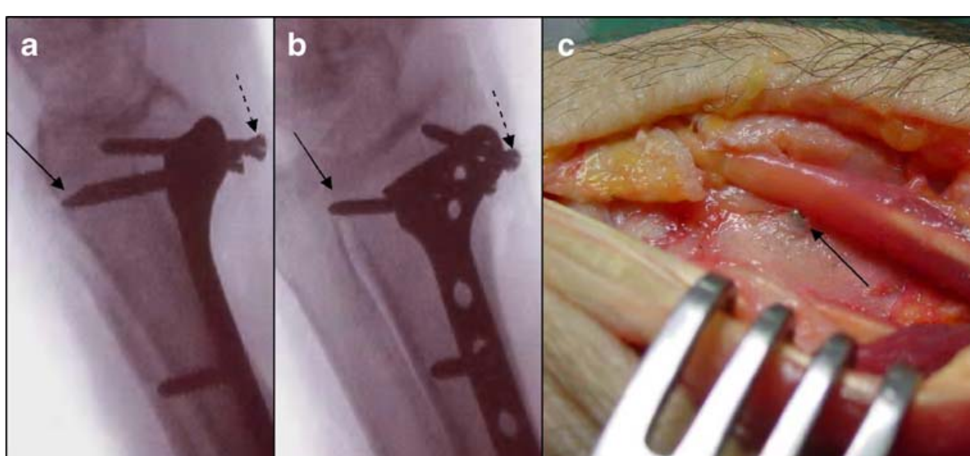

Figure 4 Screw position 4 (screw is 4 mm proud): (a) neutral lateral—screw “in” (arrow); (b) 45° pronation—screw “out” (arrow); (c) direct visualization–screw violation of extensor compartment IV (arrow). Screws occupying the remaining distal locking holes have been backed out: isolating plate position 4 (dashed arrows).

Table 1 Average length (mm) of screw prominence for radiographic detection.

Srew Position	Supination	Pronation	Lateral	Plate Lateral
1	2.0 (2–2)	N/A	6.75 (6–10)	6.0 (4–8)
2	2.5 (2–4)	N/A	2.75 (2–4)	2.5 (2–4)
3	N/A	2.5 (2–4)	3.75 (2–6)	3.75 (2–6)
4	N/A	2.25 (2–4)	4.0 (4–4)	4.5 (4–6)

were repeated for this longer screw and a consensus agreement was made regarding screw prominence, "in" or "out", for all views. This sequence was repeated for plate position 1, with screws increasing in length by 2-mm increments, until the screw tip was visualized "out" on all radiographic views. Distal-locking screw positions 2, 3, and 4 underwent the identical sequence of screw exchange and fluoroscopic/visual evaluation.

Results

Accurate fluoroscopic determination of proper screw length was variable and dependent upon which screw position was being evaluated and by which view. Table 1 summarizes the average screw prominence (shortest screw length deemed "out"—starting screw length) required for fluoroscopic evidence of cortical penetration for each screw position and for each view. The shortest value for initial detection of dorsal screw prominence is 2 mm, as this is the length of the first intentionally long screw inserted. Table 2 summarizes the extensor tendon compartment violated by each distal-locking screw position.

The radial most distal-locking screws (position 1) violated either the first (25%) or second (75%) extensor tendon compartments. Supination views align the x-ray beam with the radial aspect of the dorsal cortex and identified all prominent screws occupying position 1 (defined as 2 mm proud in this study). In contrast, the average screw prominence required before fluoroscopic detection utilizing a lateral view was 6.5 mm (i.e., a screw that appeared "in" on a lateral view was in reality 6.5 mm proud; Figs. 5 and 6).

Likewise, the ulnar most distal-locking screws (position 4) always violated the IV dorsal extensor compartment—2/8 screws were actually noted to tent the posterior interosseous nerve. Pronation views align the x–ray beam with the ulnar aspect of the dorsal cortex and identified prominent screws with an average threshold of 2.5 mm. The average screw prominence required for fluoroscopic detection was 4.0 mm on lateral views (Fig. 7).

The more central distal locking screw positions (positions 2 and 3, respectively) exit the dorsal cortex either within or close to Lister's tubercle. These plate positions displayed less variability in identifying prominent screws, utilizing the different fluoroscopic views.

Discussion

Distal radius fractures account for approximately 15% of all extremity fractures [12]. The goals of treatment are to reestablish the osseous anatomy and restore painless wrist motion and strength. Open reduction and internal fixation with plate and screw constructs has enhanced the surgeon's ability to achieve stable fracture fixation, thus reducing immobilization time and expediting return to function [1, 2, 5, 6, 8, 10, 14, 15]. The implantation of plates and screws into the distal radius requires careful consideration and handling of the adjacent soft tissues and precise placement of the hardware to avoid both short and long-term complications.

The most frequent complications after plate fixation of distal radius fractures are tendon irritation and attritional tendon ruptures—occurring in up to 50% of reported cases [1, 9, 18]. Friction over dorsally implanted plates and screws can lead to tendon fraying and subsequent tendon rupture. Low-profile dorsal plating systems were introduced to better manage the dorsal soft-tissues, but relatively high rates of extensor tendon complications continue to be reported, requiring frequent implant removal [9].

Volar fixed-angle plating has been developed to enhance stable fracture fixation while avoiding surgical exposure and violation of the dorsal soft-tissues [8, 10, 14, 15]. Commercially available volar fixed-angle plating systems utilize fixed-angle pegs, screws, or tines to

Table 2 Dorsal extensor tendon compartment violated.

Srew Position	Compartment I	Compartment II	Lister' Tubercle	Compartment III	Compartment IV
1	2/8	6/8	0	0	0
2	0	0	8/8	0	0
3	0	0	1/8	7/8	0
4	0	0	0	0	8/8

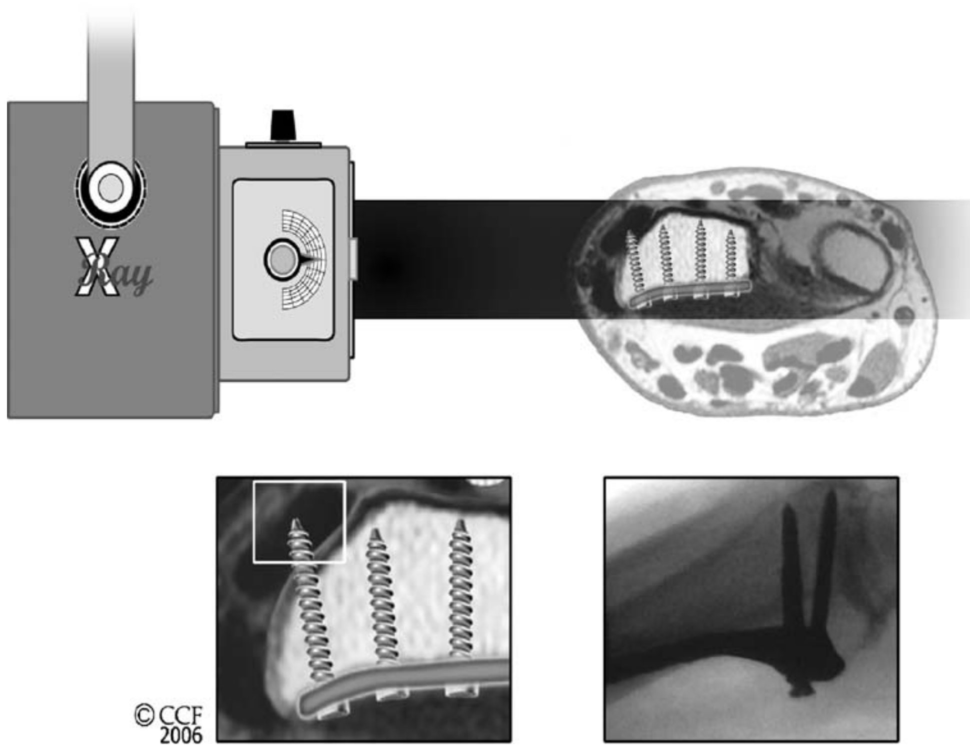

Figure 5 Cartoon depiction of the lateral radiographic projection when distal locking screw in position 1 is too long. The lateral radiograph in the bottom right corner is of a screw in position 1 protruding 6 mm out of the cortex. Reprinted with permission of the Cleveland Clinic.

support the articular fragments and subchondral bone. The volar surface of the distal radius is relatively flat and well suited for the application of plates and screws. The overlying flexor tendons course along the volar wrist, protected from the underlying bone and implanted hardware by the interposed muscle belly of the pronator quadratus. Orbay and colleagues report stable fixation, rapid fracture healing, and a low incidence of complications and/or subsequent operative procedures after volar fixation of distal radius fractures [14, 15]. However, as

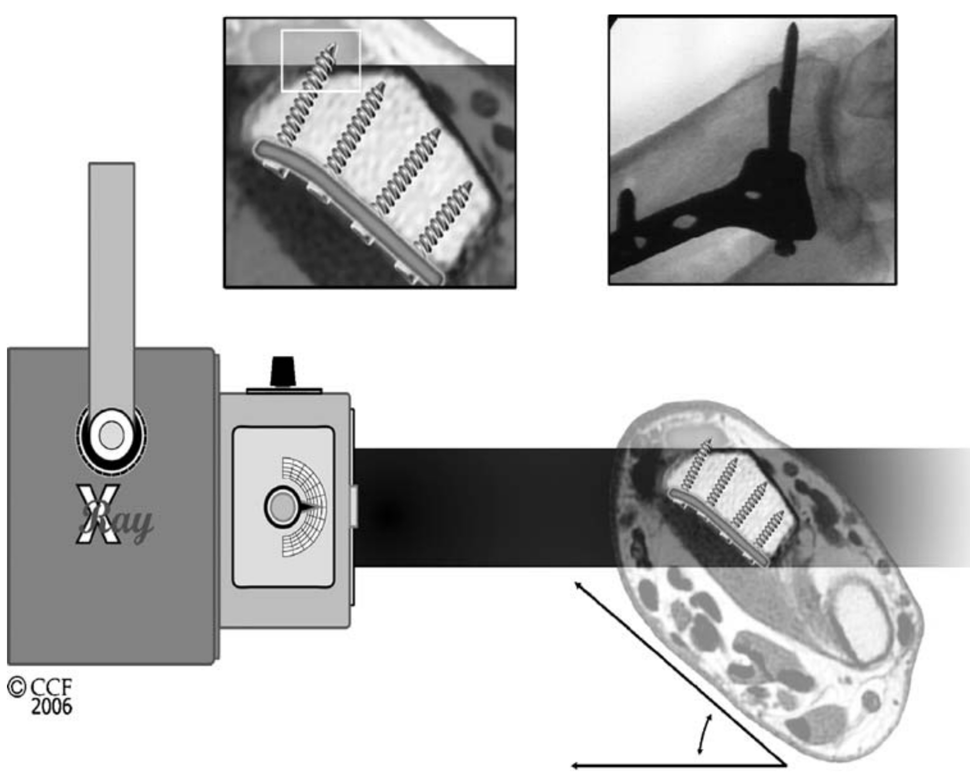

Figure 6 Cartoon depiction of the same screw length and position as in Fig. 5, but with the radiograph taken in the supinated view. The x-ray beam is aligned with the radial aspect of the dorsal cortex and easily detects the proud (6 mm) screw. Reprinted with permission of the Cleveland Clinic.

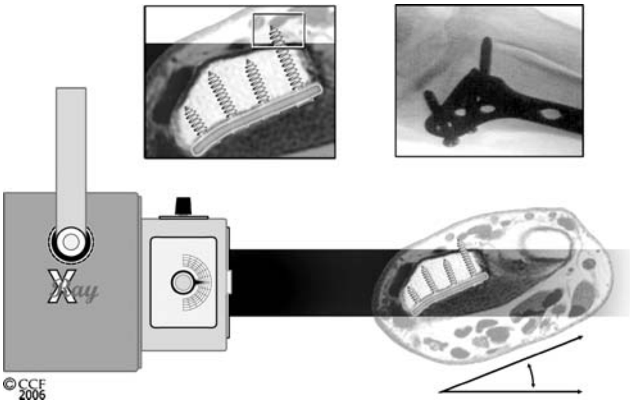

Figure 7 Cartoon depiction of the same screw length and position as in Fig. 5, but with the radiograph taken in the pronated view. The x-ray beam is aligned with the radial aspect of the dorsal cortex and easily detects the proud (6 mm) screw. Reprinted with permission of the Cleveland Clinic.

these implants have gained in popularity, complications are being increasingly reported. Improper placement of volar plates and screws can obviously lead to intra-articular penetration, flexor tendon irritation, and/or neurovascular compromise [3, 4, 13, 15, 16]. Recently, extensor tendon complications arising from the unrecognized insertion of distal-locking screws of inappropriate length are being reported [12]. Comminution of the dorsal cortex of the distal radius challenges accurate depth-gauge measurement of screw length. Thus, intra-operative, radiographic/fluoroscopic confirmation of proper screw trajectory and length, with critical attention focused on both articular and dorsal cortical violation, can minimize the occurrence of poor operative results.

Ironically, volar-locked constructs, which were innovative in addressing extensor tendon complications, are now causing dorsal soft-tissue complications by a completely different mechanism. This study sought to evaluate the risk to the extensor compartments secondary to errant screw placement, and to determine if routine intra-operative fluoroscopic evaluation could detect screws of improper length. Fluoroscopic/radiographic evaluation of hardware placement into the distal radius is challenging given the complex angular geometry of the bone. Standard PA and lateral images of the wrist do not account for the multiplanar tilts and inclinations of the distal radius and cannot reliably confirm proper screw position and length. Several investigators have evaluated the efficacy of different oblique radiographic views for assessment of the radiocarpal joint; aligning the x-ray beam with the normal radial and volar axes of the articular surface [4, 17]. These anatomic views have proven accurate and clinically useful for identifying screw penetration of the articular surface [4, 17]. Similarly, the dorsal cortex of the distal radius is inclined in more than one plane, prohibiting evaluation of the dorsal surface by a single fluoroscopic/radiographic projection. Our study evaluated the reliability of pronation and supination radiographic views in identifying dorsal screw prominence after volar fixed-angle plating and compared these results with a standard lateral radiographic view. The supination view was developed to better assess the radial portion of the dorsal cortex, encompassing the first and second dorsal extensor tendon compartments, which slope away from Lister's tubercle. Likewise, the pronation view was developed to improve fluoroscopic visualization of the ulnar portion of the dorsal cortex, containing extensor tendon compartments III and IV. The addition of these two oblique views improved our ability to detect screw penetration of the dorsal cortex compared with lateral images alone. Direct visualization of the dorsal cortex and adjacent soft tissues confirmed violation of the extensor tendons by prominent screws—frequently missed on standard lateral fluoroscopic views. We believe that this finding supports the routine application of intra-operative pronation and supination fluoroscopic imaging for accurate confirmation of appropriate and safe distal-locking screw length.

We attempted to simulate the intra-operative environment and utilize readily available surgical and fluoroscopic equipment for this study. Fluoroscopic imaging allows for "live time" imaging and immediate evaluation of the multiple views. The benefits of minimal interruption of the operative procedure, immediate image evaluation and "live time" imaging, far outweigh, in our opinion, the modestly diminished quality of the images when compared with standard radiographs. The angles of the pronation and supination radiographs were not standardized. This was intentionally done given the intra-operative environment for which these radiographs are intended. All images were taken by two fellowship-trained hand surgeons, both of whom already incorporate oblique intra-operative fluoroscopic imaging in practice. Also, a single volar-locked plating system was utilized for this study (LOCON, Wright Medical Technology, Arlington, TN). All current volar-locked plating systems incorporate multiple distal locking screws, tines, or pegs to support the articular surface. Although not evaluated in this study, different implant designs may impact the severity of soft-tissue compromise arising secondary to dorsally prominent hardware.

Volar fixed-angle plating has shown great promise in the advancement of distal radius fracture management. Unfortunately, we have seen in both our referral practice, and in the literature, a steady increase in the number of extensor tendon complications arising from dorsally prominent hardware [7, 12]. The advancement of new technologies requires critical evaluation of outcomes, allowing the identification of complications and development of solutions to increase the number of favorable outcomes. We believe this study supports the routine application of intra-operative, oblique pronation and supination fluoroscopic images for confirmation of final screw position and length during volar fixed-angle plating of the distal radius.

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