Ultrasound Imaging Improves Identification of Prominent Hardware in the Surgical Treatment of Distal Radius Fractures: A Cadaveric and Prospective Clinical Study

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Abstract

Background Volarly applied locking plates are one of several current treatment options for displaced fractures of the distal radius. Presently, surgeons use intraoperative depth gauges and fluoroscopy to select and confirm proper screw length. The contour of the dorsal cortex beneath the extensor compartments along with fracture comminution may limit the accuracy of screw length selection.

Question/Purpose To evaluate the accuracy of ultrasound (US) and fluoroscopy in the detection of dorsally prominent screws placed during volar plating of experimentally created distal radius fractures and extend this prospectively into the clinical setting.

Patients and Methods Distal radius fractures were experimentally induced in fresh cadaveric arms. The fractures were then internally fixated with volar locking plates utilizing fluoroscopic imaging. US imaging of the dorsal surface of the radius was then performed followed by dorsal dissection and direct caliper measurements to quantitate screw tips as recessed, flush, or protruding from the dorsal cortex. A small, prospective clinical study was also conducted to validate the clinical usefulness of using US to provide additional information regarding screw tip prominence.

Results Our study demonstrated that US was able to detect dorsally prominent screw tips not visible on fluoroscopy. Cadaveric dissection showed a higher statistical correlation between US imaging and actual prominence than between fluoroscopy and actual prominence.

Conclusions US examination after volar plate fixation of comminuted distal radius fractures may detect dorsal screw tip prominence when screw lengths are selected to engage the dorsal cortex.

Level of Evidence IV

Keywords
- ► distal radius
- ► fracture
- ► fluoroscopy
- ► ultrasound
- ► volar plate

Fractures of the distal radius are the most common fracture of the upper extremity[1] and represent a source of morbidity in both working-age and elderly patients. The rate of distal radius fractures in the Medicare age population is 125 per 10,000 lives and is expected to rise with increased life expectancy.[2] Over the past decade, fixation of distal radial fractures with volar locking plates has become increasingly common.[3] Recognized implant-related complications from

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the volar plates include flexor tendon synovitis and flexor tendon rupture related to the prominent volar lip of the plate as well as extensor tendon ruptures due to past pointing of the volar screws.[4–13] In our own clinical experience, we have identified patients with extensor synovitis and pain after volar plating who appear to have had appropriate screw length insertion radiographically but who were found to have screw tip prominence due to past pointing on ultrasound (US) evaluation and during surgical exploration (►**Fig. 1**).

Presently, surgeons use intraoperative depth gauges and fluoroscopy to select and confirm the proper screw length.[10,14] The accuracy of these techniques can be limited by dorsal fracture comminution. In addition, screw prominence beyond the dorsal cortex may not be detected on radiographs due to the height of Lister tubercle and depth of the dorsal compartments.[15] A postoperative US study of 46 patients found 59 prominent screws out of 230 that were placed into the distal radius with the aid of fluoroscopy, an incidence of 25%.[12] Additional fluoroscopic views as recently described by Ozer et al[16] and Dolce et al[17] have shown improved sensitivity of fluoroscopic screw tip detection in nonfractured cadaveric specimens. The purpose of this study was to assess the ability of two types of imaging modalities to detect dorsal screw prominence followed by direct dissection of the dorsal cortex of the fractured radius to determine the actual prominence.

Materials and Methods

Cadaveric upper extremities cut at the midhumerus were obtained from the Anatomical Gift Program of our institution. Lateral, posteroanterior (PA), and oblique radiographs of each specimen were obtained to document forearm and carpal anatomy and to ensure that none of the specimens had preexisting fractures or internal implants.

To produce a distal radius fracture, we constructed a "FOOSH" (fall on outstretched hand) simulator to re-create the forces of a typical fall upon an outstretched hand (►**Fig. 2**). Depending upon the angle of impact and fall height, we were able to produce fractures ranging from comminuted impacted intra-articular fractures of the distal radius to both bone fractures of the forearm. All of fractures used for this study were dorsally comminuted intra-articular fractures. Postfracture lateral, PA, and oblique radiographs were taken and the fractures were classified (AO classification 23-C2, 23-C1, 23-B3, 213-C1, 23-C1). The fractures then underwent an open reduction and internal fixation with a volar, fixed-angle distal radius locking plate (DVR Crosslock Distal Radius Plating, Zimmer Biomet, Warsaw, IN). Fifteen proximal screws and 33 distal locking screws in five cadaveric extremities were inserted after using the manufacture's depth gauge with the intention of engaging the dorsal cortex. The depth gauge was passed once to engage the dorsal cortex, and if satisfactory engagement could not be achieved, additional passes were performed. This step was performed by a fellowship-trained hand surgeon with experience in volar plating. Following placement of each screw, PA and lateral fluoroscopic images were obtained using a mini-C arm (Phillips, Andover, MA). Correct forearm positioning on the lateral images was determined by superimposition of the distal radius and ulna. Dorsal US imaging was then performed using a 12-MHz linear array transducer (HD11 XE, Phillips, Andover, MA) in both the longitudinal and transverse planes. Any prominent screws that were detected on fluoroscopy were measured on the printed fluoroscopic image using calipers with 0.5-mm increments. Image magnification was calculated and accounted for on each image separately by using the known length and screw pitch of the inserted screw versus apparent length and pitch on the fluoroscopic image. Any screws that were found to be prominent on US were measured using the electronic caliper of the US machine. Dorsal dissection of the distal radius was then performed, and the actual screw tip prominence was determined using a Castroviejo surgical caliper. Two observers were present for all measurements; however, single values were recorded for each image measurement and direct cadaveric measurement.

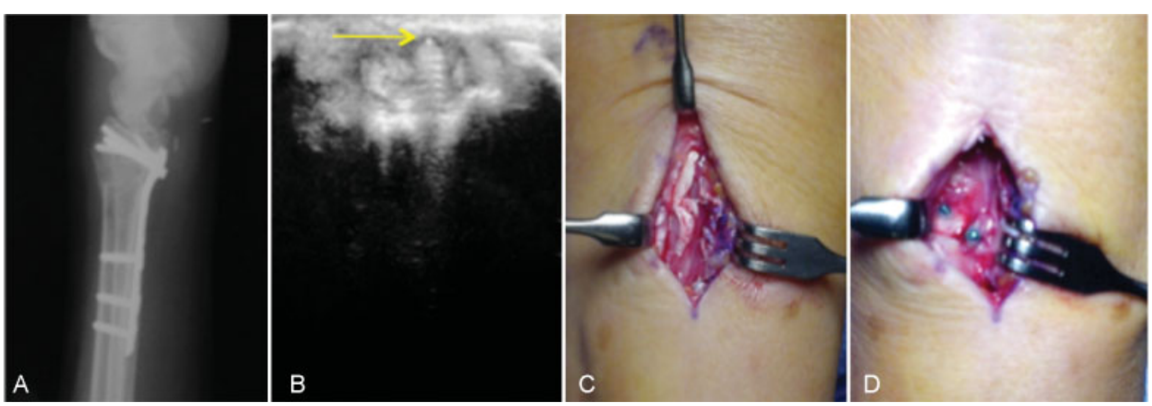

Fig. 1 (**A**) Lateral radiograph at presentation with no evidence of screw tip prominence. (**B**) Dorsal ultrasound of wrist demonstrating screw prominence; arrow identifies stair-step appearance of screw threads into fourth dorsal compartment. (**C**) Intraoperative picture of extensor digitorum communis fraying. (**D**) Prominent screw projecting into fourth dorsal compartment.

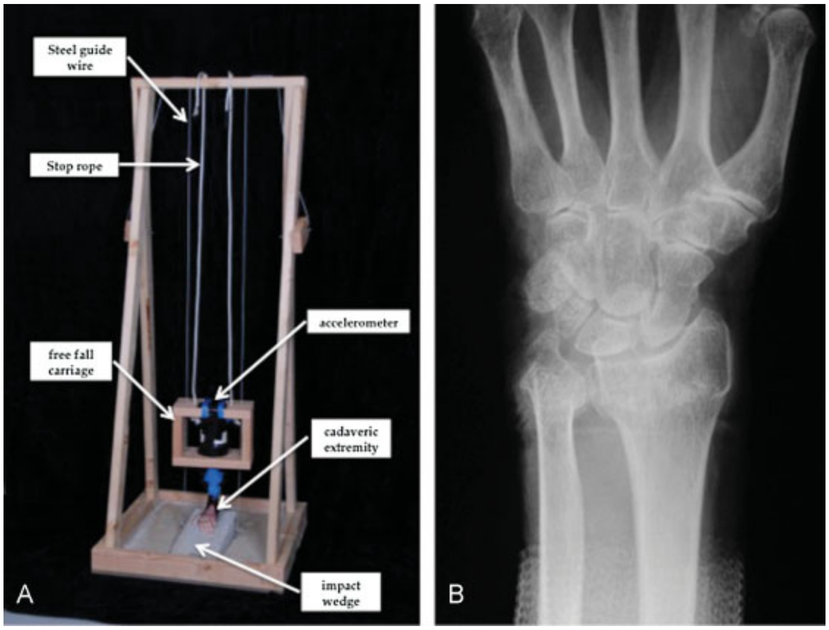

Fig. 2 (**A**) FOOSH simulator device. (**B**) Experimentally created distal radius fracture.

A small, prospective institutional review board–approved clinical study was conducted to validate the clinical usefulness of this technique. Between July 2013 and December 2013, 10 consecutive patients with distal radius fractures undergoing an open reduction and internal fixation of a distal radius fracture with a volar locking plate by a single surgeon were enrolled after written consent. Patients were not included in the study if they were younger than 18 years, had suffered prior wrist fractures, had deformities or congenital abnormalities of the wrist, had open wounds on the dorsum of the wrist, or had a concomitant wrist dislocation. The clinical subjects tended to have higher grade comminution than the cadaveric specimens. The AO classifications of the 10 study patients were 23-A3, 23-C2, 23-C2, 23-C1, 23-C2, 23-A2, 23-C3, 23-B3, 23-C2, and 23-C3. Fixed-angle distal radius locking plates were used on all patients. As in the cadaveric study, the distal screw holes were individually drilled and screw length selected using the manufacturer's depth gauge with the intention of engaging the dorsal cortex but not being prominent. The operating surgeon's practice is to use the depth gauge measurement or 1 mm shorter in the case of odd millimeter depth measurements. In addition to standard PA and lateral fluoroscopic views, the forearm was pronated and supinated under fluoroscopy to determine whether any screws appeared prominent, as is the operating surgeon's standard practice. The operating surgeon then sterilely performed US of the wrist dorsum prior to wound closure. A certified US technician was present for the first three clinical cases to assist with use of the US machine. Subsequent cases were performed without technical assistance. The operating surgeon had previously performed US for foreign bodies, masses, and suspected tendon injuries as part of his practice, but not for intraoperative decision making. The patients were not charged for the use of US. If US images demonstrated a prominent screw, the surgeon replaced the prominent screw with one that did not protrude.

Results

In the cadaveric study, US provided additional information regarding the screw tip prominence. Of the 33 distal screws inserted in the five cadaveric specimens which were imaged and then measured, 2 appeared prominent on fluoroscopy, 7 appeared prominent on US, and 11 were found to be truly prominent on dissection. Screws that were placed on both the radial and ulnar side of the plate were involved but the sample size did not allow statistical differentiation by screw hole. To statistically determine how well the two imaging modalities compared with the "gold standard" of cadaveric dissection, an interclass correlation coefficient (ICC) was calculated using a two-way mixed effect model for each technique. The calculations were performed by a biostatistician uninvolved with the data acquisition. The ICC of US to dissection was high at 0.78 ($p < 0.005$) indicating a close correlation between US imaging and actual dissection. Fluoroscopy was lower at 0.19 ($p = 0.27$). Fluoroscopic images failed to detect screws that past pointed by 1 mm or less as measured by direct dissection, whereas US had a sensitivity of 50% in detecting the screw prominence. The sensitivity of US was 100% for screws that past pointed by greater than 1 mm, whereas the sensitivity for fluoroscopy was 50% for screws that past pointed greater than 1 mm and less than and equal to 2 mm. The specificity of both US and fluoroscopy was 100% in that all screws deemed prominent on either imaging were

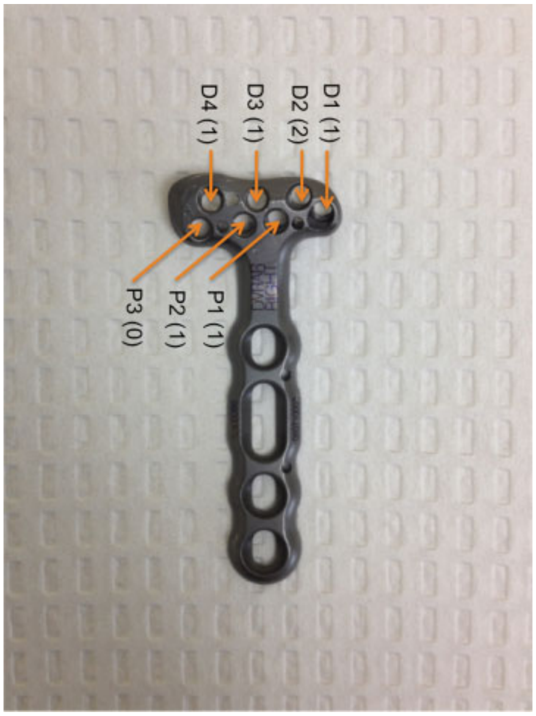

Fig. 3 Right DVR plate with labeled holes. Numbers of screws in the cadaveric specimens found prominent on US and dissection but missed by fluoroscopy are in parenthesis. In the clinical portion, prominent screws were found in P2, P3, and D4.

found to be prominent on dissection and there were no false-positive results.

Of the 68 implanted screws placed in the operating room, the use of US detected 3 prominent screws that had appeared flush or recessed on fluoroscopy despite pronating and supinating the forearm while viewing the live images. These screws measured 0.71, 1.11, and 2.17 mm above the cortex on US imaging with the tips appearing within the extensor compartments. This led the surgeon to replace the screws with ones that did not protrude. Each of the three replaced screws was from a different position in the plate (i.e., we did not identify a specific distal screw position prone to poorer visualization). The three screws were also from patients with different fracture classifications. The prominent screws came from distal drill holes D4, P2, and P3 (►**Fig. 3**) No patient developed a tendon rupture or clinical evidence of tenosynovitis postoperatively with a mean follow-up time of 8.3 months.

Discussion

The grooved dorsal contour of the distal radius along with fracture comminution may lead to unrecognized screw tip prominence when screw lengths are selected to engage the dorsal cortex. The current study uses dorsal cadaveric dissection as the "gold standard" by which fluoroscopy and US are compared. Dissections and subsequent statistical analysis demonstrated that US more closely correlated with screw prominence than fluoroscopy and was more sensitive for screws that were prominent by 1 and 2 mm (►**Fig. 4**). Although we feel that fluoroscopy remains the principle imaging technique during internal fixation, this study helps define an additional role that US might play in select cases of comminution where the surgeon intends to lag or engage the dorsal cortex or is concerned about screw tip prominence at the conclusion of the case.

Several authors have previously investigated the limitations of relying on fluoroscopy to check screw length.[5,8,11,14] Sügün et al[12] found that one-quarter of the screws they examined in patients treated with volar plates protruded from the dorsal cortical surface by 0.5 mm or more at patient follow-up when imaged by US. Their work showed that screw tip prominence of over 1.8 mm in the third and over 2 mm in the fourth extensor compartment was associated with both symptomatic and asymptomatic tenosynovitis at a mean

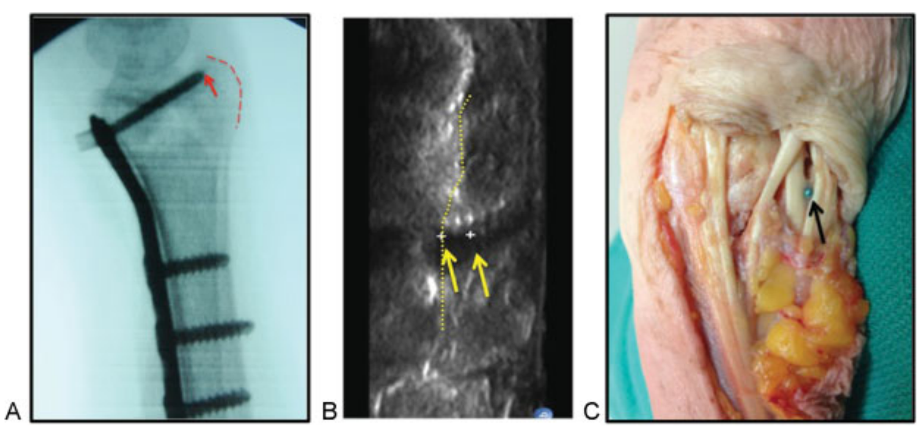

Fig. 4 (**A**) Lateral fluoroscopic image with red arrow at tip of screw and dashed line showing dorsal cortex. Screw tip appears safely within bone and below the cortex. (**B**) Ultrasound image of same wrist showing the bright stair-step echogenic reflection of the screw protruding into soft tissue. Ultrasound measurement (yellow arrows) demonstrated 1.62-mm prominence (right arrow points to tip of screw, dotted yellow line is best estimation of dorsal cortex by ultrasound). (**C**) Actual dissection showing tip of screw (black arrow). Screw protrudes into the extensor carpi radialis longus and brevis tendons 2.1 mm.

follow-up of 18 months. The clinical portion of our current study found a much lower rate of screw prominence (4%) compared with Sügün et al when using the manufacturer-supplied depth gauge to select screw length. Differences between Sügün et al's work and the current study may relate to differences in instrumentation sets or surgical technique. The operative surgeon's preference in our series is to always "round down" to the shorter screw length when the intra-operative depth gauge reading is between two of the set's lengths with increment by 2 mm. In the clinical portion, the surgeon also examined the wrist under fluoroscopy by "rolling" the wrist from pronation to supination to obtain a greater number of views of the dorsal wrist, replacing long screws and thus decreasing the screw prominence rate. In a similar light, Ozer et al[16] and Dolce et al[17] found that additional fluoroscopic views improve screw tip detection in cortically intact radiuses. Our current study demonstrates the incremental benefit of US in a cadaveric model that involves fracturing the radius before plate application.

Arora et al[5] recommend selecting screws 2 mm shorter than the measured length to prevent prominent screws in patients whose fractures can be securely fixated without engaging the dorsal cortex. In such cases, additional imaging would not be necessary based upon our data. It is also possible to use smooth pegs rather than screws to avoid sharp threads near the extensor tendons or to use screws that have a smooth tip.

The time required to learn US identification of screw tips was minimal and at the series end took no more than a few minutes of operating time for a surgeon who was experienced in the use of musculoskeletal US. The ultrasonographic signature of a prominent screw is readily recognized by the stair-step horizontal reflections from the screw threads (►**Fig. 1B**). This is also a clinically relevant point in that these horizontal US signals represent the sharp edges of the screw threads that may also cause tendon harm. Lister tubercle and the distal radioulnar joint provide easily recognized ultrasonographic landmarks. In selecting the specific US equipment to be used in this study, the authors found that lower frequency and lower resolution equipment sometimes available in a hospital for vascular access or determination of bladder distention does not provide sufficient image resolution. A moderately priced US machine and 12-MHz probe allowed for adequate visualization (after market price $15,000 to $22,000 USD).

A limitation of the study was that the operating surgeon was also the surgeon performing the fluoroscopy and US. Additionally, there were no intraobserver measurements during either the cadaver study or the clinical study. In addition, the screw prominence was not verified by surgical dissection at the time of fixation and hence there was neither verification of nor control for the accuracy of the US measurements. To reduce screw selection bias, the surgeon always selected a screw that was equal to the depth gauge measurement or 1 mm less when between two screw lengths in the set. An additional limitation in the cadaveric portion of the study was that the arms were only imaged in anteroposterior and lateral views, which would have limited the detection of protruding screw tips. To address this limitation, the clinical subjects' wrists were additionally imaged during rotation to see if additional views better detected prominent screws. Another limitation to the study was that the authors did not utilize the dorsal horizon view to detect prominent screws.[18] If this view had been utilized, more prominent screws may have been detected on fluoroscopy. Although the data demonstrated a significant difference in the two imaging modalities, the sample sizes of screws placed in the cadaveric and clinical series, 33 and 68, respectively, were small.

A technical challenge during the clinical trial was that in the three patients found to have prominent screws, we encountered difficulty identifying the specific screw in the volar plate to be replaced. In one patient, the surgeon needed to back out two screws before correctly identifying the prominent one for replacement. Sequential US after each screw could eliminate this problem. However, backing screws out a few turns while US imaging at the end of inserting all screws was a straightforward means to identify the prominent one.

Based upon the results of this study, US may be a useful adjunct to fluoroscopy at the conclusion of volar plating for comminuted distal radius fractures when threaded screws are used to engage the dorsal cortex and to rule out past pointing.

Conflict of Interest
None.

Acknowledgments
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