An Original Study

Accuracy of Detecting Screw Penetration of the Radiocarpal Joint Following Volar Plating Using Plain Radiographs Versus Computed Tomography

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Abstract

We compared standard and specialized plain radiographs with computed tomography (CT) for their ability to detect screw penetration of the articular surface of the distal radius in volar plating.

Eight human cadaveric specimens were implanted with a fixed angle volar plate and 5 screws. Two groups were evaluated: (1) no articular screw penetration or (2) intra-articular screw penetration. Radiographs were obtained of each specimen. CT using 0.4 mm thickness slices were obtained and images were reconstructed in the sagittal and coronal planes. The radiographs and CTs were evaluated based on whether or not articular penetration occurred. The sensitivity, specificity, and accuracy of each radiographic modality were evaluated. CT was found to be much more sensitive and specific in detecting screw penetration than plain radiographs. The kappa (κ) statistic demonstrated "almost perfect interobserver agreement" based on CT readings, but only "substantial interobserver agreement based on plain radiographs."

CT is more sensitive and specific and achieves a higher κ statistic than plain radiographs in detecting radiocarpal screw penetration after volar plating. CT should be used in detecting screw penetration when there is suspicion for radiocarpal joint penetration.

Distal radius fractures are the most common upper extremity injury and represent one-sixth of all fractures seen in the emergency department.[1] Some studies have reported that 1-2 mm is the maximum residual articular step-off consistent with a good clinical outcome.[2] Over the last 5 years, there has been a shift in operative treatment of distal radius fractures from external fixation towards internal fixation, particularly with the use of volar plating.[3] Many of these fractures involve the articular surface and have a high degree of comminution and osteopenia. Adequate fixation may require the plate and screws to be placed in close proximity to the radiocarpal joint, often in subchondral bone. Given the biconcave nature of the articular surface of the distal radius, along with its biplanar slopes, radiologists and orthopedic surgeons often have difficulty assessing the radiocarpal joint after implant placement postoperatively.

Previous studies evaluating dorsal plating have demonstrated anatomic tilt x-rays to be more accurate than standard x-rays in determining screw penetration.[4,5] Although computed tomography (CT) has been found to be useful in determining articular screw penetration in other joints such as the acetabulum,[6] they have also been shown to be cost-prohibitive in evaluation of the majority of distal radius fractures.[7,8]

The purpose of this study was to evaluate the accuracy of plain radiographs, both standard and specialized views, and CT in demonstrating penetration by screws utilized in a plate and screw fixation model.

Materials and Methods

Eight cadaver wrists were used in this experiment. Radiographs were taken of each wrist specimen prior to instrumentation to ensure there were no bone abnormalities or defects present. The distal radius was approached through a modified volar Henry approach and a locking, precontoured, volar wrist plate (Hand Innovations, Warsaw, Indiana) was applied. In order to direct screws to specific locations, we elected to use non-locking screws (Hand Innovations) through the plate. Each specimen had 5 screws placed within 7 possible screw holes. Screw placement and penetration varied by cadaver and was randomly assigned. Screw penetration was verified following implantation under direct visualization with a volar wrist arthrotomy. Overlaying tissues were approximated prior to obtaining plain radiographs and CT. Standard posterior-ante-

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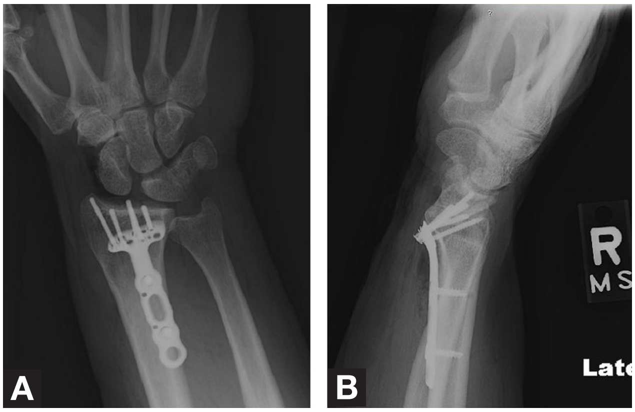

Figure 1. Standard posterior-anterior (A) and standard lateral (B) views of a right wrist demonstrating intra-articular penetration of the distal second screw.

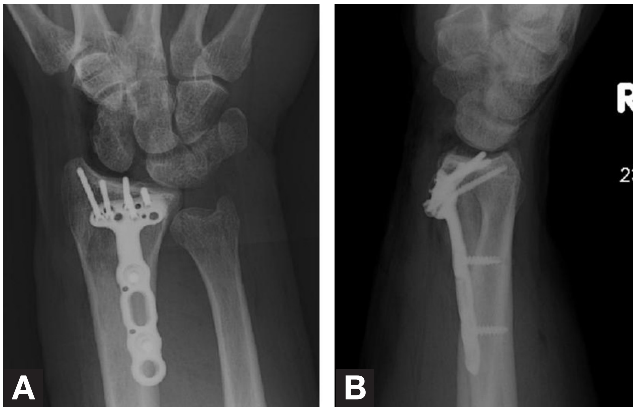

Figure 2. Anatomic tilt radiographs. Ten degree tilt posterior-anterior radiograph (A) and a 23° tilt lateral radiograph (B) demonstrating intra-articular screw penetration of the middle distal screw.

rior, anterior-posterior, oblique, and lateral radiographs were taken of each specimen (Figure 1). In addition to standard wrist views, an 11° angled posterior-anterior,[4] a 45° pronated oblique,[5] and 23° angled lateral radiograph[4] (anatomic tilt radiographs) were performed (Figure 2). A standardized system was developed for radiographic evaluation. For all radiographs, angled blocks were constructed and the axis of the forearm was measured with a precisely calibrated goniometer prior to each radiograph to maintain accurate rotation and tilt. All radiographs were taken by the same technologist and supervised by the same investigator (LR). CTs were performed on a 64-slice scanner, Somatom Definition Dual Source 64 Slice CT Scanner (Siemens, Erlangen, Germany) (Figure 3). Sagittal, coronal, and axial reconstructions with a slice thickness of 2 mm with 0 mm gap intervals were then created in a bone algorithm utilizing a Syngo CT Workplace Station workstation (Siemens). The images were downloaded on a compact disc and transferred to a standard computer workstation utilizing a high-resolution LCD monitor. All initial interpretations were made at this workstation.

Twelve blinded observers consisting of 8 orthopedic surgeons (ie, 5 senior residents, 3 board certified attending physicians) and 4 radiologists (ie, 2 musculoskeletal radiology fellows, 2 board certified attending physicians) made several determinations based on each set of radiographs, including standard and anatomic views, as well as CT. Three sets of images were evaluated for the following conditions: no articular screw penetration or intra-articular screw penetration. These images were each assessed based on location of the penetrating screw (ie, proximal ulnar, proximal middle, proximal radial, distal ulnar, distal middle, distal radial, or the radial styloid screw), as well as a confidence rating of the observer certainty for each assessment, based on a 10-point scale from 1 (not certain) to 10 (extremely certain). Radiographs and CTs were presented in random order to each observer.

The data was analyzed for accuracy, sensitivity, and specificity for radiographs and CT in determining the presence of screw penetration and the location of screw penetration. Interobserver reliability was determined based on a Kappa (κ) statistic. Sensitivity refers to the ability of a test to detect disease when it is present. Specificity is the ability of a test to detect the absence of disease when it is not present. For the purpose of this study, sensitivity refers to the proportion of cadaver wrists with screw penetration accurately identified by the observers; specificity is the proportion of those without penetration correctly identified. Accuracy is a summary measure of the

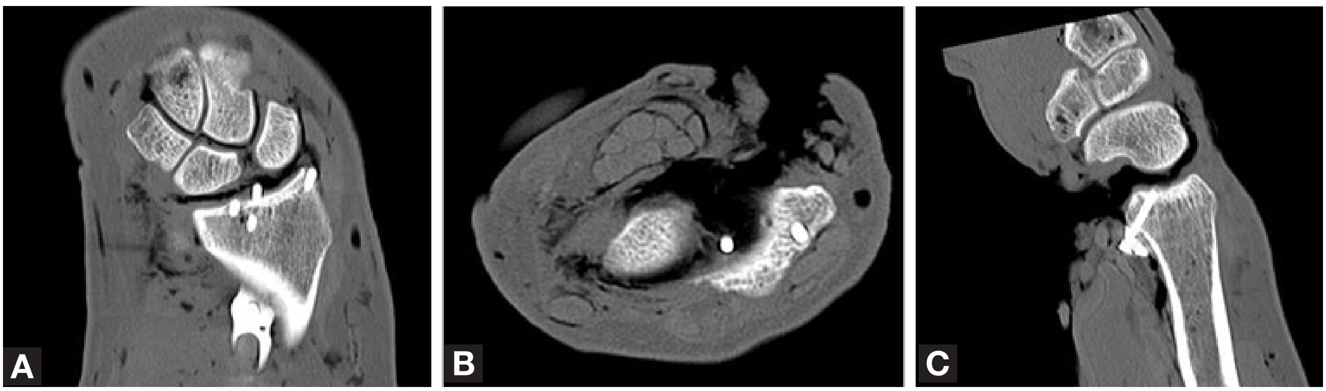

Figure 3. Computed tomography in coronal (A), sagittal (B), and axial (C) planes demonstrating screw penetration.

Table I. Detection of Articular Screw Penetration

	Sensitivity	Specificity	Accuracy
Radiographs	84.5%	91.7%	85.4%
Computed Tomography	95.2%	100%	95.8%

Table II. Detection of Location of Screw Penetration

	Sensitivity	Specificity	Accuracy
Radiographs	65.4%	93.5%	84.4%
Computed Tomography	85.3%	90.4%	88.8%

diagnostic correctness, consisting of both the positive and negative tests that were correctly interpreted. Interobserver reliability was assessed using κ statistic, which measures agreement between multiple observers, comparing actual agreement to the agreement that would be expected due to chance. Comparisons of the confidence of the observers in their determinations of the presence and location of screws by each radiograph and CT view were assessed. Statistical calculations were performed using STATA v.10. (Stata Corporation, College Station, Texas)

Results

Accuracy, sensitivity, and specificity for detection of screw penetration using radiographs are presented in Table I. Results using CT are in Table II. Table III summarizes the interobserver reliability in detecting the presence and location of screw penetration. There was approximately 10% difference in the sensitivity of CT, compared with plain radiographs in determining intra-articular screw penetration. There was also a 10% difference in specificity or accuracy of articular screw penetration between radiographs and CT. As shown in Table I, the sensitivity and specificity of CT is significantly greater than the sensitivity and specificity of plain radiographs, including anatomic views. This effect was large and statistically significant. CT also demonstrated "almost perfect interobserver agreement" based on the κ statistic, indicating, that amongst our readers, most were likely to agree on screw penetration based on the CT readings.

As shown in Table II, CT was also more accurate, sensitive, and specific for determining the location of the specific screw, which penetrated the articular surface, compared with plain radiographs. Table IV demonstrates the observer confidence in assessment of each radiographic view. Observer confidence was higher in the anatomic views, compared with the standard views and particularly in the anatomic tilt lateral compared to the standard lateral radiograph. CTs in the coronal and sagittal planes demonstrated higher observer confidence in determining screw penetration, compared with CT in the axial plane.

Table IV. Observer Confidence in Assessment of Articular Penetration

Radiographic View	Articular Penetration
Radiographs	
PA Standard	7.8
AP Standard	7.3
PA Anatomic Tilt	8.7
Oblique Standard	5.4
45° Oblique Pronated	6.3
Lateral Standard	3.6
Lateral Anatomic Tilt	8.0
Standard Views	6.0
Anatomic Tilt Views	7.6
Computed Tomography	
Axial	4.1
Coronal	9.0
Sagittal	8.6

Discussion

Our results demonstrated that CT is more sensitive, specific, and accurate in the detection of articular screw penetration, compared with radiographs. The κ statistic demonstrated "almost perfect agreement" amongst observers, confirming that most readers agree on screw penetration based on the CT findings.

Both CT and radiographs had higher specificity than sensitivity in identifying the particular position of the screw that was violating the joint space. This, however, is not as clinically significant as determining if there was in fact penetration of the joint because revision of the screws requires an open re-operation and the violating screw can be reconfirmed intraoperatively.

Internal fixation of distal radius fractures with volar plating is relatively common and familiar to most orthopedic surgeons in practice. We felt this technique would provide an optimal model to assess screw penetration detection techniques in addition to providing clinically useful information. Visualization of the screw placement is often difficult on standard posterior-anterior and lateral radiographs. Anatomic tilt radiographs have

Table III. Interobserver Agreement (Reliability) for Assessment of Articular Penetration

	κ	z	Prob>z	κ interpretation
Radiographs	0.7168	16.52	0.00000	substantial agreement
Computed Tomography	0.8389	19.28	0.00000	almost perfect agreement

been advocated and shown to improve accuracy in determining radiocarpal joint penetration in dorsally plated wrists.[4] Although other studies suggest that CT visualizes the articular joint surface better than radiographs,[6-8] an investigation comparing the efficacy of standard and anatomic radiographs with CT in evaluation of volar wrist plating of the distal radius has not been performed to date.

Several investigators have performed studies in which angled radiographs were used to determine articular fracture displacement after experimentally created fractures.[9,10] Johnson and Szabo[9] performed a cadaveric study in which they recommended 15° angled lateral radial to ulnar radiograph to be used to assess the distal radial angulation. In 2004, Boyer and colleagues[4] and Smith and Henry[5] recognized the potential usefulness of these radiographs and determined the accuracy, sensitivity, and specificity of these anatomic tilt radiographs in determining intra-articular screw penetration compared to the standard radiographs in dorsal wrist plating. However, since then, volar plating for the treatment of distal radius fractures has gained popularity and is now a more commonly employed treatment than dorsal plating.[3]

Our study differs from the aforementioned studies in that we have taken into account all radiographs, including standard and anatomic tilt views, and compared them to CT in volar wrist plating. The anatomic tilt views were developed to better assess the articular surface of the distal radius and have been shown to improve accuracy in determining radiocarpal joint violation. However, anatomic tilt views are rarely ordered by themselves. These studies are often ordered in combination with standard views postoperatively to assess the radiocarpal joint. For this reason, we attempted to simulate the clinical postoperative scenario where screws placed in subchondral bone are suspected of violating the articular surface. We allowed the readers to view all radiographs, both standard and anatomic tilt views together, as they would do so in a clinical setting under these circumstances. Standard 0.4 mm-thickness slice CT was performed as they are often done when there remains suspicion of articular penetration.

Although our sensitivity and specificity of radiographs are consistent with the numbers in the literature, one of the limitations of this study was that we asked our readers to evaluate sets of CT reconstructions at predetermined slice thickness. Radiologists at workstations with multiplanar reformatting capabilities would be able to reformat at any angle and slice thickness desired. This may increase the specificity of CT.

Other limitations of this study include that the angles (ie, 11° palmar tilt and the 23° radial inclination) used to obtain anatomic tilt are mean values based on the population average and do not represent the true value of every patient. Our study does not account for anatomic variances such as differences in size, angle measurements, and articular cartilage height. Accuracy would probably improve if the precise anatomic tilt were obtained by measuring the radioulnar slope on every cadaver. However, this is neither clinically useful nor applicable.

This study was performed in fresh frozen cadavers, which does not account for the altered articular surface found with the presence of an intra-articular fracture. However, the goal of the study was to simulate the postoperative evaluation of penetrated hardware in the distal radius, which ideally should be restored to its original anatomy.

Conclusion

Radiographs and CTs were equally accurate in the evaluation of the presence of screw penetration of the distal radial articular surface. CT is more sensitive than plain radiographs in detecting intra-articular screw penetration, as well as the location of the screw penetration. It is also more specific than plain radiographs in determining radiocarpal penetration. This study demonstrates that CT is a preferential radiographic modality in evaluating radiocarpal joint penetration. We recommend CT to determine articular cartilage penetration following distal radius fracture fixation when there is suspicion of joint violation.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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This paper will be judged for the Resident Writer's Award.