Radiographic Evaluation of the Distal Radius Using Two Novel Biplanar “Pitch-and-Roll” Views: A Preliminary Cadaveric Study

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Abstract This study’s objective was to compare the use of two biplanar angled radiographs versus standard posterior-anterior (PA) and lateral radiographs in determining preservation of the articular space with regard to pin placement in the distal radius. Various combinations of inclination (pitch) and clockwise/counterclockwise rotation (roll) were used to determine the best view of the distal radius articular surface. Optimum visualization of the articular surface presented at 12° inclination plus 15° counterclockwise rotation for the PA view and 22° inclination and 15° counterclockwise rotation for the lateral view. Ten cadaveric forearms were dissected, and ten Kirschner wires (K-wires) were placed at specific surfaces of the distal radius. Each K-wire was countersunk 2 mm below the chondral surface so all K-wires resided within the subchondral bone. Each forearm was radiographed in four views; PA, lateral, pitch-and-roll PA (PR-PA), and pitch-and-roll lateral (PR-lateral). Four blinded reviewers evaluated the radiographs and marked whether they were certain, relatively certain, or uncertain that the K-wires did not penetrate into the articular space. Reviewers demonstrated significantly less uncertainty about intraarticular penetration ($p < 0.005$) with both the PR-PA and PR-lateral views compared with standard PA and lateral views. The biconcave nature of the distal radius makes it extremely difficult to visualize placement of hardware with respect to the articular surface using standard radiographs. The use of PR-PA and PR-lateral views significantly improves the surgeon’s ability to judge the position of hardware in the

distal radius compared to standard radiographic views, thus allowing for more meaningful clinical decision in post-operative radiographs.

Keywords Distal radius · Articular surface · Radiographic view

Introduction

Distal radius fractures are common injuries and generate a high number of Emergency Department calls and consults to the orthopedist. Over the last several years, improved methods of fixation and better understanding of the acceptable anatomical alignment following reduction of these fractures have led to increased opportunities for surgical fixation of the distal radius. With only a maximal 1–2 mm articular step-off allowable for good clinical outcomes with non-operative management, a high percentage of distal radius fractures must be considered for operative treatment [2]. In addition, due to the prevalence of comminution and the often osteopenic bone associated with these fractures, optimal surgical fixation requires distal screw placement into the subchondral bone [5, 9]. Good clinical outcomes following surgery depend on getting an anatomical reduction and restoring the articular surface of the distal radius [4]. Therefore, it is vital to have a reliable method to be able to effectively evaluate the extent of the reduction and the anatomical position of distal fragments and hardware components when treating these injuries.

The anatomy of the distal radius adds to the difficulty of treating these fractures. The distal radius articular surface is both biconcave, with consideration of the radioscaphoid and radiolunate fossae, as well as biplanar due to the radial inclination and volar tilt with mean radial inclination of 22–

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24° (range 19–29°) and mean volar tilt of 11–14° (range 3–15°) [7, 11]. Because of the combined biconcave and biplanar surface of the distal radius, standard AP and lateral two-dimensional radiographs do not provide optimal visualization of the articular surface and hence do not allow accurate evaluation of distal hardware position. Previously described “sloped views” have attempted to improve radiographic evaluation of the distal radius surface but still fail to address both the biplanar and biconcave anatomy simultaneously [6, 8]. The purpose of this preliminary study was to first determine which combinations of inclination and rotation optimized radiographic visualization of the distal radius joint surface and then to compare two novel, biplanar angled radiographs versus standard PA and lateral radiographs to determine preservation of the articular surface with regard to Kirschner wire (K-wire) placement in the distal radius. This information will then be used in the development of a clinical study evaluating these optimal views in post-operative distal radius fracture patients.

Materials and Methods

An initial pilot study was conducted to determine optimal combinations of inclination (pitch) and rotation (roll) for radiographic evaluation of the distal radius. Radiographs were taken using a Sybron/Liebel-Flarsheim Hydradjust Urological Table. To standardize radiographs, a radiolucent Plexiglas platform was constructed for forearm placement with a slot underneath to hold an X-ray plate. The platform was attached to the X-ray table with a bracket that allowed for positioning of the platform freely in three planes. Two digital electrogoniometers (Penny and Giles, Long Beach, CA, USA) were attached to the platform in two planes, allowing for accurate recordings of the pitch and roll of the platform with regard to the fixed X-ray beam.

Initially, five fresh adult cadaveric forearms were attached to the platform and evaluated radiographically at different combinations of pitch and roll for both PA and lateral forearm positioning. Rotation in the direction of pronation was denoted by a negative value, whereas rotation in the direction of supination was given a positive value. Each forearm was then radiographed with various combinations of inclination and rotation. PA views were obtained at 0°, 6°, 12°, and 18° of inclination combined with –45°, –30°, –15°, 0°, 15°, 30°, and 45° roll. Lateral views of 0°, 11°, 22°, and 33° were captured combined with rolls of –45°, –30°, –15°, 0°, 15°, 30°, and 45°. Each radiograph was evaluated for visualization of the distal radius articular surface. Next, ten smooth K-wires were placed at specific locations (Fig. 1) from proximal to distal into the subchondral bone of each distal radius, and the entire radiographic series mentioned

Figure 1 Sketch depicting ten specific locations of the distal radius surface in which K-wires were placed.

above was repeated. The films were subsequently blinded and reviewed with regard to visualization of the anatomy of the distal radius and the apparent placement of the K-wires with regard to the articular space. After the authors reviewed all films, it was determined that optimal visualization of the articular surface occurred at 12° pitch with 15° roll for the PA view (Fig. 2a) and 22° pitch with –15° roll for the lateral view (Fig. 2b).

Once the ideal combination for pitch and roll had been determined for both the PA and lateral views, ten fresh cadaveric forearms (six male, four female; age range 55–95; average age 80) were used. The cadavers used reflected an osteopenic population in which a high percentage of distal radius fractures are typically seen. The forearms were dissected and disarticulated at the wrist joint, allowing for excellent visualization of the articular surface of the distal radius. Next, a series of ten smooth K-wires were placed at ten specific locations (Fig. 1) in the distal radius articular surface in a retrograde fashion.

Each K-wire was countersunk 2 mm below the chondral surface using a 2 mm countersink so that all K-wires resided within the subchondral bone. Each forearm was then X-rayed in four views: standard PA (Fig. 3a), pitch-and-roll PA (PR-PA; Fig. 3b), standard lateral (Fig. 3c), and pitch-and-roll lateral (PR-lat; Fig. 3d). Each film was then randomly assigned a number from 1 to 40 prior to review. Next, four blinded reviews consisting of one board certified orthopedic hand surgeon, one board certified orthopedic surgeon, one fifth year orthopedic resident, and one third year orthopedic resident were asked to review each of the 40 films. For each film, the reviewers were asked to indicate whether they were certain, relatively certain, or uncertain that the K-wires did not penetrate the joint space. These values were then analyzed statistically using a logistic fit of Uncertainty (with Uncertainty measured as certain=1, relatively certain=2, and uncertain=3). Agreement between reviewers was analyzed with Contingency

Figure 2 Radiolucent platform with digital angle measuring devices. **a** PR-PA view with 12° pitch and 15° pronation. **b** PR-lateral view with 22° pitch and 15° pronation.

Chi-square, followed by the computation of Kappa Coefficients. Significance was set at $p < 0.05$.

Results

There were no statistical differences among specimens, indicating the film quality was relatively uniform, and there was no significant Reviewer by Specimen interaction, indicating that reviewers tended to agree on the quality of each film. However, there were significant differences among reviewers ($p < 0.0001$). Using kappa coefficients, there was significant intraobserver reliability between the two board certified orthopedic surgeons ($p < 0.0001$), but no significant agreement or disagreement was found with the orthopedic resident reviewers.

Additionally, reviewers demonstrated significantly less uncertainty with regard to intraarticular penetration of K-wires ($p < 0.005$) with both the PR-PA and PR-lat views (mean 2.48 and 2.45, respectively) compared with standard PA and lateral views (mean 2.6 and 2.83, respectively). This finding indicated that reviewers were more likely to accurately determine preservation of the articular space with regard to hardware placement in the distal radius with the new “pitch-and-roll” technique.

Discussion

The biconcave nature of the distal radius articular surface combined with its biplanar slopes makes radiographic evaluation using standard two-dimensional radiographs

Figure 3 Radiographs depicting standard PA view (**a**) versus PR-PA view (**b**), as well as standard lateral view (**c**) versus PR-lat view (**d**).

very difficult when determining the position of hardware placed near the joint space. CT scans have proven to be cost-prohibitive for the majority of these fractures [3, 10]. Multiple authors in the past have suggested various methods and radiographic views in order to address this complex problem, yet none have been able to clinically improve radiographic evaluation with both the PA and lateral views, particularly with the increased popularity of volar plate fixation. Boyer et al. described an anatomic tilt lateral view of 11° that did help improve observer accuracy in diagnosing articular screw placement using dorsal plating, but failed to improve accuracy of the same with their anatomic tilt AP view [1]. Again, this study dealt with dorsal plating where distal screws are directed more horizontally to the articular surface. With increased use of variable angled volar plates where distal screws are directed distally and more vertically to the articular surface, the chance of a distal screw tip violating the joint space and going unrecognized with standard views is increased. In addition to a slope view, Smith et al. described an intraoperative 45° pronated oblique view with volar fixed angled plating as an additional view capable of accurately determining positioning of distal hardware in the subchondral bone [12]. However, this requires an increased number of radiographic views and may be difficult to reproduce intraoperatively. While appropriate intraoperative radiographs are vital to proper hardware positioning and successful clinical outcomes, initial post-operative follow-up radiographs are equally important in assisting with the remainder of the treatment course. Many distal radius fractures occur in osteopenic bone, frequently with significant comminution; thus, there is a real possibility of subsidence of the fracture fragments. Therefore, positioning of the distal hardware observed at the patient's first post-operative visit may not be the same as that observed intraoperatively, although it is equally, if not more, important.

In our series, we set out to determine two radiographic views that could be used post-operatively to replace our standard post-operative PA and lateral views. Previous work by Zanetti et al. demonstrated that palmar tilt decreased with pronation on a lateral view X-ray [13]. Combining this finding with descriptions of anatomic tilt or sloped views, we decided to determine which combination of inclination, (pitch) paired with pronation/supination (roll) could help give us consistently better visualization of the distal radius articular surface for post-operative radiographic evaluation. Using a model we created to simulate distal hardware placed into the subchondral bone of the distal radius, we were able demonstrate significantly less uncertainty of hardware penetration into the joint space when compared with standard PA and lateral views using four reviewers blinded to X-ray technique. Both the PR-PA

and PR-lat views significantly improved the surgeon's ability to judge the position of hardware in the distal radius when compared with the standard views in this model. Additionally, we found that there was significant intra-observer reliability between the two board certified orthopedic surgeons, but no significant agreement or disagreement was found with the orthopedic residents. This indicates that radiographic evaluation of the distal radius is a learnable skill that requires practice and experience before one is consistently able to see what more experienced reviewers see in a film.

There are some limitations inherent with this study. First, our pitch-and-roll views are based on review of ten cadaveric distal radii and do not account for anatomical variance such as differences in size, angle measurements, and articular cartilage height. While our sample size was found to be large enough statistically to give us a value representative of population averages, it may not account for differences on an individual patient level, particularly if the patient has anatomical variables that fall outside of the normal ranges for population averages. In these cases, the surgeon would need to assess whether the anatomic variances would exclude use of the pitch-and-roll views. Secondly, this study was conducted using intact fresh cadaver distal radius specimens. Certainly, one would expect the distal radius surface to be altered with the presence of intraarticular fractures, but this study attempts to simulate post-operative evaluation of distal hardware placement, in which, ideally, the distal radius surface would be restored to its near anatomic, pre-fracture state. For this study, we attempted to enlist reviewers with a wide range of experience and training. However, all of our reviewers were a part of the same orthopedic residency training program and may not be representative of all surgeons that operate on distal radius fractures. Finally, this study was based on a cadaveric model to simulate post-operative radiographic evaluation of distal hardware placed into the subchondral bone of the distal radius. The equipment available for this study limited our ability to take radiographs with varying angles; therefore, we had to construct the platform apparatus for this study. In this preliminary study, the platform apparatus was used to determine the most beneficial angle measurements for evaluation of the distal radius in cadaver specimens. For reproducibility of the PR-PA and PR-lat views for use in our post-operative clinics, we are currently instituting the use of positioning guides to assist with obtaining accurate radiographic views in all patients treated with volar plate fixation.

In conclusion, both the PR-PA view (12° pitch/ 15° pronation) and the PR-lateral view (22° pitch/ 15° pronation) significantly improve the surgeon's ability to judge hardware position in the distal radius, when compared to standard PA and lateral views. This may allow for improved

clinical decisions to guide post-operative care of surgically treated distal radius fractures. Additionally of note, accurate radiographic evaluation of the biconcave and biplanar anatomy of the distal radius is a skill that requires practice and experience for consistency.

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