Essential Radiographic Evaluation for Distal Radius Fractures

Robert J. Medoff, MD

Department of Orthopaedic Surgery, University of Hawaii, 30 Aulike Street #506, Kailua, HI 96734, USA

Because the interpretation of the radiographs of distal radius fractures has such a profound impact on care of these injuries, accurate assessment of standard radiographs is essential for appropriate management [1,2]. Radiographs are a two-dimensional representation of a three-dimensional structure. Subtle changes in radiographic landmarks can provide significant information that can be used to understand the pattern of fragmentation and extent of the injury. Unfortunately much of this information often goes unnoticed simply because the physician is not trained to recognize it. Although computed axial tomography and MRI can provide more detailed imaging of the fracture pattern, the extra expense and delay in treatment from obtaining a CT scan at the time of a reduction are often practical limitations limiting its routine use [3–8]. By recognizing detailed features on standard radiographic images and identifying abnormal variation of certain key parameters, the surgeon can create a more accurate visual image of the actual osseous deformity, resulting in a more informed and rational approach to treatment [9]. The purpose of this article is to provide specific guidelines for improved interpretation of radiographs in patients with distal radius fractures.

Normal radiographic landmarks

Radiographic evaluation of the distal radius normally includes a posteroanterior (PA) and lateral projection. Oblique radiographs often are included as a supplemental view. As is discussed subsequently, a modified lateral projection in which the beam is angled 10° proximally should be a standard view to assess fracture reduction and to provide more detailed visualization of the articular surface.

On the PA projection, several basic anatomic structures are identified easily (Fig. 1). The radial styloid is seen in profile; the articular surface of the distal radius, proximal and distal carpal rows, distal radioulnar joint, and distal ulna also are recognized easily. The articular surface of the distal radius makes a smooth, concentric arc with the proximal articular surface of the proximal carpal row. In addition, the arcs of the articular surfaces on both sides of the midcarpal joint are congruent and concentrically aligned.

On the PA projection, a transverse, radiodense line can be seen approximately 3–5 mm proximal to the distal border of the radius, and it is aligned with the base of the lunate and proximal pole of the scaphoid. This feature has been nicknamed the carpal facet horizon. In the normal radius, the carpal facet horizon is caused by the projection of the subcortical bone of the volar rim of the lunate facet (Fig. 2A). This structure is normally proximal to the distal margin of the radius, because the normal volar tilt of the articular surface of the distal radius places the volar rim more proximally than the dorsal rim. Its projection on the radiograph is radiodense, because the subcortical bone of the volar rim of the lunate facet is aligned parallel to the radiographic beam.

The relationship of the articular surface of the distal radius is reversed in a fracture or malunion in which there is dorsal angulation of the distal fragment. In this circumstance, the dorsal rim of the lunate facet migrates proximally and rotates dorsally in relation to the volar rim. As a result the subchondral bone of the dorsal rim becomes oriented parallel to the radiographic beam and
creates the carpal facet horizon on the PA view (Fig. 2B). Because this single landmark can represent two different anatomic structures of the osseous geometry, it is essential to always correlate the PA view with the lateral view for evaluating displacements of the articular surface and for determining whether an implant is positioned properly.

This relationship also provides a method to distinguish the dorsal and volar corners of the sigmoid notch on a PA film. This is often critical in determining whether a displaced fragment should be approached from the volar or the dorsal side. In addition, if the interval between the dorsal or volar corners of the ulnar border of the radius is widened in relation to the head of the ulna, it may suggest a displaced distal radioulnar joint. Because widening of the distal radioulnar joint removes the osseous stability from seating of the ulnar head in the sigmoid notch, this finding may be a contributing source of distal radioulnar joint (DRUJ) instability.

The lateral projection is an integral part of a complete examination. Despite this, distortion of the image may occur if the arm is not positioned properly. Often a radiograph technician positions the arm for a lateral film in an extreme position of supination or pronation of the forearm; in this circumstance, simply superimposing the radius and ulna may result in an oblique projection of the articular surface. A simple solution to this problem is to use the relative position of the pisiform to the distal pole of the scaphoid as the reference for judging the quality of the lateral projection. On a true lateral projection of the distal radius, the
pisiform should overlap the distal pole of the scaphoid. If the pisiform is significantly dorsal to the distal pole of the scaphoid, the forearm is positioned in relative pronation; if the pisiform is volar to the distal pole of the scaphoid, the forearm is positioned in relative supination (Fig. 3A,B).

In a standard lateral projection, the radiograph beam is oriented perpendicular to the long axis of the radial shaft. Because the radial inclination of the ulnar two thirds of the articular surface is 10° to the long axis of the shaft, this results in an oblique projection of the joint surface on the standard lateral view. The 10° lateral projection positions the articular surface in profile, allowing direct visualization of any offset in the sagittal plane and accurate identification of the apical ridges of the dorsal and volar rims. This projection is performed simply by elevating the distal forearm 10° from horizontal or by aligning the beam 10° proximally (Fig. 4A,B).

The radial styloid is visualized on the lateral projection as a V-shaped outline superimposed over the lunate with a base extending from the dorsal and palmar margins of the distal radius. Identification of the radial styloid on the lateral view is important to ensure appropriate placement of trans-styloid K-wires or a radial column plate (see Fig. 3A).

The articular surface of the distal radius normally forms a smooth, unbroken arc on the lateral view that is normally concentric with the arc of the proximal lunate; this feature is especially prominent with the 10° lateral projection. Normally the lunate is located centrally within the articular surface of the distal radius and is congruent with the teardrop on the palmar side (Fig. 4B). Incongruency of the base of the lunate with the articular margin of the radius can indicate displaced intra-articular fracture elements or subluxation or dislocation of the radiocarpal joint (Fig. 5).

The radius of curvature of the distal radius articular surface should match the radius of curvature of the proximal pole of the lunate. Flattening of the arc of curvature of the distal radius implies dissociation and incongruency of the articular surface across the dorsal and volar margins of the lunate facet. Occasionally this subtle feature may be the only radiographic evidence of articular disruption (Fig. 6).

The central axis of the lunate is normally collinear with the volar cortex of the radial shaft. Migration of the central axis of the lunate to the volar side suggests significant radiocarpal instability.
The teardrop is the U-shaped outline of the volar rim of the lunate facet; it is identified easily on the lateral view and is particularly distinct on the 10° lateral projection (see Fig. 4A,B). The relationship of the lunate to the articular surface of the teardrop can be critical in defining the direction of carpal instability. In addition, dorsal rotation of the teardrop, often seen in conjunction with axial loading injuries, can produce significant articular incongruity that can be overlooked easily even if radial inclination and volar tilt have been restored. Careful assessment of the teardrop should be a standard part of radiographic evaluation for distal radius fractures.

Radiographic parameters

*Posteroanterior view*

Radial inclination is well recognized as a useful measurement of the radial slope on the PA projection. Historically this parameter has been described as the angle between the long axis of the radial shaft and a line connecting the tip of the radial styloid with the ulnar corner [10]. Because the ulnar corner may be a different anatomic structure with volar and dorsal angulation of the distal articular surface, this measurement should use a reference point midway between the volar and dorsal ulnar corners to eliminate variation caused by dorsal angulation. This central reference point is defined as the CRP (Figs. 7 and 8).

A similar problem is encountered in measuring ulnar variance, defined as the difference in axial length between the ulnar corner of the distal radius and the most distal extent of the ulnar head on the PA view. For reasons described previously, the measurement of ulnar variance is more accurate and consistent when defined as the difference in axial length between the ulnar head and the CRP. Similarly the measurement of radial height is more accurate when defined as the difference in axial length between the tip of the radial styloid and the CRP (Fig. 9).

The radiocarpal interval is a measurement of the articular interval across the radiocarpal joint and represents the combined thickness of the articular cartilage on both sides of the joint. The

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Fig. 5. Radiograph showing a markedly abnormal AP distance and migration of the carpus with dorsal fragmentation, dislocating dorsally from the articular surface of the volar rim (teardrop).

Fig. 6. Radiograph showing flattening of the arc of curvature of the articular surface of the distal radius as compared with the arc of curvature of the proximal pole of the lunate. This indicates discontinuity between the dorsal and volar rims of the lunate facet.

Fig. 7. Central reference point (CRP) of the ulnar border, used for measuring radial inclination, radial height, and ulnar variance to reduce variation caused by excess dorsal or volar angulation of the distal fragment.
parameter is measured as the separation between the proximal pole of the scaphoid to the distal radius (Fig. 9). Intra-articular fractures with impaction of the proximal carpal row into a fracture defect reduce this value; a radiocarpal interval in excess of 3 mm implies overdistraction of the joint, usually in the context of an external fixator, and has been associated with increased potential for morbidity and complications [11].

**Lateral view**

Volar tilt is measured on the lateral view as the angle formed between a perpendicular to the longitudinal axis of the radial shaft and a line formed by connecting the apex of the volar and dorsal rim (Fig. 10) [10]. In practice, the apices of the dorsal and volar rim are identified more clearly on the 10° lateral view.

On the lateral view the teardrop is identified easily and represents the volar rim of the lunate facet. This radiographic landmark is even more prominent on the 10° lateral view. Normally a line drawn down the central axis of the teardrop (parallel to the subchondral bone of the volar rim) creates an angle of 70° to a line extended from the central axis of the radial shaft (Fig. 10). In extra-articular fractures of the distal radius with dorsal angulation of the distal fragment, the teardrop angle is reduced by the amount of dorsal rotation. As normal volar tilt is restored with reduction of the fracture, the teardrop angle returns to normal.

Axial loading injuries, however, create a different set of circumstances that can affect adversely the teardrop angle. In these cases, the lunate is driven into the lunate facet, resulting in dissociation of the volar and dorsal articular surfaces. As the lunate is impacted further into the metaphyseal cavity it causes the volar rim to rotate dorsally into the metaphyseal defect, resulting in severe articular incongruity between the dorsal and volar sides of the joint surface. Because of the large loads produced by the wrist and finger flexors on the volar surface of the radiocarpal joint, these are particularly unstable injuries. In this situation, reduction maneuvers may restore volar tilt and radial inclination measurements back to normal, only to retain significant abnormalities of the teardrop angle. This depression in the teardrop angle represents significant residual dorsiflexion of the volar rim fragment and frequently is the only evidence that reduction is incomplete and articular incongruity remains.
In a normal distal radius, the distance between the apex of the dorsal rim and the apex of the volar rim of the lunate facet is fixed and defines the anteroposterior (AP) distance. This parameter is measured between the apex of the dorsal and volar rims as seen on the lateral view (Fig. 11). Distal radius fractures, particularly axial loading injuries, can cause the volar and dorsal rim fragments to explode away from each other as the lunate is driven into the articular surface. Again, the 10° lateral projection allows more accurate identification of these landmarks. If the AP distance is elevated above normal values, discontinuity between the volar and dorsal rims is implied (Fig. 12). Frequently this is the only evidence of discontinuity across the sigmoid notch.

Radiographs of 40 wrists in 20 healthy volunteers ranging in age from 19–85 years were obtained to determine normal values for the parameters discussed previously. The sample studied was typical of the local population in the state of Hawaii, with most patients having mixed ethnic backgrounds (Caucasian, Hawaiian, Polynesian, Filipino, and Asian mixtures); the sample contained an equal number of men and women. On the PA view, radial inclination, ulnar variance, radial height, radial width, and radiocarpal interval were measured. Measurement of radial inclination, ulnar variance, and radial height was modified to use the central reference point between the dorsal and volar corners of the ulnar border of the radius. Volar tilt, AP distance, and teardrop angle were measured on the standard lateral view and on the 10° lateral view. In addition, mean values for radial width, radiocarpal interval, AP distance, and teardrop angle were determined. A student’s t-test was used to calculate whether any differences between genders were statistically different. In addition, a student’s t-test was used to calculate whether values measured on the standard lateral radiograph were significantly different from corresponding values measured on the 10° lateral film.

Normal values for these parameters are summarized in Tables 1–3. The 10° lateral radiograph, which shows the articular surface of the distal radius in greater detail and allows more precise identification of the points of reference, did not significantly affect measurement of volar tilt, AP distance, and teardrop angle as compared with the standard lateral radiographs. AP distance was the only parameter that demonstrated statistic differences between genders.

Miscellaneous

In addition to the radiographic landmarks and parameters present in a normal wrist, two additional parameters may be useful in the context of a distal radius fracture. The first is articular step-off, which represents a translational discontinuity or ledge in the articular surface [12–14]. This abnormality usually is identified on the PA view (Fig. 13A), but may be noted on the standard or 10° lateral view also.

Articular separation is a second parameter that is useful to identify gaps in the articular surface caused by incomplete apposition of articular elements [15]. Although no long-term studies have quantified what threshold of articular separation adversely affects clinical outcome, it would
stand to reason that large segmental defects in the articular surface would be associated with long-term morbidity. For instance, a significantly widened AP distance on the lateral view would suggest articular separation across the lunate facet, with potential for the lunate to collapse into a metaphyseal defect (Fig. 13B).

Patterns of injury

Fractures of the distal radius typically occur in defined patterns. By identifying the actual physical components and the mechanism of injury, a rational approach to treatment can be formulated that is based on the fracture components present and on the predominant direction of instability.

Fragment specific classification

The fragment specific classification system is a useful tool to identify the five major cortical fracture elements that are commonly associated with distal radius fractures either alone or in any combination. Specifically these fracture components are the radial column, ulnar corner, dorsal wall, volar rim, and free intra-articular fragments (Figs. 14 and 15).

Table 1
Normal radiographic parameters of the wrist, PA projection

<table>
<thead>
<tr>
<th></th>
<th>Radial inclination (°)</th>
<th>Radial height (mm)</th>
<th>Ulnar variance (mm)</th>
<th>Radiocarpal interval (mm)</th>
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<tbody>
<tr>
<td>Average</td>
<td>23.6±2.5</td>
<td>11.6±1.6</td>
<td>−0.6±0.9</td>
<td>1.9±0.2</td>
</tr>
<tr>
<td>Women</td>
<td>24.7±2.5</td>
<td>11.2±1.5</td>
<td>−0.6±0.8</td>
<td>1.9±0.2</td>
</tr>
<tr>
<td>Men</td>
<td>22.5±2.1</td>
<td>12.0±1.6</td>
<td>−0.6±1.0</td>
<td>2.0±0.2</td>
</tr>
<tr>
<td>T-value</td>
<td>2.13</td>
<td>−1.15</td>
<td>0.00</td>
<td>−1.11</td>
</tr>
<tr>
<td>P</td>
<td>0.04</td>
<td>0.26</td>
<td>1.00</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Average data, n = 40; gender-based data, n = 20.

The radial column fragment is typically the largest fragment element (Fig. 16). This fragment often involves more than simply the tip of the radial styloid and extends proximally into the tricortical column of bone; typically, this fragment includes the very terminal fibers of the brachioradialis insertion. This fragment is identified easily on the PA view. Although often present as a single fracture component, comminution of the radial column can occur and indicates a more unstable fracture pattern (see Fig. 15). Reduction of the radial column fragment should restore radial length and radial inclination; radial translation of this fragment with a radial buttress plate can close the sigmoid notch against the ulnar head and help stabilize the DRUJ. Segmental defects between the radial column and the proximal shaft should be identified and often require structural graft to maintain length of the radial column.

The ulnar corner fragment can be identified on the PA or oblique view and often is displaced proximally (Fig. 16). It consists of the dorsal corner of the DRUJ and may include a portion of the dorsal surface of the lunate facet. Shortening or widening of the ulnar corner fragment in relation to the ulnar head can result in abnormalities of the DRUJ and should be corrected.

Dorsal bending and axial loading injuries to the distal radius often result in comminution of the dorsal wall, with one or more dorsal wall

Table 2
Normal radiographic parameters of the wrist, standard lateral projection

<table>
<thead>
<tr>
<th></th>
<th>Volar tilt (mm)</th>
<th>AP dist (mm)</th>
<th>Teardrop angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (n = 40)</td>
<td>11.2±4.6</td>
<td>19.1±1.7</td>
<td>70.7±4.2</td>
</tr>
<tr>
<td>Women (n = 20)</td>
<td>12.2±5.6</td>
<td>17.8±1.0</td>
<td>70.8±4.7</td>
</tr>
<tr>
<td>Men (n = 20)</td>
<td>10.2±3.2</td>
<td>20.4±1.1</td>
<td>70.5±3.7</td>
</tr>
<tr>
<td>T-value</td>
<td>0.98</td>
<td>−5.5</td>
<td>0.16</td>
</tr>
<tr>
<td>p</td>
<td>0.35</td>
<td>&lt;0.01</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Average data, n = 40; gender-based data, n = 20.

Table 3
Comparison of standard lateral to 10° lateral projection, normal wrists

<table>
<thead>
<tr>
<th></th>
<th>Volar tilt (°)</th>
<th>AP distance (mm)</th>
<th>Teardrop angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal lateral</td>
<td>11.2±4.6</td>
<td>19.1±1.7</td>
<td>70.7±4.2</td>
</tr>
<tr>
<td>10° lateral</td>
<td>8.9±4.0</td>
<td>18.7±1.7</td>
<td>71.6±4.1</td>
</tr>
<tr>
<td>T-value</td>
<td>−1.19</td>
<td>−7.40</td>
<td>0.84</td>
</tr>
<tr>
<td>p</td>
<td>0.24</td>
<td>0.48</td>
<td>0.42</td>
</tr>
</tbody>
</table>

n = 40.
fragments that may rotate into dorsiflexion. The dorsal wall fragment is recognized easily by close inspection of the lateral radiograph. The presence of a dorsal wall fragment implies dorsal instability; in middle aged and older patients it often is associated with a significant metaphyseal defect as well. Occasionally the dorsal wall fragment may rotate 90° in an orientation parallel to the radiographic beam and may appear as a radiodense line crossing transversely at the proximal extent of the fracture. A similar finding is seen less commonly in the context of a volar bending injury with volar rotation of a volar wall fragment. By correlating the lateral radiograph to the PA view, the correct fracture pattern can be differentiated despite the similar radiographic appearance of this radiodense linear feature.

Occasionally dorsal wall fractures also may occur with dorsal shearing injuries. In this situation, translation of the carpus dorsally is recognized by displacement of the lunate dorsally off the teardrop as seen on the lateral view. Dorsal fixation and palmar translation of the carpus is required for treatment of this type of fracture pattern.

Impacted intra-articular fracture elements can be visualized on the PA or lateral projection by noting the subchondral bone of the articular surface within the metaphyseal bone. Occasionally an intra-articular fragment may be rotated

Fig. 13. Articular step-off and articular separation with intra-articular fractures. (A) Articular step-off seen as discontinuity of the carpal facet horizon. (B) Articular separation seen on the lateral projection; note the elevation of the AP distance and the marked depression of the teardrop angle.

Fig. 14. Fragment classification system showing the common cortical fracture components, the radial column, ulnar corner (dorsal), volar rim, dorsal wall, and free intra-articular fragments. Most intra-articular fracture patterns contain a subset of these five major cortical fragments. (Courtesy of Trimed, Inc., Valencia, CA; with permission.)

Fig. 15. Comminuted fracture from an axial loading injury demonstrating all five major cortical fragments.
a full 180° and facing proximally. Impacted articular fragments are almost always associated with axial loading injuries.

Volar rim fracture elements commonly are comminuted. Typically two patterns of displacement are noted. In the first, the fracture element is translated into the palmar soft tissue; this type is usually the result of volar bending or shearing injuries. In this mechanism, simple buttress support of the volar rim is usually adequate for stable reduction and fixation.

The second category of volar rim injuries is caused by an axial loading mechanism and results in dorsiflexion of the volar rim fragment into the metaphyseal cavity (see Fig. 15). This type of instability is more difficult to control and can be associated with subluxation of the carpus from the articular surface. These injuries are associated with depression of the teardrop angle and an incongruity between the arc of curvature of the volar fragment and dorsal fragment on the lateral view. Restoration of articular congruency and stability is accomplished only if the teardrop angle is corrected.

Summary

Fractures of the distal radius can be complex injuries, often generating multiple fragments with distortion of the normal anatomy in all three dimensions. Superficial assessment of the injury on the standard PA and lateral radiographs often can result in incomplete recognition of the injury pattern and a misdirected approach to treatment. In addition, failure to recognize subtle radiographic findings may result in the acceptance of a reduction that has significant residual incongruency and articular surface disruption.

Standard radiographs of the distal radius can provide a wealth of information about the topography of the bone if the surgeon knows what to look for. The ability to recognize detailed landmarks and parameters on the radiographic images and convert this information into a three-dimensional visual image is a skill that requires education and training. As more aggressive treatments have emerged for anatomic restoration of the bony and articular anatomy, accurate identification of the pattern of injury has become essential.

Parameters such as the teardrop angle, AP distance, and articular separation have been recognized only recently. Because these parameters reflect the congruency of the articular surface, it would be natural to assume that postreduction films in which these parameters are abnormal would compromise clinical outcome. Because nearly all historical studies do not include routine evaluation of these parameters, knowledge of radiographic correlation with clinical outcome is still incomplete. At the same time, previous studies to assess outcome of distal radius fractures may be compromised by the failure to recognize residual deformity and articular incongruency that would have been evident with measurement of these parameters.

With careful understanding of the radiographic landmarks, radiographic parameters, and patterns of injury, the surgeon can visualize a more accurate picture of the fracture itself and the reduction. As a result, treatment decisions for distal radius fractures can be based on a more thorough understanding of the anatomy of the injury, and future grading of radiographic results may reflect more accurately the precision of the articular restoration.

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References


