A Radiologist’s Guide to Wrist Alignment: The Good, Bad, and Ugly

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Objectives

1. Review basic adult wrist anatomy

2. Discuss how to evaluate alignment on radiographs:
   - Distal radius, distal ulna, distal radioulnar joint (DRUJ)
   - Carpal bones
   - Carpometacarpal bones

3. Discuss the traumatic and non-traumatic disorders that cause wrist malalignment

4. Review the classification of carpal instability
Osseous Anatomy

Scaphoid (S)
Lunate (L)
Triquetrum (Tq)
Pisiform (P)
Hamate (H)
Capitate (C)
Trapezoid (Td)
Trapezium (Tm)
Radius (R)
Ulna (U)
Metacarpals (*)
Anatomy: Main Ligaments

Intrinsic ligaments
- Scapholunate (SL)
- Lunotriquetral (LT)

Volar carpal ligaments
- Radioscaphocapitate (RSC)
- Scaphotriquetral (ST)
- Radiolunotriquetral (RLT)
- Ulnolunate (UL)
- Ulnotriquetral (UT)

Dorsal carpal ligaments
- Dorsal scaphotriquetral (DST)
- Dorsal radiotriquetral (DRT)
Evaluation of the Wrist

- **Radiograph** (4 standard views)
  - Posteroanterior (PA) — shoulder abducted 90°, elbow flexed 90°, forearm in neutral position
  - Oblique — radial side of wrist elevated 30° from table, ulnar side of wrist resting on table
  - Lateral — shoulder adducted, elbow flexed 90°, distal forearm and hand resting on ulnar side
  - Scaphoid — PA view with wrist in ulnar deviation
  - Many other dedicated views
- **CT** — especially helpful for 3D reconstruction for surgeon
- **MRI** — evaluate soft tissues, ligaments, tendons, marrow edema.

**PA view**
Extensor carpi ulnaris tendon groove should be profiled at radial base of ulnar styloid

**Lateral view**
1. Pisiform should be located b/t the volar cortices of scaphoid and capitate
2. Radial styloid should overlap with carpus
3. Ulna should overlap radius

**Anatomy**
- Distal Radius & Ulna
- Carpal bones
- CMC
- Carpal Instability

**St technologies**
- CT
- MRI
• **Lateral view:** angle between (1) tangent of distal radius articular surface and (2) line perpendicular to the mid-radius shaft

• **Normal:** average 11 degrees (2 to 20 degrees)

• Aka palmar tilt, volar inclination

• **Purpose:** to assess deformities associated with fractures of distal radius and operative planning in correcting deformities
  - Colles fracture: dorsal angulation > 15º may be associated with unsatisfactory grip strength and endurance
  - Dorsal angulation of > 30º volar tilt from normal position can increase load on ulnocarpal joint by 200%
Radial Inclination Angle

- **PA view**: angle between (1) line connecting radial styloid tip and ulnar aspect of distal radius and (2) line perpendicular to longitudinal axis of radius
- **Normal**: 21-25º
- Aka radial deviation or ulnar inclination
- **Purpose**:
  - **Decreased**: may predict poorer functional outcome following distal radial fractures (< 5º)
  - **Increased**: may be seen in deformities such as Madelung deformity or posttraumatic growth arrest (of ulnar side of radius)
Radial Length

• **PA view**: distance between (1) tip of radial styloid and (2) ulnar head articular surface (draw lines perpendicular to radial shaft)

• **Average**: 10-13 mm

• **Purpose**: quantifies distal radial deformity from fractures or developmental abnormalities

• Loss of radial length = predictor of less favorable outcome in distal radial fractures

Anatomy:
- Distal Radius & Ulna
- Carpal bones
- CMC
- Carpal Instability
Ulnar Variance

• **PA view**: draw line perpendicular to mid shaft radius and at most ulnar aspect of distal radius, then measure distance between this line and ulnar dome

• **Positive** = distal ulna is distal to line
• **Negative** = distal ulna is proximal to line

• Normal values vary by ethnic group

• **Purpose**: evaluate fracture deformities of distal radius, operative planning/follow-up of radioulnar length-equalization procedures

• Relates to anatomy and biomechanics
  • Thicker triangular cartilage (i.e. negative ulnar variance) allows greater tension transfer and decrease in risk of perforation of disk
  • Change in 1 mm ulnar variance can alter mechanical transfer by 25%

Normal: the distal radius and ulna are aligned
Negative Ulnar Variance

- Thicker triangular fibrocartilage, which may be protective
- Associated with Kienboch’s disease, posttraumatic acute scapholunate dissociation, radial ulnar impingement
- Kienbock’s disease
  - Short ulna leads to increased shear forces on ulnar wrist and particularly the lunate
  - Osteonecrosis of the lunate
  - Radiographs may show lunate sclerosis, lunate cortical collapse and advanced osteoarthritis

Kienbock’s disease: Lunate sclerosis and ulnar negative variance on PA view (A); abnormal marrow signal in lunate and scapholunate ligament partial tear on coronal T2 FS MRI (B)

Ulnar impingement
Negative ulnar variance, cortical remodeling and sclerosis of the ulna as it contacts the medial radius.
Positive Ulnar Variance

- Thinner triangular fibrocartilage, which may be predisposed to rupture

- May be associated with poorer outcomes if associated with fractures, for example:
  - Poor outcomes seen in 40% of patient’s with Colles fracture and > 5 mm + ulnar variance
  - In Galleazzi fractures, > 10 mm + ulnar variance indicates complete disruption of interosseous membrane at the DRUJ

- May lead to ulnocarpal impaction
  - Chronic degeneration from ulnar impaction
  - TFCC progressively deteriorates, leading to chondromalacia of the lunate, triquetrum, and ulna
  - Radiographs: + ulnar variance and degenerative changes of involved bones
  - MRI may show edema or LT ligament tear

Ulnocarpal impaction with positive ulnar variance, subchondral sclerosis of the lunate and distal ulna, and cortical remodeling of the proximal lunate.
DRUJ Dislocation

- **Cause:** may be isolated or associated with other injuries (Galleazzi fracture, Essex-Lopresti injuries, distal radius fractures)

- **Radiographic findings:**
  - Abnormal rotation of ulna with ulnar styloid overlying central portion of distal ulna (PA view)
  - Widening of radioulnar distance (PA view)
  - Superimposition of radius and ulna (PA)
  - Posterior or anterior displacement of ulna (lateral view)

The radioulnar distance is widened, consistent with DRUJ dislocation. There is also a comminuted fracture of the mid radial shaft in this Galleazzi fracture dislocation.
Carpal Alignment: Gilula Arcs

3 smooth carpal arcs on neutral PA view

- **Arc 1**: proximal surfaces of the scaphoid, lunate, and triquetrum
- **Arc 2**: distal surfaces of the same bones
- **Arc 3**: curvature of proximal surfaces of capitate and hamate

Disruption suggests ligamentous disruption/laxity or carpal fracture

2 common variants:

- Triquetrum shorter in proximal-distal dimension than adjacent lunate (abnormal 1\textsuperscript{st} arc)
- Type II lunate (proximal hamate with apposing hamate facet on lunate, leading to disrupted 2\textsuperscript{nd} arc)

Note: Lunate should be trapezoid-shaped. A “triangular lunate” may reflect tilting, dislocation, or fracture

PA view (A) of type II Lunate with disruption of 2\textsuperscript{nd} Gilula arc, also seen on coronal T1 (B) and T2 (C) weighted MR sequences
Carpal Height

**Carpal height (CH):** distance from base of 3rd metacarpal to distal radial articular surface

- **Purpose:** quantify carpal collapse

- **Carpal height ratio:** Carpal height / length of 3rd metacarpal
  - Normal: 0.54 ± 0.03

- **Alternative:** Carpal height / capitate length
  - Normal: 1.57 ± 0.05

- **Carpal height index:** Carpal height ratio of diseased hand / that of normal hand
  - Normal: 1.000 ± 0.015

- Carpal collapse associated with rheumatoid arthritis, scapholunate advanced collapse, and Kienbock disease

**Alternative carpal height ratio**

CH / Capitate length – adjusts for the individual and can be used when the entire 3rd metacarpal is not included in the field of view
Joint Space

- All joint spaces should be 1-2 mm and of similar width
- Causes of widening: ligamentous abnormalities, increased joint fluid, synovial hypertrophy
- Causes of narrowing: arthritis, trauma, carpal coalition
- Scapholunate distance: measured at mid-portion and may be abnormal if > 2 mm
  - Widening can imply scapholunate dissociation

Carpal coalition
PA view (A) and coronal T1 weighted MR image (B) show absence of lunotriquetral joint space from osseous coalition. Ulnar styloid fracture also present.
Carpal Axes

- Measured on **lateral view**
- Longitudinal axes of the 3rd metacarpal, capitate, lunate, and radius should fall on the same line, usually within 10º

**Radial axis (R):** Line parallel to radial shaft

**Lunate axis (L):** Line drawn through midpoints of proximal and distal surfaces

**Capitate axis (C):** Line drawn through centers of head and distal surface

**Scaphoid axis (S):** Line drawn through midpoints of proximal and distal poles

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**Anatomy**

- Distal Radius & Ulna
- Carpal bones
- CMC
- Carpal Instability
**Carpal Angles**

- **Purpose:** To identify instability of the proximal carpal row (intercalated segment).
- Normally, proximal carpal bones are constrained to one another and flex/extend as a unit, with normal carpal angles measured on LATERAL view, as seen below.
- Abnormal carpal angles can reflect underlying carpal malalignment: Volar and Dorsal intercalated segmental instability (VISI and DISI).

<table>
<thead>
<tr>
<th>Normal Scapholunate (SL) angle</th>
<th>Normal Capitolunate (CL) angle</th>
<th>Normal Radiolunate (RL) angle</th>
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<tr>
<td>30-60º</td>
<td>0-30º</td>
<td>-15 to +15º</td>
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</table>
Volar Intercalated Segmental Instability (VISI)

- **Causes:** Disruption of lunotriquetral interosseous ligament +/- midcarpal stabilizers (triquetrohamatocapitate, dorsal radiocarpal ligaments)
- Abnormal flexion of unconstrained proximal carpal row (scaphoid and lunate)
- Volar tilt of the lunate and scaphoid, dorsal tilt of the capitate
- SL angle is decreased (<30º), CL angle is increased (>30º).
Dorsal Intercalated Segmental Instability (DISI)

- **Causes:** Disruption of scapholunate interosseous ligament or scaphoid fracture-
  scaphoid is no longer constrained to lunate and proximal carpal row
- **Volar tilt of the scaphoid and dorsal tilt of the lunate**
- **Both the SL and CL angles are increased** (SL>60°; CL>30°)
Pisotriquetral Joint

**Major stabilizers:** Flexor carpi ulnaris tendon (FCU), pisohamate ligament (PHL), pisometacarpal ligament (PML), and pisotriquetral ulnar ligament

**Radiographic evaluation:**

- **AP view:** pisiform should be superimposed over triquetrum
- **Lateral view:** pisiform should be superimposed over scaphoid tuberosity, between volar convexities of scaphoid and capitate
- Semi-supinated oblique view and ulnar border view may improve visualization of joint

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Pisiform subluxation. (A) PA view of wrist shows inferior displacement of pisiform relative to triquetrum with normal contralateral wrist for comparison (B). Axial (C) and sagittal (D) fat-suppressed T2 weighted MR images demonstrate tear of pisotriquetral joint capsule and widening of joint.
Carpometacarpal Joint Alignment

- Width of 2nd through 5th CMC joint spaces should be uniform, measuring 1-2 mm.
- Radiographic evaluation: Parallel M lines
  - on PA view, two parallel lines resembling “M”
  - Proximal line = curvatures of distal surfaces of trapezoid, capitate, and hamate
  - Distal line = bases of 2nd through 5th metacarpals
  - Break in line suggests abnormality

PA view shows disruption of the ulnar aspect of the “M” line. Multiplanar CT (B, C, D) images confirm 4th and 5th CMC fracture dislocations.
Mayo Classification of Carpal Instability

Biomechanics

- Movement of the wrist starts at the distal carpal row, then passive following of the proximal row (mostly at the capitolunate portion).
- For radial and ulnar deviation, proximal row moves together (flexed for radial deviation and extended for ulnar deviation)
- Stability can be affected at any level of the wrist, by diseases that affect morphology of bones, ligaments, and muscles of this region

4 types of Carpal Instability (Mayo Classification)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Carpal instability dissociative (CID)</td>
<td>Derangement within or between bones of same carpal row</td>
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<tr>
<td>Carpal instability non-dissociative (CIND)</td>
<td>Derangement between radius and proximal carpal row or between proximal and distal carpal rows</td>
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<tr>
<td>Carpal instability complex (CIC)</td>
<td>Combination of CID and CIND</td>
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<tr>
<td>Carpal instability adaptive (CIA)</td>
<td>Origin of instability is proximal or distal to wrist</td>
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Carpal Instability Dissociative (CID)

Derangement within or between bones of same carpal row

Proximal carpal row
• Scapholunate dissociation
• Lunotriquetral dissociation
• Scaphoid fracture

Distal carpal row
• Axial carpal dislocations
Proximal Carpal Row CID: Scapholunate Dissociation

- Most frequent carpal instability pattern
- Causes: traumatic injuries to SL ligament, unstable scaphoid fractures, rheumatoid arthritis, CPPD, and Kienbock’s disease
- Possible findings:
  - Widening of SL distance
  - Partial to complete tear of SL ligament on MRI
  - If severe failure of scaphoid stabilizers, scaphoid and lunate will rotate in opposite directions, leading to SL > 60º and DISI
- Chronic progression leads to scapholunate advanced collapse (SLAC)
  - Severe RS narrowing and progressive proximal migration of capitate to between scaphoid and lunate
  - Carpal height will decrease

(A) PA view shows SLD. (B) PA view of SLAC wrist with widened SLD, carpal collapse (decreased CH), and proximal migration of capitate. (C) Lateral view of SLAC wrist shows increased SL angle (DISI).
SLAC and SNAC

Scaphoid non-union advanced collapse (SNAC)

Wrist arthritis that develops following a non-union scaphoid fracture

PA view (A) shows non-union scaphoid fracture and arthrosis of the distal scaphoid, radial styloid, and midcarpal joint. Lateral view (B) shows DISI (SL angle > 60°), which implies the lunate is unrestrained from the scaphoid.

Progression of arthrosis in SLAC and SNAC (Watson)

**Stage I:** Arthrosis of radial styloid-distal scaphoid articulation

**Stage II:** Involvement of proximal radionscaphoid joint (SLAC) or scaphocapitate joint (SNAC)

**Stage III:** Involvement of scaphocapitate and lunocapitate joints

**Stage IV:** Pancarpal arthrosis with preservation of radiolunate joint (articulation b/t proximal pole of scaphoid and radius often preserved in SNAC)

Carpal Instability:

<table>
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<tr>
<th>CID</th>
<th>CIND</th>
<th>CIC</th>
<th>CIA</th>
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Proximal Carpal Row CID: Lunotriquetral Dissociation

- Results from injury to LT ligament
- Causes: attrition by age, positive ulnar variance, perilunate injuries
- May see:
  - Normal radiograph (including normal LT joint space)
  - Disruption of Gilula’s arcs, proximal migration of triquetrum
  - Volar translation of lunate axis from flexion of scaphoid, leading to VISI
  - May see partial to complete tear on MRI (only 50% sensitive), may only see fluid about torn ligament

PA view (A) shows disruption of the lunotriquetral articulation and 1\textsuperscript{st} and 2\textsuperscript{nd} carpal arcs. Lunate is triangular in shape. Lateral view (B) shows VISI with a decreased scapholunate angle < 30°.
Distal Carpal Row CID: Axial Carpal Dislocations

- Rare - there is high degree of intrinsic biomechanical stability in distal carpal row
- Causes: blast or crush injuries
- 3 groups, with splitting of distal carpus into two columns (radial and ulnar)
  1. **Axial ulnar disruption**: Radial column remains stable with regard to radius while column displaces in ulnar and proximal direction
  2. **Axial radial disruption**: Ulnar column remains stable with regard to radius while radial column displaces in radial and proximal direction
  3. **Combined disruption**
- May be purely ligamentous or associated with carpal bone fractures
CIND: Radiocarpal Instability
Derangement b/t radius and proximal carpal row

- Derangement of extrinsic radiocarpal ligaments allow proximal row to slide along articular surface of distal articular radius, in radial or ulnar fashion
- Causes: injury of extrinsic carpal ligaments, carpal malpositioning from distal radius/ulna anatomic abnormalities (RA, Madelung deformity), following excision of distal ulna
- 3 common forms:
  - **Ulnar translocation** — proximal carpal row slides in ulnar direction along distal articulating radius
  - **Radial dislocation** — proximal carpal row slides in radial direction
  - Pure radiocarpal dislocation
- Evaluate with radial inclination, radial length, and volar tilt

PA views of patient with rheumatoid arthritis taken baseline (A), 2 years (B), and 5 years (C) show progressive ulnar translocation of proximal row.
CIND: Midcarpal Instability

Derangement b/t between proximal and distal carpal rows

- Dysfunction of both radiocarpal and midcarpal joints,
- Major stabilizers: Triquetrohamocapitate (THC), dorsalateral scaphotrapeziotrapezoid, and radioscpaphocapitate (RSC) ligaments
- 4 major types:
  - Anterior: entire proximal carpal row flexes volarly leading to VISI pattern
    - Failure of mostly THC ligament
  - Posterior: dorsal subluxation of capitate and dorsal tilting of scaphoid and lunate
    - From additional failure of volar RSC ligament, usually in young patients with hypermobile wrists
  - Combined: additional dorsal subluxation of lunate, scaphoid, and capitate
  - Extrinsic: from injury or osseous injury outside wrist, causing dorsal tilting of distal articulating radius and dorsal tilt of lunate, usually from malunited distal radius fracture
Carpal Instability Complex (CIC)/Perilunate Instability

- Carpal instability complex combines features of both CID and CIC, mostly from perilunate injuries

- 2 patterns of perilunate injuries:
  1. Perilunate dislocation (lesser arc injury) – purely ligamentous disruption surrounding lunate
  2. Perilunate fracture-dislocation (greater arc injury) – disruption of ligament(s) about the lunate PLUS fracture of one of adjacent bones (scaphoid, trapezium, capitate, hamate, or triquetrum

  - Nomenclature: trans – “fractured bone”, i.e. transcaphoid perilunate dislocation

<table>
<thead>
<tr>
<th>Mayfield Classification</th>
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<tr>
<td>Stage 1</td>
<td>Scapholunate dissociation</td>
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<tr>
<td>Stage 2</td>
<td>+ Lunocapitate disruption</td>
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<tr>
<td>Stage 3</td>
<td>+ Lunotriquetral dissociation</td>
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<tr>
<td>Stage 4</td>
<td>Lunate dislocation</td>
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Lesser arc injury
Greater arc injury
4 Stages of Perilunate Instability

Stage 1: Scapholunate dissociation or scaphoid fracture
- Hyperextension of the distal carpal row pulls the scaphoid into extension
- Since the lunate cannot extend as much as the scaphoid, the scapholunate ligament ruptures, from palmar to dorsal
- If wrist is radially deviated, scaphoid fractures instead of SLD

Stage 2: Lunocapitate dislocation
- With further wrist extension, scaphoid-distal row complex dislocates dorsally relative to lunate

Stage 3: Lunate triquetrum disruption or triquetrum fracture
- With further hyperextension, the ulnar limb of THC ligament pulls the triquetrum dorsally, either tearing the lunotriquetral ligament or fracturing the triquetrum

Stage 4: Lunate dislocation
- Intact radioscapophocapitate ligament pulls capitate into radiocarpal space, then pushes the lunate in palmar direction until it dislocates in a rotary manner

Carpal Instability: CID CIND CIC CIA
**Carpal Instability Complex (CIC)**

Features of both CID and CIND

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**Transcaphoid perilunate dislocation (stage II)**
PA view (A) shows triangular shaped lunate, displaced scaphoid waist fracture, and disruption of all 3 Gilula arcs. Lateral view (B) demonstrates dorsal dislocation of the scaphoid-distal row complex relative to the lunate. Prefix “trans-” denotes the fractured bone.

**Lunate dislocation (stage IV).**
Frontal view (C) shows a “pie-shaped” lunate with disruption of the 1st and 2nd Gilula Arcs. Lateral view (D) demonstrates migration of the capitate in the radiocarpal space with dislocation of lunate in a rotary fashion, producing a "spilled-teacup" appearance.
Carpal Instability Adaptive (CIA)

Origin of instability is proximal or distal to wrist

Similar to radiocarpal instability in CIND, except cause related to carpal malpositioning from distal radius/ulna abnormalities:

- **Malunion of distal radial fracture:**
  - Dorsal angulation of distal articulating surface of radius causes proximal row to conform to abnormal tilt
  - Leads to flexion of the midcarpal joint with slackening of the palmar midcarpal ligaments

- **Madelung deformity:**
  - Developmental growth disturbance of distal radial physis, starting in adolescence
  - Bowing of distal radius leading to volar tilt while ulna continues to grow linearly
  - Potential causes: dyschondrosteosis, enchondromatosis, hereditary multiple exostoses, mesomelic dwarfism, and Turner syndrome

- Important to exclude intracarpal ligament injury

Madelung deformity. PA view (A) and coronal T1 weighted MR (C) of the wrist show markedly increased radial inclination angle and foreshortening of the ulnar aspect of the distal radius. Lateral view (B) and sagittal T1 weighted MR (D) show marked dorsal subluxation of the distal ulna.
Summary

- Evaluation of the wrist starts with the plain radiograph, which should include at least posteroanterior, oblique, and lateral views.
- Alignment of the distal radius and ulna is evaluated with volar tilt, radial inclination angle, radial length, and ulnar variance.
- Alignment of the carpal bones is evaluated with Gilula arcs, carpal height, joint space, and carpal angles.
- Alignment of the CMC joint is evaluated by the parallel “M” lines.
- The two main patterns of carpal malalignment are volar and dorsal intercalated segmental instability (VISI and DISI), which are determined by carpal angles.
- The 4 types of carpal instability according to the Mayo classification are: dissociative (CID), non-dissociative (CIND), complex (CIC), and adaptive (CIA).
  - CID implies derangement between bones of same carpal row, most commonly from scapholunate or lunotriquetral disruption.
  - CIND results from radiocarpal or midcarpal instability.
  - CIC results from perilunate injuries, which are categorized based on the Mayfield classification – including perilunate and lunate dislocations.
  - CIA results from instability proximal or distal to the wrist.
References