Ligament Origins Are Preserved in Distal Radial Intraarticular Two-Part Fractures: A Computed Tomography-Based Study

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Abstract

Background Operative fixation of intraarticular distal radius fractures is increasingly common. A greater understanding of fracture patterns will aid surgical fixation strategy. Previous studies have suggested that ligamentous insertions may less commonly be involved, but these have included heterogeneous groups of fractures and have not addressed Lister's tubercle.

Purpose We hypothesize that fracture lines of distal radial intraarticular 2-part fractures have reproducible patterns. They propagate through the cortical bone between ligament origins and do not involve Lister's tubercle.

Methods Axial CT scans of two-part intraarticular distal radius fractures were assessed independently by two examiners. The fractures were mapped onto a grid and the cortical breaches expressed as a percentile of the total radial width or length. The cortical breaches were compared with the ligamentous insertions on the distal and Lister's tubercle. Associated injuries were also documented.

Results The cortical breaches occurred between the ligamentous insertions in 85%. Lister's tubercle was not involved in 95% of the fractures. Three major fracture patterns emerged: radial styloid, dorsal, and volar. Each major pattern had two subtypes. Associated injuries were common. Scapholunate dissociation was associated with all types, not just the radial styloid fracture pattern.

Conclusions The fracture patterns of two-part intraarticular fractures mostly involved the interligamentous zones. Three major groups were identified: dorsal, volar, and radial styloid. Lister's tubercle was preserved with fractures tending to propagate radial or ulnar to this structure. We suggest conceptualizing fracture fragments as osseoligamentous units to aid prediction of fracture patterns and associated injury.

Study Design Diagnostic III

Level of Evidence 3

Keywords

- anatomy
- computerized tomography
- distal radius
- fracture
- ligaments

It has been demonstrated that articular involvement in distal radius fractures is associated with poorer radiographic and clinical outcomes.^{1,2} Young patients will typically have high-energy injuries with complex fracture patterns and extensive soft tissue damage. Subsequently, an increased trend toward operative intervention for distal radius fractures has been observed.^{2,3} A preoperative analysis of the fracture pattern is critical to surgical strategy. In this regard, computed-tomography (CT) scans are superior to standard x-rays.⁴

Although several classifications for distal radius fractures exist,^{5–8} and DePalma demonstrated that even with comminuted fractures the ligaments remain intact,⁹ no one has attempted to characterize articular fragmentation patterns and their relationship to the extrinsic ligaments of the radiocarpal joint. As different studies reported,^{10–12} the distribution of the fracture lines seems to be reproducible. Tanabe¹⁰ observed that fracture patterns related to mechanism grouping flexion, extension, and neutral fractures. They did not relate the fracture pattern to osseous features (such as Lister's tubercle) or ligamentous origins. Mandziak et al¹¹ described the fracture pattern only according to the ligamentous origins. However, both authors included mixed groups of distal intraarticular radius fractures.

In Mandziak's paper, most fracture lines met the cortex of the distal radius *between* the ligamentous origins. Three regions were particularly vulnerable to fracture:

1. the origin of the thin radioscapulohumate ligament (or area between the short and long radiolunate ligaments), which is not a true ligament in a mechanical or histological sense¹³
2. the central sigmoid notch region
3. the area between the radioscapophcapitate and dorsal radiocarpal ligaments.

We hypothesized, therefore, that fracture lines of distal radial intraarticular *two-part* fractures (DRIF) had reproducible fracture patterns, propagated to the cortical bone *between* ligament origins, and did not involve Lister's tubercle. We also aimed to document the injuries associated with these fractures.

The authors had three specific hypotheses:

1. The sagittal radial styloid fractures connect the cortex between the short and the long radio-lunate ligament and the dorso-radial aspect between the radioscapophcapitate (RSC) ligament and the dorsal radiocarpal ligament without breaching through Lister's tubercle.
2. The dorsal fractures connect the central sigmoid notch and zones between the RSC and the dorsal radiocarpal ligament, without breaching through Lister's' tubercle.
3. The volar fractures connect the sigmoid notch and either the volar cortex between the short and the long radiolunate ligament or the zone between the RSC and the dorsal radiocarpal ligament (► Fig. 1a).

Material and Methods

Patients' Demographics

The research had ethics approval from the hospital ethics committee. Patients gave informed consent and had a CT scan of the wrist as a part of their preoperative assessment using the Picture Archiving and Communication System (PACS) of two teaching hospitals between April 2003 and May 2008. All fractures were classified according to the AO Classification System.¹⁴ The inclusion criteria were: (1) distal radial intra-articular two-part fracture (DRIF) and (2) preoperative CT scan of adequate image quality. Associated ulna styloid fractures were included.

Fig. 1 (A) The articular rim was divided into eleven zones for analysis, corresponding to ligamentous attachments (marked with red bars). Zone 1, short radiolunate ligament (SRL); zone 2, radioscapulohumate ligament (RSL); zone 3, long radiolunate ligament (LRL); zone 4, radioscapophcapitate ligament (RSC); zones 5, 6, and 7, the gap between the radioscapophcapitate (RSC) and dorsal radiocarpal ligaments (DRC) divided into three zones for analysis; zone 8, dorsal radiocarpal ligament (DRC); zone 9, dorsal radioulnar ligament (DRU); zone 10, central sigmoid notch region; zone 11, volar radioulnar ligament (VRU). Note: zones 6 and 7 were defined radially and ulnarly to Lister's tubercle respectively. (B) The coordinate system: cortical breach zone were assessed as percentiles of the maximal radial width or as a percentile of the maximal sigmoid notch height both measured from the volar ulnar border to allow comparison of data between radii of different size.

Radiographic Assessment

Multiplanar CT (axial and reconstructive coronal and sagittal images) was used. A representative axial slice through the subchondral region was chosen, which demonstrated the articular fragmentation. The axial slices were transposed onto a standardized template and the coordinates of each fracture were mapped similar to Mandziak's paper (►Fig. 1a). The standardized coordinate-system model of an axial distal radius measures 100 pixels (width) $\times$ 75 pixels (height). The circumference of the model was divided into 11 zones and as a modification, Lister's tubercle was defined (L) and zone 7 was set ulnar to it, whereas zone 6 was set radial to it.¹¹

As the radius size varies between people,^{15,16} cortical breaches were measured as a percentile of the maximal radial coronal width or as a ratio of the maximal radial sagittal height (►Fig. 1b). This allowed comparison of all the fracture patterns.

Throughout the manuscript all percentiles are provided as means. Each cortical breach was defined using this coordinate system and the proximity to radiocarpal and radioulnar ligament origin was analyzed.

With sagittal CT images and three-dimensional reconstructive images, we identified displacement, defined as 1mm.¹⁷ We defined the displacement direction using the fracture fragment that was separated from the radial shaft on

the axial CT. For example, dorsal fractures were identified by the dorsal component being fractured and separated from the shaft.

All measurements were repeated independently by two examiners. The kappa value was 0.954, demonstrating excellent interobserver agreement. Associated lesions were also noted on the CT scans.

Statistical Analysis

Nonparametric statistical analysis was by an independent statistician. Mean and standard deviation (SD) were calculated for quantitative measurements. Chi-square test was used to compare proportions. The level of significance was $p = 0.05$.

Results

Patients' Demographics

Forty-two scans from 42 patients met the inclusion criteria. The mean age was 41 years (range 15–77) at the time of trauma. In the 27 men and 15 women, the dominant arm was involved 64% and 52% respectively.

Cortical Breach Distribution (►Fig. 2)

Seventy-one of the 84 cortical breaches occurred in an interligamentous zone (85%) and only two fractures (5%) involved Lister's tubercle.

Fig. 2 Fracture distribution pattern as absolute numbers and percentages (in brackets) of all cortical breaches of DRIF in an interligamentous zone.

Fig. 3 Radial styloid fractures, all propagated to a similar point on the volar cortex. The oblique group propagated radial to Lister's tubercle. The sagittal group propagated ulnar to Lister's tubercle. Percentage of total cortical breaches are provided in brackets.

All of the interligamentous cortical breaches were located in four main site sites:

1. dorsally between Lister's tubercle and RSC ($n = 20$ breaches; mean position $78^{\text{th}} \pm 7$ percentile)
2. dorsally between the DRC and Lister's tubercle ($n = 12$; mean $34^{\text{th}} \pm 9$ percentile)
3. volarly between the SRL and LRL ($n = 20$; mean $54^{\text{th}} \pm 12$ percentile)
4. central sigmoid notch ($n = 20$; mean $31^{\text{st}} \pm 10$ percentile)

Fracture Distribution

The DRIF were of three main types:

1. radial styloid (20 patients),
2. dorsal ulnar (13 patients)
3. volar (9 patients)

Radial Styloid Fracture Group ($n = 20$)

There were two types of radial styloid fractures ($\rightarrow$ Fig. 3):

1. radial styloid oblique (RSO) (12 patients)
2. radial styloid sagittal (RSS) (8 patients)

Both the oblique and sagittal fractures propagated to the same volar area ($57^{\text{th}} \pm 16$ percentile); however, the dorsal breach point varied. In the oblique group, the fracture exited between Lister's tubercle and the RSC ($74^{\text{th}} \pm 14$ percentile). In the sagittal group, the dorsal fracture was between the DRC and Lister's tubercle ($32^{\text{nd}} \pm 8$ percentile).

Dorsal Fracture Group ($n = 11$ patients)

There were two types of dorsal fractures ($\rightarrow$ Fig. 4):

1. dorsal ulnar corner (DUC) (6 patients)
2. dorsal coronal (DC) (5 patients)

Both involved the sigmoid notch ($33^{\text{rd}} \pm 9$ percentile) and breached dorsally either ulnar or radial to Lister's tubercle. In the DUC group, the fracture lines breached the radius between the DRC and Lister's tubercle ($35^{\text{th}} \pm 10$ percentile). In the DC group, the fracture propagated between Lister's tubercle and the RSC ($65^{\text{th}} \pm 5$ percentile).

Volar Fracture Group ($n = 9$ patients)

There were two types of volar fracture ($\rightarrow$ Fig. 5):

Fig. 4 Dorsal fractures: all propagated to the sigmoid notch. Dorsal ulnar corner fracture propagated ulnar to Lister's tubercle. Dorsal coronal fracture propagated radial to Lister's tubercle. Percentage of total cortical breaches are provided in brackets.

Fig. 5 Volar fracture group: all volar fractures had a similar breach point in central sigmoid notch. However, the fractures were either volar ulnar or volar coronal. Percentage of total cortical breaches is provided in brackets.

Table 1 Associated lesions with distal intraarticular two-part radius fractures

<i>Associated injuries</i>	<i>Radial styloid fractures (n = 20) n (%)</i>	<i>Dorso ulnar fractures (n = 13) n (%)</i>	<i>Volar fractures (n = 9) n (%)</i>	<i>All lesions n</i>	<i>In % of all DRIF</i>
Scaphoid fracture	1	2	0	3	
Lunate fracture	2	1	1	4	
Triquetrum fracture	2	1	0	3	
Hamate fracture	1	1	0	2	
Carpal fracture	6 (30)	5 (38)	1 (11)	12	(28)
Scapho-lunate diastasis*	2 (10)	2 (15)	2 (22)	6	(14)
Ulnar styloid fracture	6 (30)	4 (31)	2 (22)	12	(29)
Total associated lesions	14	11	5	30	
Total patients with concomitant lesions	9/45	8/62	5/56	22	52

Total numbers of concomitant lesions and percentages of the respecting fractures are listed.

*Scapho-lunate diastasis (>3mm) measured according to Linscheid.^{15,16}

1. volar-ulnar-corner (VUC) (5 patients)
2. volar coronal (VC) (4 patients)

Both fracture types pass through the central sigmoid notch ($30^{\text{th}} \pm 10$ percentile). In the VUC group, the fracture breached between the LRL and the SRL ($54^{\text{th}} \pm 11$ percentile) and the coronal group between Lister's tubercle and close to the RSC origin. ($95^{\text{th}} \pm 5$ percentile).

Associated Lesions (~Table 1)

Thirty associated lesions were found radiographically in 22 patients (52% of all DRIF). Only 10% of the radial styloid fractures had a scapholunate diastasis, whereas 22% in the VUC group had a diastasis of more than 3 mm. Since arthroscopy was not performed, it is not possible to state whether these were preexisting lesions. Carpal fractures were least frequent in the VUC group. Overall, associated bony lesions were not significantly more frequent in any group ($p = 0.6$).

Mechanism of Injury

Twenty-nine patients had high-energy trauma or a fall from greater than standing height (69%; low energy trauma = trauma resulting from a fall of standing height or less, high energy trauma = an industrial injury, a fall from a greater height). No fractures in the low energy group involved a ligamentous zone, whereas thirteen fracture lines involved a ligamentous zone in the high-energy group ($p = 0.004$). Eleven of the twelve carpal fractures occurred in the high energy group ($p = 0.045$).

Discussion

Two-part intraarticular distal radius fractures occur in reproducible patterns. The fracture patterns observed were significantly associated with interligamentous zones similar to the findings of Mandziak.¹¹ Lister's tubercle was preserved. Our hypothesis was confirmed.

The authors postulate that the ligaments are important in the etiology of intraarticular two-part fractures of the distal radius.^{18,19} Ligaments are under maximum tension at the extremes of motion. When an individual falls onto the outstretched hand, the wrist is forced past the physiological range, creating greater tension in the ligaments. The ligaments transmit this tension to the radius,¹⁸ while the bone directly adjacent to the ligament does not receive the tensile forces. The bone fails at this interface, between the ligament attachments.

The exception is the high-energy injury where the forces are much greater, and the fracture patterns and associated injuries are more complex and random.

The authors also postulate that the fibrocartilage insertion of the ligament may have a "dampening" effect on the fracture forces by allowing a more gradual transfer of these forces to the bone and, therefore, be protective of fractures at the location.¹⁸

Three common groups of DRIF were noted: dorsal, volar, and radial styloid. Subsequently, these groups had two subtypes, each having a major ligament attachment: the dorsal

group with the DRC, the volar ulnar corner with the SRL, the volar coronal with the SRL and LRL, and the radial styloid with the LRL and RSC.

In this light, the fracture fragments can be conceptualized as a osseo-ligamentous units. This concept predicts where fractures are likely to occur and suggests a biomechanical reason as to why they occur in these locations. Other classification systems^{5,8,10,14,20,21} only assess osseous fragments or injury mechanisms.

Associated bony lesions with DRIF are frequent, the most common being ulna styloid fractures. Associated fractures were more frequent in the radial styloid and dorsal ulnar fracture groups. Intercarpal injuries are also common.²² We found that scapholunate dissociations did not have a stronger association with radial styloid fractures (or chauffeurs fractures) contrary to previous articles.²³ They were more commonly associated with fractures that involved the lunate facet, and the highest percentage frequency was noted with volar fractures; but again, we could not rule out a preexisting diastasis.

There are limitations with our study. First, this is a retrospective analysis in two centers. Also, the patient sample only included those undergoing internal fixation. There was a selection bias of younger and more highly functional patients to have CT scans. More severe injuries were included. Nevertheless, as data was collected from two trauma centers, it may be a representative sample. Second, only intraarticular two-part fractures were assessed. These tended to be lower energy. The impact of the ligamentous origins in high energy or more highly comminuted distal intraarticular radius fractures was not addressed. As this was a radiographic study, and we did not directly verify the origins of the ligamentous attachments, we made several assumptions as to the interligamentous zones based on previous anatomical studies. Further study could be undertaken to address 3- and 4-part fracture groups to expand this osseo-ligamentous concept to more complex fractures.

Note

Study performed at the University of Adelaide, Department of Orthopaedics and Trauma, Royal Adelaide Hospital, and Modbury Public Hospital, South Australia, Australia.

Conflict of Interest

None.

References

- Goldfarb CA, Rudzki JR, Catalano LW, Hughes M, Borrelli J Jr. Fifteen-year outcome of displaced intra-articular fractures of the distal radius. *J Hand Surg Am* 2006;31(4):633–639
- Koval KJ, Harrast JJ, Anglen JO, Weinstein JN. Fractures of the distal part of the radius. The evolution of practice over time. Where's the evidence? *J Bone Joint Surg Am* 2008;90(9):1855–1861
- Knirk JL, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults. *J Bone Joint Surg Am* 1986;68(5):647–659
- Pruitt DL, Gilula LA, Manske PR, Vannier MW. Computed tomography scanning with image reconstruction in evaluation of distal radius fractures. *J Hand Surg Am* 1994;19(5):720–727
- Medoff RJ. Essential radiographic evaluation for distal radius fractures. *Hand Clin* 2005;21(3):279–288
- Melone CP Jr. Distal radius fractures: patterns of articular fragmentation. *Orthop Clin North Am* 1993;24(2):239–253
- Jupiter JB, Fernandez DL. Comparative classification for fractures of the distal end of the radius. *J Hand Surg Am* 1997;22(4):563–571
- Frykman G. Fracture of the distal radius including sequelae—shoulder-hand-finger syndrome, disturbance in the distal radio-ulnar joint and impairment of nerve function. A clinical and experimental study. *Acta Orthop Scand* 1967 (Suppl 108):3
- DePALMA AF. Comminuted fractures of the distal end of the radius treated by ulnar pinning. *J Bone Joint Surg Am* 1952;24-A(3):651–662
- Tanabe K, Nakajima T, Sogo E, Denno K, Horiki M, Nakagawa R. Intra-articular fractures of the distal radius evaluated by computed tomography. *J Hand Surg Am* 2011;36(11):1798–1803
- Mandziak DG, Watts AC, Bain GI. Ligament contribution to patterns of articular fractures of the distal radius. *J Hand Surg Am* 2011;36(10):1621–1625
- Baumbach SF, Schmidt R, Varga P, Heinz T, Vécsei V, Zysset PK. Where is the distal fracture line location of dorsally displaced distal radius fractures? *J Orthop Res* 2011;29(4):489–494
- Berger RA, Blair WF. The radioscapulohumeral ligament: a gross and histologic description. *Anat Rec* 1984;210(2):393–405
- Muller ME, Nazarian S, Koch P, Schatzker J. The comprehensive classification of fractures of long bones. New York: Springer-Verlag; 1990
- Baumbach SF, Krusche-Mandl I, Huf W, Mall G, Fialka C. Linear intra-bone geometry dependencies of the radius: radius length determination by maximum distal width. *Eur J Radiol* 2012;81(5):947–950
- Windisch G, Clement H, Tanzer K, et al. Promontory of radius: a new anatomical description on the distal radius. *Surg Radiol Anat* 2007;29(8):629–633
- Mehta JA, Bain GI, Heptinstall RJ. Anatomical reduction of intra-articular fractures of the distal radius. An arthroscopically-assisted approach. *J Bone Joint Surg Br* 2000;82(1):79–86
- Thomopoulos S, Marquez JP, Weinberger B, Birman V, Genin GM. Collagen fiber orientation at the tendon to bone insertion and its influence on stress concentrations. *J Biomech* 2006;39(10):1842–1851
- Thomopoulos S, Williams GR, Gimbel JA, Favata M, Soslowsky LJ. Variation of biomechanical, structural, and compositional properties along the tendon to bone insertion site. *J Orthop Res* 2003;21(3):413–419
- Bradway JK, Amadio PC, Cooney WP. Open reduction and internal fixation of displaced, comminuted intra-articular fractures of the distal end of the radius. *J Bone Joint Surg Am* 1989;71(6):839–847

- 21 Melone CP Jr. Articular fractures of the distal radius. *Orthop Clin North Am* 1984;15(2):217-236
- 22 Pilný J, Kubes J, Hoza P, Mechl M, Visna P. [Scapholunate instability of the wrist following distal radius fracture]. *Acta Chir Orthop Traumatol Cech* 2007;74(1):55-58
- 23 Helm RH, Tonkin MA. The chauffeur's fracture: simple or complex? *J Hand Surg [Br]* 1992;17(2):156-159