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Risk Factors for the Incidence of the Volar Lunate Facet Fragments in Distal Radius Fractures

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Abstract

Background The volar lip of the distal radius is the key structure for wrist joint stability. Rigid fixation of the volar lunate facet (VLF) fragment is difficult because of its unique anatomy, and a high rate of postoperative displacement was demonstrated.

Purposes The aim of the study is to identify risk factors for VLF in distal radius fractures (DRFs) and to reconsider the important point for primary fixation.

Patients and Methods One hundred fifty-five patients who underwent open reduction and internal fixation for an DRF were included and classified into one of the following two groups: VLF(+)or VLF(−). Demographic data, including age, sex, body mass index (BMI), laterality, trauma mechanism, and AO Foundation/Orthopaedic Trauma Association (AO/OTA) classification were recorded. Several parameters were investigated using wrist radiographs of the uninjured side and computed tomography scans of the injured side. Univariate and multivariate logistic regression analyses were performed to evaluate the risk factors for VLF.

Results There were 25 patients in the VLF(+) group and 130 patients in the VLF(−) group. The incidence of VLF was 16.1%. The VLF(+) group tended to have a higher BMI and higher energy trauma mechanism. The odds ratio for the sigmoid notch angle (SNA), volar tilt (VT), and lunate facet curvature radius (LFCR) were 0.84, 1.32, and 0.70, respectively, with multivariate analysis, which was significant. A smaller SNA, larger VT, and smaller LFCR are potential risk factors for VLF.

Conclusion Over-reduction of the VT at primary fixation should be avoided because it could place an excess burden on the VLF and cause subsequent postoperative fixation failure and volar carpal subluxation.

Level of Evidence IV

Keywords
- distal radius fracture
- volar lunate facet fragment
- loss of reduction
- risk factor

Volar locking plate fixation for distal radius fractures (DRFs) obtains rigid fixation, enables early return to activities of daily living, and achieves good clinical results.[1] However, a standard volar locking plate may not be suitable for patients with a volar lunate facet (VLF) fragment, which has been investigated in the last two decades.

As Harness et al and other researchers reported, a loss of reduction results in an articular incongruity and volar carpal subluxation, which directly leads to pain and impaired function of the affected wrist.[2,3] Because the rotation center of the wrist motion is the radiolunate joint, the volar aspect of the lunate fossa must bear a shearing force (axial load) due

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to volar flexion of the wrist. Additionally, because the VLF is an attachment site for the short radiolunate ligament, volar distal radioulnar ligament of the triangular fibrocartilage complex (TFCC), and volar capsule, tensile traction force is applied during wrist motion. VLF is the keystone for the radiocarpal joint (RCJ) and distal radioulnar joint (DRUJ), and the above-mentioned morphological features of VLF could explain the difficulty in its stable fixation. The fixation failure rate was shown to be approximately 4 to 13%.[3,4] If the VLF showed motion during direct intraoperative testing, supplemental fixation should be used to avoid a loss of reduction.[5] Several techniques to stabilize the small VLF have been described, such as capsular suture, spring wire fixation, unique mini or hook plates, distally positioned special volar plates, temporally radiolunate fixation, and external fixation.[6–9]

We hypothesized that there was a specific morphology of the pre-injured distal radius that could affect VLF occurrence. The first purpose of the present study was to identify the risk factors for VLF in DRF. The second purpose was to reconsider important points in VLF primary fixation based on that information.

Patients and Methods

All patients who underwent open reduction and internal fixation (ORIF) for DRFs from December 2014 to January 2020 at levels 1 and 2 trauma centers were included in the current study. Demographic data, such as age, sex, body mass index (BMI), laterality, trauma mechanism, and AO Foundation/Orthopaedic Trauma Association (AO/OTA) classification were recorded. Wrist radiographs of the uninjured side and computed tomography (CT) scans of the injured side were evaluated. Patients who were younger than 18 years of age and who exhibited radiographic pathology or past trauma affecting the contralateral distal radius were excluded. All patients were classified into one of the following two groups: VLF(+) or VLF(−). A previous study defined VLF as a VLF fragment that has a volar cortex length of less than 10 mm from the distal edge on a sagittal CT slice, which is cut 5 mm radial from the ulnar edge of the distal radius.[10]

Evaluation of the anteroposterior (AP) radiograph is shown in ►**Fig. 1**. According to the distal joint surface (line 1), the lunate was classified as type 1 or type 2. The longitudinal bone axis was drawn to bisect the radial and ulnar edge of the distal radius (line 2). A line perpendicular to line 2 that passes the mid-point of dorso-ulnar and volar-ulnar cortex of the distal radius was drawn (line 3). The mid-point above and the tip of the radial styloid were connected (line 4). The angle between lines 3 and 4 was defined as radial inclination (RI). A line parallel to line 3 and passing the most distal point of the ulnar head was drawn (line 5). The distance between lines 3 and 5 was defined as the ulnar variance (UV). The UV is negative if line 5 is proximal to line 3 (as presented), otherwise it is positive. The sigmoid notch orientation line was drawn at the DRUJ (line 6). The angle between lines 2 and 6 was defined as the sigmoid notch angle (SNA).[11] The SNA is positive if line 6 is oriented toward the ulnar head with respect to line 2 (as presented), and it is negative if it is oriented toward the radial styloid.

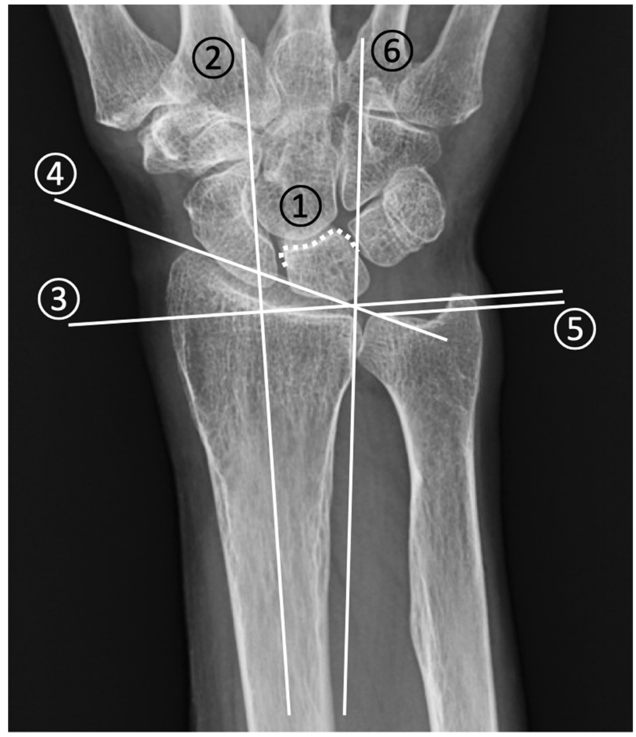

Fig. 1 Anteroposterior (AP) radiograph evaluation. Line 1. The distal joint surface of the lunate was classified as type 1 or type 2. Line 2. Longitudinal bone axis of the distal radius. Line 3. A line perpendicular to line 2 and passing the mid-point of dorso-ulnar and volar-ulnar cortex of the distal radius. Line 4. The mid-points above and the tip of radial styloid were connected. Line 5. A line parallel to line 3 and passing the most distal point of ulnar head. Line 6. The sigmoid notch orientation line at the distal radioulnar joint (DRUJ). Radial inclination (RI) was defined as the angle between lines 3 and 4. Ulnar variance (UV) was defined as the distance between lines 3 and 5, which is negative if line 5 is proximal to line 3 (as presented). The sigmoid notch angle (SNA) was defined as the angle between lines 2 and 6, which is positive if line 6 is oriented toward the ulnar head with respect to line 2 (as presented).

Evaluation of the lateral radiograph is shown in ►**Fig. 2**. The volar edge of the radius was drawn (line 1). A line perpendicular to line 1 and passing the volar edge of the lunate facet of distal radius was drawn (line 2). The volar edge and the dorsal edge of the lunate facet were connected (line 3). The angle between lines 2 and 3 was defined as volar tilt (VT). A line parallel to line 1 and passing the mid-point of the volar and dorsal edges of distal joint surface of the lunate was drawn (line 4). The distance between lines 1 and 4 was defined as the lunate volar translation (LVT).[3] The LVT is negative if line 4 is dorsal to line 1 (as presented), otherwise it is positive. A circle was placed at the lunate facet of the distal radius and passing the volar and dorsal edge (circle 5). The curvature radius of the above circle was measured as the lunate facet curvature radius (LFCR). A line parallel to line 3 and passing the most proximal point of circle 5 was drawn (line 6). The distance between lines 3 and 6 was defined as the lunate facet depth (LFD).

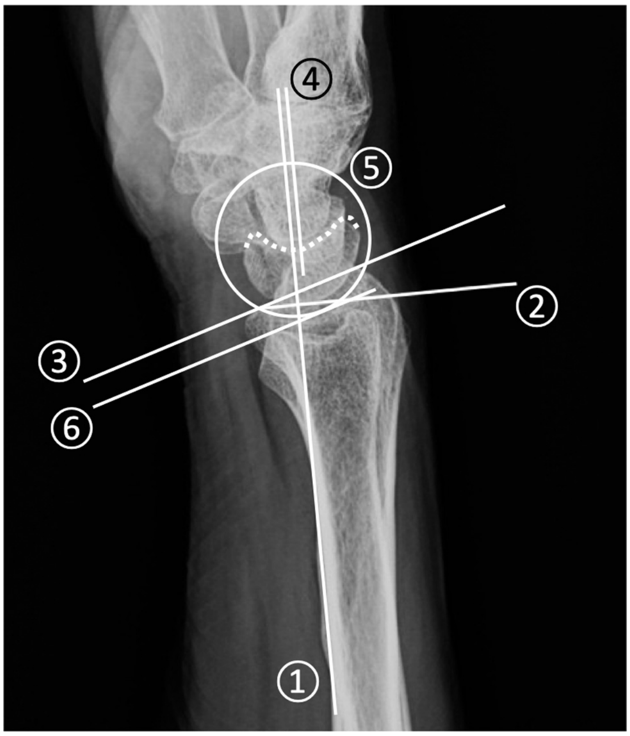

Fig. 2 Lateral radiograph evaluation. Line 1. Volar edge of the radius. Line 2. A line perpendicular to line 1 and passing the volar edge of the lunate facet of distal radius. Line 3. The volar and dorsal edges of lunate facet were connected. Line 4. Draw the line parallel to line 1 and passing the mid-point of volar and dorsal edge of distal joint surface of lunate. Circle 5. Apply the circle at the lunate facet of distal radius and passing the volar and dorsal edge. Line 6. Draw the line parallel to line 3 and passing the most proximal point of circle 5. The volar tilt (VT) was defined as the angle between lines 2 and 3. The lunate volar translation (LVT) was defined as the distance between lines 1 and 4, which is negative if line 4 is dorsal to line 1 (as presented). The lunate facet curvature radius (LFCR) was measured as the curvature radius of Circle 5. The lunate facet depth (LFD) was defined as the distance between lines 3 and 6.

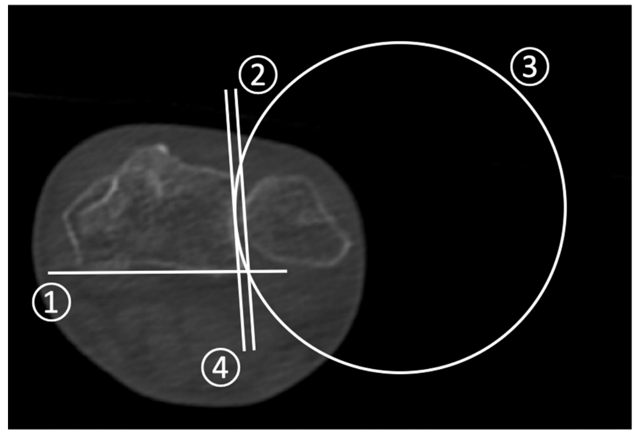

Fig. 3 Axial CT slice evaluation. Line 1. Volar edge of the distal radius. Line 2. The volar and dorsal edges of the ulnar facet were connected. Circle 3. The circle at the ulnar facet of the distal radius and passing the volar and dorsal edge. Line 4. A line parallel to line 2 and passing the most radial point of circle 3. The sigmoid notch divergence angle (SNDA) was defined as the angle between lines 1 and 2, which is <90 degrees if line 2 is oriented toward the radius (as presented). The ulnar facet curvature radius (UFCR) was measured as the curvature radius of Circle 3. The ulnar facet depth (UFD) was defined as the distance between lines 2 and 4.

The axial CT slice was evaluated and is shown in ►**Fig. 3**. A line along the volar edge of the distal radius was drawn (line 1). The volar and dorsal edges of the ulnar facet were connected (line 2). The angle between lines 1 and 2 was defined as the sigmoid notch divergence angle (SNDA).[12] The SNDA is <90 degrees if line 2 is oriented toward the radius (as presented), and it is >90 degrees if it is oriented toward the ulna. A circle is placed at the ulnar facet of the distal radius and passing the volar and dorsal edges (circle 3). The curvature radius of the above circle was measured as the ulnar facet curvature radius.[11] A line parallel to line 2 and passing the most radial point of circle 3 was drawn (line 4). The distance between lines 2 and 4 was defined as the ulnar facet depth.

Statistical Analysis

All radiographic evaluations were performed by a single observer (S.M.). Data were presented as the mean ± standard deviation and analyzed using JMP Pro 15.0 (SAS Institute, Cary, NC). The Student's *t*-test was used to compare the demographic data and radiographic parameters. Fisher's exact test was performed to analyze categorical data. Univariate and multivariate logistic regression analyses were used to evaluate the risk factors for the incidence of VLF. We calculated the odds ratio (OR) with 95% confidence interval (95% CI), and provided *p*-values. Factors included in the multivariate model were those with $p < 0.1$ in the univariate analysis. $p < 0.05$ was considered to be statistically significant.

Results

There were 25 patients in the VLF(+) group and 130 patients in the VLF(−) group. The incidence of VLF was 16.1%. Demographic and radiological parameters in both groups are shown in ►**Table 1**. For demographic data, the VLF(+) group tended to show a higher BMI and high energy trauma mechanism compared with that of the VLF(−) group. Because all the VLF fracture types are classified as AO/OTA B3.3 and C3, significant difference was detected in AO/OTA type between the VLF(+) and VLF(−) group ($p < 0.01$). For radiographic parameters, SNA in the AP radiograph and SNDA in the axial CT slice tended to be smaller in the VLF(+) group compared with that in the VLF(−) group. In terms of the lateral radiograph, a larger VT, LVT, and LFD and a smaller LFCR were recorded in VLF(+) group with significance (p <0.01, = 0.015, <0.01, <0.01, respectively).

The results of the univariate and multivariate logistic regression analyses are presented in ►**Table 2**. The results of univariate logistic model indicated that BMI, SNA, VT, LVT, LFCR, and LFD should be selected for the multivariate logistic model. Among them, the ORs of SNA, VT, and LFCR were 0.84, 1.32, and 0.70, respectively, which were significantly different between the groups. A smaller SNA, a larger VT, and a smaller LFCR are possible risk factors for VLF.

Table 1 Patient demographics in distal radius fractures with and without VLF

	VLF(+)	VLF(−)	*p*-Value
	(*N* = 25)	(*N* = 130)	
Age (y)	62.2 ± 17.8	65.8 ± 17.7	0.379
Sex (male/female)	6/19	32/98	1.000
BMI (kg/m^2)	24.4 ± 4.4	22.8 ± 3.6	0.094
Laterality (right/left)	13/12	53/77	0.378
Trauma mechanism (fall/traffic accident/fall from height)	14/8/3	101/13/16	0.017
AO/OTA (type A/B/C)	0/6/19	38/55/37	<0.001
lunate (type 1/2)	21/4	115/15	0.513
Radial inclination (degree)	21.4 ± 3.1	21.2 ± 3.0	0.755
Ulnar variance (mm)	0.3 ± 1.6	0.0 ± 1.5	0.306
Sigmoid notch angle (degree)	−1.1 ± 4.8	0.7 ± 4.5	0.093
Volar tilt (degree)	20.3 ± 3.3	14.1 ± 4.4	<0.001
Lunate volar translation (mm)	0.5 ± 2.1	−0.7 ± 2.4	0.015
Lunate facet curvature radius (mm)	11.5 ± 1.8	14.0 ± 2.5	<0.001
Lunate facet depth (mm)	4.8 ± 0.7	3.6 ± 0.9	<0.001
Sigmoid notch divergence angle (degree)	88.2 ± 3.8	90.0 ± 3.6	0.050
Ulnar facet curvature radius (mm)	18.7 ± 5.3	17.9 ± 5.1	0.489
Ulnar facet depth (mm)	1.5 ± 0.6	1.5 ± 0.7	0.694

Table 2 Logistic regression analysis of risk factors for VLF occurrence

	Univariate analysis			Multivariate analysis		
	Odds ratio	95% CI	*p*-Value	Odds ratio	95% CI	p-Value
Age	0.989	0.97–1.01	0.366			
Female sex	1.034	0.40–3.04	0.948			
BMI	1.11	1.00–1.24	0.003	1.10	0.95–1.28	0.213
Right side	1.57	0.67–3.72	0.301			
Trauma mechanism (comparison: fall)						
Fall from height	1.35	0.35–5.24	0.662			
Traffic accident	4.44	1.56–12.60	0.005			
Type 2 lunate	1.46	0.44–4.83	0.535			
Radial inclination	1.02	0.89–1.18	0.746			
Ulnar variance	1.17	0.89–1.55	0.262			
Sigmoid notch angle	0.92	0.84–1.01	0.075	0.84	0.72–0.96	0.017
Volar tilt	1.53	1.29–1.82	<0.001	1.32	1.05–1.73	0.026
Lunate volar translation	1.28	1.04–1.57	0.021	1.02	0.76–1.38	0.882
Lunate facet curvature radius	0.53	0.39–0.72	<0.001	0.70	0.49–0.95	0.036
Lunate facet depth	4.67	2.51–8.69	<0.001	1.53	0.68–3.80	0.326
Sigmoid notch divergence angle	0.88	0.79–0.99	0.037			
Ulnar facet curvature radius	1.03	0.95–1.12	0.464			
Ulnar facet depth	1.13	0.59–2.16	0.719			

Discussion

DRFs with VLF fragments are challenging for surgeons to manage due to their high rate of postoperative fixation failure. We investigated the characteristics of the pre-injured distal radius and identified risk factors for VLF occurrence to reveal the important point for primary fixation. The incidence of the VLF was 16.1% in the current study, which was relatively higher than that in previous studies (7.0–13.5%).[4,8,13]

The volar lip of the distal radius is the key structure for RCJ and DRUJ stability. Because the lunate is the rotation center of the RCJ motion, a strong axial load is applied here when the wrist is in volar flexion. The volar lip is a stable buttress for the palmar dislocation. Critical ligaments, such as the short radiolunate ligament, TFCC, and volar capsule, also attach to this site and increase joint stability. VLF is defined as the fracture of the volar lip, which may not be effectively supported by the standard anatomical locking plates alone. This is because the volar lip is a unique anatomical feature, sloping downward from the proximal to the distal side and from the radial to the ulnar side. Loss of reduction was associated with a short volar cortex (7 mm, 9 mm, and 12 mm by Nanno et al, Benis et al, and Beck et al, respectively).[3,14,15] We used Obata et al's VLF definition, which was a length of 10 mm or less.[10] To avoid postoperative VLF displacement, the position of volar locking plates should be as distal and ulnar as possible for VLF coverage. Izawa et al showed that the plate should cover more than 65% of the VLF volar cortex to prevent postoperative fixation failure.[13] However, plate placement far beyond the watershed line could increase the potential risk of interference with the median nerve and flexor tendon. Anatomical variation of the distal radius was demonstrated by several studies. Tolat et al investigated the transverse section of the cadaveric specimens and reported four types of ulnar facets (flat face, ski slope, C type, and S type).[16] O'Shaughnessy et al investigated DRUJ morphology using an AP X-ray, and they demonstrated a 6% prevalence of reverse obliquity of the ulnar side of the distal radius. They also concluded that reverse oblique morphology correlated with ulnar-sided wrist pathology including DRUJ arthritis.[17] Kumar et al analyzed the volar surface of the uninjured distal radius using CT scans, and they showed that considerable variation occurs in volar surface curvature morphology.[18]

In the current study, a smaller SNA, larger VT, and smaller LFCR were shown to be the possible risk factors for VLF occurrence. With a larger SNA in the AP radiograph, axial load from the lunate should be applied toward the radial bone axis. However, with a smaller SNA (reverse oblique type[17]), it would be applied in the ulnar direction, which can result in fracture of the distal volar lip. A larger VT and smaller LFCR in the lateral radiograph means that the deep lunate facet is tilting in the volar direction. The axial load from the lunate strongly affects the volar lip of the distal radius owing to these structural features. It is always technically demanding to treat postoperative VLF displacement and subsequent volar dislocation of the lunate, and Orbay et al proposed the volar opening wedge osteotomy as a salvage procedure for this, which was based on the concept that decreased VT should relieve the burden on the volar lip.[19] Our results support their concept because a larger VT is a potential risk for VLF occurrence. Because a non-anatomical joint surface will cause cartilage wear and limit a patient's range of motion, it is not realistic to modify the SNA and LFCR during primary fixation. A short VLF volar cortex and the initial lunate facet subsidence were shown to be risk factors for VLF postoperative reduction loss and volar carpal subluxation.[3,14,15] To resolve this problem, over-reduction of the VT at primary fixation, which could place an excess burden on the VLF, should be avoided. This was consistent with the results of another study, which suggested that volar angulation deformity of the distal radius often results in DRUJ stiffness with subsequent painful forearm rotation, and it should be corrected to a VT of 10 degrees.[20]

There are several limitations associated with the present study. First, all patients in our cohort underwent ORIF for a DRF, and those who received conservative treatment were excluded. This might cause selection bias to the outcome in the current study. Second, inter- and intraobserver reliability of the radiographic parameters was not proved in this study. This could be improved using more than one reviewer and multiple examinations, but some of these parameters were shown to have excellent reliability in other studies, and our goal was not to assess the inter- and intraobserver reliability.[12,21] Third, radiographic parameters include a CT scan of the injured side. Accurate measurement can be achieved in the axial CT slice with minimal fracture displacement, but displacement of the fracture line results in an inaccurate measurement. A CT scan of the uninjured side would better detect the risk factors for VLF occurrence, but we did not routinely perform a CT scan of the uninjured side and we cannot provide these results due to the retrospective nature of this study. Fourth, the small number of patients might introduce the risk of errors in the statistical analysis. Although there is a relatively low incidence of VLF in DRFs, which is related to this limitation, further study with sufficient number of patients is necessary.

Ethical Review Approval
The study protocol and research were performed in accordance with the Ethics Committee of our institution (SHIN22-033 and RGMC2021-028).

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Conflict of Interest
None declared.

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