Title of the paper

Volar locking plate fixation for intra-articular distal radius fractures with volar lunate facet fragments distal to the watershed line

Running title: Volar plate fixation for distal radius fracture

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ABSTRACT

Background: Standard volar plating of distal radius fractures may not adequately fixate the volar lunate facet (VLF) fragment, leading to volar carpal subluxation. In this study, we hypothesized that the size of the VLF fragments distal to the watershed line might affect the reduction loss after distally placed volar locking plate fixation for intra-articular distal radius fracture, and aimed to prove that small displaced VLF fragments was a risk factor in causing reduction loss.

Methods: Twenty-seven hands in 27 patients with intra-articular distal radius fractures with VLF fragments distal to the watershed line were treated using Acu-Loc 2 volar distal radius locking plate fixation.

Results: At final follow-up, the mean Mayo Performance Score was 90.9 and the mean Quick Disabilities of Arm, Shoulder and Hand score was 13.6. On radiography, 5 patients had reduction loss of > 2 mm in ulnar variance from immediately postoperatively to final follow-up (group 1), while 27 had no reduction loss (group 2). Compared with group 2, the VLF fragment in group 1 had significantly smaller mean longitudinal, transverse, and anteroposterior lengths, and joint surface area. Three-dimensional computed tomography revealed that the fracture patterns of the radiocarpal and distal radioulnar joints in group 1 were mainly volar displaced VLF fragments.

Conclusions: Distally placed volar locking plate fixation effectively treats intra-articular distal radius fractures with VLF fragments distal to the watershed line by stabilizing the fragments. However, small displaced VLF fragments may increase the risk of reduction loss in ulnar variance.
Key words: distal radius fracture, volar locking plate, watershed line, distal radioulnar joint, volar lunate facet fragment
Introduction

Distal radius fracture is the most common upper extremity fracture, accounting for 15% of all fractures\textsuperscript{1}. The standard treatment for distal radius fracture is volar locking plate fixation; this restores anatomy, joint congruity, and stability, which enables early rehabilitation and an early return to activities of daily living\textsuperscript{2-9}. Volar locking plate fixation achieves good clinical results for most distal radius fractures\textsuperscript{2-9}.

Recently, many studies have reported that standard volar locking plates designed to be positioned proximal to the watershed line may not be able to adequately stabilize and buttress volar lunate facet (VLF) fragments distal to the watershed line in intra-articular distal radius fractures, even though volar locking plate fixation is a well-established technique for distal radius fractures\textsuperscript{2,3,6}. Standard volar plating of distal radius fractures reportedly leads to inadequate fixation of the VLF fragment, resulting in volar carpal subluxation\textsuperscript{3}.

Various distally placed volar locking plates are currently available for treating intra-articular distal radius fractures with fragments distal to the watershed line\textsuperscript{4,5,8,9}. These distally placed plates designed specifically for implantation distal to the watershed line enable direct fixation of very distal VLF fragments\textsuperscript{4,5,8,9}. Therefore, distally placed plate fixation has been the most commonly used procedure for intra-articular distal radius fractures with VLF fragments distal to the watershed line\textsuperscript{4,5,8,9}. Several studies report good clinical results and efficacy of distally placed plate fixation\textsuperscript{4,5,8,9,11}. However, some studies report reduction loss of the VLF fragment or distal radioulnar joint (DRUJ) instability in patients with small VLF fragments, even after treatment with a distally placed volar locking plate\textsuperscript{4,5,8,9,12}. One study reported that a small, distally located VLF fragment cannot be stabilized with volar distally
placed locking plate fixation alone\(^{12}\). Even with improvements in distal radius fracture fixation, it remains difficult to stabilize and maintain the VLF fragment in certain fracture patterns\(^{2}\).

To date, minimal data have demonstrated a correlation between fracture patterns of the radiocarpal joint and DRUJ that involve VLF fragments and reduction loss of the VLF fragments in intra-articular distal radius fractures. The VLF fragment involves the sigmoid notch and can affect the stability of the DRUJ\(^{14}\). Computed tomography (CT) is useful in accurately assessing the radiocarpal joint and the DRUJ surface disruption in relation to the VLF fragments\(^{14}\).

In the current study, we hypothesized that the size of the VLF fragments might affect the reduction loss after surgery, and aimed to prove that small displaced VLF fragments was a risk factor in causing reduction loss. Additionally, we evaluated the clinical outcomes of a distally placed volar locking plate for intra-articular distal radius fracture with a VLF fragment distal to the watershed line, and characterized the fracture patterns of cases of intra-articular distal radius fractures with fragments distal to the watershed line in which the DRUJ involving the VLF fragment developed reduction loss. This information will further the understanding of fracture patterns of the DRUJ in intra-articular distal radius fractures with VLF fragments distal to the watershed line, and enable clinicians to offer more appropriate treatments with distally placed plate fixation for distal radius fractures, especially for preventing loss of reduction of the VLF fragment.
Materials and Methods

The present study protocol was approved by our institutional review board, and was conducted in accordance with the Declaration of Helsinki. From 2015 to 2018, we recruited 27 consecutive patients with unstable intra-articular distal radius fractures with VLF fragments distal to the watershed line treated using distally placed volar locking plate. Patients with bilateral distal radius fractures were excluded. All fractures were fixed using the Acu-Loc 2 distal plate plating system (Acumed, Hillsboro, OR, USA) (Figure 1). This plate is precontoured to the volar rim for placement distal to the watershed line, enabling purchase of the VLF fragment. Acu-Loc 2 distal locking plate fixation is indicated for cases of unstable intra-articular distal radius fractures with VLF fragments distal to the watershed line. The distal small VLF fragments distal to the watershed line cannot be adequately buttressed with standard volar locking plates. In each case, the plate was placed distal to the watershed line on the distal radius, and was covered by the pronator quadratus and fibrous tissue of the intermediate fibrous zone. In addition, the distally placed plate provided an adequate buttress for the VLF fragment with anchoring fiberwires from the volar joint capsule to the most distal holes of the plate, which addresses a limitation of distally placed volar plate fixation in the management of distal radius fractures involving small VLF fragments. A single surgeon (MN) performed all volar locking plate fixation procedures. A short-arm splint was applied to immobilize the wrist in a neutral position for 1–3 weeks postoperatively, allowing movement of all interphalangeal and metacarpophalangeal joints. Wrist range of motion exercises were started after splint removal. All patients provided written informed consent before examination and treatment.

The clinical results were evaluated at the final follow-up examination using
the Mayo Performance Wrist Score\textsuperscript{15} and the Japanese Society for Surgery of the Hand Version-Quick Disability of Arm, Shoulder, and Hand questionnaire (Quick DASH-JSSH)\textsuperscript{16} score. The Quick DASH-JSSH\textsuperscript{16} score is a patient-oriented questionnaire that is widely used to assess the outcomes of distal radius fracture treatment. The other outcome measures assessed at final follow-up were the range of motion of the wrist, grip strength, and complications.

Three radiographic parameters (volar tilt (VT), radial inclination (RI), and ulnar variance (UV)) were examined on standard anteroposterior and lateral views of the wrist joint taken in the standardized limb position preoperatively, immediately postoperatively, and at final follow-up. Reduction loss was defined as a change in UV of greater than 2 mm from immediately postoperatively to final follow-up, referencing to the report of Ueno et al.\textsuperscript{7}. The patients were divided into those with reduction loss (group 1) and those with no reduction loss (group 2) (Figure 2).

All patients underwent preoperative coronal, sagittal, and axial CT imaging, and three-dimensional reconstructive images were created from multislice CT scans (3DCT) (Emotion 6; Siemens, Munich, Germany). The longitudinal and the anteroposterior length of the VLF fragment were measured by the distance from the volar ridge of the VLF fragment to the proximal fracture line and the joint surface line in the sagittal plane of the CT image using the software provided with the CT, respectively. Moreover, the transverse length of the VLF fragment was measured by the distance from the palmar edge of the DRUJ to the fracture line in the axial plane of the CT image. The joint surface area of the VLF fragments was measured using free software (image J 1.52a; https://imagej.nih.gov/ij/download.html) in the 3DCT image (Figure 3).

The fracture patterns of intra-articular distal radius fractures with sigmoid notch
involvement were assessed on preoperative CT images in all patients. Rozental and Blazar\textsuperscript{14}) classified intra-articular distal radius fractures into five fracture patterns based on the sigmoid notch involvement and fracture displacement. Type 1a comprises nondisplaced, comminuted fractures with no sigmoid notch involvement. Type 1b comprises displaced comminuted fractures with disruption of the radiocarpal joint, but without extension into the sigmoid notch. In types 1a and 1b, the sigmoid notch fragment, although still congruent with the ulna, is completely separated from the remaining fracture fragments. Type 2 comprises sigmoid notch extension without any fragment displacement (fracture extension into the sigmoid notch without displacement). Type 3a comprises sigmoid notch involvement with rotation and/or translation of the VLF fragment. Type 3b comprises sigmoid notch involvement with rotation and/or translation of the volar and dorsal fracture fragments. In the present study, the Rozental classification was modified by adding two fracture types (Figure 4). Fractures that involved the sigmoid notch with rotation and/or translation of the dorsal die punch fragment were defined as type 3c, while fractures that involved the sigmoid notch with rotation and/or translation of a free fragment or more than three fracture fragments were defined as type 4 (Figure 4).

All analyses were performed with the software program IBM SPSS Statistics 21.0J (IBM Japan Ltd., Tokyo, Japan). The Student’s unpaired t-test was used to compare the size of the VLF fragment in group 1 versus group 2. The association between the reduction loss in UV and the size of the VLF fragment was examined. Furthermore, the association between the new classification of the DRUJ fracture and the reduction loss in UV was evaluated. A p value of < 0.05 was considered statistically significant.
Results

Distally placed volar locking plate fixation was used to treat 27 patients (27 hands (10 right, 17 left); 11 men, 16 women; mean age 58.2 years, range 23–79 years) with unstable intra-articular distal radius fractures with fragments distal to the watershed line. The mean follow-up duration was 15.3 months (range 9–38 months). Fractures were classified in accordance with the AO/ASIF classification system as type C1 (n = 6), C2 (n = 2), and C3 (n = 19).

Group 1 comprised 22 patients (22 hands (15 left, 7 right); 9 men, 13 women; mean age 59.7 years, range 25–79 years), while group 2 comprised 5 patients (5 hands (two left, three right); two men, three women; mean age 51.6 years, range 23–75 years). Consequently, 18.5% (=5/27 cases) were evaluated as reduction loss.

There were no significant differences between groups 1 and 2 regarding age, AO/ASIF classification, or duration of follow-up. Anatomical union was obtained in all patients. At final follow-up, the mean Mayo Performance Score was 90.9 (range, 70–100; classified as excellent in 11, good in 15, fair in one, and poor in 0), mean Quick DASH-JSSH score was 13.6 (range, 6.8–20.5), and mean grip strength was 79.4 ± 16.8% of the contralateral side. The mean range of motion in the wrist was 60.0 ± 8.3° for volar flexion, 64.7 ± 6.8° for dorsiflexion, 83.5 ± 12.0° for internal rotation, and 86.3 ± 7.3° for external rotation.

Patients were monitored during the follow-up period for complications, including wound infection, nonunion, tendon rupture, lunate dislocation, subluxation, traumatic osteoarthritis, range of motion limitation, persistent neuropathy, and complex regional pain syndrome. There were no complications in either group except plate removal. Plate removal was performed in 25 cases (92.6%); the mean period from internal fixation to
implant removal was 7.3 months (range, 5-15 months). All cases have no symptoms with tendon.

At final follow-up, the mean VT was 8.8° (range, -5–23.5°), mean RI was 23.4° (range, 11.3–31.9°), and mean UV was 2.1 mm (range, 0–10.5 mm) (Table 1). The UV at final follow-up significantly increased compared with the UV immediately postoperatively. The VT and RI did not change significantly from immediately postoperatively to final follow-up. The average reduction losses were 0.4 ± 3.0° (range, -4.7–5.1°) for VT, 0.7 ± 2.9° (range, -2.7–9.7°) for RI, and 0.6 ± 0.9 mm (range, -0.1–3.3 mm) for UV.

In group 1, the VLF fragments had a mean longitudinal length of 6.7 mm, transverse length of 9.0 mm, anteroposterior length of 7.6 mm, and radiocarpal joint surface area of 38.9 mm². Conversely, in group 2, the VLF fragments had a mean longitudinal length of 8.2 mm, transverse length of 11.9 mm, anteroposterior length of 9.4 mm, and radiocarpal joint surface area of 57.6 mm². All VLF fragment lengths and area were significantly smaller in group 1 than in group 2 (Table 2).

Fracture patterns were classified as type 2 (n = 7), type 3a (n = 5), type 3b (n = 11), and type 4 (n = 4). Especially, in group 1, the classifications were type 3a (n = 1), type 3b (n = 1), and type 4 (n = 3).
Discussion

Several biomechanical studies have reported that the centroid of force application is located palmary on the VLF\textsuperscript{17}. The VLF forms an articular portion of the sigmoid notch, and serves as the attachment for the short radiolunate ligament\textsuperscript{13}. The VLF is considered the keystone of the radiocarpal joint and DRUJ that affects carpal stability\textsuperscript{11}. Therefore, failure of fixation of VLF fragments in distal radius fractures can lead to reduction loss and volar carpal subluxation\textsuperscript{11}.

Recently, various distally placed volar locking plates have been used to fix the VLF fragments\textsuperscript{4, 5, 8, 9}. The indication for distally placed plate fixation is the presence of VLF fragments that are distal to the watershed line and cannot be secured by standard volar plate fixation\textsuperscript{2-5, 7-12}. However, some studies report that reduction loss of the VLF fragments occurs in patients with distal radius fractures with small VLF fragments located very distal to the watershed line, even with the use of a distally placed volar locking plate\textsuperscript{4, 5, 8, 9, 12}. It is difficult to achieve adequate fixation of small VLF fragments using only a distally placed volar plate, regardless of implant improvements\textsuperscript{11}.

Several techniques other than a distally placed volar plate have been described for preventing reduction loss and achieving stable fixation of the VLF fragment. These techniques include: 1) anchoring the fiberwires attached to the volar joint capsule to the most distal holes of the plate to prevent volar displacement of the VLF fragment\textsuperscript{18}, 2) supporting the subchondral bone of the VLF fragment via artificial bone grafting in the fracture void, 3) insertion of very distal raft screws to support the subchondral bone of the VLF fragment\textsuperscript{6}, 4) insertion of one or more screws into the VLF fragment to achieve a distance of 3 mm or less between the joint surface and screw, 5) additional
fixation with Kirschner wires or external fixation, and 6) plate coverage of the VLF fragment of 60% in the longitudinal direction and 70% in the transverse direction\(^7\). In the present study, all of these techniques were performed to achieve fixation of the VLF fragment.

Some studies in which distal radius fractures with VLF fragments distal to the watershed line were treated using the Acu-Loc 2 distal plate report good clinical results, with mean reduction losses in UV of 0.45 mm to 1.19 mm\(^4,5,8,9\). Similarly, the current study achieved a mean reduction loss in UV of 0.7 mm; the Acu-Loc 2 distal plate fixation was successfully used to stabilize the VLF fragments with no reduction loss in 5 of 27 patients.

A previous study reported that the presence of a VLF fragment with a longitudinal length of less than 15 mm is a risk factor for volar carpal translation in cases treated using standard volar locking plate fixation\(^2\). However, there are few reports on the risk factors for reduction loss of the VLF fragment with distally placed volar locking plate fixation. In the present study, the dimensions of the VLF fragment in group 1 (longitudinal length ≤ 7 mm, transverse length ≤ 9 mm, and anteroposterior length ≤ 8 mm) were risk factors for reduction loss in UV in cases treated using the distally placed volar locking plate. Thus, the dimensions of the VLF fragment were predictors of reduction loss in UV. It is difficult to stabilize the VLF fragment in fractures with measurements smaller than these. Small, displaced VLF fragments as above may increase the risk of reduction loss in UV.

Rozental and Blazar\(^{14}\) recommend using CT in the preoperative evaluation of comminuted distal radius fractures with sigmoid notch involvement with VLF fragments. Fracture patterns of the sigmoid notch may be important prognostic
indicators, and a better understanding of fracture patterns may enable clinicians to secure the VLF fragment and improve the clinical outcomes\textsuperscript{14}. We modified the Rozental classification to more precisely evaluate fracture patterns in the radiocarpal joint and DRUJ on CT. Consequently, the fracture patterns in most patients who had reduction loss (group 1) were classified as the new types 3 with a small anteroposterior length and articular surface area of the displaced VLF fragment, or as type 4 with a comminuted sigmoid notch and a free VLF fragment.

In the current study, no patient had volar dislocation of the VLF fragment beyond the plate. However, reduction loss in UV occurred in 5 patients with intra-articular distal radius fractures with a small VLF fragments distal to the watershed line. Small VLF fragments are reportedly prone to fixation failure, avascular necrosis, and subsequent resorption, and often result in volar carpal subluxation\textsuperscript{6}. The distally placed plate provided an adequate buttress for the VLF fragment with anchoring fiberwires from the volar joint capsule to the most distal holes of the plate, which addresses a limitation of distally placed volar plate fixation in the management of distal radius fractures involving small VLF fragments; however, very small VLF fragments were still depressed, rotated, or absorbed, resulting in UV reduction loss (Figure 5). The use of distally placed plate fixation in type 4 fractures may cause reduction loss, and so it is necessary to further improve the implant, or to graft the osteochondral bone to the fractured area in cases with a very small VLF. The present study showed that it is of utmost importance to preoperatively evaluate the size of the VLF fragments and the fracture pattern of the DRUJ involving the VLF fragments.
Limitations

The present study had some limitations. First, the sample size was relatively small. A larger sample size may provide more detailed information. Furthermore, the present study only focused on a particular type of distal radius fracture with VLF fragments distal to the watershed line, with no comparable control group. Additionally, a logistic analysis could not be evaluated due to a small sample size. Second, the present data were evaluated retrospectively. Third, all measurements were performed by a single examiner. Therefore, interobserver reliability could not be evaluated. Fourth, arthroscopy and MRI examination have not performed for all cases. Other factors that may cause reduction loss in UV, such as TFCC injury could not be evaluated. Finally, the current study had a relatively short follow-up duration. Future studies will address long-term evaluation of distal-placed volar locking plate fixation for intra-articular distal radius fractures with VLF fragments.

Conclusions

The current study demonstrated good clinical outcomes for distally placed volar locking plate fixation in intra-articular distal radius fractures with VLF fragments distal to the watershed line. This plating method may be effective in stabilizing the VLF fragment. However, the presence of small displaced VLF fragments may be a risk factor for UV reduction loss in intra-articular distal radius fractures with fragments distal to the watershed line.

Conflict of Interest

The authors declare no conflicts of interest.
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**Figure legends**

**Figure 1:** Fixation with Acu-Loc 2 distal plate plating system for VLF fragments distal to the watershed line

**Figure 2:** Anteroposterior view of radiographs at both immediately postoperatively and final follow-up in group 1 and 2
A. group 1 (reduction loss in ulnar variance), B. group 2 (no reduction loss in ulnar variance)

**Figure 3:** Evaluation of the dimensions and the area of the volar lunate facet fragment on computed tomography
A. Sagittal plane, B. Axial plane, C. Three-dimensional computed tomography
   a: longitudinal length, b: lateral length, c: anteroposterior length,
   d: radiocarpal joint surface area of the volar lunate facet fragment

**Figure 4:** New classification of intra-articular distal radius fractures involving the sigmoid notch on three-dimensional computed tomography

   Two additional fracture types were added to the Rozental classification.

   **Type 1:** no sigmoid notch involvement

   **Type 2:** fracture extension into the sigmoid notch without displacement

   **Type 3a:** sigmoid notch involvement with a displaced volar lunate facet fragment

   **Type 3b:** sigmoid notch involvement with displaced volar and dorsal fracture
fragments

**Type 3c**: sigmoid notch involvement with a displaced dorsal die punch fragment

**Type 4**: sigmoid notch involvement with a free fragment or more than three fracture fragments

**Table 1**: Comparison of the three radiographic parameters preoperatively, immediately postoperatively, and at final follow-up.

**Table 2**: Comparison of the dimensions and the joint surface area of the volar lunate facet fragment on three-dimensional computed tomography between group 1 (patients with reduction loss) and group 2 (patients with no reduction loss).

**Figure 5**: Displacement and depression of a small volar lunate facet fragment
Fig. 1
Fig. 2

A

B
Fig. 4

Dorsal side

Volar side

Type 1
Type 2
Type 3a

Type 3b
Type 3c
Type 4

Added classification
Fig. 5
Table 1

|                          | Unaffected side | Before surgery | Immediately after surgery | After surgery |
|--------------------------|-----------------|----------------|---------------------------|--------------|
| **Volar tilt (°)**       | 14.2 ± 7.6      | -10.7 ± 19.3   | 8.0 ± 4.9                 | 8.3 ± 6.4    |
| **Radial inclination (°)** | 25.4 ± 2.9    | 11.3 ± 7.7     | 23.6 ± 4.3                | 23.4 ± 4.2   |
| **Ulnar variance (mm)**  | 1.6 ± 1.3       | 2.8 ± 6.5      | 1.2 ± 1.5                 | 2.1 ± 2.6    |

NS: not significant

(*) p < 0.05
Table 2

| Dimension and area of volar lunate facet fragment | Group 1 (Reduction loss group) | Group 2 (No reduction loss group) |
|---------------------------------------------------|-------------------------------|----------------------------------|
| Longitudinal length (mm)                          | 6.7±2.3                       | 8.2±2.5                          |
| Transverse length (mm)                            | 9.0±3.6                       | 11.9±6.1                         |
| Anteroposterior length (mm)                       | 7.6±2.7                       | 9.4±3.6                          |
| Surface area of the radiocarpal joint (mm²)       | 38.9±20.4                     | 57.6±35.4                        |

(*: p < 0.05)