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# The Effect of Fracture Type on Restoration of Radiographic Parameters and Early Loss of Reduction in Surgical Treated Distal Radius Fractures

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**Abstract:** Purpose: Early loss of reduction remains a challenging complication in distal radius fracture management. There are limited data on factors that correlate with early loss of reduction. The Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification has become a popular way of evaluating complex fracture patterns. This study aims to determine the impact of fracture pattern, as determined by the AO classification, on restoration of intraoperative parameters, early loss of reduction, and time to fracture union in operatively treated distal radius fractures. Methods: Following IRB approval, adult patients with surgically treated acute distal radius fractures at a single level I institution were identified. Retrospective chart and radiographic review were used to obtain AO classification, postoperative radiographic parameters, early loss of reduction, time to fracture union, as well as any complications. Results: 422 patients with operatively treated distal radius fractures were included in this study. Across fracture patterns, there were no significant differences in restoration of radial height or inclination. Higher severity fracture classifications had decreased restoration of volar tilt. Overall, simple fractures (A2, C1) and partial articular fractures (B1, B2, B3) had higher rates of satisfactory alignment restoration compared to comminuted fractures (A3, C2, C3). Although there were differences in restoration of radiographic parameters, fracture type did not correlate with loss of reduction within 30 days. C type fractures correlated with increased weeks to radiographic healing. Conclusions: This study establishes that distal radius fracture pattern, as determined by the AO classification, has a significant impact on intraoperative restoration of parameters but does not correlate with early loss of reduction. Furthermore, more difficult fracture patterns may have a longer time to fracture union, but fracture type does not appear to have an effect on postoperative complications.

**Keywords:** distal radius; loss of reduction; AO classification



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## 1. Introduction

Distal radius fractures are one of the most common upper extremity injuries, accounting for up to 2.5% of all emergency department visits with trends of increasing incidence [1]. These injuries have a bimodal incidence, with elderly patients typically presenting after low energy injuries such as a fall from standing onto an outstretched hand, and younger patients presenting after higher energy injuries. Volar locked plating (VLP) has emerged as a common means of successfully surgically treating distal radius fractures. Surgical treatment of distal radius fractures offers a range of advantages over nonsurgical treatment, particularly when the fracture is comminuted or displaced. One of the primary benefits is the ability to achieve anatomic restoration, as open reduction allows precise realignment of fracture fragments. This precise alignment contributes to improved functional outcomes, reducing the risk of malunion or nonunion, and improving range of motion, strength, and grip function [2]. Furthermore, surgical treatment of distal radius fractures can improve articular congruity which may decrease the risk of post-traumatic arthritis and long-term pain or functional deficits and allow for earlier mobilization and rehabilitation, often leading to a faster overall functional recovery.

As surgeons have gained expertise with locked volar plates, the indications for their use have continued to expand. Surgeons have begun to use locked volar plates for more complicated fracture patterns including intra-articular fractures, distal volar lunate facet/ulnar corner fracture fragments, and fractures with complex comminution [3,4]. However, there are significant complications that surgeons must be aware of, ranging from median nerve injuries and tendon irritation to infection and loss of reduction [5,6]. Previous reports demonstrate complication rates up to 39% [5]. Of these, early loss of reduction plays a significant part in causing poor surgical outcomes, excessive healthcare expenses, and patient dissatisfaction. Despite the importance of hardware failure, understanding the factors that lead to early loss of reduction remains challenging.

The risk of hardware failure with VLP ranges from 2 to 15% depending on surgeon experience [6–8]. In closed management of distal radius fractures, studies have explored how age, osteoporosis, Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification, and initial loss of radial alignment all contribute to the risk of re-displacement after closed reduction [9–11]. However, while early studies have emphasized technical factors such as plate and subchondral screw placement, there are few studies that explore the contributing factors and risks associated with loss of reduction in operatively treated fractures [12,13]. By better understanding how fracture patterns affect intraoperative alignment and loss of reduction, surgeons can identify which cases may be more susceptible to early failure and consider alternative treatment options such as combination plating or external fixation.

Multiple classification systems such as Frykman, Fernandez, universal, and AO have been developed in attempts to characterize the severity of distal radius fractures [14,15]. The AO classification has become popular due to its ease of use, high communicability, and improved interobserver reliability [16]. The AO classification system provides a standardized language used to describe distal radius fractures, increasing the uniformity with which the severity of the fracture may be described (Table 1). The simplicity and clarity with which the AO classification system communicates information has led to an increase in its utilization in clinical research and education. Though the AO classification does an effective job of communicating fracture patterns, its prognostic value is still debatable.

**Table 1.** AO classification of distal radius fractures.

| **Extra-articular Fractures** |
| --- |
| A1: Ulna fracture, intact distal radius<br>A2: Simple or impacted metaphyseal distal radius fracture<br>A3: Comminuted metaphyseal distal radius fracture |
| **Partial Articular Fractures** |
| B1: Sagittal/radial styloid partial articular distal radius fracture<br>B2: Dorsal shear partial articular distal radius fracture<br>B3: Volar rim/shear partial articular distal radius fracture |
| **Complete Articular Fractures** |
| C1: Simple metaphyseal/simple articular distal radius fracture<br>C2: Simple articular/multi-fragmentary metaphyseal distal radius fracture<br>C3: Multi-fragmentary articular distal radius fracture |

The AO classification system for distal radius fractures, although widely used, is not without its limitations. One of its key weaknesses is its complexity, with numerous fracture types and modifiers that can make it challenging for clinicians to quickly and accurately classify fractures, especially for those with less experience. This complexity can also result in interobserver variability, as different healthcare providers may classify the same fracture differently, leading to inconsistent treatment recommendations and outcomes.

Moreover, the system relies on subjective judgment for certain fracture characteristics, such as comminution, further contributing to variation in reliability. The classification system may not account for all possible variations of distal radius fractures, and it does not consider patient-specific factors like age, comorbidities, or activity level, which can impact treatment. Additionally, it may not always adequately address the complex decision-making process for surgical treatment, as surgeons need to consider multiple factors beyond the classification, such as displacement. Lastly, while the system describes the fracture, it does not inherently guide prognosis or provide comprehensive data on long-term outcomes and complications associated with each fracture type. These limitations underscore the need for a careful and comprehensive approach when using the AO classification system for distal radius fractures.

There is evidence that worse AO fracture types (Group C fractures) may lead to an increased risk of loss of reduction in closed management [17]. However, in operative treatment, its impact on restoration of normal radiographic parameters and early loss of reduction has yet to be studied. Understanding these correlations may allow for improved utility of the classification and more accurate preoperative counseling for patients.

During intraoperative fixation of distal radius fractures, restoration of anatomic distal radius parameters (as defined by radial height 10–13 mm, radial inclination 21–25 degrees, and 10 degrees of volar tilt) remains a common goal of surgery. However, the importance of radiographic restoration on functional outcomes is highly debated. Studies in small populations have found that mild variations in radiographic parameters correlate poorly with functional outcome [18]. These studies raise concerns regarding restoration of "normal" parameters as a surrogate for successful surgical treatment.

Overall, the purpose of this study is to determine the impact of fracture pattern and severity, as determined by the AO classification system, on intraoperative restoration of radiographic anatomic parameters, early loss of reduction, and time to fracture union in operatively treated distal radius fractures. By better understanding how AO fracture type affects operative outcomes, the prognostic value of the classification may be notably improved.

## 2. Methods

After receiving institutional review board approval, we retrospectively identified all patients surgically treated for a distal radius fracture at a single safety net level I trauma center between 1 January 2014 and 31 December 2018 treated by two fellowship-trained hand surgeons. We performed a thorough retrospective chart review and radiographic review of all patients meeting our inclusion criteria.

### *2.1. Subjects*

Adult patients (age 18 or older) with acute distal radius fractures treated surgically at a single level I Trauma institution with a minimum of a 6-week follow-up during the study period were included. Demographic information including sex, age, history of diabetes, tobacco use, and laterality were collected to analyze and account for possible confounders. Patients were excluded if they had a previous ipsilateral distal radius fracture, distal radius fractures treated non-surgically, an age of less than 18 years, those fractures treated by non-hand fellowship-trained surgeons, and patients with less than a 6-week postoperative follow-up. Patients with previous ipsilateral distal radius fractures were excluded as our aim was to determine which distal radius fractures were able to be restored back to normal radiographic parameters surgically, and we were unable to determine radiographic alignment in these patients prior to their most recent fracture met normal parameters.

### *2.2. Data Acquisition*

Data were collected using retrospective chart and radiograph review. Radiographs were reviewed by two orthopedic residents to obtain AO classification of fracture at time of injury, immediate postoperative distal radius parameters (inclination, height, and volar tilt), and any early loss of reduction. Disagreement between reviewers was determined by the senior author, a fellowship-trained orthopedic hand surgeon. Restoration of radiographic parameters postoperatively was defined as radial height 8–13 mm, radial inclination 21–25 degrees, and volar tilt greater than or equal to 0 degrees [19]. Early loss of reduction was defined as loss of these parameters or displacement of intra-articular fragments within 30 days post-operation. Radiographs are typically obtained at each visit until radiographic union is obtained, and visits are typically scheduled at 2, 4, 6, and 12 weeks post-operation. Wrist spanning bridge plates are typically removed 12 weeks after the index surgery. The postoperative course was reviewed to identify complications and time to radiographic healing. The final radiographic assessment was made at the determination of radiographic healing by the treating surgeon.

### *2.3. Statistical Analyses*

Continuous data were tested for normality using the Shapiro–Wilks test; due to the data's distribution the Mann–Whitney Wilcoxon, or Kruskal–Wallis was used to assess differences across the data. To test multiple comparisons, the Dwass–Steel–Critchlow–Fligner multiple comparison procedure was used. The Fisher's exact test was used to assess all the categorical variables.

One-way analysis of variance (ANOVA) was used to determine the relationship between AO classification of distal radius fractures and postoperative radial height, tilt, and inclination, as well as complications. Chi-squared analysis was used to analyze the effect of AO classification on restoration of radiographic parameters and early loss of reduction. One-way ANOVA was also used to test for significant differences time to radiographic healing.

Statistical significance was considered $p \leq 0.05$.

## 3. Results

### *3.1. Patient Demographics*

A total of 681 distal radius fractures were initially identified and 422 patients with distal radius fractures were ultimately included in this study with AO classifications ranging from A2 and C3. In total, 259 patients were excluded due to a less than 6-week follow-up. There was a statistically significant difference between AO classification groups with regards to sex. Females were more prone to simple fracture patterns such as extra-articular fractures (Group A) and simple complete articular fractures (C1) ($p < 0.001$). Males exhibited higher energy fracture patterns including partial articular fractures (Group B) and comminuted intra-articular fractures (C2/C3) ($p < 0.001$). Age ($p = 0.082$), tobacco use ($p = 0.558$), and diabetes ($p = 0.940$) did not have a strong correlation with fracture classification. In total, 16 open fractures were initially identified, of which 5 patients met inclusion criteria. Open fractures included 1 A2, 1 B3, 1 C1, 1 C2, and 1 C3 fracture type. Average follow-up was 13.9 weeks (range 6–42 weeks). A total of 78/422 patients were included in a 6-week radiographic follow-up but subsequently did not complete a follow-up until a radiographic union was confirmed. The majority of fracture types A2–C2 were treated with volar locking plates (VLPs) that were rarely supplemented with additional k-wires for small fracture fragment control/stabilization. In C3 type fractures, when the fracture or carpus was too unstable for isolated volar locking plate fixation, a dorsal bridge plate was used in isolation (seven patients) or combination with VLP (three patients). Wrist spanning bridge plates were routinely removed 12 weeks after initial placement. Detailed demographic information is provided in Table 2.

**Table 2.** Demographic information of distal radius fractures classified by AO fracture type.

| | A2 | A3 | B1 | B2 | B3 | C1 | C2 | C3 | *p* Value |
|---|---|---|---|---|---|---|---|---|---|
| N | 66 | 23 | 7 | 11 | 24 | 104 | 105 | 82 | |
| Sex (M/F) | 27/39 | 8/15 | 5/2 | 7/4 | 16/8 | 42/62 | 52/53 | 59/23 | <0.001 |
| Age | 44.2 ± 14.1 | 49.3 ± 15.2 | 34.7 ± 6.2 | 39.3 ± 9.4 | 41.8 ± 13.7 | 43.7 ± 14.1 | 46.2 ± 14.0 | 43.1 ± 14.0 | 0.082 |
| Diabetic (Y/N) | 6/60 | 2/21 | 1/6 | 1/10 | 4/20 | 15/89 | 12/93 | 12/70 | 0.940 |
| Tobacco (Y/N) | 18/48 | 11/12 | 2/5 | 4/7 | 11/13 | 33/71 | 31/74 | 26/56 | 0.558 |
| Laterality (R/L) | 18/45 | 11/11 | 5/2 | 5/6 | 12/12 | 42/60 | 45/55 | 23/50 | 0.065 |
| Fixation | | | | | | | | | |
| Volar Plate | 66 | 23 | 4 | 8 | 23 | 102 | 104 | 75 | <0.001 |
| Bridge Plate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | <0.001 |
| K-Wires | 0 | 0 | 1 | 1 | 1 | 3 | 3 | 7 | 0.100 |

### *3.2. Effect of AO Classification on Restoration of Parameters and Early Loss of Reduction*

Table 3 summarizes the relationship between AO classification, restoration of parameters postoperatively, and early loss of reduction. Across all AO fracture patterns, operative treatment led to satisfactory restoration of radial height and radial inclination. There were no significant differences in restoration of radial height between AO classification types ($p = 0.913$). Similarly, there were no significant differences in restoration of radial inclination between AO classification types ($p = 0.900$). However, higher severity fracture classifications (C1, C2, C3) did have decreased restoration of volar tilt (degrees) ($p = 0.046$). Partial articular (Group B) fractures had a greater restoration of volar tilt, likely due to an intact articular column. Complete articular patterns (Group C) had the lowest rates of volar tilt restoration, further exacerbated by the amount of comminution.

**Table 3.** Intraoperative restoration of parameters and early loss of reduction in distal radius fracture based on AO classification.

| | A2 | A3 | B1 | B2 | B3 | C1 | C2 | C3 | *p* Value |
|---|---|---|---|---|---|---|---|---|---|
| Radial Height (mm) | | | | | | | | | 0.913 |
| Mean | 11.2 | 10.9 | 11.7 | 12.0 | 11.1 | 11.1 | 11.2 | 11.3 | |
| SD | 1.9 | 2.2 | 1.5 | 2.0 | 1.9 | 2.0 | 2.6 | 2.3 | |
| N | 66 | 23 | 7 | 11 | 24 | 104 | 105 | 82 | |
| Radial Inclination (°) | | | | | | | | | 0.900 |
| Mean | 20.7 | 19.9 | 21.4 | 20.3 | 20.5 | 20.0 | 20.3 | 20.2 | |
| SD | 3.2 | 3.3 | 2.8 | 3.0 | 4.2 | 2.9 | 3.6 | 3.5 | |
| N | 66 | 23 | 7 | 11 | 24 | 104 | 105 | 82 | |
| Volar Tilt (°) | | | | | | | | | 0.046 |
| Mean | 6.2 | 5.6 | 6.4 | 7.6 | 7.1 | 4.6 | 4.7 | 3.3 | |
| SD | 5.6 | 5.1 | 4.6 | 4.7 | 5.1 | 5.2 | 6.1 | 7.0 | |
| N | 66 | 23 | 7 | 11 | 24 | 104 | 105 | 82 | |
| Restoration of Parameters<br>Yes<br>No | 55 (83.33%)<br>11 (16.66%) | 15 (65.22%)<br>8 (34.78%) | 7 (100%)<br>0 (0%) | 8 (72.73%)<br>3 (27.27%) | 18 (75%)<br>6 (25%) | 83 (79.81%)<br>21 (20.19%) | 69 (65.71%)<br>36 (34.29%) | 47 (57.32%)<br>35 (42.68%) | 0.003 |
| Early Loss of Reduction<br>Yes<br>No | 1 (1.52%)<br>65 (98.48%) | 2 (8.70%)<br>21 (91.30%) | 0 (0%)<br>7 (100%) | 1 (9.09%)<br>10 (90.91%) | 1 (4.17%)<br>23 (95.83%) | 6 (5.77%)<br>98 (94.23%) | 12 (11.43%)<br>93 (88.57%) | 11 (13.41%)<br>71 (86.59%) | 0.164 |

Overall, restoration of alignment was defined as a radial height between 8 and 13 mm, a radial inclination of 21–25 degrees, and a volar tilt greater than or equal to 0 degrees. When considering overall restoration of alignment immediately postoperatively, there was a significant difference in percentage of patients with adequate restoration between fracture groups ($p = 0.003$). Simple fracture types (A2, C1) and partial articular fracture types (B1, B2, B3) had higher rates of alignment restoration compared to comminuted fracture types, both extra- (A3) and intra-articular (C2, C3). Although there were differences in restoration, fracture type did not correlate to a significant difference in the percentage of patients with loss of reduction within 30 days ($p = 0.164$). Ten patients with C3 fractures were treated with a bridge plate. One patient (10%) treated with a wrist spanning bridge plate was noted to have loss of reduction within 30 days postoperatively.

### 3.3. Time to Radiographic Union

Time to radiographic union is summarized in Table 4. We found that patients with higher AO fracture types correlated with increased weeks to radiographic healing ($p = 0.001$).

**Table 4.** Time to radiographic union of distal radius fractures classified by AO fracture type.

| | **A2** | **A3** | **B1** | **B2** | **B3** | **C1** | **C2** | **C3** | ***p* Value** |
|---|---|---|---|---|---|---|---|---|---|
| Radiographic Healing (weeks) | | | | | | | | | 0.001 |
| Mean | 7.0 | 6.4 | 6.0 | 6.5 | 6.5 | 7.1 | 7.4 | 8.6 | |
| SD | 3.9 | 2.1 | 0.6 | 2.6 | 1.9 | 2.9 | 2.6 | 3.1 | |
| N | 53 | 17 | 6 | 11 | 17 | 91 | 83 | 66 | |

### 3.4. Complications

Complications noted, beyond any postoperative loss of reduction, included infection, symptomatic hardware, EPL tendon rupture, nonunion, and neuropathy. No differences were noted between fracture types with regards to complications. A full summary of complications may be found in Table 5.

**Table 5.** Complications by AO fracture type.

| | **A2** | **A3** | **B1** | **B2** | **B3** | **C1** | **C2** | **C3** | ***p* Value** |
|---|---|---|---|---|---|---|---|---|---|
| Infection | | | | | | | | | |
| N | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0.574 |
| Symptomatic Hardware | | | | | | | | | |
| N | 1 | 0 | 0 | 1 | 1 | 5 | 6 | 3 | 0.703 |
| EPL Tendon Rupture | | | | | | | | | |
| N | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0.205 |
| Nonunion | | | | | | | | | |
| N | 5 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0.288 |
| Neuropathy | | | | | | | | | |
| N | 2 | 0 | 0 | 0 | 0 | 3 | 4 | 4 | 0.843 |

## 4. Discussion

The purpose of this study was to identify how fracture pattern and severity, as described by the AO classification, affect intraoperative fracture reduction as well as subsequent early loss of reduction and time to fracture union. While many studies have explored factors that lead to re-displacement in nonoperatively treated distal radius fractures, there is limited knowledge of the factors that contribute to loss of reduction in operatively treated fractures [8]. This study adds to the utility of the AO classification by demonstrating that higher energy fracture types have worse restoration of anatomic parameters intraoperatively and increased time to fracture union; however, this does not correlate with a substantial difference in early hardware failure, loss of fracture reduction, or complications. Understanding this relationship can assist surgeons in establishing realistic expectations during surgery and in providing more accurate guidance to patients when establishing their postoperative expectations. This may make a significant impact on the evaluation of successful operative care in distal radius fractures, especially at higher volume centers that see a wider range of complex fracture types.

The significance of achieving proper anatomic alignment in distal radius fractures has been a subject of extensive debate in the existing literature. While some studies have shown that restoration of parameters such as ulnar variance and volar tilt can have an impact on patient grip strength and functional outcomes, other studies have shown no difference in range of motion, pain, and advanced patient functional questionnaires [19,20]. A recent study by Chung et al. demonstrated that in a database of 166 patients, precise restoration of distal radius anatomy did not make a significant functional impact [18]. This study was performed on older patients, aged > 60, to assess if the increasing demands of a healthier and more active geriatric population are affecting outcomes after distal radius surgery. However, other studies evaluating the impact of anatomic restoration on function have found significant differences in outcomes such as in the disabilities of the arm, shoulder, and hand (DASH) questionnaire scores and grip strength. While different studies have highlighted various parameters as influential, multiple studies have highlighted ulnar variance and volar tilt as consistently important factors [18,20]. Ultimately, the impact of anatomic restoration remains debatable, especially due to a lack of studies with significant power in respect to higher energy fractures in younger populations. Although the importance of radiographic restoration remains questionable, it is important to understand the factors which may lead to inadequate reduction. Madsen et al. showed that in a database of 576 distal radius fractures treated with volar locked plating, operative treatment of very few fractures restored anatomic volar tilt and shortening of the distal radius was seen in as many as 9–22% of patients [21].

This study adds to the literature by showing that fracture patterns, as determined by the AO classification, have a significant impact on the precision of surgical realignment. While radial inclination and height did not significantly vary between fracture types, volar tilt was more difficult to reproduce in higher energy fracture patterns with notable comminution. Comminution was found to be a negative predictor of anatomic postoperative alignment with decreased rates of restoration in both extra-articular and intra-articular fracture patterns. Partial articular fractures were found to be protective factors likely due to an intact column of articular bone. Ultimately, this shows that surgeons treating highly impacted distal radius fractures may reasonably expect to have difficulty restoring intraoperative alignment, specifically in relation to volar tilt. As discussed, the importance of precise restoration remains debatable with some studies suggesting no impact (especially in older patient populations) and others highlighting volar tilt and ulnar variance as important factors in grip strength and function. Either way, understanding how fracture patterns affect the difficulty of reduction provides surgeons with better tools to manage their intraoperative expectations and more adequately evaluate the technical success of distal radius surgery.

Hardware failure with subsequent loss of reduction is an uncommon but significant complication of operatively treated distal radius fractures. Loss of reduction can have a significant impact on patient outcome scores and the overall cost of care of these injuries as the rate of revision open reduction internal fixation or subsequent wrist salvage procedures are increased after initial failure. Quantifying the incidence of loss of reduction has remained difficult as there are no universal standards regarding what constitutes loss of reduction nor when reoperation is required. Retrospective studies of postoperative radiographs suggest that most distal radius fractures treated with VLP have some settling of the fracture postoperatively, though the rates of malalignment requiring revision remain low [22]. This study shows that although fracture patterns do affect anatomical restoration of parameters, fracture type is not predictive of early loss of reduction within 30 days post-operation ($p = 0.164$). Our overall rate of early loss of reduction, defined as <30 days, was 8.06% (34/422) which is in line with the rates reported in the literature. These findings add to the utility of the AO classification by showing that although certain fracture patterns may have worse anatomic restoration intraoperatively, this is not associated with early loss of fracture reduction. Other studies have emphasized technical factors such as screw placement/diameter and stabilization of the volar lunate/ulnar corner fragment in maintaining fracture reduction [12,23]. The underlying cause of fracture reduction loss postoperatively is likely related to these proposed factors more than fracture characteristics, such as comminution and articular involvement.

The AO classification has gained popularity in describing distal radius fractures due to its interobserver reliability and ease of communication. Our analysis of the effect of the AO classification on operative anatomic restoration and early loss of fracture reduction improves its utility. The effects of many variables such as type of fixation, obesity, and smoking have been analyzed to determine what factors influence patient satisfaction after distal radius surgery. However, the influence of fracture type has not been studied in high volume databases. In this study, fracture type was found to have a significant influence on the time to radiographic healing. On average, C type fractures took 1–2 weeks longer to heal radiographically compared to their lower energy counterparts. Our data suggest that higher energy fractures take longer to heal radiographically; however, based on previous small studies, this finding does not appear to have an effect on functional recovery as patients with C type fractures have adequate functional outcomes at long-term postoperative follow up after operative fixation with VLP [24]. Future evaluations may be enhanced by further analysis of PROMs and grip strength comparisons by fracture type.

It is important to note that there are limitations to our study, including those inherent to a retrospective chart review. We chose to quantify early loss of reduction as <30 days from the date of surgery. While we recognize that this may not capture all malunions and ultimate loss of reduction, we chose to keep this short timeframe as we believe this better represents the impact of the fracture pattern and hardware adequacy compared to other factors such as patient activity, bone quality, ability to heal, and adherence to restrictions. Another limitation is the mixed treatment modalities, especially the use of additional bridge plates in C3 type distal radius fractures. Though the ability to restore alignment and maintain reduction may be influenced by a bridge plate, we believe that including all treatment modalities gives a better picture of the fracture patterns' impact rather than the choice of hardware. We recognize that the choice of hardware remains surgeon-specific and may vary affecting the applicability of our findings. Lastly, as in any retrospective study, there are limitations which must be recognized including potential selection bias, data completeness, unidentified confounding variables, incomplete follow-up, and inability to measure or capture certain variables. These most significantly pertain to our evaluation of time to radiographic healing. However, we believe our high follow-up rate at 6 weeks (82%) and adequate rate of final follow-up (55%), especially at a safety net level 1 county trauma hospital, allow for adequate interpretation of the data in this study's context.

The future direction of research regarding the applicability of the AO classification of distal radius fractures is likely to involve several key areas of investigation and improvement, including validation, predictive modeling, and creation of a treatment algorithm to guide surgeon decision making. Furthermore, future research focus on assessing and comparing the long-term outcomes of distal radius fractures classified using the AO system could provide insights into which fracture types/subtypes are associated with the best or worst functional and patient reported outcomes. Future research on the applicability of the AO classification of distal radius fractures is likely to be characterized by a combination of validation, refinement, data-driven decision making, and a focus on patient-centered care. The ultimate goal is to enhance the precision and effectiveness of fracture management while considering individual patient characteristics and preferences.

## 5. Conclusions

This study establishes that distal radius fracture pattern, as determined by the AO classification, has a significant impact on intraoperative restoration of parameters but does not correlate with early loss of reduction. Furthermore, more difficult fracture patterns may have a longer time to fracture union, but fracture type does not appear to have an effect on postoperative complications.

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## References

1. Nellans, K.W.; Kowalski, E.; Chung, K.C. The epidemiology of distal radius fractures. *Hand Clin.* **2012**, *28*, 113–125. [CrossRef] [PubMed]
2. Inclan, P.M.; Dy, C.J. How to treat distal radius fractures: Right patient, right care, right time, and right cost. *Hand Clin.* **2021**, *37*, 205–214. [CrossRef]
3. Nanno, M.; Kodera, N.; Tomori, Y.; Takai, S. Volar locking plate fixation for intra-articular distal radius fractures with volar lunate facet fragments distal to the watershed line. *J. Nippon. Med. Sch.* **2020**, *87*, 24–31. [CrossRef] [PubMed]
4. Anakwe, R.; Khan, L.; Cook, R.; McEachan, J. Locked volar plating for complex distal radius fractures: Patient reported outcomes and satisfaction. *J. Orthop. Surg. Res.* **2010**, *5*, 51. [CrossRef] [PubMed]
5. Rosenauer, R.; Pezzei, C.; Quadlbauer, S.; Keuchel, T.; Jurkowitsch, J.; Hausner, T.; Leixnering, M. Complications after operatively treated distal radius fractures. *Arch. Orthop. Trauma Surg.* **2020**, *140*, 665–673. [CrossRef] [PubMed]
6. Li, Y.; Zhou, Y.; Zhang, X.; Tian, D.; Zhang, B. Incidence of complications and secondary procedure following distal radius fractures treated by volar locking plate (Vlp). *J. Orthop. Surg. Res.* **2019**, *14*, 295. [CrossRef]
7. Hsu, C.-L.; Yang, J.-J.; Yeh, T.-T.; Shen, H.-C.; Pan, R.-Y.; Wu, C.-C. Early fixation failure of locked plating in complex distal femoral fractures: Root causes analysis. *J. Formos. Med. Assoc.* **2021**, *120 Pt 2*, 395–403. [CrossRef]
8. Vosbikian, M.M.; Ketonis, C.; Huang, R.; Costanzo, J.A.; Ilyas, A.M. Reduction loss after distal radius fracture fixation with locked volar plates. *J. Surg. Orthop. Adv.* **2017**, *26*, 160–165.
9. Gluck, J.S.; Chhabra, A.B. Loss of alignment after closed reduction of distal radius fractures. *J. Hand Surg. Am.* **2013**, *38*, 782–783. [CrossRef]
10. Lafontaine, M.; Hardy, D.; Delince, P. Stability assessment of distal radius fractures. *Injury* **1989**, *20*, 208–210. [CrossRef]
11. Walenkamp, M.M.J.; Mulders, M.A.M.; van Hilst, J.; Goslings, J.C.; Schep, N.W.L. Prediction of distal radius fracture redisplacement: A validation study. *J. Orthop. Trauma* **2018**, *32*, e92–e96. [CrossRef]
12. Drobetz, H.; Black, A.; Davies, J.; Buttner, P.; Heal, C. Screw placement is everything: Risk factors for loss of reduction with volar locking distal radius plates. *World J. Orthop.* **2018**, *9*, 203–209. [CrossRef] [PubMed]
13. Drobetz, H.; Schueller, M.; Tschegg, E.K.; Heal, C.; Redl, H.; Muller, R. Influence of screw diameter and number on reduction loss after plating of distal radius fractures. *ANZ J. Surg.* **2011**, *81*, 46–51. [CrossRef] [PubMed]

14. Kleinlugtenbelt, Y.V.; Groen, S.R.; Ham, S.J.; Kloen, S.J.; Haverlag, R.; Simons, M.P.; Scholtes, V.A.B.; Bhandari, M.; Goslings, J.C.; Poolman, R.W. Classification systems for distal radius fractures. *Acta Orthop.* **2017**, *88*, 681–687. [CrossRef]
15. Wæver, D.; Madsen, M.L.; Rölfing, J.H.D.; Borris, L.C.; Henriksen, M.; Nagel, L.L.; Thorninger, R. Distal radius fractures are difficult to classify. *Injury* **2018**, *49* (Suppl. S1), S29–S32. [CrossRef]
16. Jayakumar, P.; Teunis, T.; Giménez, B.B.; Verstreken, F.; Di Mascio, L.; Jupiter, J.B. Ao distal radius fracture classification: Global perspective on observer agreement. *J. Wrist Surg.* **2017**, *6*, 46–53. [CrossRef] [PubMed]
17. Myderrizi, N. Factors predicting late collapse of distal radius fractures. *Malays. Orthop. J.* **2011**, *5*, 3–7. [CrossRef]
18. Chung, K.C.; Cho, H.E.; Kim, Y.; Kim, H.M.; Shauver, M.J.; WRIST Group. Assessment of anatomic restoration of distal radius fractures among older adults: A secondary analysis of a randomized clinical trial. *JAMA Netw. Open* **2020**, *3*, e1919433. [CrossRef]
19. Dario, P.; Matteo, G.; Carolina, C.; Marco, G.; Cristina, D.; Daniele, F.; Andrea, F. Is it really necessary to restore radial anatomic parameters after distal radius fractures? *Injury* **2014**, *45* (Suppl. S6), S21–S26.
20. Wollstein, R.; Allon, R.; Zvi, Y.; Katz, A.; Werech, S.; Palmon, O. Association between functional outcomes and radiographic reduction following surgery for distal radius fractures. *J. Hand Surg. Asian Pac. Vol.* **2019**, *24*, 258–263. [CrossRef]
21. Madsen, M.L.; Wæver, D.; Borris, L.C.; Nagel, L.L.; Henriksen, M.; Thorninger, R.; Rölfing, J.D. Volar plating of distal radius fractures does not restore the anatomy. *Dan. Med. J.* **2018**, *65*, A5497. [PubMed]
22. Gruber, G.; Gerald, G.; Gruber, K.; Clar, H.; Zacherl, M.; Fuerst, F.; Bernhardt, G.A. Volar plate fixation of AO type C2 and C3 distal radius fractures, a single-center study of 55 patients. *J. Orthop. Trauma* **2008**, *22*, 467–472. [PubMed]
23. O'Shaughnessy, M.A.; Shin, A.Y.; Kakar, S. Stabilization of volar ulnar rim fractures of the distal radius: Current techniques and review of the literature. *J. Wrist Surg.* **2016**, *5*, 113–119. [CrossRef] [PubMed]
24. Bolmers, A.; Luiten, W.E.; Doornberg, J.N.; Brouwer, K.M.; Goslings, J.C.; Ring, D.; Kloen, P. A comparison of the long-term outcome of partial articular (AO type b) and complete articular (AO type c) distal radius fractures. *J. Hand Surg. Am.* **2013**, *38*, 753–759. [CrossRef]