Article

Ultrasound-Guided vs. Conventional Dorsoulnar Fragment Reduction Combined With Volar Locking Plate Fixation for Distal Radius Fractures: A Comparative Clinical Study

Ann. Ital. Chir., 2025 96, 11: 1560–1570
https://doi.org/10.62713/aic.4258

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AIM: Distal radius fractures (DRFs) are among the most common traumatic injuries. Reduction of dorsoulnar fragments combined with volar locking plate fixation yields satisfactory outcomes. However, conventional fluoroscopy-guided techniques present inherent limitations in accuracy. This study aimed to evaluate the feasibility and efficacy of ultrasound-guided reduction of dorsoulnar fragment (DUF) combined with volar locking plate fixation for DRFs.

METHODS: This retrospective study included 116 patients with DRFs who underwent reduction of dorsoulnar fragments combined with volar locking plate fixation at our hospital between January 2022 and January 2024. Patients were allocated into two groups based on the intraoperative guidance technique: the observation group (n = 54, ultrasound-guided) and the control group (n = 62, X-ray-guided). Surgical indicators, healing progress, and outcome measures were assessed, including wrist function (Gartland-Werley score), range of motion (dorsiflexion, volar flexion, supination, pronation), radiological parameters (volar tilt, radial inclination, radial height), Visual Analog Scale (VAS) score, Modified Mayo Wrist Score (MMWS), grip strength, and complications.

RESULTS: Baseline characteristics and all preoperative outcome metrics (Gartland-Werley score, range of motion, radiological parameters, VAS score, MMWS, grip strength) showed no significant differences between the two groups ($p > 0.05$). The observation group demonstrated significantly shorter operation time, less intraoperative blood loss, and reduced hospital stay compared to the control group ($p < 0.05$). No significant difference in fracture healing time was observed ($p > 0.05$). Postoperatively, both groups exhibited significant reductions in Gartland-Werley scores ($p < 0.001$), with lower scores in the observation group ($p < 0.001$). Dorsiflexion, volar flexion, pronation, and supination angles significantly improved in both groups ($p < 0.001$); the observation group demonstrated larger dorsiflexion, pronation and supination angles ($p < 0.001$), but no intergroup difference was observed in volar flexion ($p > 0.05$). The radiological outcomes improved significantly in both groups postoperatively ($p < 0.001$). The observation group achieved superior volar tilt and radial height ($p < 0.001$), while radial inclination showed no significant difference ($p > 0.05$). The complication rate was significantly lower in the observation group than in the control group ($p < 0.05$).

CONCLUSIONS: Ultrasound-guided reduction of dorsoulnar fragments combined with volar locking plate fixation significantly enhanced postoperative wrist function, anatomical alignment, and reduced complication rates compared to conventional X-ray guidance. These findings suggest that intraoperative ultrasound is a valuable adjunct for dorsoulnar fragment (DUF) reduction in DRF fixation, contributing to greater precision and improved clinical outcomes.

Keywords: distal radius fracture; ultrasound guidance; X-ray guidance; dorsoulnar fragment reduction; volar locking plate; wrist function

Introduction

Distal radius fractures (DRFs) are among the most common fractures, with incidence continuing to increase [1]. The epidemiology follows a bimodal pattern: high-energy trauma predominates in younger individuals, whereas osteoporosis-related low-energy falls are the primary cause in elderly populations [2]. With global population aging, the burden of geriatric DRFs is expected to rise further. Anatomical reduction and stable fixation are critical for restoring wrist function, as joint surface step-off exceeding 2 mm significantly increases the risk of post-traumatic arthritis [3]. Among fixation strategies (e.g., single volar plating, single dorsal plating, or fragment-specific fixation), the volar locking compression plate (VLCP) has become the preferred surgical approach for unstable or comminuted DRFs due to its biomechanical advantages [4,5]. VLCP, acting as an internal fixator for mechanical bridging, demonstrates relatively low failure rates. Precise subchondral placement of distal screws is particularly crucial

Submitted: 9 July 2025 Revised: 8 August 2025 Accepted: 20 August 2025 Published: 10 November 2025
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to support the joint surface and prevent secondary displacement, with biomechanical superiority validated in DRFs involving displaced dorsal ulnar fragments [6].

Despite these advances, treatment of complex DRFs with dorsoulnar fragment (DUF) involvement remains challenging [7]. The DUF is pivotal for wrist stability, serving as the attachment site for the dorsal distal radioulnar ligament, providing dorsal cortical support, and preventing dorsal angulation [8]. Key challenges in DUF reduction include: (1) limited surgical exposure via sole volar approach, which restricts direct visualization and manipulation of the fragment; and (2) limitations of conventional intraoperative C-arm fluoroscopy, which provides only two-dimensional imaging, insufficient for accurate assessment of three-dimensional DUF positioning, reduction accuracy, and chondral integrity [9].

Compared to traditional fluoroscopy, ultrasound guidance offers several distinct advantages. It enables real-time dynamic visualization, allowing direct, radiation-free monitoring of bone fragment reduction and offering superior evaluation of cartilage interfaces compared with X-ray [10]. Ultrasound also provides higher soft-tissue resolution, permitting concurrent assessment of peri-wrist joint soft tissue injuries such as triangular fibrocartilage complex tears, thereby reducing the likelihood of missed associated injuries [11]. Additionally, ultrasound markedly decreases radiation exposure, minimizing procedural radiation doses for both surgeons and patients and reducing the risk of iatrogenic tissue damage [12]. Previous clinical studies have further shown that point-of-care ultrasound demonstrates high sensitivity and specificity in evaluating the adequacy of radial fracture reduction, with accuracy comparable to standard radiography in certain settings [13,14].

However, robust evidence confirming that ultrasound guidance directly improves outcomes in displaced DRFs, especially complex subtypes with DUFs, remains lacking [15]. Existing data largely focus on arthroscopy-assisted techniques, with limited systematic evaluation of ultrasound-guided reduction and fixation [9,16]. To address this gap, the present study provides the first systematic assessment of ultrasound-guided DUF reduction combined with VLCP fixation for complex DRFs. Through retrospective cohort analysis, we compared clinical outcomes, including reduction accuracy, complication rates, and functional recovery, between ultrasound-guided and fluoroscopy-guided techniques, to provide evidence supporting precision and minimally invasive treatment of complex DRFs.

Materials and Methods

Research Subjects

This retrospective study analyzed 116 patients with DRFs who underwent DUF reduction combined with volar locking plate internal fixation at Liangzhu Branch, The First Affiliated Hospital, Zhejiang University School of Medicine (First People's Hospital of Yuhang District) between January 2022 and January 2024. Of these, 54 patients underwent ultrasound-guided surgery, while 62 received conventional (non-ultrasound-guided) procedures. The study was approved by the Institutional Ethics Committee of Liangzhu Branch, The First Affiliated Hospital, Zhejiang University School of Medicine (First People's Hospital of Yuhang District) (Ethical code number: LZYY202215) and conducted according to the World Medical Association's Declaration of Helsinki. Written informed consent was obtained from all participants.

Inclusion and Exclusion Criteria

Inclusion criteria were: (1) radiographically confirmed diagnosis of DRFs; (2) acute closed DRFs ($\leq$3 weeks from trauma); (3) age 18–80 years; (4) preoperative wrist computed tomography (CT) showing DUF displacement $>$2 mm, consistent with a fracture fragment in the dorsoulnar distal radius; and (5) treatment with volar locking plate internal fixation.

Exclusion criteria were: (1) absence of preoperative wrist CT examination; (2) open, old, or pathological fractures; (3) comorbidities including severe cardiocerebrovascular disease [New York Heart Association (NYHA) functional class III–IV, left ventricular ejection fraction (LVEF) $<$40%, American Society of Anesthesiologists (ASA) status $\geq$IV, Modified Rankin Scale (mRS) $\geq$4], depression, or other psychiatric disorders; (4) soft tissue injuries of the forearm; (5) osteofascial compartment syndrome; and (6) incomplete clinical data.

Surgical Methods

All surgeries were performed by the same experienced surgical team.

Control group: Patients were positioned supine under brachial plexus anesthesia, and a pneumatic tourniquet was inflated to 30 kPa following limb exsanguination. A volar Henry incision was made at the wrist, exposing the radial artery and flexor carpi radialis tendon. The radial insertion of the pronator quadratus muscle was sharply incised, and subperiosteal elevation allowed retraction of the muscle, exposing the volar fracture site. Reduction was achieved by manual traction and lever manipulation, followed by temporary Kirschner wire fixation. C-arm fluoroscopy (Arcadis Orbic 3D, Siemens, Henkestr, Germany) confirmed restoration of palmar tilt, ulnar variance and radial height. An appropriately sized VLCP was then applied to the volar aspect of the distal radius. Locking screws were inserted through the proximal and radial distal plate holes, while the ulnar distal plate holes (corresponding to the DUF region) were left temporarily unfixed. C-arm X-ray imaging (anteroposterior, lateral, and oblique views) assessed DUF displacement. Under fluoroscopic guidance, the DUF was reduced via traction, thumb pressure, or percutaneous Kirschner wire levering. After satisfactory reduction, 1–2 temporary Kirschner wires were placed through a small dorsal incision or percutaneously, followed by screw fixation of the remaining ulnar distal plate holes. Final fluoroscopic images confirmed reduction and implant placement, followed by removal of all temporary wires. All radiographic parameters were re-measured postoperatively by two blinded raters, demonstrating excellent reliability (Intraclass correlation coefficient (ICC) $\geq$0.89, κ = 0.85). The wound was irrigated, the pronator quadratus repaired, and layered closure completed.

Observation group: Patients were positioned supine under brachial plexus anesthesia, and a pneumatic tourniquet was inflated to 30 kPa. A volar Henry incision was made, exposing the interval between the radial artery and the flexor carpi radialis tendon. The radial insertion of the pronator quadratus was incised, and subperiosteal elevation exposed the volar fracture. After initial reduction of the volar fragment with traction and levering, temporary Kirschner wires were inserted. A sterile ultrasound probe (7–13 MHz, Fujifilm Sonosite S-Nerve, Bothell, WA, USA) covered with a sterile sheath was placed on the dorsoulnar aspect of the distal radius. Under real-time ultrasound guidance, the DUF was reduced by traction and Kirschner wire levering until real-time ultrasound imaging confirmed restoration of dorsal cortical alignment and anatomic reduction, defined as an articular step-off of $\leq$1 mm and an articular gap of $\leq$1 mm at the dorsoulnar articular surface. A VLCP was applied, with screws inserted through the proximal and radial distal holes. One to two Kirschner wires were then placed percutaneously from the volar side to engage and temporarily stabilize the DUF, followed by fixation with locking screws in the ulnar distal plate holes. Ultrasound was repeated to confirm the final position of the DUF and to evaluate for potential screw penetration into the extensor tendons. If ultrasound demonstrated the screw tip near or penetrating the extensor tendons, the screw length was adjusted. Final C-arm fluoroscopy confirmed overall fracture reduction and implant position. Postoperative radiographic parameters were re-measured by two blinded raters, showing excellent reliability (ICC $\geq$0.89, κ = 0.85). Temporary wires were removed, the wound irrigated, the pronator quadratus repaired, and layered closure completed.

Observation Indicators and Data Collection Procedures

Trained researchers collected patient data using a standardized process, which included:

(1) Baseline clinical data: Demographic and clinical characteristics, including sex, age, height, weight, AO fracture classification, injury mechanism, and side of fracture.

(2) Surgical metrics and healing progression: Operative time and intraoperative blood loss were recorded as surgical metrics. Healing progression was evaluated by length of hospital stay and fracture healing time. Fracture healing was defined according to clinical criteria (e.g., blurred fracture line, continuous callus formation, absence of local tenderness, longitudinal percussion pain, and abnormal activity) on X-ray images obtained every two weeks from postoperative week 4 to week 10, expressed in days [17].

(3) Gartland-Werley score for wrist function: Surgeons assessed the Gartland-Werley score preoperatively and at 12 months postoperatively. The total score ranges from 0–38, with higher values indicating worse outcomes. The scoring system includes four domains: residual deformity (radial/dorsal malalignment), subjective assessment (pain, mobility limitation, and functional loss reported by patients), objective assessment (surgeon-evaluated wrist range of motion, distal radioulnar joint pain, grip strength), and complications (arthritis, neuropathy, impaired finger function) [18].

(4) Wrist range of motion: Measured preoperatively and at 12 months postoperatively using a goniometer, including dorsiflexion, volar flexion, supination, and pronation [19].

(5) Imaging outcomes: Anteroposterior and lateral radiographs were obtained preoperatively and at 12 months postoperatively. Radiographic parameters (volar tilt, radial inclination, and radial height) were measured using ImageJ software (version 1.46, National Institutes of Health, Bethesda, MD, USA) [20]. Absolute values were analyzed, as clinical practice emphasizes the quality of postoperative anatomical reduction over relative improvement.

(6) Visual Analog Scale (VAS) score: Pain intensity was assessed with a 10-cm VAS, where 0 represented “no pain” and 10 indicated “worst imaginable pain”. Higher scores indicated greater pain severity. Evaluations were performed preoperatively and at 12 months postoperatively [21].

(7) Modified Mayo Wrist Score (MMWS): Evaluated preoperatively and at 12 months postoperatively. The total score (0–100) was classified as excellent (90–100), good (80–89), fair (65–79), or poor (<65). The scale consists of four domains: pain (25 points), active flexion/extension arc (25 points), grip strength (25 points), and return to work/activities (25 points) [6].

(8) Grip strength: Measured preoperatively and at 12 months postoperatively using a Jamar dynamometer (Sammons Preston, Bolingbrook, IL, USA). Patients were seated upright with the elbow flexed at 90° and the wrist in a neutral position. Three trials per hand were recorded, averaged, and compared with the uninjured contralateral side [22].

(9) Postoperative complications: Complications occurring within 12 months postoperatively were documented. Early complications ($\leq$3 months) included carpal tunnel syndrome, whereas late complications (3–12 months) included extensor tendon rupture, distal radioulnar joint instability, and delayed fracture union. Delayed union was defined as failure of fracture healing by 16 weeks postoperatively, requiring both absence of bridging callus in $\geq$3 cortices on orthogonal views and load-dependent pain with direct tenderness at the fracture site.

This study utilized both the Gartland-Werley score and the MMWS to evaluate postoperative wrist function recovery following DRFs. The dual-scale approach pro-

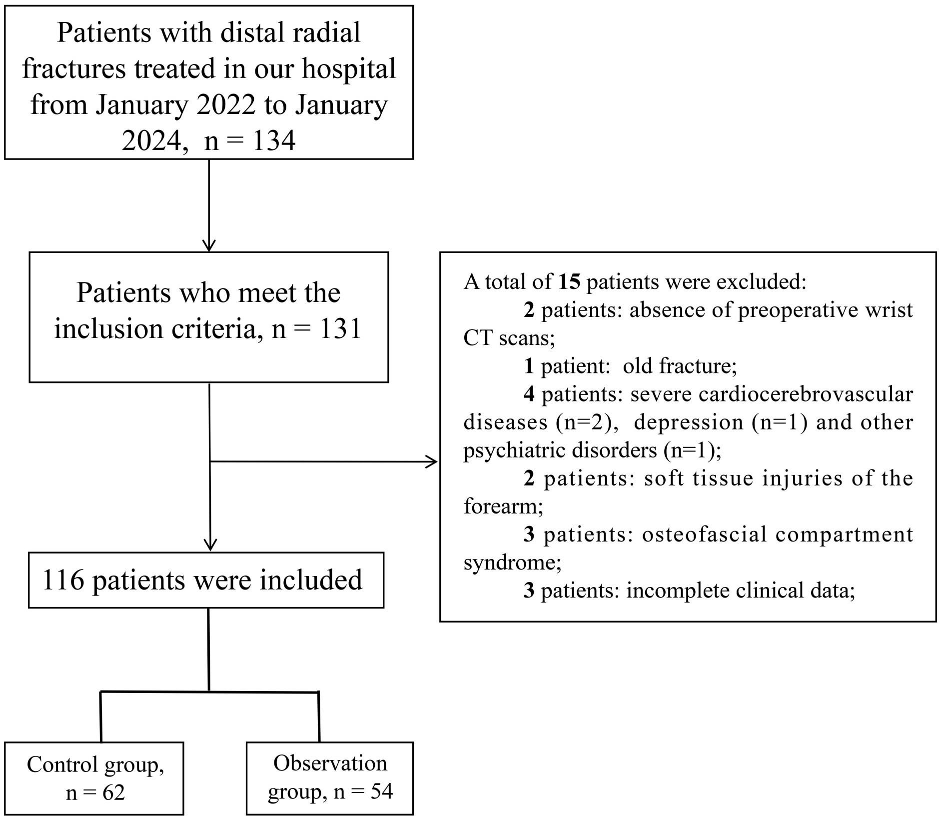

Fig. 1. The selection flow chart of patients.

vides a multidimensional framework: the Gartland-Werley score emphasizes complication-related disability and subjective symptoms [23], whereas the MMWS comprehensively evaluates pain, motion, grip strength, and functional recovery [24]. The combined use of these scales enhances the detection capability for diverse clinical recovery trajectories, thereby providing a more comprehensive assessment of patient prognosis.

Statistical Analysis

Data were analyzed using SPSS (version 21.0, IBM Corporation, Armonk, NY, USA). The normality of continuous variables was evaluated with the Kolmogorov-Smirnov test, and results were expressed as mean ± standard deviation ($\bar{x} \pm$ s). For normally distributed continuous variables, between-group differences were examined using independent samples *t*-tests, while within-group pre- and post-treatment comparisons utilized paired samples *t*-tests. Non-normally distributed variables were reported as median (interquartile range) [Median (IQR)] and analyzed with non-parametric methods. Categorical data were presented as frequency (percentage) [n (%)]. For categorical variables, the Pearson chi-square test was applied when the expected frequency (T) $\geq$5 and the total sample size (n) $\geq$40; when 1 $\leq$ T $<$ 5 and n $\geq$40, the continuity-corrected chi-square test was applied. A p-value < 0.05 was considered statistically significant.

Results

Comparison of Baseline Characteristics Between Groups

As shown in Fig. 1, a total of 116 patients with DRFs who underwent DUF reduction combined with volar locking plate internal fixation were enrolled based on the inclusion and exclusion criteria. Of these, 54 patients underwent ultrasound-guided surgery (observation group), while 62 underwent non-ultrasound-guided procedures (control group). No statistically significant differences were observed between the two groups in gender, age, height, weight, AO fracture classification, injury mechanism, or side of fracture ($p > 0.05$) (Table 1).

Comparison of Surgical Indicators and Healing Progress Between Groups

As presented in Table 2, operation time, intraoperative blood loss, and length of hospital stay were significantly lower in the observation group compared to the control group ($p < 0.05$). No statistically significant difference was observed in postoperative fracture healing time between the two groups ($p > 0.05$).

Comparison of Wrist Function Between the Two Groups

Before surgery, no statistically significant differences were identified between the two groups in Gartland-Werley scores or wrist range of motion (including dorsiflexion, volar flexion, pronation, and supination) ($p > 0.05$). Fol-

Table 1. Comparison of baseline characteristics between groups [$\bar{x} \pm$ s, n (%)].

Variable	Observation group (n = 54)	Control group (n = 62)	t/χ^2 value	p-value
Gender			0.025	0.875
Male	21 (38.89)	25 (40.32)		
Female	33 (61.11)	37 (59.68)		
Age (years)	57.30 ± 10.62	60.23 ± 11.69	1.405	0.163
Height (cm)	162.48 ± 7.37	164.27 ± 8.51	1.202	0.232
Weight (kg)	63.61 ± 7.91	64.56 ± 7.28	0.673	0.502
AO fracture type			1.028	0.598
B1	17 (31.48)	24 (38.71)		
B2	10 (18.52)	8 (12.90)		
C3	27 (50.00)	30 (48.39)		
Injury mechanism			0.015	0.903
Accident	25 (46.30)	28 (45.16)		
Falling	29 (53.70)	34 (54.84)		
Side of fracture			0.594	0.441
Left hand	24 (44.44)	32 (51.61)		
Right hand	30 (55.56)	30 (48.39)		

Table 2. Comparison of surgical indicators and healing progress between groups [$\bar{x} \pm$ s].

Variable	Observation group (n = 54)	Control group (n = 62)	t/χ^2 value	p-value
Operation duration (min)	60.80 ± 17.92	73.45 ± 22.32	3.333	0.001
Intraoperative blood loss (mL)	44.57 ± 9.80	57.32 ± 12.20	6.144	<0.001
Length of hospital stay (days)	6.33 ± 1.25	8.73 ± 1.65	8.726	<0.001
Fracture healing time (weeks)	9.35 ± 2.57	9.27 ± 2.44	0.172	0.864

lowing surgery, Gartland-Werley scores significantly decreased in both groups relative to preoperative levels ($p < 0.001$), with the observation group showing significantly lower scores than the control group ($p < 0.001$). Postoperatively, dorsiflexion, volar flexion, supination, and pronation in both groups were significantly improved compared to preoperative levels ($p < 0.001$). Moreover, dorsiflexion, supination, and pronation in the observation group were significantly greater than in the control group ($p < 0.001$), whereas no significant difference in volar flexion was observed between groups ($p > 0.05$) (Table 3).

Comparison of Radiological Outcomes Between the Two Groups

Before surgery, no statistically significant differences were observed between the two groups in volar tilt angle, radial inclination angle, or radial height ($p > 0.05$). After surgery, all the parameters (volar tilt, radial inclination, radial height) significantly increased in both groups compared to preoperative levels ($p < 0.001$). Furthermore, the observation group exhibited significantly greater volar tilt and radial height than the control group ($p < 0.001$). However, no significant difference in radial inclination was observed between the two groups ($p > 0.05$) (Table 4).

Comparison of Postoperative VAS Scores, MMWS, and Grip Strength Between the Two Groups

As presented in Table 5, no statistically significant differences were observed between the two groups in VAS scores, MMWS, or grip strength before surgery ($p > 0.05$). Following surgery, VAS scores significantly decreased in both groups, while MMWS and grip strength significantly increased compared to preoperative values ($p < 0.001$). Additionally, the observation group exhibited significantly lower VAS scores ($p < 0.001$) and significantly higher MMWS and grip strength compared to the control group ($p < 0.05$).

Comparison of Postoperative Complications Between the Two Groups

Over the 12-month postoperative follow-up, the overall complication rate in the observation group was 11.11%, which was significantly lower than the 27.42% observed in the control group ($p < 0.05$). The incidence of individual complications and intergroup differences is detailed in Table 6 and illustrated in Fig. 2.

Discussion

This retrospective study demonstrates that ultrasound-guided DUF reduction combined with VLCP fixation for DRFs offers significant advantages over conventional fluoroscopy-guided procedures in perioperative efficiency, functional recovery, and radiological outcomes, underscoring its clinical translational value.

The ultrasound-guided DUF reduction combined with VLCP fixation group (observation group) achieved a significantly shorter operative time and reduced intraoperative blood loss compared to the conventional fluoroscopy-

Table 3. Comparison of Gartland-Werley scores and wrist joint mobility [$\bar{x} \pm$ s, Median (IQR)].

Variable	Observation group (n = 54)	Control group (n = 62)	Z/t	p-value
Gartland-Werley score (points)				
Before surgery	14 (12, 16)	14 (12, 16)	0.643	0.520
After surgery	3 (3, 4)**	5 (4, 6)**	5.307	<0.001
Dorsiflexion (°)				
Before surgery	42.94 ± 3.78	43.35 ± 3.87	0.575	0.566
After surgery	54.76 ± 4.86**	49.27 ± 3.54**	7.013	<0.001
Volar flexion (°)				
Before surgery	41.41 ± 4.43	41.45 ± 4.86	0.046	0.963
After surgery	47.78 ± 5.85**	48.66 ± 6.08**	0.791	0.443
Supination (°)				
Before surgery	69.81 ± 4.26	70.13 ± 4.54	0.390	0.698
After surgery	85.56 ± 6.71**	81.39 ± 5.45**	3.692	<0.001
Pronation (°)				
Before surgery	62.74 ± 3.87	63.58 ± 4.16	1.120	0.265
After surgery	78.11 ± 5.75**	72.65 ± 5.52**	5.212	<0.001

Notes: Compared with preoperative values within the same group, **$p < 0.001$.

Table 4. Comparison of radiological outcomes between groups [$\bar{x} \pm$ s].

Variable	Observation group (n = 54)	Control group (n = 62)	t-value	p-value
Volar tilt (°)				
Before surgery	6.46 ± 0.33	6.51 ± 0.42	0.705	0.482
After surgery	12.48 ± 2.63**	9.27 ± 2.11**	7.289	<0.001
Radial inclination (°)				
Before surgery	8.05 ± 1.26	8.29 ± 1.58	0.895	0.372
After surgery	21.52 ± 3.81**	20.83 ± 3.74**	0.983	0.328
Radius height (mm)				
Before surgery	5.47 ± 1.29	5.62 ± 1.33	0.614	0.540
After surgery	11.69 ± 1.84**	9.28 ± 1.13**	8.618	<0.001

Notes: Compared with preoperative values within the same group, **$p < 0.001$.

Table 5. Comparison of VAS scores, MMWS, and grip strength between groups [$\bar{x} \pm$ s].

Variable	Observation group (n = 54)	Control group (n = 62)	t-value	p-value
VAS score (points)				
Before surgery	4.72 ± 1.05	4.66 ± 1.12	0.296	0.768
After surgery	1.07 ± 0.26**	1.35 ± 0.28**	5.553	<0.001
MMWS (points)				
Before surgery	41.74 ± 6.13	40.21 ± 6.61	1.286	0.201
After surgery	76.56 ± 12.98**	71.32 ± 14.33**	2.052	0.042
Grip strength (%)				
Before surgery	44.36 ± 8.24	43.70 ± 8.35	0.427	0.670
After surgery	76.72 ± 10.66**	68.47 ± 13.72**	3.577	0.001

Abbreviations: VAS, Visual Analog Scale; MMWS, Modified Mayo Wrist Score.

Notes: Compared with preoperative values within the same group, **$p < 0.001$.

Table 6. Comparison of overall postoperative complications between groups [n (%)].

Variable	Observation group (n = 54)	Control group (n = 62)	χ^2 value	p-value
Total complications	6 (11.11)	17 (27.42)	4.829	0.028
Extensor tendon rupture	2 (3.70)	3 (4.84)	<0.001	1.000
Carpal tunnel syndrome	1 (1.85)	6 (9.68)	1.890	0.169
Distal radioulnar joint instability	2 (3.70)	5 (8.06)	0.352	0.533
Delayed fracture union	1 (1.85)	3 (4.84)	0.136	0.712

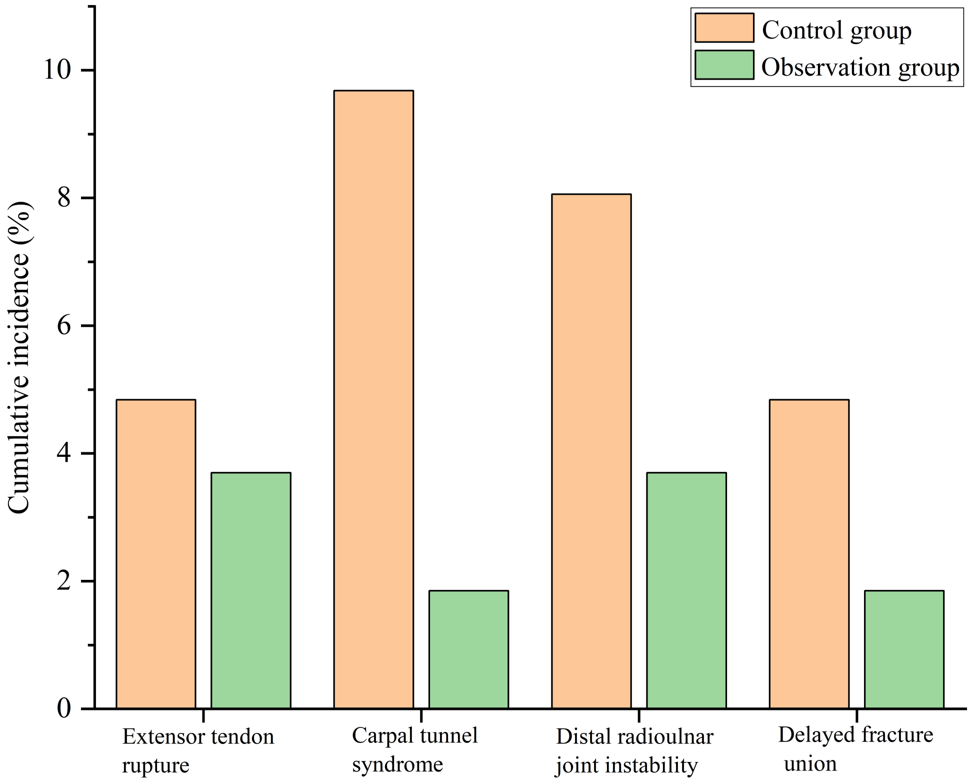

Fig. 2. Cumulative incidence of postoperative complications over 12 months.

guided group (control group), consistent with previous studies on ultrasound-assisted fracture reduction [25,26]. These advantages are attributed to the real-time multiplanar imaging capabilities of ultrasound, which allow continuous monitoring of bone fragment reduction and prevent repeated adjustments necessitated by the inherent limitations of two-dimensional fluoroscopy [27]. Additionally, ultrasound guidance technology minimizes blind soft-tissue dissection, thereby reducing the risk of iatrogenic vascular injury [28].

Postoperative pronation/supination and dorsiflexion ranges of motion were significantly better in the observation group, suggesting that precise ultrasound-guided DUF reduction, especially in regions critical to the distal radioulnar joint (DRUJ), can effectively restore DRUJ stability [29]. The absence of a significant difference in volar flexion between groups may be attributed to sufficient support provided by volar plating, as both techniques maintain volar mechanical structures [30]. The observation group also demonstrated superior radiographic correction of volar tilt and radial height. This improvement is likely due to the dynamic multiplanar assessment capability of ultrasound, which allows for detailed visualization of articular step-offs and dorsal fragment displacements, thereby guiding more precise reduction [31,32]. In contrast, conventional fluoroscopy, limited by two-dimensional imaging, often fails to detect dorsal fragment malalignment [33]. Although ulnar inclination improvement was significant in both groups, no intergroup difference was observed, indicating that this parameter primarily depends on radial styloid reduction and volar locking plate fixation, with limited sensitivity to reduction guidance methods [30,33].

Functional outcomes, including MMWS and grip strength, were also superior in the observation group compared to the control group. Since functional recovery is a primary goal of DRF treatment, accurate anatomical restoration, including palmar tilt and radial height, remains crucial for favorable prognostic outcomes [6]. The precise restoration of radial height and volar tilt in the observation group likely optimized load transmission across the wrist, thereby enhancing functional recovery [34].

The observation group exhibited significantly lower postoperative VAS scores, attributed to radiation-free real-time imaging associated with ultrasound, which shortened reduction assessment time and reduced stress responses caused by surgical trauma [35]. Ultrasound dynamically visualized the spatial relationships among dorsal bone fragments, extensor tendons, and the interosseous membrane, thereby preventing injuries from repeated clamping or excessive soft-tissue traction [28]. Additionally, precise ultrasound-guided reduction of dorsal bone fragments restored anatomical congruence of the radiocarpal and DRUJ, alleviating pain associated with abnormal stress distribution across the articular surface [36,37].

This study revealed a significantly lower overall complication rate in the ultrasound-guided group compared to the conventional X-ray-guided group. This finding contrasts with recent reports on the complication burden associated with isolated volar locking plate (VLP) fixation for DRFs. A study on isolated VLP fixation reported an overall complication rate of 26.8% within 12 postoperative months, comparable to that observed in the control group of our study, but significantly higher than that of our observation group [38]. Notably, a systematic review and meta-analysis of randomized controlled trials confirmed the high prevalence of complications following VLP fixation, reporting an overall complication incidence rate of 30.8% (with a minimum follow-up of 3 months), among which median nerve-related complications (7.1%) were particularly prominent [39]. We propose that the significantly reduced complication rate in our observation group results from ultrasound technology effectively overcoming risk factors inherent in conventional VLP fixation. Median nerve-related complications, frequently reported at 7.1% in the literature, were proactively prevented in our observation group. Ultrasound allowed preoperative quantitative assessment of carpal tunnel volume and median nerve edema, thereby providing an objective basis for concomitant transverse carpal ligament release in patients with comorbid neuropathy. Crucially, its intraoperative real-time visualization enabled precise monitoring of surgical instrument trajectories (e.g., drill bits and screws), thereby mitigating transient or sustained increases in carpal tunnel pressure or direct median nerve compression caused by improper manipulation or suboptimal plate positioning [40].

The significant intergroup difference in overall complication incidence was primarily reflected in several aspects. Extensor tendon injury was increased because the control group relied solely on X-ray evaluation of dorsal cortical alignment, carrying a hidden risk of screw penetration [41]. In contrast, ultrasound enabled dynamic multiplanar imaging (sagittal/axial), allowing precise monitoring of distances between guidewires or screws and the extensor pollicis longus tendon, effectively preventing iatrogenic tendon irritation or cortical perforation [42]. Carpal tunnel syndrome (CTS) prevention was facilitated by ultrasound, which quantitatively assessed carpal tunnel volume and median nerve edema, enabling concurrent transverse carpal ligament release in patients with preoperative neuropathy [43,44]. Real-time monitoring of instrument trajectories further reduced the risk of iatrogenic intra-tunnel pressure elevation or plate malpositioning [45]. Maintenance of DRUJ stability depended on the quality of dorsolunar fragment reduction [46]. Ultrasound enabled dynamic evaluation of fragment rotation angles and sigmoid notch congruence, reducing DRUJ dislocation rates [47]. In contrast, conventional X-ray guidance often failed to detect coronal plane displacements, leading to unrecognized ulnar styloid base fractures and late DRUJ instability [48]. Fracture healing was promoted under ultrasound guidance by achieving precise reduction with minimal soft-tissue stripping, preserving periosteal blood supply and the fracture microenvironment, thereby preventing delayed union [28].

Gartland-Werley scoring incorporates subjective symptoms (pain, dysfunction) and objective signs (range-of-motion limitations, complications) [17]. The superior scores in the observation group directly correlate with enhanced correction of articular step-offs, improved DRUJ stability, and reduced secondary injury. These findings further support that ultrasound guidance facilitates functional recovery through enhanced reduction accuracy and minimized iatrogenic trauma.

Although ultrasound guidance demonstrated numerous advantages in this study, potential limitations should be acknowledged. The primary concern pertains to intraoperative sterility. Manipulation of the ultrasound probe near the surgical field carries the risk of contamination, which may elevate the likelihood of surgical site infections. Consequently, stringent aseptic protocols are essential, including the use of sterile coupling agents and fully covered sterile probe sheaths [49]. Additionally, ultrasound-guided techniques involve a distinct learning curve. Surgeons must acquire proficiency in interpreting ultrasonographic anatomy and mastering probe manipulation to visualize volar-dorsal fragments and dynamically assess reduction quality. Achieving this expertise requires dedicated training and extensive procedural experience [50]. In this study, all ultrasound-guided procedures were performed by orthopedic surgeons with specialized training and extensive experience, minimizing variability due to operator skill. Future research should further evaluate how the learning curve may influence widespread adoption of the technique.

The present study has several limitations. The retrospective design introduces potential selection and information biases, including insufficient adjustment for confounding factors such as dorsal bone fragment size, preoperative soft tissue injuries, and the preference of the surgeon for using ultrasound assistance in complex fractures. The 12-month follow-up period is insufficient to evaluate late-onset complications, such as extensor tendon ruptures, which peak at 18–24 months postoperatively, and post-traumatic arthritis, which may progress over 2–5 years. Additionally, the single-center design limits the generalizability of the findings, as it does not account for variations in equipment, surgeon experience, and rehabilitation protocols across institutions. Future research should involve multicenter randomized controlled trials with larger sample sizes and extended follow-up periods to assess long-term complications. Moreover, this study did not compare three-dimensional (3D) navigation technologies, such as the O-arm, which are primarily used to assess articular step-off displacement exceeding 2 mm. In contrast, the reduction of dorsoulnar fragments relies more on dynamic monitoring and fine fragment adjustment, where ultrasound demonstrates greater practicality. Prospective studies are needed to directly compare the efficacy of ultrasound, two-dimensional fluoroscopy, and 3D navigation for fragment-specific reduction.

Conclusions

This study demonstrates that, in the treatment of distal radial fractures involving dorsal ulnar bone fragments, ultrasound-guided DUF reduction combined with volar locking plate internal fixation provides significant advantages over conventional X-ray guidance. These include superior functional recovery, more anatomically precise reduction, and fewer complications. Thanks to its real-time and multi-planar dynamic imaging capabilities, ultrasound provides a reliable method for the precise repositioning of the dorsal-radial fracture fragments in DRFs. It can effectively assist in the intraoperative localization and monitoring of hidden dorsal fracture fragments, thereby enhancing surgical safety and improving patient prognosis, and holding significant clinical promotion value.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

ZBS, DML and JS designed the research study and wrote the first draft. MXZ and YFF performed the research. ZBS and SZL analyzed the data. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was approved by the Institutional Ethics Committee of Liangzhu Branch, The First Affiliated Hospital, Zhejiang University School of Medicine (First People's Hospital of Yuhang District) (Ethical code number: LZYY202215) and conducted according to the World Medical Association's Declaration of Helsinki. Written informed consent was obtained from all participants.

Acknowledgment

Not applicable.

Funding

This study is supported by Science and Technology Development Project of Hangzhou (Grant 20220919Y099).

Conflict of Interest

The authors declare no conflict of interest.

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