European Journal of Orthopaedic Surgery & Traumatology (2023) 33:3419–3428
https://doi.org/10.1007/s00590-023-03558-2

ORIGINAL ARTICLE

Operative treatment of distal radius fractures involving the volar rim–A systematic review of outcomes and complications

Ali Lari[1] · Abdullah Nouri[1] · Mohammad Alherz[2] · Carlos Prada[3]

Received: 12 March 2023 / Accepted: 23 April 2023 / Published online: 6 May 2023

Abstract

Purpose Distal radius fractures involving the volar rim are a subset of unstable and extremely distal fractures involving the volar lunate and/or scaphoid facets. Volar rim fractures (VRF) are challenging to manage and different treatment options have been described. This study aimed to compare outcomes and assess the rates of complications and implant removal for different treatment methods of wrist fractures involving VRF.
Methods A systematic review of studies published in MEDLINE, EMBASE, Web of Science and Cumulative Index to Nursing and Allied Health literature (CINAHL) was conducted to assess the operative outcomes of VRF. Data on patient demographics, implant usage, postoperative outcomes, complications, and implant removal were compiled.
Results Twenty-six studies met the inclusion criteria with a total of 617 wrists. The most commonly used implants were 2.4 mm variable-angle volar rim plate (DePuy Synthes) (17.5%), Acu-Loc II (Acumed) (14%) and standalone hook plates (13%). The average outcome measures were Q-DASH (10.9 ± 7), MWS (85.8 ± 7.5), PRWE (15.9 ± 12.1), and DASH (14 ± 8.5). The overall complication rate was 14% ($n = 87$), with 44% ($n = 38$) involving flexor tendon problems. The implant removal rate was 22%, with routine removal being performed in 54% and non-routine removal in 46% of cases.
Conclusion The current treatment of VRF yields favorable functional outcomes across different treatment options. However, these fractures have a high rate of complications and re-interventions, particularly for symptomatic implants.
Level of Evidence Therapeutic IV.

Keywords Volar rim fracture · Volar marginal fragment · Lunate facet fracture · Distal radius · Operative treatment · Outcomes

Introduction

Distal radius fractures (DRF) involving a volar rim fragment comprise a subset of unstable intra-articular fractures with involvement of the volar lunate and/or scaphoid facets. These fractures are generally difficult to treat as they are small and at the articular margin. Thus, they are unamenable to buttressing by standard fixed-angle volar locking plates (VLP) [1]. Volar rim fractures (VRF) are generally uncommon, occurring in 1–11% of all distal radius fractures [2]. The lack of consensus on the definition of VRF has led to varying descriptions and terminologies—collectively referred to as volar rim fractures/fragments (VRF), volar marginal fragments (VMF) or volar lunate facet fragments (VLF). For the purpose of this review, they will be referred to as VRF.

The presence of VRF predisposes to radio-carpal subluxation and failure of fixation when addressed with conventional

✉ Ali Lari
Dr.alilari@gmail.com

Abdullah Nouri
abdullahfanouri@gmail.com

Mohammad Alherz
Alherzm@tcd.ie

Carlos Prada
pradac@mcmaster.ca

1 Department of Orthopedic Surgery, AlRazi National Orthopedic Hospital, Kuwait City, Kuwait

2 Department of Anatomy, Trinity College Dublin, Dublin, Ireland

3 St Joseph's Health Care, Hand and Upper Limb Centre, University of Western Ontario, London, ON, Canada

volar buttress plating [3]. When less than 15 mm of lunate facet length is available for fixation, there is a higher risk of implant failure, even if the plate is appropriately positioned [4]. Thus, failure to address the VRF is associated with loss of postoperative reduction and subsequent failure of fixation [5]. Harness et al. reported universal fixation failure with the initial use of conventional plates that neglected VRF in their series of seven patients [6]. Further, in a study examining carpal injuries in VRF, Harris et al. reported high rates (80%) of carpal dislocation associated with the initial injury [7]. The authors reported significantly higher rates of postoperative failure of fixation (24%), carpal instability (56%) and revision surgery (12%) in VRF compared to cases without VRF. This has subsequently led to the advent of several strategies to address these challenging fractures.

Firstly, adequate preoperative fracture assessment is crucial. As the fragments are typically small, the use of computed tomography (CT) becomes essential to evaluate the geometry and size of the fragments and have a proper surgical plan. Second, adequate intraoperative exposure is vital to ensure reduction of these fragments [8]. Finally, an appropriate implant that is properly positioned should be used to address each fragment. These options include specific rim plates, hook plates, spanning plates, Kirschner wires, screws and different types of cerclages. Perhaps, one of the most frequently used methods of fixation have been the low-profile volar locking plates specifically designed to be placed distal to the watershed line to buttress the more distal fragments.

Although many of the implants have been specifically designed to address VRF with placement beyond the watershed line, there is no consensus on the optimal implant and their safety profile. No clear superiority has been proven among the different fixation methods and there is still controversy regarding the risk of flexor tendon injury and the subsequent need for implant removal [9, 10]. Currently, the approach to fixation depends largely on surgeon preference and experience due to a lack of guidelines to aid in planning and execution. In addition, there have been no trials comparing different fracture characteristics and implant superiority.

The current work aims to review the literature on fixation methods for distal radius fractures with VRF. The objectives being (1) to compare the outcomes of different treatment methods and techniques and (2) to assess and compare the rate of complications and implant removal among techniques.

Methods

The search and selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was prospectively registered with PROSPERO (International Prospective Register of Systematic Reviews) (ID: CRD42022327483).

Search strategy

A systematic search of Medline, Embase, Web of Science and CINAHL (Cumulative Index to Nursing and Allied Health Literature) databases was performed using the following keywords: (Fracture) AND ((Distal radius) OR (Distal end radius) OR (Radial) OR (radius)) AND ((marginal) OR (rim) OR (volar)). This search strategy was undertaken to maximize the inclusion of potentially pertinent articles and minimize the effect of variation in definitions and terminology attributed to volar rim fractures. Articles published on or before the 21st of May, 2022 were included. Finally, reference lists of relevant articles were reviewed to identify additional articles that were potentially missed in the initial search.

Eligibility criteria

Studies that met the following inclusion criteria were reviewed: (1) reporting outcomes of operatively treated DRF involving the volar rim; (2) reporting clinical outcomes of at least 5 patients; (3) patient age ≥ 18 years; (4) English or Spanish reporting. Volar rim fractures were defined as (1) small volar distal fragments that were not amenable to buttress plating with conventional volar plates or (2) fragments with less than 15 mm of cortical length available for fixation. Although VRF were defined as such, we included all studies that described volar rim fractures.

Studies were excluded if they met any of the following criteria: (1) cadaveric or biomechanical studies; (2) studies that do not specifically described the presence of volar rim fracture/fragment; (3) review articles; and (4) studies whose full-text was not available. Further, studies that described volar shear (Barton) fractures were not included.

Study screening

Titles and abstracts were independently screened for relevance by two authors (A.L, A.N) using Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. www.covidence.org). Potentially relevant articles underwent full-text screening, with any conflicts between the authors being resolved by discussion and consensus with the senior author (C.P).

Quality assessment

Study quality assessment was conducted using the methodological index for non-randomized studies (MINORS) tool [11]. A score of 0, 1 or 2 is given for each of the 12 items on the MINORS checklist with a score of up to 16 for non-comparative studies and 24 for comparative studies. Methodological quality was categorized prior as follows: a score of 0–8 or 0–12 was considered poor quality, 9–12 or 13–18 was considered fair quality, and 13–16 or 19–24 was considered excellent quality, for non-comparative and comparative studies, respectively.

Data extraction

Two authors (A.L, A.N) independently extracted relevant data from the included studies to a previously piloted Microsoft Excel spreadsheet (Microsoft, Redmond, Washington, USA). These data included general article information (title, author, date of publication, journal, originating country and contact information), sample data and methodological information (study design, sample size, level of evidence, inclusion/exclusion criteria), patient demographic and surgical procedure details (age, gender, diagnoses, method of operative interventions), and relevant outcome measures (follow-up period, patient reported outcome scores, complications and revision surgery, satisfaction, pain score and return to previous level of activity). Scoring systems utilized included Disabilities of the Arm, Shoulder and Hand (DASH), quick DASH (Q-DASH), Patient-rated wrist evaluation (PRWE) and the Mayo wrist score (MWS). Further, when available, specific information on the implant systems utilized and associated complications was extracted.

Data analysis

Descriptive statistics including the mean, range and measures of variance (e.g. standard deviations, 95% confidence intervals [CI]) were utilized where applicable. Data were synthesized into pooled demographics, treatment, and outcome measures. Due to the heterogeneity of the included outcome measures, subgroup analysis was not possible. Measures of spread were calculated from each study if individual data were reported.

Results

After the removal of duplicates from the initial search, a total of 4852 were retrieved for title and abstract screening (Fig. 1). A total of 4738 were excluded after the initial title/abstract review. Next, 114 studies underwent full-text review. A total of 26 studies were included in the final analysis.

Case data

The study designs and demographics are detailed in Table 1. There were four retrospective case–control studies and one prospective cohort study. The rest of the studies were retrospective reports. The total number of wrists and patients included were 617 and 611, respectively. There was a slight female preponderance in the sample group ($n = 309$, 53%). The mean age of patients included was 51.9 years with a mean follow-up of 18.4 months (Range 3–68 months). The AO classification system DRF was the most commonly reported.

Interventions and implants

The types of implants used, and the subsequent rates of removal are detailed in Table 2. The most common implant used in isolation was the 2.4 mm variable-angle volar rim plate by DePuy Synthes, utilized in 17.5% ($n = 108$) of the fractures. Standalone hook plates were used in 13% ($n = 81$) of the fractures. These included the Arthrex volar hook plate and the Aptus 2.5 mm (Medartis) hook plate. The hook plate extension in the Geminus volar locking plate was used in 3.4% ($n = 21$) [3]. The Acu-Loc II system (Acumed) was used in 14% of the fractures ($n = 88$). Kirschner wires were used as wire loops or spring wires in 18 patients (2.6%). Mini-locking plates and 2.4 mm volar plates of different designs were used in 188 fractures (30%).

Patient reported outcome measures (PROMs)

The aggregate PROM scores are depicted in Table 3. Twenty out of 26 studies (77%) included at least one PROM. In their series of 42 patients, Huang et al. found a significantly higher Mayo Wrist Score (MWS) using the Acu-Loc II implant when compared to the Synthes volar rim plate ($P = 0.0006$) [12].

Range of motion (ROM)

The reported data on ROM in 21 out of the 26 studies are depicted in Table 3. The aggregate mean values for ROM included flexion (54.4° ± 13.4°), extension (58.6° ± 10.9°), pronation (79° ± 7.2°), and supination (76.8° ± 7.5°).

Complications and revision surgery

The complications and subsequent re-interventions are reported in Table 4. The overall complication rate excluding implant removal was 14% ($n = 87$). The majority of these (44%) involved flexor tendon pathology. Loss of reduction was a recurring finding reported in 5 of the studies [3, 6, 13, 14].

Data for loss of reduction were only reported in 5 studies (19%). There were reports of radiographic loss of reduction in subsequent studies ($n = 12$) [3, 6, 13, 14]. Imatani et al. reported loss of volar tilt and loss of ulnar variance; however,

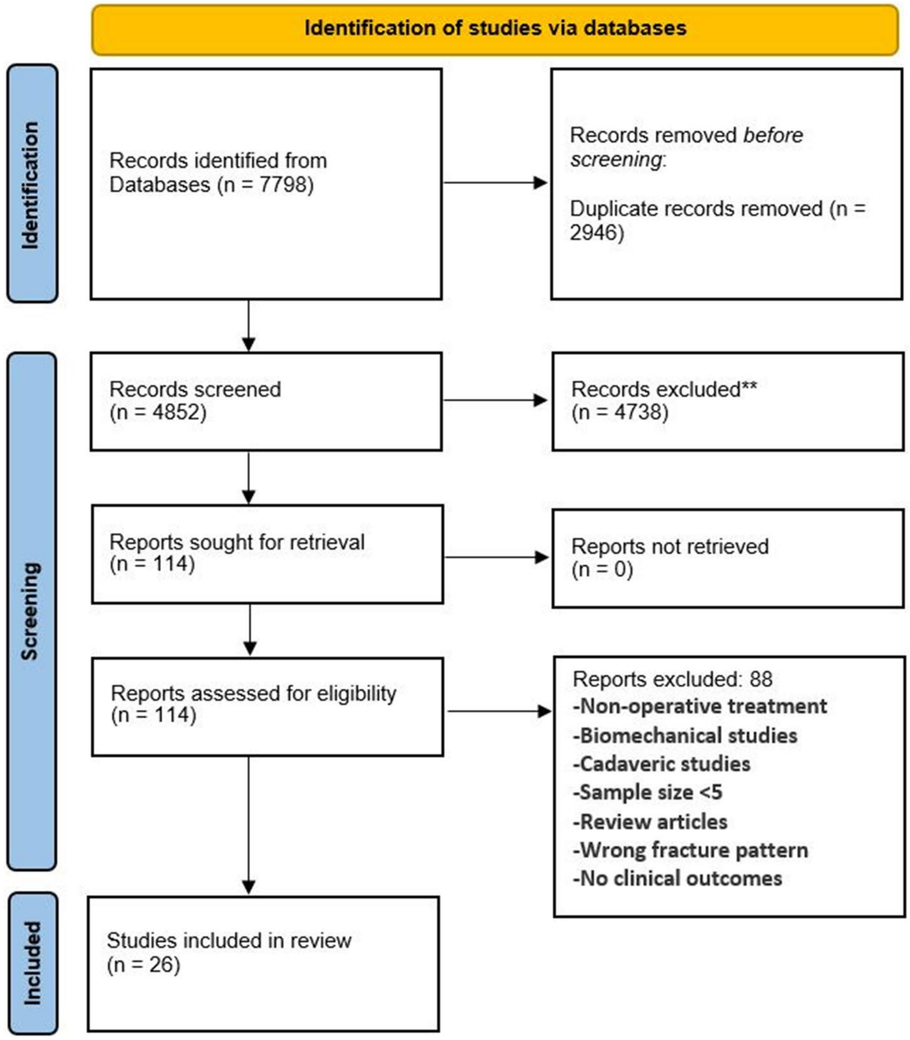

Fig. 1 PRISMA flow diagram summarizing the study selection process

none required re-intervention as fragments all healed. Other less common complications included: complex regional pain syndrome ($n=3$, 0.5%), carpal tunnel syndrome and median nerve neuropathy ($n=8$, 1.3%), intra-articular implants and implant breakage ($n=3$, 0.44%).

Implant removal

The overall implant removal rate was 22% ($n=122$) across the 21 studies (81%) reporting this measure. In the removal group, implants were removed routinely in 54% ($n=53$) and non-routinely in 46% ($n=44$) of cases.

The Synthes volar rim plate was removed in 43% ($n=46$) of wrists. In three studies, the authors advocated for routine implant removal and subsequently removed all implants after fracture consolidation (range 3–9 months) [10, 15, 16]. Goorens et al. reported one case of flexor pollicis longus (FPL) tendinopathy that resolved after plate removal. Hayakawa et al. used the volar rim plate in 14 patients and reported complications of flexor tendon adhesions ($n=8$), median nerve adhesions ($n=4$) and flexor tenosynovitis ($n=1$). However, no symptoms were reported in their sample group. In a cohort of 36 patients, Kara et al. reported a 42% implant removal rate for symptomatic flexor tendon pathology using the Synthes volar rim plate [9]. Using the same implant, Spiteri et al. and Chen et al. reported 15% and 4% implant removal rates, respectively [17, 18].

Hook plates were reported to have been removed in 6% of the fractures ($n=6$). Gavaskar et al. reported one case of FPL tendinitis and implant removal [19], and O'Shaughnessy et al. reported 4 cases of flexor tendon pathology. The Acu-Loc II plate was reported to be removed in 34% of wrists. Symptomatic implants due to flexor tendon irritation resolved once the plate was removed [12, 14].

Table 1 Study designs and demographics of the included articles. MINORS; methodological index for non-randomized studies

Study	Study type	Minors	Sample size—wrists (Patients)	Female N (%)	Age mean (range)	Follow-up mean months (range)	Fracture classification
Harness [6]	Case series	9	7	3 (43%)	51.4 (38–71)	24.4 (5–72)	AO B3.2, B3.3
Bakker [25]	Case series	8	8 (6)	2 (33%)	47	6.5 (3–9)	AO—C & volar rim
Moore [21]	Cohort	9	9	5 (55.6%)	42 (18–72)	9.7 (4–17)	AO Type C3
Orbay [3]	Cohort	5	24	17 (71%)	64.3 (38–87)	68.4 (30–120)	-
Kachooei [26]	Cohort	13	10	9 (90%)	54 (23–71)	14 (2–26)	AO 23B3 23C
O'Shaughnessy [27]	Cohort	11	25	18 (72%)	55 (21–89)	13 (3–30)	AO B/C
Marcano [2]	Cohort	18	28	16 (57%)	52 (19–82)	12	AO 23-B3
Harness [28]	Case series	9	5	2 (40%)	58 (41–82)	3	AO B3.3 or C
Kara [9]	Cohort	8	36	8 (22%)	46.4 (26–69)	23.8 (12–48)	AO C2 C3
Abe [29]	Prospective Cohort	12	7	6 (86%)	57 (31–83)	9 (5–19)	AO B3.3
Spiteri [17]	Cohort	9	26	NR	40 (28–68)	12	AO 23B3, 23C3
Goorens [15]	Case series	8	10	5 (50%)	52.2 (17–80)	11 (5–19)	AO Type C
Lee [30]	Cohort	14	32	17 (53%)	52.3 (33–69)	14.5 (10–24)	Medoff & volar rim
Naito [31]	Cohort	10	32	21 (66%)	59.4 (22–86)	13.8 (12–30)	AO B3, C /C2, C3
Chen [18]	Case control	19	47	37 (79%)	53.2 (39–66)	15.8 (12–18)	AO B3 or C
Biondi [32]	Cohort	9	23	3 (13%)	38 (19–78)	21 (16–31)	Medoff & volar rim
Fardellas [33]	Cohort	5	15	7 (47%)	59 (23–88)	–	AO types B,C
Obata [16]	Case control	9	25	11 (44%)	57.8 (NR)	12	AO B3 C1 C3
Nanno [13]	Cohort	13	27	11 (41%)	58.2 (23–79)	15.3 (9–38)	AO C1,C2,C3
Biondi [34]	Cohort	11	68	26 (38%)	46.5 (19–82)	34 (12–61)	Hintringer—Rim
Meng [35]	Cohort	12	38 (35)	20 (57%)	52.5 (19–70)	12 (11–15)	AO
Garg [36]	Cohort	10	6	2 (33%)	50.8 (31–72)	43.3 (26–66)	AO Type B3, C1
Hayakawa [10]	Case Control	23	14	12 (85.7%)	63.8 (56.7–70.9)	12.1 (11.5–12.7)	AO B2, B3 C1.3, C2.2, C2.3, C3
Gavaskar [19]	Cohort	8	18	6 (33%)	33 (19–51)	18.7 (-)	AO:2R3B3, C3
Huang [12]	Cohort	17	42	23 (55%)	51 (23–91)	24 (minimum)	AO 2R3 B2/3
Imatani [14]	Case series	8	35	22 (63%)	55 (15–87)	–	AO 2R3B3, 2R3C1, 2R3C2, 2R3C3
Aggregate scores			617 (611)	309 (53%)	51.9	18.4	

Discussion

Distal radius fractures involving VRFs are challenging to manage due to the small fragment sizes which impede strong osseous fixation and the limited intraoperative visualization [20]. This systematic review has shown that the different implants and strategies specifically designed to treat these fractures achieve acceptable short to midterm outcomes with relatively high complication rates and frequent planned and unplanned revision surgeries (26%). The increased risk profile of these fractures highlights the need for a common classification to identify different fracture patterns within this group and their ideal treatment strategies.

The most frequently utilized implants to treat these injuries are volar locking plates and standalone hook plates specifically designed to be positioned distal to the watershed line. Kirschner wires and mini-fragment plates were also used and may be of particular importance in extremely distal fractures with small, avulsed fragments. Augmentation with other techniques such as wire loops, spring wires or high strength sutures may also be necessary [14, 21].

Thus, the decision for type of fixation appears to be dynamic, with consideration for the fracture pattern, the surgeon's expertise, and implant availability. For instance, the fixation can be augmented with dorsal plating if dorsal instability is suspected [17], or K-wires if the fragment is too small to be buttressed even with the specially designed implants [21]. The current data suggest that there is increased awareness of the risk of failure associated with VRFs, and that these fractures can be addressed with existing techniques and implants. Furthermore, failure of fixation and displacement of the VRF should be followed by prompt revision in the acute phase, and potentially salvage procedures if failure is chronic [22]. However, the implications of minor loss of reduction remain unclear [13].

Table 2 Types of implants utilized, rates of removal and the reasons for removal

Study	System company	Implant type	Implant removal. N (%)	Reason and time for implant removal
Harness [6]	Synthes	DR VLP	NR	NR
Bakker [25]	TriMed Inc	Hook plate + VLP	NR	NR
Moore [21]	Hand Innovations	DR VLP + Spring K-wire fixation	0	–
Orbay [3]	Geminus	DR VLP + Hook plate	NR	NR
Kachooei [26]	Synthes	2.4 mm VA-RIM Plate	NR	NR
O'Shaughnessy [27]	TriMed	Hook plate	5 (19%)	(4) Flexor tendon pathology (1) Dorsal pin removal. Mean removal: 8 months (3–14)
Marcano [2]	NR	NR	0	–
Harness [28]	Stryker	Vari-Ax LCP	0	-
Kara [9]	Synthes	2.4 mm VA-RIM Plate	15 (42%)	(15) Flexor tenosynovitis (Mean 20 months)
Abe [29]	NR	Dual plate—2.0 mm Hook plate + 2.4 mm LCP	0	-
Spiteri [17]	Synthes	2.4 mm VA-RIM Plate	4 (15%)	(1) Long screw dorsal penetration (1) Flexor tendon irritation (1) Articular screw (1) TFCC debridement
Goorens [15]	Synthes	2.4 mm VA-RIM Plate	10 (100%)	Routine removal at 4 months
Lee [30]	Synthes	2.4 mm VA-LCP Plate	11 (34%)	Patients Request (No clinical symptoms)
Naito [31]	Acumed Synthes	2.4 mm Acu-Loc 2 2.4 mm VA-RIM Plate	0	–
Chen [18]	Synthes	2.4 mm VA-LCP / FA-LCP	2 (4%)	(2) Flexor tendon irritation
Biondi [32]	Medartis	Aptus—2.5 mm Hook plate	0	–
Fardellas [33]	Extradistale newclip technics	Volar Rim locking plate	14 (93%)	(8) Flexor tendon pathology (All) (6) Routine after consolidation
Obata [16]	Acumed Synthes	2.4 mm—Acu-Loc 2 2.4 mm—VA-RIM Plate	12 (50%)	(12) Routine removal at 3-6 m
Nanno [13]	Acumed	2.4 mm Acu-Loc 2	25 (93%)	Reason NR. Time: 7.3 months (5–15)
Biondi [34]	Medartis	Aptus: Rim plate	0	–
Meng [35]	-	AO distal radius VLP	0	–
Garg [36]	-	Looped Kirschner wires + VLP	NR	–
Hayakawa [10]	Synthes	2.4 mm VA-RIM Plate	14 (100%)	Routine after union—Intraoperative findings: (8) Flexor tendon adhesions, (1) flexor tenosynovitis, (4) median nerve adhesions [Mean: 6 months (4–7)]
Gavaskar [19]	Arthrex	Volar Hook plate	1 (6%)	(1) FPL tendinitis—at 9 months
Huang [12]	1. Synthes 2. Acumed	1. 2.4 mm VA-LCP 2. Acu-Loc VLP	6 (14%)	Symptomatic implant (4) Synthes, (2) Acumed
Imatani [14]	1. Acumed 2. Stryker	1. Acu-Loc plate 2. Mini-locking plates / K-wires	3 (8.6%)	(3) Flexor tendon irritation
Aggregate			Overall implant removal rate Total: 122	Overall Routine: 53 Overall Non-Routine: 44 Nanno 2020: 25 (Reason NR)

NR: Not reported, DR; distal radius, VLP; volar locking plate, K-wire; Kirschner wire, LCP; locking compression plate, TFCC; triangular fibrocartilage complex,

Table 3 Summary of the range of motion, patient reported outcome measures (PROM) and visual analog scale scores (VAS)

Study	Range of motion (mean)		PROM (Mean, SD)		VAS (Mean, SD)
Harness [6]	F 37° E 48° / P 75° S 75° / RD 14° UD 15°		NR		NR
Bakker [25]	F 49.5° E 50° / P 79.4° S 73.8°		NR		NR
Moore [21]	F 46° ± 5° E 51° ± 8° / P 80° ± 6° S 68° ± 10°		PRWE: 17 ± 13.6		NR
Orbay [3]	NR		Q-Dash: Hook NR OWO: Q-DASH 7.4 ± 3.29		NR Hook OWO: *VAS = 0
Kachooei [26]	F-E 6/10 Full—P-S 7/10 Full		NR		NR
O'Shaughnessy [27]	F-E Arc 94°		NR		NR
Marcano [2]	F 83% ± 22% E 92% ± 18% / P 96% ± 12% S 95% ± 15% RD 80% ± 26% UD 77% ± 17% (% CLS)		DASH: 13 ± 17		NR
Harness [28]	F 42° ± 28.9° E 50° ± 17.3° / P 82° ± 2.9° S 68° ± 20.2° RD. 13° ± 2.9° UD 15° ± 5°		NR		* 1 (Range 0–2)
Kara [9]	NR		MWS: Excellent 28%, Good 47%, moderate 14% poor 11%"		NR
Abe [29]	F 55° ± 7.6° E 63° ± 11.1°		Q-DASH: 3 ± 3.1		** 9.3 ± 9.8
Spiteri [17]	F 39° E 43° / P 65° S 57° / RD 18° UD 19°		DASH: 17.6		* 3
Goorens [15]	F-E Arc 144° / P-S Arc 160°		Q-DASH: Pre: 23 (0–34.1) Post: 25 (0–43.2)		* 1.5
Lee [30]	F 74.3° E 71.5° / RD 19.3° UD 25.5°		DASH: 15.36	MWS: 76.3	NR
Naito [31]	F 72.8° ± 12.1° E 73.9° ± 10.7° P 85.5° ± 6.8° S 86.6° ± 3.9°		Q-DASH: 9.2 ± 10.7	MWS: 93.7 ± 5.7	* 1.4 ± 1.9
Chen [18]	VA-LCP 94.8% CLS F-E 93.8% CLS S-P	FA-LCP 82.8% CLS F-E 84.5% CLS S-P	DASH: P = 0.02 (VA): 9.2 (FA): 12.8	MWS: (VA): 93.8 (FA): 83.5	NR
Biondi [32]	F—E Arc 90° / P-S Arc 150° / RD 17° UD 36°		DASH: 13.5	PRWE: 9.3	* 1.1
Fardellas [33]	NR		DASH: 33.61	PRWE: 38.47	NR
Obata [16]	F 70.0° ± 17.0° E 71.6° ± 15.1° P 88.8° ± 2.9° S 82.9° ± 10.1°	Q-DASH: 8.5 ± 9.5	MWS: 91.5 ± 7.6	* 1.0 ± 0.9	
Nanno [13]	F: 60° ± 8.3° E: 64.7° ± 6.8° / P 83° ± 12° S 86° ± 7.3°		Q-DASH: 13.6	MWS: 90.9	NR
Biondi [34]	F-E Arc 96° / P-S Arc 144° / RD 3° UD 18°		DASH: 6	PRWE: 3	* 1
Meng [35]	NR		DASH: 4.6 ± 2.5	MWS: 94 ± 5.7	NR
Garg [36]	F 52.5° ± 17.7 E 58.3° ± 14.7 / P 72.5° ± 7.6 S 74.2° ± 9.2		PRWE: 12.3 ± 10.6		NR
Hayakawa [10]	"Satisfactory"—NR		Q-DASH: Satisfactory—NR		NR

Table 3 (continued)

Study	Range of motion (mean)		PROM (Mean, SD)		VAS (Mean, SD)
Gavaskar [19]	F-E Arc 105° ± 10.2 P-S Arc 145° ± 9.3	MWS: 75 ± 5.3		PRWE: 15.2 ± 4.3	NR
Huang [12]	100% of CLS: Acu 12/21 / Synthes 4/21. The Rest: 75–100% of motion		MWS: P = 0.006 Acu-Loc 86.19 ± 12.03 Synthes 76.67 ± 8.99		*1.19 ± 1.33
Imatani [14]	NR		zQ-DASH: 9.5	MWS: 81.7	
Aggregate	Flex 54.4° ± 13.4°	Ext 58.6° ± 10.9°	Q-DASH 10.9 ± 7	DASH 14 ± 8.5	VAS: 1.24
	Pro 79° ± 7.2°	Sup 76.8° ± 7.5°	MWS 85.8 ± 7.5	PRWE 15.9 ± 12.1	

F; flexion, E; extension; P; pronation, S; supination, RD; radial deviation, UD; Ulnar deviation, CLS; Contralateral side. DASH; Disabilities of the arm, shoulder and hand, PRWE; patient-rated wrist evaluation, MWS; Mayo Wrist Score, Q-DASH; Quick—Disabilities of the arm, shoulder and hand. VA; Variable angle, FA; Fixed angle. *; scale out of 10, **; scale out of 100

Table 4 Complications, rates of flexor tendon pathology re-interventions in the included articles. FPL; flexor pollicis longus, FDP; flexor digitorum profundus, CRPS; complex regional pain syndrome, CTS; carpal tunnel syndrome

Study	Problems/complications (N/%)	Flexor tendon pathology	Other complications
Harness [6]	7 (100%)	None	(4) Radio-carpal subluxation (7) Loss of reduction
Bakker [25]	0 (0%)	None	None
Moore [21]	1 (11%)	None	(1) CTS
Orbay [3]	2 (8.3%)	None	(2) Loss of reduction (8.3%)
Kachooei [26]	5 (50%)	None	(4) Stiffness (1) Ulnar resection arthroplasty for radius shortening and impingement
O'Shaughnessy [27]	5 (20%)	(4) Flexor tendon symptoms	(1) pin backing out
Marcano [2]	0 (0%)	None	None
Harness [28]	0 (0%)	None	None
Kara [9]	20 (55.5%)	(15) Flexor tenosynovitis (3/15) Partial 2nd FDP rupture	(2) CRPS (3) CTS
Abe [29]	0 (0%)	None	None
Spiteri [17]	6 (23%)	(1)	(1) Median nerve axonotmesis – Improved (1) Median nerve paresthesia
Goorens [15]	1 (10%)	(1) FPL tendinitis—Resolved after removal	
Lee [30]	0 (0%)	None	None
Naito [31]	0 (0%)	None	None
Chen [18]	8 (17%)	(2) VA-LCP (6) FA-LCP	-
Biondi [32]	0 (0%)	None	None
Fardellas [33]	8 (53%)	(8) 22 total tendons – (7/22) synovitis, (10/22) partial rupture (5/22) total ruptures	None
Obata [16]	0 (0%)	None	None
Nanno [13]	5 (19%)	None	5 (19%) Loss of reduction
Biondi [34]	3 (4%)	None	(1) Breakage of implant intra-op (1) Intra-articular screw (1) Loss of dorsal wall reduction
Meng [35]	0 (0%)	None	None
Garg [36]	1 (17%)	None	(1) CRPS
Hayakawa [10]	4 (28.5%)	None	(2) Transient median nerve neuralgia (2) Chronic wrist pain
Gavaskar [19]	1 (6%)	(1)	None
Huang [12]	6 (14%)	None	None
Imatani 14	4 (11%)	(1)	(3) (9%) Loss of reduction
Aggregate	87		

The current findings demonstrate that outcomes are satisfactory, and most patients regain nearly complete ROM with little to no pain during daily activity. A notable, yet unexplained finding is the reduced wrist flexion postoperatively. The variety of fracture patterns and treatment options make it difficult to stratify outcomes for each treatment option. In addition, the versatile strategies utilized by surgeons reflect the lack of consensus on the optimal management of each fracture type.

The rates of implant removal in this review are considerably higher than those in standard distal radius plating [23]. In a systematic review, Yamamoto et al. reported a removal rate of 3–19% depending on the geographic location of the case [23]. The current results demonstrate a removal rate of 22%, despite the specifically designed low-profile plates to avoid flexor tendon irritation. Notably, some authors advocate for routine preemptive removal to avoid common complications such as flexor tendon pathology, but the economic ramifications of this practice are unknown. There also appears to be conflicting evidence on the rates of flexor tendon pathology. Using the Synthes volar rim plate, Kara et al. reported flexor tendon pathology in 42% of the patients, as opposed to Naito et al. (0%) and Spiteri et al. (4%). However, at least in the short term, the overall rate of flexor tendon irritation appears to be low despite the plate's position over the watershed line. This finding suggests that the surgeon should practice vigilance rather than perform routine removal.

Despite recent advancements in implant designs and management of VRFs, surgeons should establish realistic expectations and counsel patients on the risk of failure and the potential need for re-interventions, including implant removal [24].

This review is limited by the predominance of retrospective studies representing a low level of evidence. Further, the wide spectrum of fracture patterns and methods of fixation limited comparative analysis. Lastly, the variation in terminology and the lack of a clear definition for this subset of fracture may have inhibited a complete review of the literature. The current findings are generalizable to fractures, which fit the described case definition, and the treatment options, which are reported herein.

Further investigation into the common geometries of these fracture patterns can facilitate appropriate classification and clarity for the most appropriate treatment options. Finally, registry-based data would be beneficial to aggregate data for these uncommon fractures.

The current findings suggest that the treatment of distal radius involving the volar rim yields favorable functional outcomes across the currently reported treatment options. However, these fractures are associated with a high complication and re-intervention rates, particularly for symptomatic implants.

Acknowledgements The authors would like to thank Dr. Jorge Orbay for his input and help during the writing phase of the manuscript

Author contributions All authors have agreed to the submission of the current version of the manuscript and that all authors have made substantial contributions to the work submitted in the forms of design, data acquisition, analysis, writing, editing, reviewing and final approval of the version to be published. We, the authors of this submission, confirm that we have not published the same or a very similar study with the same or very similar results and major conclusions in any other journals. These include English or non-English language journals and journals that are indexed or not indexed in PubMed, regardless of different words being used in the article titles, introduction and discussion.

Funding This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Declarations

Conflicts of Interest All authors certify that they have no affiliations with/or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical approval No ethical approval was required for the purpose of this study.

References

1. Orbay J (2005) Volar plate fixation of distal radius fractures. Hand Clin 21:347–354. https://doi.org/10.1016/J.HCL.2005.02.003
2. Marcano A, Taormina DP, Karia R et al (2015) Displaced intra-articular fractures involving the volar rim of the distal radius. J Hand Surg Am 40:42–48. https://doi.org/10.1016/j.jhsa.2014.09.013
3. Orbay JL, Rubio F, Vernon LL (2016) Prevent collapse and salvage failures of the volar rim of the distal radius. J Wrist Surg 05:017–021. https://doi.org/10.1055/S-0035-1570745
4. Beck JD, Harness NG, Spencer HT (2014) Volar plate fixation failure for volar shearing distal radius fractures with small lunate facet fragments. J Hand Surg Am 39:670–678. https://doi.org/10.1016/j.jhsa.2014.01.006
5. Andermahr J, Lozano-Calderon S, Trafton T et al (2006) The volar extension of the lunate facet of the distal radius: a quantitative anatomic study. J Hand Surg Am 31:892–895. https://doi.org/10.1016/j.jhsa.2006.03.010
6. Harness NG, Jupiter JB, Orbay JL et al (2004) Loss of fixation of the volar lunate facet fragment in fractures of the distal part of the radius. J Bone Joint Surg Am 86:1900–1908. https://doi.org/10.2106/00004623-200409000-00007
7. Eardley-Harris N, MacLean SBM, Jaarsma R et al (2022) Volar marginal rim fractures of the distal radius have a higher rate of associated carpal injuries—a comparative cohort study. J Wrist Surg 11:195–202. https://doi.org/10.1055/S-0041-1729990
8. Orbay JL, Badia A, Indriago IR et al (2001) The extended flexor carpi radialis approach: a new perspective for the distal radius fracture. Tech Hand Up Extrem Surg 5:204–211. https://doi.org/10.1097/00130911-200112000-00004
9. Kara A, Celik H, Oc Y et al (2016) Flexor tendon complications in comminuted distal radius fractures treated with anatomic volar rim locking plates. Acta Orthop Traumatol Turc 50:665–669. https://doi.org/10.1016/J.AOTT.2016.04.001

10. Hayakawa K, Okamoto H, Kojima T et al (2021) Volar RIM plate rarely causes flexor tendon complications in a short period despite its plate prominence over the watershed line: a descriptive study. J Hand Surg Asian-Pacific 26:194–206. https://doi.org/10.1142/S2424835521500181
11. Slim K, Nini E, Forestier D et al (2003) Methodological index for non-randomized studies (MINORS): development and validation of a new instrument. ANZ J Surg 73:712–716. https://doi.org/10.1046/J.1445-2197.2003.02748.X
12. Huang Y, Chen C, Lin K et al (2022) Functional outcomes following fixation of a marginal distal radius fracture with two commonly used volar locking plates: a retrospective cohort study. BMC Musculoskelet Disord 23:18. https://doi.org/10.1186/s12891-021-04984-1
13. Nanno M, Kodera N, Tomori Y, Takai S (2020) Volar locking plate fixation for intra-articular distal radius fractures with volar lunate facet fragments distal to the watershed line. J Nippon Med Sch 87:24–31. https://doi.org/10.1272/jnms.JNMS.2020_87-106
14. Imatani J, Kondo H (2022) Volar lunate facet rim fractures: K-I classification and technique. J Wrist Surg. https://doi.org/10.1055/s-0041-1739144
15. Goorens C, Geeurickx S, Wernaers P et al (2017) Midterm follow-up of treating volar marginal rim fractures with variable angle lcp volar rim distal radius plates. J Hand Surg Asian Pac 22:184–187. https://doi.org/10.1142/S0218810417500228
16. Obata H, Naito K, Kaneko A et al (2020) Clinical outcomes in distal radius fractures accompanied by volar lunate facet fragments: a comparison between dorsal and volar displaced fractures. J Hand Surg Asian Pac 25:417–422. https://doi.org/10.1142/S2424835520500447
17. Spiteri M, Ng W, Matthews J, Power D (2017) Functional outcome of fixation of complex intra-articular distal radius fractures with a variable-angle distal radius volar rim plate. J Hand Microsurg 9:11–16. https://doi.org/10.1055/s-0037-1601325
18. Chen M, Yang S et al (2019) Variable-angle locking compression plate fixation of distal radius volar rim fractures. Iowa Orthop J 39:55–61
19. Gavaskar A, Parthasarathy S, Balamurugan J et al (2021) Volar hook plate stabilization of volar marginal fragments in intra-articular distal radius fractures. Injury 52:85–89. https://doi.org/10.1016/j.injury.2020.10.004
20. Heifner JJ, Orbay JL (2022) Assessment and management of acute volar rim fractures. J Wrist Surg 11:214–218. https://doi.org/10.1055/S-0041-1732338
21. Moore A, Dennison D (2014) Distal radius fractures and the volar lunate facet fragment: kirschner wire fixation in addition to volar-locked plating. Hand (N Y) 9:230–236. https://doi.org/10.1007/s11552-013-9585-7
22. Orbay MC, Orbay JL (2022) Classification and management of failed fixation of the volar marginal fragment in distal radius fractures. J Wrist Surg 11:219–223. https://doi.org/10.1055/S-0041-1735885
23. Yamamoto M, Fujihara Y, Fujihara N, Hirata H (2017) A systematic review of volar locking plate removal after distal radius fracture. Injury 48:2650–2656. https://doi.org/10.1016/J.INJURY.2017.10.010
24. Lari A, Alherz M, Jarragh A (2021) Dissociating advances in orthopaedic trauma management from the climbing patient expectations. Eur J Trauma Emerg Surg. https://doi.org/10.1007/S00068-021-01705-0
25. Bakker A, Shin A (2014) Fragment-specific volar hook plate for volar marginal rim fractures. Tech Hand Up Extrem Surg 18:56–60. https://doi.org/10.1097/BTH.0000000000000038
26. Kachooei AR, Tarabochia M, Jupiter JB (2015) Distal radius volar rim fracture fixation using depuy-synthes volar rim plate. J Wrist Surg 5:2–8. https://doi.org/10.1055/s-0035-1570740
27. O'Shaughnessy M, Shin A, Kakar S (2015) Volar marginal rim fracture fixation with volar fragment-specific hook plate fixation. J Hand Surg Am 40:1563–1570. https://doi.org/10.1016/j.jhsa.2015.04.021
28. Harness N (2016) Fixation options for the volar lunate facet fracture: thinking outside the box. J Wrist Surg 5:9–16. https://doi.org/10.1055/s-0035-1570739
29. Abe Y, Suzuki M, Wakita H (2017) Dual plating technique for volar rim fracture of the distal radius using depuy-synthes 2.0 m and 2.4 mm locking plates. J Hand Surg Asian Pac 22:423–428. https://doi.org/10.1142/S0218810417500447
30. Lee J, Lee S, Sim Y et al (2018) Juxta-articular plate fixation in distal radius intra-articular fractures with accompanying volar free fragments beyond the watershed line. Clin Orthop Surg 10:135–141. https://doi.org/10.4055/cios.2018.10.2.135
31. Naito K, Sugiyama Y, Kinoshita M et al (2019) Functional outcomes in volar-displaced distal radius fractures patients with marginal rim fragment treated by volar distal locking plates. J Hand Microsurg 11:100–105. https://doi.org/10.1055/s-0038-1675245
32. Biondi M, Keller M, Merenghi L et al (2019) Hook plate for volar rim fractures of the distal radius: review of the first 23 cases and focus on dorsal radiocarpal dislocation. J Wrist Surg 8:93–99. https://doi.org/10.1055/s-0038-1667306
33. Fardellas A, Vernet P, Facca S, Liverneaux P (2020) Flexor tendon complications in distal radius fractures treated with volar rim locking plates. Hand Surg Rehabil 39:511–515. https://doi.org/10.1016/j.hansur.2020.06.003
34. Biondi M, Poggetti A, Fagetti A et al (2021) Fragment specific fixation with APTUS wrist system for volar rim fractures of the distal radius: a multicentric study. Eur J Trauma Emerg Surg. https://doi.org/10.1007/s00068-021-01710-3
35. Meng H, Wang B et al (2021) Influence of volar margin of the lunate fossa fragment fixation on distal radius fracture outcomes: a retrospective series. World J Clin Cases 9:7022–7031. https://doi.org/10.12998/wjcc.v9.i24.7022
36. Garg B, Bansal T, Mehta N (2021) The "AIIMS hairpin loop" technique for 'extreme' volar rim fractures of distal radius. J Clin Orthop Trauma 15:46–50. https://doi.org/10.1016/j.jcot.2020.10.049